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Marine Plastics: Innovative Solutions to Tackling Waste

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Foreword

The global ocean is under threat: climate change, ocean acidification, overfishing, loss of biodiversity, and marine pollution—the list goes on. The ocean is a resilient system, as evidenced by the fact that despite these incredible external pressures, it remains a largely functioning ecosystem today. But the ocean's resilience is not infinite, and each day these pressures continue to threaten the stability of the very thing that makes life on our planet possible.

Of these threats, anthropogenic debris in the aquatic environment has gained an enormous amount of attention in recent years, as human-made items and waste accumulate on beaches and in virtually all of the world's waterways. Of the various forms of anthropogenic aquatic debris, abandoned, lost, and discarded fishing gear (ALDFG or *ghost gear*) is widely recognized to be the most harmful of them. This is unsurprising as it is purposely designed to catch aquatic life and, depending on the gear type, is exceedingly efficient at it whether it is under human control or not. Though there remains no firm, universally accepted scientific estimate of the amount of fishing gear lost in the world's ocean, rivers, and lakes each year, it is unquestionably one of the most uniquely impactful forms of aquatic debris and a significant threat to fish populations, global food security, fisher livelihoods, aquatic ecosystems, and the health and prosperity of coastal communities.

No fisher ever wants to lose their gear—this is the means by which they harvest species from the ocean, rivers, and lakes to feed their families and to help feed the world. However, wherever fishing occurs, there will be some amount of gear loss, even in the most well-managed of fisheries. There are many legitimate causes for gear loss during normal fishing operations: rough weather; snags on unseen elements beneath the water's surface; unintended interaction with other lost or actively deployed gear; and interaction with other marine traffic (i.e. shipping and recreational vessels driving over gear and not realizing it is there) are all common causes for gear loss. Crucially, another of the key drivers for fishing gear finding its way into the aquatic environment is a lack of available, accessible, and affordable end-of-life options for fishing gear. In such cases, gear either finds its way into a landfill or may be stored indefinitely on land. But where no storage or disposal options exist, gear at the end of its life often finds its way into the world's rivers, lakes, and oceans.

Nearly, all modern fishing gear is made of a suite of recyclable plastics—primarily polyethylene (PE), polypropylene (PP), and polyamide (PA or nylon). This represents a valuable resource to be collected, if it can be done effectively. Some companies have recognized the potential in fishing gear as a resource and built business models based on this, some of which are highlighted in this book. Though there is tremendous opportunity if the material can be effectively accessed, there remain significant challenges to doing so.

Port-side collection facilities where fishers can conveniently deposit their gear at the end of its useful life are still few and far between, making initial collection challenging. While most fishing gear is made of highly recyclable materials, there are still relatively few facilities that can effectively process it in its native form. Most gear by its very nature is designed to entangle, so it is typically incompatible with facilities made to recycle consumer plastics, as it can easily get caught up in processing machinery. And for those recycling companies who do specialize in fishing gear recycling, getting access to material can be challenging. Fishing gear tends to be heavy and bulky, meaning some level of pre-processing (cleaning, sorting, shredding, etc.) is usually required, and there are often complex and expensive logistics and transport considerations which vary significantly by region. There is also a carbon footprint tied to shipping heavy material often hundreds or thousands of kilometres to a recycling facility capable of processing it.

But for every challenge, there will be people who see an opportunity. Innovators who think differently and strive to solve a challenge previously thought too costly or too difficult to overcome. The contributors to this book understand the challenges associated with effective collection and recycling of fishing gear, as well as the accompanying opportunities. The following chapters and case studies present a clear pathway to a more circular approach to the fishing gear life cycle at a time when this is urgently needed. We do need to be cognizant when speaking of circularity that not all recycling is truly circular. This term should only apply when the products created from recycled materials can themselves be effectively and efficiently recycled repeatedly, keeping the proverbial loop closed. But while we may be some way off from true circularity at this relatively early stage, we should also remember that every step in the right direction is a step worth taking. And that, to me, is worth applauding.

Vancouver, Canada
October 2022

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Preface

2021 marked the start of the United Nations (UN) Decade for Ocean Science (2021–2030), calling for enhanced engagement and interdisciplinary collaboration across ocean sciences. One of the main concerns of the Ocean Decade is the continuously degrading ocean health, caused by anthropogenic emissions and input of hazardous substances such as nano-, micro-, and macro-plastics into the oceans (United Nations, 2021).

There is neither a single, nor fast, solution which will solve global marine plastic pollution. Global action is necessary alongside a variety of different tools. It requires strong international and interdisciplinary collaboration. At the same time, the challenges are so diverse, for example, over different geographical areas or different sources of plastic pollution by plastics, that both understanding the problem and developing solutions must emanate from a regional scale. While this publication focuses on the Northern Periphery and Arctic Area (North-eastern Atlantic), many of the discussions and conclusions are also valid for other geographic regions.

Discarded fishing gear constitutes a large part of marine plastics. Preventing future discharge of fishing gear into the ocean is a vital step in combating plastic pollution. Circular economy is one of the tools in the European Green deal, targeting waste minimization. Closing the loop for waste fishing nets by transferring them to a resource could be a solution for preventing discharge at sea: exploring this opportunity is at the core of this book.

Part I of this book explores the environmental challenges of marine plastics in the North-eastern Atlantic in Chap. 1, employs ecosystem services to describe and communicate the impacts from discarded fishing gear in Chap. 2, and discusses the challenges and opportunities in implementing circular economy as the principle to hinder discarding of the fishing gear into the oceans in Chap. 3.

Part II of the book deals with different ways of solving the problem identified in Part I, where Chap. 4 presents a circular business model for SMEs in the fishing gear industry. This is followed by Chap. 5, where new products which can be produced from recycled fishing gear are identified. A way of making the value chain of recycled fishing gear more mature and better functioning is to identify and connect relevant parties, and this is explored in Chap. 6, through a quadruple helix and organizational network analysis. Various resource management measures have been developed due to the growing concerns of the harmful effects of abandoned, lost, and discarded fishing gear (ALDFG); in Chap. 7, these measures are evaluated through a material flow analysis (MFA) to enable a quantified system-based understanding of material flows and stocks. Chapter 8 highlights how volunteers can contribute to the testing and refining of digital tools used to improve data collection. Furthermore, Chap. 9, the final chapter in Part II, highlights the value chain collaboration and volunteering by NGOs as success factors that enhance marine plastic recycling.

Part III of the book deals with the recycling of waste fishing gear and the development of systems supporting both recycling and recycling opportunities. The case of the Swedish recycling company Sotenäs Marine Recycling Centre (SMRC), which is seen as a pioneer in the Nordic countries when it comes to the collection and handling of EOL fishing gear, is then described in Chap. 10. A possible adsorption of heavy metals to nets during fishing could hamper the use of the nets in new products, and this issue is addressed in Chap. 11. Discarded fishing nets may find use as a secondary resource in value chains as an alternative to fisheries. An example could be within the production of construction materials, which is explored in Chap. 12. Ecolabels are increasingly used to communicate the fact that products are made in a more environmentally friendly manner and reflect consumer interest in ecolabelled products from recycled fishing gear as shown in Chap. 13. Finally, a realistic, local Norwegian strategy for circular economy for plastics from the fishing sector is developed based on an evaluation of fishing gear resource management policies using a multi-criteria perspective, in Chap. 14. This strategy can be used for inspiration in other countries.

In summary, the journey, on which this book takes the reader, goes from identifying the problem of marine plastics waste and more specifically, of discarded plastic fishing gear which is the dominant plastic pollutant in the Northern and Arctic oceans in Part I. It then turns its focus in Part II on how to solve this problem. Finally, in Part III, Part I is taken further and presents value-creating opportunities from marine plastic waste.

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Lyngby, Denmark — Lisbeth Mølgaard Ottosen
Thurso, UK — Neil A. James

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This book is a collaborative work between many people, whom we want to thank for their assistance in writing this book.

Firstly, we would like to thank colleagues in the two projects Circular Ocean and Blue Circular Economy for inspiring collaborations during the projects and enthusiasm in knowledge dissemination through chapters in this book. The openness and interdisciplinary mind-set enabled a holistic view on the challenges with discarded fishing gear, which is a foundation for this book. The two projects were funded through the EU Interreg Northern Periphery and Arctic Programme, and we are deeply grateful for this funding support, which made it all possible.

In addition to the project partners, numerous individuals and organizations have contributed to the two projects through interviews, discussions at meetings and seminars, and continuous involvements. The book would not have been the same without these valuable inputs.

Our gratitude is extended to Joel Baziuk for setting the scene for the book in his Foreword.

Special thanks to Adjunct Associate Professor Sandra Elizabeth Tippett-Spirtou for her excellent work in coordinating the work on behalf of the Editorial Team, representing all the co-authors of this book, and keeping a tight timeline for fulfilling the requirements set by the publisher.

Finally, we would like to thank the publisher for providing us with the opportunity to reach a wider audience on this important topic.

Contents

List of Figures

List of Tables

Part I
Challenges of Marine Plastics with a Focus on the Northeastern Atlantic

Chapter 1
Marine Mammals and Interactions with Debris in the Northeastern Atlantic Region: Synthesis and Recommendations for Monitoring and Research

Neil A. James and Anika Große

Abstract Marine plastic pollution is a global problem, affecting a wide variety of marine organisms through the processes of ingestion and entanglement. Despite numerous reports of entanglement and ingestion of plastic debris by marine mammals, there is a lack of clear understanding regarding the spatial distribution and drivers of interactions between marine mammals and marine plastics in the northeastern Atlantic area. To address this, we undertook a synthesis of the published and grey literature in order to acquire information on known documented cases of ingestion of, or entanglement with, debris relating to marine mammals. We found that 62% of the 37 species present in the region were reported to have either ingested, or become entangled in, debris. There was a predominance of threadlike plastic related to entanglement, but it was also present in the ingestion data. However, we observed a great deal of inconsistency regarding the reporting of marine mammal–debris interactions. We therefore highlight the need for and recommend the development of a standardised approach to recording debris interacting with marine mammals.

Keywords Marine mammals · Entanglement · Ingestion · Fishing gear · Plastics · Northeastern Atlantic · Marine pollution

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1.1 Introduction

The global production of plastics continues to increase year on year, with 460 million tonnes produced in 2019 (OECD 2022). This is likely to increase, with projections from a business-as-usual scenario predicting a threefold increase in the amount of plastics use, waste, and cumulative presence in aquatic environments (OECD 2022). The most recent comprehensive study estimates that in 2016, 19–23 million tonnes of plastics entered the aquatic environment (Borrelle et al. 2020). This is likely to at least double to 44 million tonnes per year by 2060 (OECD), but according to some projections may increase to 53 million tonnes per year by 2030 (Borrelle et al. 2020). Across the European Union, the proportion of collected plastics that are recycled is increasing each year as initiatives and legislation encourage the move to a more circular economy but approximately 23.4% of collected plastics in the EU still go to landfill (Plastics Europe 2021). However, due to both deliberate and unintentional mishandling and disposal of plastic waste, a significant proportion of that which is produced ends up in the environment. Due to waste mismanagement, plastics can be transported by wind or rain into river systems and subsequently be transported into the marine environment. In addition, plastic debris can enter the aquatic environment through direct dumping (intentional and accidental) and through wastewater treatment works, for instance in the form of microplastic fibres from textiles during domestic or industrial washing (Murphy et al. 2016).

Marine plastics are impacting a broad range of animals across the globe, including birds (Provencher et al. 2015; O'Hanlon et al. 2017), turtles (Schuyler et al. 2013), fish (Thiel et al. 2018), crustaceans (Lavers et al. 2020), and marine mammals (Gall and Thompson 2015). Further, the impacts of plastic debris are not experienced by a species in isolation but in combination with other significant pressures including oil pollution, habitat change/distribution, persecution, pathogens, and climate change. Plastic debris can cause harm to marine organisms through ingestion and entanglement (Weldon 2020) and can introduce invasive, non-native species by acting as rafts (Derraik 2002). Ingested plastics can cause death if feeding and/or breathing is restricted, can cause physical damage, for example through lacerations to the oesophagus or digestive tract, or impact mobility, for example, by increasing the mass of the individual and therefore their energetic requirements for swimming and/or flying. There is concern that ingested plastics may also transfer micropollutants, adsorbed from the environment to the detriment of an individual's health. Additionally, plasticisers, which are commonly added to plastics, often to increase flexibility and plasticity, can leach into the environment due to their unstable nature. They can cause significant biological effects, including impacting reproduction (invertebrates, fish and amphibians), development (crustaceans and amphibians), and changes in gene expression (Oehlmann et al. 2009). Entanglement can impact marine organisms by entangling part of the body such as a leg, wing, head or flipper, or trap the entire individual. Fishing nets which are lost or discarded at sea can continue to capture individuals long after they enter the environment and are so-called *ghost nets*. Abandoned, lost, or otherwise discarded fishing gear (ALDFG), including nets, rope and other associated equipment, are particularly problematic and harmful to a range of biota (Wilcox et al. 2016). There is a significant lack of data concerning the amount of ALDFG which enters the marine environment, within local, regional, and global scales.

Despite significant public awareness regarding plastic pollution, the impact of plastics on marine mammals is poorly understood, especially at the population level. There is an urgent need to quantify the impact of plastics to understand the most common impacts, the scale of these impacts, which species are most affected, which types of plastics are most harmful, and identify the geographical areas in which species are most affected. Reviews addressing the impact of marine mammal debris ingestion and entanglement (Laist 1997; Gall and Thompson 2015; Weldon 2020) have been invaluable in highlighting impacts across the globe and developing and understanding of the field. We are now in need of regionally specific information regarding the current state of knowledge of marine mammal–debris interactions in order to develop baseline data, to initiate regional coordinated efforts and to be able to monitor the severity of impacts over spatial and temporal scales.

Here, using peer-reviewed scientific studies and reports from the grey literature, we compile incidences of debris ingestion and entanglement in marine mammals within the northeastern Atlantic region. We assess the current state of knowledge regarding marine mammal–debris interactions and provide recommendations for monitoring and research.

1.2 Methods

We collated instances of entanglement in and ingestion of debris within the scientific and grey literature. We used the search terms *plastic entanglement* and *marine mammals*, and keywords *marine, mammals, northern, Atlantic, debris, northern, Atlantic*, at ScienceDirect (https://www.sciencedirect.com/) and included all articles. We examined papers for data on entanglements and ingestion and used the primary source for our study, following references to their source material. Where we were unable to source the original document referenced to verify reports, we did not include their data, even when other authors had used and referenced these sources. We collected data from published studies and reports up to and including 30 May 2018.

We determined 37 species of marine mammals to be present within the northeastern Atlantic region (Table 1.1). These species were deemed to regularly occur within the region, as determined using the occurrence dataset at the Global Biodiversity Information Facility (https://www.gbif.org/). Included in the region were 7 species of pinnipeds (walrus and seals) and 29 cetaceans. The cetaceans comprised 8 species of Mysticetes (baleen whales) and 21 species of Odontocetes (toothed whales, including dolphins). Polar bear, *Ursus maritimus*, was also included. Information on the health of the global population of each species in the form of conservation status was sourced from the IUCN Red List (IUCN 2022).

Table 1.1 Species present within the northeastern Atlantic region, with their IUCN red list status, a species-specific global health indicator (IUCN 2022)

Group	Sub-grouping	Family	Scientific name	Common name	IUCN red list status
Carnivora		Ursidae	*Ursus maritimus*	Polar bear	Vulnerable
Carnivora	Pinnipedia	Odobenidae	*Odobenus rosmarus*	Walrus	Vulnerable
Carnivora	Pinnipedia	Phocidae	*Cystophora cristata*	Hooded seal	Vulnerable
Carnivora	Pinnipedia	Phocidae	*Erignathus barbatus*	Bearded seal	Least concern
Carnivora	Pinnipedia	Phocidae	*Halichoerus grypus*	Gray seal	Least concern
Carnivora	Pinnipedia	Phocidae	*Pagophilus groenlandicus*	Harp seal	Least concern
Carnivora	Pinnipedia	Phocidae	*Phoca vitulina*	Harbor seal, common seal	Least concern
Carnivora	Pinnipedia	Phocidae	*Pusa hispida*	Ringed seal	Least concern
Cetecea	Mysticeti (baleen whales)	Balaenidae	*Balaena mysticetus*	Bowhead whale, greenland whale	Least concern
Cetecea	Mysticeti (baleen whales)	Balaenidae	*Eubalaena glacialis*	North Atlantic right whale	Endangered
Cetecea	Mysticeti (baleen whales)	Balaenidae	*Eubalaena australis*	Southern right whale	Least concern
Cetecea	Mysticeti (baleen whales)	Balaenopteridae	*Balaenoptera acutorostrata*	Common minke whale	Least concern
Cetecea	Mysticeti (baleen whales)	Balaenopteridae	*Balaenoptera borealis*	Sei whale	Endangered
Cetecea	Mysticeti (baleen whales)	Balaenopteridae	*Balaenoptera musculus*	Blue whale	Endangered
Cetecea	Mysticeti (baleen whales)	Balaenopteridae	*Balaenoptera physalus*	Fin whale	Endangered
Cetecea	Mysticeti (baleen whales)	Balaenopteridae	*Megaptera novaeangliae*	Humpback whale	Least concern

(continued)

Table 1.1 (continued)

Group	Sub-grouping	Family	Scientific name	Common name	IUCN red list status
Cetecea	Odontoceti (toothed whales)	Physeteridae	*Physeter macrocephalus*	Sperm whale, cachalot	Vulnerable
Cetecea	Odontoceti (toothed whales)	Kogiidae	*Kogia breviceps*	Pygmy sperm whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Hyperoodon ampullatus*	Northern bottlenose whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Mesoplodon bidens*	Sowerby's beaked whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Mesoplodon europaeus*	Gervais' beaked whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Mesoplodon mirus*	True's beaked whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Mesoplodon densirostris*	Blainville's beaked whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Ziphiidae	*Ziphius cavirostris*	Cuvier's beaked whale, goose-beaked whale	Least concern
Cetecea	Odontoceti (toothed whales)	Monodontidae	*Delphinapterus leucas*	Beluga, white whale	Least concern
Cetecea	Odontoceti (toothed whales)	Monodontidae	*Monodon monoceros*	Narwhal	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Delphinus delphis*	Common dolphin, saddleback dolphin	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Globicephala macrorhynchus*	Short-finned pilot whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Globicephala melas*	Long-finned pilot whale	Data deficient

(continued)

Table 1.1 (continued)

Group	Sub-grouping	Family	Scientific name	Common name	IUCN red list status
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Grampus griseus*	Risso's dolphin, grampus	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Lagenorhynchus acutus*	Atlantic white-sided dolphin	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Lagenorhynchus albirostris*	White-beaked dolphin	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Orcinus orca*	Killer whale, orca	Data deficient
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Pseudorca crassidens*	False killer whale	Data deficient
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Stenella coeruleoalba*	Striped dolphin	Least concern
Cetecea	Odontoceti (toothed whales)	Delphinidae	*Tursiops truncatus*	Common bottlenose dolphin	Least concern
Cetecea	Odontoceti (toothed whales)	Phocoenidae	*Phocoena phocoena*	Harbour porpoise	Least concern

For each species, we recorded data on the number of individuals for which incidences of debris entanglement or ingestion were reported. We also record the year in which the individual was assessed, although this was not available for all reports, and in some instances only available as a date range. The type of debris (ingested or entangled) was recorded: we considered debris to be any item or material which does not naturally originate from the marine environment. We only included debris which were considered to be lost, abandoned, or derelict, and hence we omitted bycatch data which concerns active fishing efforts. Using the recommendations of Provencher et al. (2017) as a basis, we categorised debris as one of the following categories: threadlike (including ropes, nets, twine, and monofilaments), film (sheet-like plastics including single-use bags), hard (fragments and whole pieces), fishing hooks, and other (all other items including plastics and non-plastic items such as wood and metal). We included fishing hooks as a separate category following a review of the data and noticing multiple reports of this sector-specific debris. We did not find any reports of foam in our dataset, and therefore omitted this category from our study. Instances where the debris type was reported as unknown, where it was not reported, or we were unable to determine the type within the primary source, were categorised as unknown. The mass, size/dimensions, and colour of debris were very rarely reported and so we did not collate these metrics. Some studies omitted key information including the number of individuals affected and year of occurrence.

1.3 Results

1.3.1 Entanglement

Of the marine mammals occurring in the northeastern Atlantic, we found instances of entanglement in 38% of species (14 of 37 species; Table 1.2). 43% (3 of 7 species) of the pinniped species were recorded to have become entangled in debris (Fig. 1.1). When considering whales, we found reports of entanglement in debris within the region for approximately a third of species (34%; 10 of 29 species), with toothed whales displaying a higher abundance and proportion of entangled species (38%; 8 of 21 species) than baleen whales (25%; 2 of 8 species). The Polar bear was found entangled in debris in two studies, although it should be noted that for one of these reports debris was within the mouth, and may have been attempted ingestion, or exploratory behaviour.

In cases where entanglement was recorded, for most species it was from a single study or report (57%; 8 species), which included 1 species of pinniped, 1 baleen whale, and 5 toothed whales. There were 6 species for which entanglement was recorded in more than one study or report with species including 2 pinnipeds, 1 baleen whale, and 3 toothed whales.

Entanglement of marine mammals was predominantly and overwhelmingly a result of threadlike debris, in cases where the debris type was identified. Threadlike debris, which included ropes, nets, and monofilaments, was responsible for 97% (98 of 102 individuals) of entanglements and was reported for 14 different species. The remaining instances of entanglement were caused by film (1%, 1 individual, 1 species; Polar bear), and other types of debris (2%, 2 individuals, 2 species), whilst in 42 cases involving 1 species (Grey seal) the debris type was unknown.

Table 1.2 Summary information for marine mammal species where debris entanglement and/or ingestion have been reported in the northeastern Atlantic. Numbers indicate the number of individuals for which debris entanglement or ingestion was recorded

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Polar bear	Threadlike (1), Film (1)	2	Bergmann et al. (2017)	–	–	–	Svalbard	2	2016
Walrus	–	–	–	–	–	–	–	–	–
Hooded seal	–	–	–	–	–	–	–	–	–
Bearded seal	Threadlike (1)	1	Bergmann et al. (2017)	–	–	–	Svalbard	1	2016
Grey seal	Threadlike (33), Other (1), Unknown (42)	76	Allen et al. (2012), Unger et al. (2017), Sayer and Williams (2015)	Fishing hook (2), Other (1)	3	Unger et al. (2017)	UK, North Sea and Baltic Sea, Germany;	79	2004–2015
Harp seal	–	–	–	–	–	–	–	–	–
Harbour seal, common seal	Threadlike (6), Other (1)	7	Unger et al. (2017), Bergmann et al. (2017), Bravo Rebolledo et al. (2013)	Threadlike (2), Film (1), Hard (1), Fishing hook (3), Other (4)	10	Bravo Rebolledo et al. (2013)	North Sea and Baltic Sea, Germany, Svalbard	17	1997–2016
Ringed seal	–	–	–	–	–	–	–	–	–

(continued)

Table 1.2 (continued)

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Bowhead whale, Greenland whale	–	–	–	–	–	–	–	–	–
North Atlantic right whale	–	–	–	–	–	–	–	–	–
Southern right whale	–	–	–	–	–	–	–	–	–
Common minke whale	Threadlike (7)	7	Lusher et al. (2018), CSIP Annual Report (2015), CSIP Annual Report (2011), CSIP Annual Report (2010)	Film (1), Hard (1), Fishing hook (1), Unknown (1)	4	Baulch and Perry (2014), De Pierrepont et al. (2005), CSIP Annual Report (2011)	Ireland, Belgium, UK, France	11	1990–2015
Sei whale	–	–	–	Hard (1), Unknown (1)	2	Baulch and Perry (2014), CSIP Annual Report (2012)	UK	2	2005–2012
Blue whale	–	–	–	–	–	–	–	–	–
Fin whale	Threadlike (1)	1	Smiddy et al. (2002)	Threadlike (1)	1	Smiddy et al. (2002)	Ireland	1	2000

(continued)

Table 1.2 (continued)

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Humpback whale	–	–	–	Threadlike (1), Film (1), Hard (1), Unknown (1)	2	O'Brien et al. (2007), Besseling et al. (2015)	Ireland, Netherlands	2	2006–2012
Sperm whale, cachalot	Threadlike (2)	2	Lusher et al. (2018), CSIP Annual Report (2011)	Threadlike (1*), Hard (1*), Unknown (1)	3*	Baulch and Perry (2014), Martin and Clarke (1986), Lambertsen and Kohn (1987)	Belgium, Denmark Strait, Iceland	5*	1977–2015
Pygmy Sperm whale	–	–	–	Film (1), Hard (1)	2	CSIP Annual Report (2015), CSIP Annual Report (2014)	UK	2	2014–2015
Northern bottlenose whale	–	–	–	Threadlike (1), Film (1), Hard (4), Unknown (2)	7	Baulch and Perry (2014), CSIP Annual Report (2012), Fernández et al. (2014), Simmonds (2012)	UK	7	2005–2014
Sowerby's beaked whale	–	–	–	Hard (1), Unknown (1)	2	Berrow et al. (2010), Baulch and Perry (2014)	Ireland, UK	2	2005–2012

(continued)

Table 1.2 (continued)

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Gervais' beaked whale	–	–	–	–	–	–	–	–	–
True's beaked whale				Film (1), Hard (2) Unknown (1)	3	Gassner et al. (2005), Lusher et al. (2015)	Ireland	3	1997–2013
Blainville's beaked whale	–	–	–	–	–	–	–	–	–
Cuvier's beaked whale, goose-beaked whale				Threadlike (1), Film (4), Hard (1), Unknown (2)	7	Lusher et al. (2018), Baulch and Perry (2014), CSIP Annual Report (2015), CSIP Annual Report (2011), Santos et al. (2001), Simmonds (2012)	Ireland, UK	7	1999–2015
Beluga, white whale	–	–	–	–	–	–	–	–	–
Narwhal	–	–	–	–	–	–	–	–	–

(continued)

Table 1.2 (continued)

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Common dolphin, saddleback dolphin	Threadlike (22)	22	Lusher et al. (2018)	Threadlike (3), Film (1), Hard (11)	15	Lusher et al. (2018), CSIP Annual Report (2010)	Ireland, UK	37	2003–2015
Short-finned pilot whale	–	–	–	–	–	-	–	–	–
Long-finned pilot whale	Threadlike (3)	3	Lusher et al. (2018)	Film (1), Hard (1)	2	Laist (1997), CSIP Annual Report (2014)	Ireland, France, UK	5	1990–2015
Risso's dolphin, grampus	Threadlike (1)	1	Lusher et al. (2018)	Film (1), Fishing hook (1)	2	Lusher et al. (2018)	Ireland	3	1990–2015
Atlantic white-sided dolphin	Threadlike (1)	1	Lusher et al. (2018)	–	–	–	Ireland	1	1990–2015
White-beaked dolphin	–	–	–	Film (1), Unknown (2)	3	Baulch and Perry (2014), CSIP Annual Report (2015), CSIP Annual Report (2012)	UK	3	2005–2015

(continued)

Table 1.2 (continued)

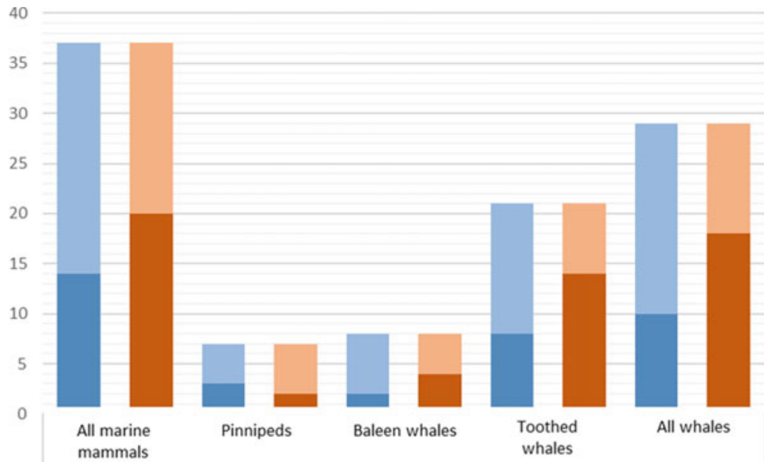
Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Killer whale, orca	–	–	–	Threadlike (1), Film (1), Hard (1), Fishing hooks (2), Unknown (1)	3	Baulch and Perry (2014), CSIP Annual Report (2012), CSIP Annual Report (2014)	UK	3	2005–2014
False killer whale	–	–	–	–	–	–	–	–	–
Striped dolphin	Threadlike (4)	4	Lusher et al. (2018)	Threadlike (1), Film (2), Hard (3)	5	Lusher et al. (2018), Hernández-Milián (2014)	Ireland	9	2002–2014
Common bottlenose dolphin	Threadlike (3)	3	O'Brien and Berrow (2007), Lusher et al. (2018)	Film (1), Hard (2), Other (1), Unknown (1)	4	Lusher et al. (2018), Baulch and Perry (2014)	Ireland, UK	7	2005–2014

(continued)

Table 1.2 (continued)

Species	Entanglement debris	Incidences of entanglement	Entanglement reference (s)	Ingested debris	Incidences of ingestion	Ingestion Reference(s)	Location	Total incidences	Year
Harbour porpoise	Threadlike (14)	14	Unger et al. (2017), Marine Stranding Network (2015)	Threadlike (5), Film (5), Hard (13), Fishing hook (1), Other (1), Unknown (14)	33	Unger et al. (2017), Lusher et al. (2018), Baulch and Perry (2014), Kastelein and Lavaleije (1992), CSIP Annual Report (2011), CSIP Annual Report (2010), CSIP Annual Report (2009), Hernández-Milián (2014)	North Sea and Baltic Sea, Germany, Ireland, UK, Netherlands	47	1991–2015

The number of individuals that were reported to be entangled in, or having ingested, different types of debris (threadlike, film, hard, fishing hook, other, or unknown) is also presented. Individuals may have ingested more than one type of debris; hence, the total number of individuals is not necessarily equal to the sum of individuals per debris type. Asterisk (*) indicates that the number of individuals was likely higher, but the actual number was not reported in the source material



	All marine mammals		Pinnipeds		Baleen whales		Toothed whales		All whales	
No report	23	17	4	5	6	4	13	7	19	11
Incidence reported	14	20	3	2	2	4	8	14	10	18

Fig. 1.1 Number of species for which entanglement in (dark blue) and ingestion of (light orange) debris have been reported within the northeastern Atlantic region, using data compiled from studies in Table 1.2

The number of species for which there were no reports found are displayed for entanglement (light blue) and ingestion (light orange). Species are categorised as pinnipeds, baleen whales and toothed whales (Table 1.1), whilst all whale species (baleen and toothed whales) and all marine mammals are also displayed. At the bottom, the total number of species for which there was no report found, and where an incidence was reported for each category is displayed.

1.3.2 Ingestion

We found that just over half of marine mammal species in the northeastern Atlantic (54%; 20 of 37 species) were reported to have ingested debris. For 29% of pinnipeds (2 of 7 species) there were recorded instances of debris ingestion. Meanwhile 62% of whale species (18 of 29 species) had ingested debris within the region, which corresponds to half of baleen whales (50%; 4 of 8 species), and two-thirds of toothed whales (67%; 14 of 21 species). Although there was one report of a Polar bear with debris within its mouth, we could not ascertain whether the debris was ingested, either deliberately or accidently, and therefore this report was included within the entanglement category. Consequently, we did not find a report of Polar bears ingesting debris with the region.

Where species were recorded to have ingested debris, in the vast majority of cases there was more than one report (80%; 16 of 20 species), including for 3 baleen whales, 13 toothed whales, but no species of pinnipeds. There were 4 species (20%) where ingested debris was reported in a single study, including 2 pinnipeds, 1 baleen whale, and 1 toothed whale.

Individuals found to have ingested debris, and where debris type was identified, we found that plastic fragments were the dominant debris type, being present in 45% of cases (44 of 98 individuals). Film was found in 23% of individuals that ingested debris (23 individuals, 15 species), with threadlike debris in 17% (17 individuals, 10 species), fishing hooks in 8% (8 individuals, 6 species), and other debris types in 6% (6 individuals, 4 species). There were 29 cases where the debris type was not determined or reported.

1.3.3 Entanglement and Ingestion

There were 12 species for which there was evidence of debris ingestion and entanglement, including 2 pinnipeds (Grey seal and Harbour seal) and 10 cetaceans (baleen whales: Common minke whale, Fin whale; toothed whales: Sperm whale, Common dolphin, Long-finned pilot whale, Risso's dolphin, Atlantic white-sided dolphin, Striped dolphin, Common bottlenose dolphin, and Harbour porpoise). We found no reports of entanglement in, or ingestion of, debris in 38% (14 of 37) of species that occur in the northeastern Atlantic (Fig. 1.2). For 14% of species (5 of 37) entanglement or ingestion of debris was recorded in a single study or report within a single location, whilst in 19% of species (7 of 37) incidences were from more than one report, from a single location. The remainder of species (30%; 11 of 37) had multiple reports of entanglement and/or ingestion of debris from more than one location.

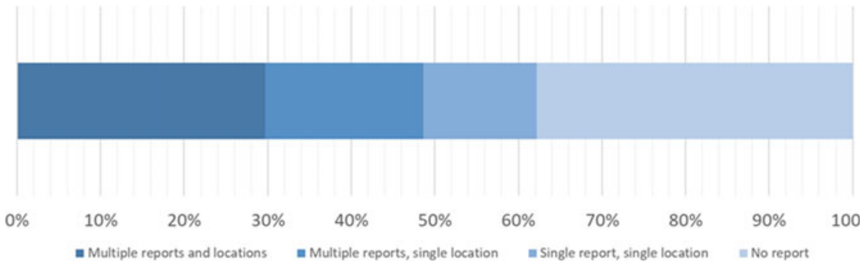


Fig. 1.2 Proportion of reports of debris entanglement or ingestion in marine mammals categorised according to the number of reports and locations for each of the 37 species in the northeastern Atlantic region, using data compiled from studies in Table 1.2

There were 11 distinct locations which were associated with reports of debris entanglement or ingestion by marine mammal species in the northeastern Atlantic region: UK, Ireland, Germany, Netherlands, Iceland, Denmark Strait, North Sea, Baltic Sea, Svalbard, Belgium, and France. Reports from both the UK and Ireland each included 13 species associated with entanglement or ingestion of debris, which were the joint equal, highest number of species across the 11 regions.

1.4 Discussion

Marine debris is having an impact on a significant proportion of marine mammal species within the northeastern Atlantic, with 62% of the 37 species present in the region reported to have either ingested or become entangled in debris. Marine mammals are facing a multitude of pressures including, but not limited to climate change, depletion of prey (e.g. through overfishing), habitat destruction, and noise and chemical pollution. Therefore, any impact of marine debris will add to the suite of pressures already faced by marine species, which is particularly important for the more highly endangered species. Both Sei whale and Fin whale are classified as endangered according to the IUCN Red List (IUCN 2022), and both were reported to have ingested and become entangled in debris. Meanwhile, Polar bears and Sperm whales are classified as vulnerable according to the IUCN Red List (IUCN 2022), with the latter species reported to have both become entangled in, and ingested debris. Given the evidence of interactions with debris and their conservation status, we recommend a comprehensive monitoring programme and assessment of the risk of debris to Sei whales, Fin whales, Sperm whales and Polar bears to better understand the level of impact with the northeastern Atlantic, and how this changes spatially and temporally.

The predominance of threadlike debris as the primary cause of marine mammal entanglements is unsurprising since nets, ropes, and monofilament are designed to capture marine biota. Presumably, the majority of this material is derived from fishing activity, which can enter the marine environment either deliberately or by accident. Threadlike debris has been assessed to be one of the most harmful types of marine litter and causing the most damage to marine animals (Wilcox et al. 2016). Our study reiterates the impact of threadlike debris on individuals, with reports of entanglement in more than a third of mammal species (14 of 37 species) in the northeastern Atlantic. To reduce the impact of threadlike debris, it is important to reduce the flow of material into the marine environment. Both behavioural and technological changes may be needed for a comprehensive reduction in both deliberate and accidental inputs. The marking of fishing gear to identify the user, and the introduction of European Union (EU) legislation, particularly around the extended producer responsibility (EPR) scheme of the EU Single Use Plastic Directive may assist efforts to reduce threadlike debris in the environment. In addition, organised and ad hoc volunteer beach clean efforts remove a significant mass of debris, including threadlike material. This helps prevent debris entering or reentering marine waters and particularly reduces the risk of seal species interacting with debris on beaches, for instance at haul out sites, and during pupping.

The dataset compiled in this study is likely to be an underestimate for several reasons. It is possible that studies and reports containing instances of debris ingestion or entanglement fell outside our search criteria. A limitation of our study is that it was conducted only in English, which potentially excludes those in one of the other primary languages within the region. The presence of marine mammal–debris interactions reported in languages other than English may be pertinent to the grey literature, where reports are frequently compiled for environmental charities, governmental departments, and non-governmental organisations (NGOs) in native languages. This represents a potential gap, and presents an opportunity for future studies. In addition, there are likely to be a significant number of ad hoc incidences of entanglement of marine mammals in non-published sources. For instance, volunteers beach clean-up programmes may record but not publish such incidences, whilst there may be a significant number of reports made by members of the public on social media. These sources could be used in the future to complement published data on marine mammal entanglements. To assist the collection of ad hoc data, we recommend the use of citizen/community science, which also has the benefit of raising awareness and public engagement. Crowdsourcing websites such as https://www.wildlifeanddebris.com can be used to collate reports of entanglement in debris across the globe. Although ingestion of debris by deceased and decomposing marine mammals may be observed, instances are likely to be fewer than for cases of entanglement, and more difficult to verify.

Ingestion of debris was reported in over half of the species present in the north-eastern Atlantic, and from our dataset appears to occur in more species that entanglements. The major difference here was the higher number of species of toothed whales reported to have ingested debris in comparison to those that have become entangled (14 and 8 respectively). It is perhaps surprising however that ingestion of debris was found in a higher proportion of toothed whales than baleen whales (67 and 50% respectively). Baleen whales are filter feeders, and so we might expect plastics and other debris to be ingested as they intake significant volumes of water during feeding. Toothed whales are carnivorous, active predators, whose diet consists primarily of fish, squid, and for some species other marine mammals such as seals and otters. We would perhaps expect toothed whales, with a selective feeding behaviour to ingest less debris than the more passive and indiscriminate feeding method of baleen whales. Although debris consumed by prey, such as fish, may be passed on to toothed whales when predated, we may expect this to occur to a greater extent with smaller items such as microplastics (items <5 mm in size). One possible explanation is that in some instances toothed whales intentionally consume debris after mistakenly identifying it as prey. Species of turtles known to consume gelatinous prey are also found to consume marine debris, especially film-type debris, such as plastic bags (Mrosovsky et al. 2009; Schuyler et al. 2013). Evidence suggests that turtles preferentially consume debris resembling jellyfish (Schuyler et al. 2014), with Green turtle (*Chelonia mydas*) and Loggerhead turtle (*Caretta caretta*) ingesting prey in 61.8 and 16.7% of encounters respectively (Fukuoka et al. 2016). Although toothed whales may mistake squid, a key prey for this group, for film debris, the use of sophisticated sonar in hunting is likely to reduce this rate of consumption. Other explanations for the greater number of species of toothed whales identified as ingesting debris in comparison to baleen whales is that toothed whales may feed in regions (either geographically or within the water column) within the northeastern Atlantic with higher densities of debris, or that they are more likely to die, and become available for necropsy, as a result of debris ingestion. We are currently unable to verify these suggestions, but these could form hypotheses for future studies.

Climate change is causing changes in the distribution of marine species including many fish, which require specific temperatures to live and breed in. The current and predicted northward shift of spawning grounds and distribution, for example of Atlantic cod (*Gadus morhua*) and Atlantic mackerel (*Scomber scombrus*) (Drinkwater 2005; Bruge et al. 2016), will consequently result in a shift in active fishing areas. Unless changes are implemented to further prevent the loss of ALDFG, then it is likely that we will observe more items of debris lost in more northernly regions. Therefore, entanglement of marine mammals may increase in the coming years and decades in the northeastern Atlantic region as their own distribution changes to track prey, and because of increased fishing and associated ADFLG loss in the region.

We observed a great deal of inconsistency regarding the reporting of marine mammal–debris interactions. In the majority of cases, information regarding debris colour, mass, and dimensions was absent. In addition, some reports omitted the number of individuals impacted, and/or the year in which the interaction was recorded. These omissions highlight the need for a standardised approach to recording debris interacting with marine mammals. We recommend following the suggested guidelines in Provencher et al. (2017), with the addition of fishing hooks as a separate category. We noted fishing hooks were ingested by 8 individuals from 6 species, and whilst this was not the most dominant type of debris ingested, we recommend its separate inclusion given the direct link to fishing and the potential for significant harm inflicted on individuals. Using a standardised approach to recording debris in interactions with marine mammals allows comparative studies across regions and time. Standardised approaches may allow an assessment of the effectiveness of initiatives and legislation aimed at reducing marine debris, and, potentially, of the effectiveness of clean-up operations. They also allow the identification and quantification of the most prevalent types of debris interacting with species and offers the potential for identifying the source of debris, which can be difficult given the distribution of debris through ocean currents. Indeed, even entangled individuals can travel large distances before stranding on shorelines. Figure 1.3 shows a dead juvenile Humpback whale entangled in ropes, with a buoy attached, which was associated with a lobster fishery in Nova Scotia, Canada. This individual washed up on the north coast of Scotland, and therefore may have travelled approximately 4000 km.

Whilst marine debris is impacting marine mammals, causing injury and death to individuals, it is difficult to ascertain population level effects. To better understand the severity of the threat to marine mammals, a coordinated and international monitoring and reporting scheme is needed. We support the approaches of collaborative projects

Fig. 1.3 A juvenile Humpback whale entangled in threadlike debris, Scrabster beach, Scotland, May 2019. The debris was identified as coming from a lobster fishery in Nova Scotia, Canada, approximately 4000 km away where the individual landed. Photograph by the author

such as the Global Ghost Gear Initiative, and Scottish Entanglement Alliance (SEA), which aims to understand, mitigate, and raise awareness of marine animal entanglements in Scotland, whilst engaging with the inshore fishing industry. It is important that approaches to reducing the quantity of marine debris, and the frequency of interactions with wildlife, are collaborative and include relevant stakeholders including fishers, port authorities, NGOs, government, scientists, and the community.

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Chapter 2
A Conceptual Framework for Assessing and Managing Abandoned, Lost and Discarded Fishing Gear

Arron Wilde Tippett

Abstract Abandoned, lost or otherwise discarded fishing gear (ALDFG) is a complex problem that causes negative ecological, economic and social impacts. In order to understand cause-and-effect chains spanning socio-economic and ecological systems and identify and assess potential improvement measures, a holistic approach is necessary. In this chapter, we introduce a framework for assessing ALDFG and aquaculture gear from commercial fishing and fish farming activities in Norway. The proposed framework integrates the Drivers, Pressures, States, Impacts and Responses (DPSIR) framework with ecosystem accounting, to assess impacts and improvement measures more holistically and explicitly. The framework includes indicators for each aspect, derived from international and national frameworks and data sets. Drivers and pressures are related to existing data sets on fishing and aquaculture production and ALDFGs, whereas the ecosystem accounting framework is used as a lens for developing the state and impact aspects of the model. A leverage points view of circular economy solutions to the problem of ALDFG is taken for the Responses aspect of the model.

Keywords ALDFG · Circular economy · Leverage points · Ecosystem services · DPSIR framework

2.1 Introduction

Marine and coastal ecosystems are under increasing pressure from pollution and over-exploitation of resources driven by industries such as fishing and aquaculture (IPBES 2019). These drivers and pressures are inhibiting the planet's ability to provide a safe operating space for humanity (Barbier 2017; Bratman et al. 2019; Orth et al. 2020). In Norway alone, coastal areas and oceans are estimated to provide between 12,000 and

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14,000 million Euros of ecosystem services per year (Skre 2017). However, these services are being impacted by pollution of ocean and coastal areas with plastic fishing and aquaculture gear. It is estimated that 380 tonnes of plastic waste from commercial fishing enter Norwegian waters each year (Deshpande et al. 2020).

Abandoned, lost or otherwise discarded fishing gear (ALDFG) are dispersed throughout marine habitat biomes and can impact a range of ecosystem services (ES). In the water column, ghost fishing by ALDFG can impact fish populations for several months before they become a feature of the sea floor where they are found to disturb important nursery areas for fish (Brown and Macfadyen 2007; Laist 1997). ALDFG on beaches and other coastal habitats are now a common feature across Norway. This can reduce the aesthetic value of coastal areas as well as having an impact on the biochemical flows within sediments.

There are currently several policies and measures in place to help manage ALDFGs. In this chapter, a framework to assess and manage ALDFG is presented, as a tool to link and trace drivers, activities, pressures, states, impacts and responses in a holistic manner. The framework includes aspects and indicators that help structure, monitor and manage key elements.

2.2 Background and Key Concepts

The proposed framework builds on several key concepts and frameworks briefly introduced in this section.

2.2.1 DPSIR

Drivers, Pressures, State, Impact, Response (DPSIR) is an internationally recognised, holistic framework, to provide an understanding of the cause-and-effect associations between human activities and the natural environment. The origins of DPSIR can be found in the OECD's (Organisation of Economic Co-Operation and Development) PSR (Pressure, State, Response) framework (OECD 1994). PSR was designed to provide structure for the OECD's environmental policies and reporting. The flexibility of PSR has meant that other international institutions have been able to adapt the framework to their own requirements, such as the Driver-Pressure-State-Impact-Response (DPSIR) developed by the European Environmental Agency (EEA 1999). DPSIR is now used at multiple levels of governance from the EU and OECD to small communities. Table 2.1 provides a description of the constituent parts of the DPSIR framework and the more recent DAPSIR-ALDFG framework (Drivers-Activities-Pressures-State-Impact-Response.

DPSIR has proved to be a powerful tool for understanding causal relationships between human developments and the natural environment. However, certain conceptual changes to the framework have been required to operationalise the framework at

Table 2.1 Responses and leverage points for managing ALDFG in fisheries and aquaculture

Leverage points, listed in increasing level of effectiveness (Meadows 1999)	Example of response measure	Increased stocks and flows	Reduced stocks and flows
12. Constants, parameters, numbers (such as subsidies, taxes, standards)	Beach and ocean clean-ups	F4	S2
11. The sizes of buffers and other stabilising stocks, relative to their flows	Support for increased gear repair and reuse	F1	F3
10. The structure of material stocks and flows (such as transport networks, population age structures)	Port reception facilities	F2, S3	F3
9. The lengths of delays, relative to the rate of system change Gear redesign: biodegradeable		S3?	S3?
8. The strength of negative feedback loops, relative to the impacts they are trying to correct against	Gear retrieval regulation/practices (time spent retrieving lost gear reduces time for commercial fishing)	F2, S3	F3, S2
7. The gain around driving positive feedback loops	Reward schemes, such as, e.g. gear payback systems	F2, S3	F3, S2
	Reward schemes (or raw material prices) to incentivise products with recycled content from fisheries and aquaculture	F7, S6	F3–F6
6. The structure of information flows (who does and does not have access to information)	Public records of gear material balance	F2	F3
	Ecolabels of new products with recycled content	F5, S4	F3–F6
5. The rules of the system (such as incentives, punishments, constraints)	Extended producer responsibility	F1, F2, F4–F7, S3–S6	F3, S2
4. The power to add, change, evolve, or self-organise, system structure	Circular economy and business models	All	All
3. The goals of the system			
2. The mindset or paradigm out of which the system arises (goals, structures, rules)			
1. The power to transcend paradigms			

lower levels of governance. The initial improvement to the framework was suggested by Cooper (2013), who aimed to link the different aspects of the DPSIR framework by providing slight elaborations on their definitions. Cooper finds that the original DPSIR framework does not allow for direct relationships between the five aspects of the framework. For example, the Drivers aspect, initially conceived as "social, demographic or economic developments in societies" (Cooper 2013), is too broad to allow for a direct coupling with the Pressures aspect of the framework. He further suggests that the Drivers category should be defined as "an activity or process intended to enhance human welfare" and can be broken down into two categories: distinct Drivers, "activities proximal to at least one Pressure"; and Underlying Drivers, social or economic developments, identical to the Drivers in the original framework. This elaboration allows each distinct driver to be linked to at least one pressure, allowing for the highlighting of causal relationships between these two aspects of the framework.

Elliott et al. (2017) furthermore make a clearer distinction between the two types of Drivers by adding the Activities aspect, which replaces the Distinct Drivers from Cooper's (2013) framework. The Pressures aspect of the framework is coupled to both the Activity and the State (change) by the two authors (Cooper 2013; Elliott et al. 2017). Pressures are defined as those aspects which are caused by at least one Activity that contribute to a change in the State. The next part of the framework is State (change) (Atkins et al. 2011). Cooper (2013) defines State as "an attribute or set of attributes of the natural environment that reflect its integrity regarding a specified issue". Elliott et al. (2017) suggest using a framework similar to Natural Capital Accounting here, whereby changes to ecosystems and the ecosystem services they produce should be used as proxies for the state. This leaves the benefits from the ecosystem services as the logical measure for the Impacts (Welfare) in the Elliott et al. (2017) framework. Responses (Measures) are the final part of the framework and relate to actions that can be taken to positively change the system. Elliott et al. (2017, p. 38) recommend that each measure should address one or more of the 10 tenets for successful environmental management, which state that measures should be: ecologically sustainable, technologically feasible, economically viable, socially desirable, legally permissible, administratively achievable, politically expedient, ethically defensible, culturally inclusive and effectively communicable.

2.2.2 Natural Capital Accounting

Natural capital is now recognised as integral to the World Economy (Barbier 2019) and attempts are being made to standardise and integrate natural capital accounting into the System of National Accounts (SNA) (UN 2021) and business decision-making frameworks (Natural Capital Coalition 2016). Natural capital is made up of three main components: subsoil assets, such as minerals and fossil fuels; abiotic flows, such as wind and solar energy; and ecosystem capital, made up of ecosystems and the services that flow to us and create value (Maes et al. 2013). Generally, economic activity has prevailed at the cost of natural capital. Nevertheless, economics is now viewed as a solution to natural capital loss by providing a frame for natural capital valuation (Polasky and Daily 2021). An important concept associated with natural capital is ecosystem services (ES). This concept details the flow of contributions from natural systems to humans, such as global and local climate regulation, coastal protection, water purification and air filtration. It is more than twenty years since Costanza et al. (1997) estimated that ES were worth an average of US$33 trillion per year globally. Researchers have since been trying to understand, and value, the multiple contributions that we receive from nature (IPBES 2016, 2019; Millennium Ecosystem Assessment 2005; TEEB 2010). More recently, ES assessments have moved towards the spatial distribution of both the flow of services and the ecosystem stocks, using accounting methodologies. The most significant development has been the publication of a full ecosystem accounting framework by the United Nations (2021). It is hoped that this framework will provide policy and decision makers with the data that they need to incorporate ecosystem stocks and service flows into their planning decisions. The process results in the development of accounts for a certain geographically bound system. The ecosystem extent account provides a tabular description of the hectares of each ecosystem type within the system. The ecosystem condition account describes the condition of each ecosystem within the ecosystem extent account. The condition can be measured by assessing the pressures, generally in terms of pollutants or land use change, on the ecosystems within the system. A full natural capital account, consisting of the ecosystem extent, ecosystem condition and ecosystem service flows can contribute to a range of aspects of the DAPSIR-ALDFG framework.

2.2.3 Circular Economy

The Circular Economy is described by Kirchherr et al. (2017) as

> An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling, and recovering materials, or energy, in production/distribution and consumption processes… with the aim to accomplish sustainable development… It is enabled by novel business models and responsible consumers.

The roots of the Circular Economy concept can be found in a range of academic disciplines, such as Ecological Economics and Industrial Ecology (Bruel et al. 2019). One of the first Ecological Economists, Kenneth Boulding, coined the phrase the *cowboy economy* to describe the current system of economics where supposed limitless resources can be exploited recklessly and success is measured on the throughput of resources through the system (Boulding 1966). Boulding proposes an alternative economy, the *spaceman economy*, as a more realistic view of our interaction with the environment. The *spaceman economy* is more similar to what we now call the Circular Economy: resources are limited and a cyclical reproduction of materials is necessary, albeit with the inevitable loss of energy from the system. The success criteria for the *spaceman economy* is based on the quality, and extent of capital stocks, rather than the throughput of resources. Recent conceptions of the Circular Economy are less radical than Boulding's proposal of changing our entire economic system. Rather, the Circular Economy has been designed to fit within our current economic system and to improve our use of resources and reduce externalities, in the form of pollution. The Circular Economy is thus more a set of principles that can be followed by individuals, organisations and institutions, in order to help them to reduce their environmental footprint (Kirchherr et al. 2017).

2.2.4 Leverage Points Analysis

Meadows (1999) developed the leverage points analysis to highlight "places to intervene in a system". The analysis interventions are divided in those which will have a deep system impact and those which will have a shallow impact. For example, changing the goals of a system is viewed as a deep leverage point, whereas changing the strength of feedback loops within a system is viewed as a shallow leverage point. Recent reviews assessing the use of leverage points have highlighted that mainly shallow leverage points are addressed, and therefore, we now have to focus on deeper leverage points in order to affect valuable changes. In this chapter, leverage points are used to categorise various responses within the DPSIR model to highlight the type of impact on the system they are likely to have.

2.2.5 Sustainability Indicators

Four of the main types of indicators used for Sustainability assessments are descriptive, performance, efficiency and welfare (EEA 1999). Descriptive indicators are used to describe the actual situation. For example, a descriptive indicator for the activity of the aquaculture industry could be the exported fish per year. A performance indicator is normally developed against a policy or a regional/national target and provides an indication of the distance of the current situation from the target. Efficiency indicators are those which assess the interaction between different aspect. This type of indicator would help to show how changes in technologies or policies effect different aspects of a system. Finally, welfare indicators are those which tell us whether we are better off. Typically, this would be gross domestic product (GDP), but this is limited to economic welfare; therefore, we may want to use an indicator which captures more of the natural environment, such as Gross Ecosystem Product (GEP) (Ouyang et al. 2020), the economic contribution of ecosystems to society.

2.3 The DAPSIR-ALDFG Framework

The DAPSIR-ALDFG framework combines the introduced concepts into a joint framework to assess and manage ALDFG. The framework builds on the DPSIR indicator system to accommodate a traceable and measurable linkage between drivers, activities, pressures, states, impacts and responses in the fisheries and aquaculture sector and associated production systems. Figure 2.1 shows an outline of the framework from a systems perspective. The framework encompasses both physical and non-physical elements within these systems, such as ecosystems (physical) and policy measures (non-physical). In the following sections, aspects and indicators of the framework will be elaborated.

2.3.1 Aspects

Several aspects are based upon the themes presented earlier in this chapter, such as natural capital accounting and circular economy.

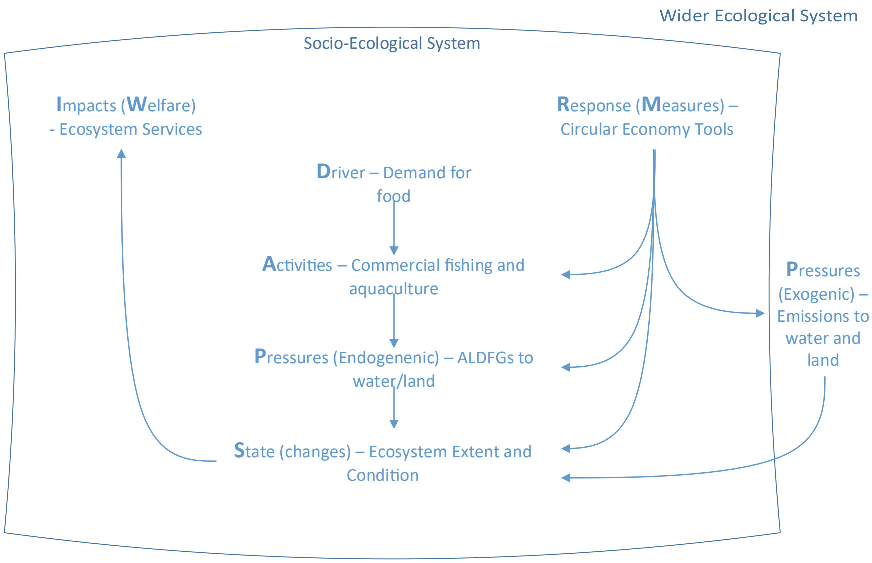

Fig. 2.1 DAPSIR-ALDFG framework. Modified from Cooper (2013), Elliott et al. (2017)

2.3.1.1 Drivers

A driver is a broad human activity that enhances human welfare (Cooper 2013) or our basic human needs (Elliott et al. 2017). In the case of ALDFG, the demand for fish is the main driver. In the study by Skirtun et al. (2022), they formulate the driver as "global seafood demand and a stable wild-capture production", they use statistics from a private company, Det Norske Veritas (DNV). In this study, we take global seafood demand as the main driver and suggest the OECD-FAO projections on the demand for aquaculture and fish products. OECD (Organisation for Economic Co-operation and Development) and FAO (Food and Agriculture Organisation of the United Nations) are international organisations which have been working internationally for over 60 years in the pursuit of prosperity and the defeat of hunger respectively. The OECD et al. (2022) outlook reports provide us with a projection of the demand for fish over the next 30 years. These reports can help us to understand the direction of travel of the commercial fishing and aquaculture. This may indicate whether the ALDFG and aquaculture gear issues will increase or decrease in the coming years.

2.3.1.2 Activities and Subactivities

Activities are broken down into aquaculture and capture fisheries in Norway. This links with the driver of food demand as we would expect a positive effect of demand for food globally on the production of fish from aquaculture and fisheries.

The subactivities associated with the activities are the large parts of the fisheries and aquaculture industry. For aquaculture, we consider salmon production and for fisheries, different types of fishing gear. The activities link to the pressures which are the abandonment, loss or discard of fishing or aquaculture gear in the marine environment. Subactivities include fishing/aquaculture in adverse weather conditions (Skirtun et al. 2022), fishing crew training (poor maintenance of fishing gear) and damage by wildlife, as described by Richardson et al. (2021).

2.3.1.3 Pressures

Each sub activity results in specific pressures on the biotic and abiotic environment resulting in a change in the state. The pressures are divided into the different fishing and aquaculture gear discarded into the marine environment. The pressures in this case are divided into the different OSPAR categories of marine waste (Lacroix et al. 2022) as these are used for data collection or beach cleans. This means that the pressures can be linked to on-going studies about the abundance of different types of fishing and aquaculture gear which is found on beaches, giving a long-term estimate of the pressure that such gear is putting on the environment.

One aspect missing from the pressures here is the limit or reference value for the type of gear: how much of the gear in the natural environment can be present before its state changes significantly? And what about the welfare that is derived from the natural environment?

2.3.1.4 State

The ecosystem accounting framework is used here to describe the state (change). Ecosystem accounting begins with the calculation of the extent, and then the condition, of each ecosystem type. In this case, we have used the IUCN framework to describe coastal and marine ecosystems (Keith et al. 2020). We suggest that the condition of each ecosystem can be calculated using the volume of ALDFG or aquaculture gear in each ecosystem. It will be important to decide on reference values for these condition variables in order to determine if an ecosystem is in optimal or suboptimal condition. Reference values can be calculated in a number of ways, using protected areas, expert elicitation, etc. In the case of plastics, these are now ubiquitous (Villarrubia-Gómez et al. 2018) and as such, it is difficult to find a perfectly intact marine or coastal environment unaffected by plastics.

The state of the biotic and abiotic marine and coastal environments are all affected by pressures from ALDFG. The condition of different ecosystem types is affected by the addition of ALDFG; therefore, we require data on both the extent and condition of each relevant ecosystem type. The abiotic environment, including the water column, subsea sediment and soil substrates are all affected by ALDFG.

2.3.1.5 Impact

Ecosystem services are used to describe the impact on welfare as a result in state changes. Ecosystems provide bundles of services to human beings (Klain et al. 2014). A change in the extent or condition of ecosystems, can thus have a multitude of effects on the services that they can provide (Grizzetti et al. 2019). An appropriate indicator here may be the Gross Ecosystem Production (in NOK) per hectare of ecosystem type (Ouyang et al. 2020).

Ecosystem services break down into three broad categories, provisioning, regulating and cultural services (Haines-Young and Potschin-Young 2018). These services provide different benefits to us such as, food provisioning, climate control, and recreational opportunities respectively.

The cascade model of ecosystem services (Haines-Young and Potschin-Young 2018) proposes that ecosystems in good condition, provide certain ecosystem services from which we benefit. Interference with the condition of ecosystems can result in changes to the ecosystem services and thus the benefits that we receive. There are multiple links between marine plastic and ecosystem condition/ecosystem services (Beaumont et al. 2019). Here we identify a number of the impacts from ALDFG or aquaculture gear.

Impact on Provisioning Services

ALDFG nets in the Marine and Marine/Terrestrial (coastal) environments can result in reductions in ecosystem services, and thus, our welfare. Once lost in the water column, nets can continue to catch fish for months reducing the potential catch for commercial fishermen (Macfadyen et al. 2009). Fishing gear is also associated with increased costs of commercial fishing due to entanglements, damage to gear and loss of operating time, these costs amounted to over 1 million pounds of losses for Scottish fishermen (Riddington et al. 2014).

Impacts on Cultural Services

Nature-based tourism around bird watching can bring large economic benefits to rural areas (Schwoerer and Dawson 2022). Debris from fishing and aquaculture activities can also impact on bird species: Ingestion of plastics can result in the reduction in fitness of individual birds and furthermore reduce their ability to rear young (Browne et al. 2015).

Culturally important animals, such as whales, are known to be particularly vulnerable to entanglement due to the their feeding behaviour and morphology (Saez et al. 2021).

In the Marine/Terrestrial environment ALDFG impact on the aesthetic value of coastal areas, reducing associated cultural ecosystem services (Leggett et al. 2018). Moreover, it is often volunteer groups responsible for cleaning beaches (Cyvin et al. 2021) resulting in hours of unpaid labour and exposure of vulnerable groups to potentially contaminated and hazardous debris (Campbell et al. 2016).

Impacts on Regulating Services

Coral reefs are important nurseries for young fish, which will be the source of fish catch in the future. Derelict nets often accumulate on reefs (Chiappone et al. 2002) and can result in physical damage to coral reefs (Al-Jufaili et al. 1999). Paradoxically, the removal of nets from coral reefs is also associated with considerably damage to the reef structure (Donohue et al. 2001) Moreover, fishing gear can also act as reefs in themselves, providing additional complexity to the habitat (Erzini et al. 1997).

2.3.1.6 Response

Responses (Measures) are those attempts by individuals, groups, municipalities or governments to "prevent, compensate, ameliorate or adapt to changes in the state of the environment" (EEA 1999). To illustrate this, we use the leverage points framework by Meadows (1999) to describe various responses or measures that could help impact different aspects of the DAPSIR-ALDFG model. As the leverage point analysis follows a systems perspective, Fig. 2.2 is presented to provide a reference for which elements within the fisheries and aquaculture system and end-of-life treatment responses target. Although a more detailed systems perspective could have offered

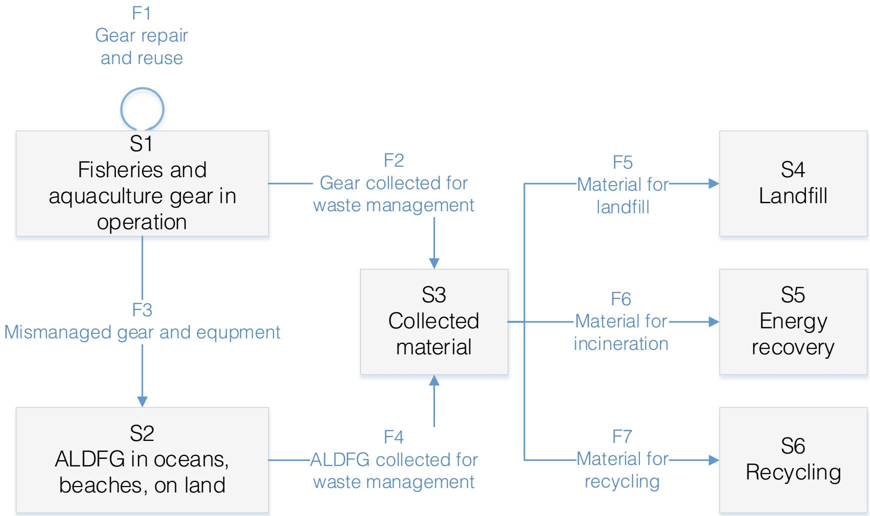

Fig. 2.2 Fisheries and aquaculture system with respect to ALDFG and gear management. F = flows, S = stocks

a more elaborate discussion of responses, a reduced model is used to illustrate the main points.

Figure 2.2 shows stocks and flows of fisheries and aquaculture gear and equipment. Activities and subactivities in fisheries and aquaculture involve gear in use (S1). Gear is frequently repaired and reused directly (F1), extending their time in operation. Gear is delivered for further waste management (F2) at ports and other collection points (S3). Gear loss due to for example weather conditions or gear conflicts, as well as gear dumping generates a flow (F3) of ALDFG in nature (S2). Ocean and beach cleanup activities may retrieve parts of this gear (F4) for storage, sorting and waste management (S4). Collected gear and ALDFG will be sorted and further processed depending on their condition, value and available technology and infrastructure. Possible end-of-life options involve landfill (F5, S4), incineration and energy recovery (F6, S5) and ideally recycling (F7, S6).

To consider responses for managing gear from fisheries and aquaculture more efficiently, we will analyze them according to which type of leverage points they target in the described system. Table 2.1 shows the 12 leverage points introduced by Meadows (1999), listed in increasing order of effectiveness.

At the lowest level, we find responses that target constants, parameters and numbers. Although several examples could be listed here, ocean and beach cleanups are good examples of such measures. Although they are critical to mitigate problems arising from ALDFG, they are not effective at targeting the original problems, which is gear loss and dumping. Targeting buffers and other stocks, such as supporting increased repair and recycling (flow F1 in Fig. 2.2), may for instance discourage gear dumping activities. This could be done through a number of measures, e.g. training and education or introducing taxes and fees on gear.

Port reception facilities is another response that discourages gear dumping by introducing infrastructure that facilitates more efficient collection of gear. This would not only discourage dumping but also increase the incentive to retrieve lost gear in capture fisheries as it could minimise the time gear which is not in operation occupies space on board vessels.

Gear redesign to reduce the impact of gear once it is lost or dumped could delay the time between gear becoming mismanaged (ALDFG) and negatively affecting ecosystem services. If efficient, this measure would reduce stock S2 (ALDFG in nature) without necessarily affecting flows in and out of that stock. However, caution should be made with respect to these types of measures as they may quickly incentivise more gear dumping, thereby increasing both flow F3 and stock S2.

Extended producer responsibility is an important, systemic response that ultimately target all stocks and flows in the system. By making gear producers responsible for collecting and managing obsolete gear, the potential ALDFG stock may be minimised, while material for downstream solutions after collection would increase. Although this measure is systemic, it is still a regulatory measure, required from industry through government regulation.

The potential to change the system at a deeper level is found in intervention points that fundamentally alter how the system works, evolve and self-organise, and furthermore introduce new goals and paradigm mindsets, ultimately leading to transcending paradigms. These types of responses require inner system drive. Circular economy responses such as circular business models all represent possible deep and effective changes to tackle ALDFG, as they integrate economic and environmental goals and are driven by system actors rather than regulatory action. They also cover all stocks and flows in the system depicted in Fig. 2.2 as they could positively create a demand for raw material (originating from activities in and beyond stock S4), as well as facilitate business opportunities in other places of the system, e.g. collection infrastructure and transport services. This book covers several examples of circular business models in relation to fisheries and aquaculture. Regulatory action to incentivise circular business models may still be useful in reducing barriers to establishing new enterprises, products and services.

2.3.2 Indicators

The DAPSIR-ALDFG framework helps organise aspects in a causal and traceable manner. To trace interactions across the system and monitor and verify performance of responses, creating system trajectories is useful. Figure 2.3 shows a system tracing example from the Norwegian fisheries and aquaculture industries. Once trajectories are identified, assessment and management indicator inventories can be built to

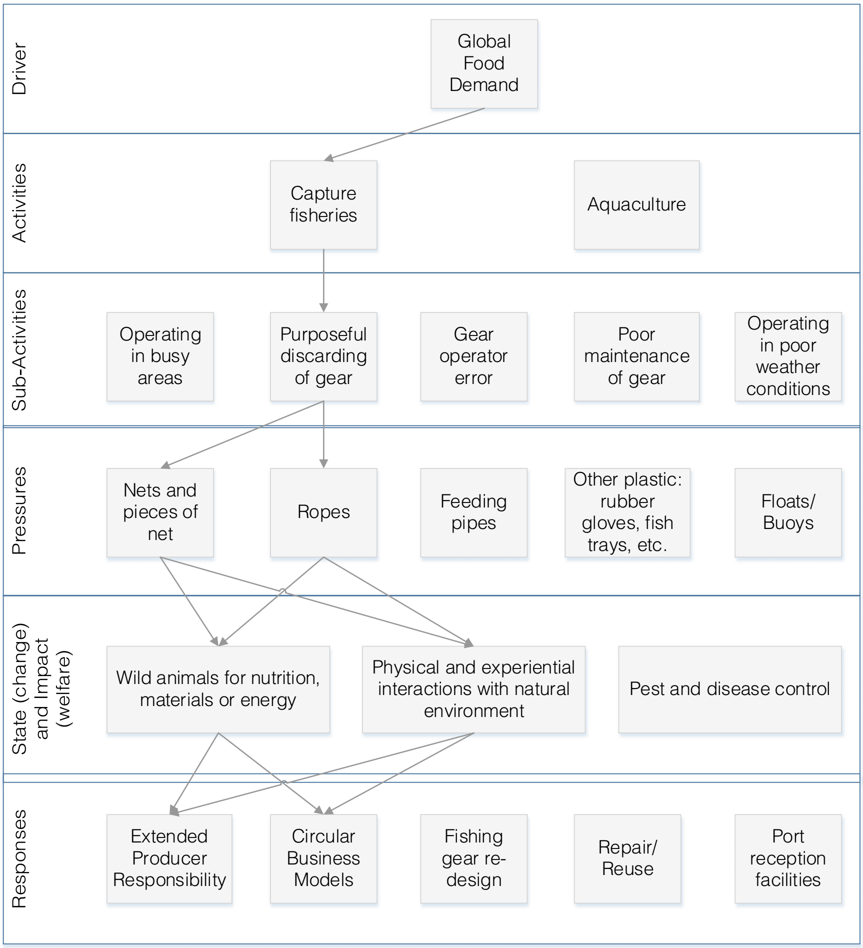

Fig. 2.3 Example of a trajectory in DAPSIR-ALDFG framework. Modified from Cooper (2013), Elliott et al. (2017), Smyth et al. (2015)

monitor system improvement. The indicator inventories would depend on trajectories to be considered, as well as data accessibility. A list of indicators for assessing and managing ALDFG in Norway is provided in Table 2.2.

2.4 Conclusions

In this chapter, we have presented the DAPSIR-ALDFG framework for assessing and managing ALDFG from commercial fishing and aquaculture in Norway. Several frameworks were used to build the model: ecosystem accounting for the states and

Table 2.2 Indicator inventory for ALDFG in Norway

Aspect	Indicator	Data sources
Driver	Global seafood demand: exports of fish for human consumption projections (descriptive indicator to indicate the direction of travel of the industries)	OECD/FAO (OECD et al. 2022)
Activities	Sea fishing. Fishermen, by contents and year	SSB
	Export of salmon, fresh and frozen, fish-farm bred	SSB
Subactivities	% fishers spend engaging in poor sub activities	No data source
	% aquaculture managers engage in poor sub activities	No data source
Pressures	PVC pipes (aquaculture)	OSPAR
	Ropes/cords (aquaculture/fishing)	OSPAR
	Buoys (aquaculture)	OSPAR
	Fish trays (aquaculture)	OSPAR
	Nets and pieces of nets (Fishing)	OSPAR
State	Ecosystem extent: hectares of each ecosystem type	Ecosystem extent accounts
	Ecosystem condition: ALDFG per ha of coastal ecosystems	Ecosystem condition accounts
	ALDFG per m3 of water column	
	ALDFG per m3 of soil substrate	
	ALDFG per m3 of subsea sediment	
Impact	Gross ecosystem production (NOK) per area of ecosystem type	Ecosystem extent and condition accounts
Response	Positive change in ecosystem condition accounts	Ecosystem extent and condition accounts
	Return on ecosystem based approach investment (change in ecosystem extent and condition per NOK spent)	Ecosystem extent and condition accounts

impacts, and the responses were framed around circular economy tools and categorised by the type of leverage point they may affect. The responses that have the potential to act at the deepest leverage points are the circular business models and the extended producer responsibility schemes. The practical responses, such as beach cleans and repairing of gear, can affect the stocks and flows of the fishing and aquaculture gear but may not provide the systematic change that is required to address the problem. All the indicators within the model were connected to suggested data sources to enable future modelling once ecosystem accounts are created for Norway's marine and coastal environments. This DAPSIR-ALDFG model can provide policy makers with a clear insight into how aquaculture and commercial fishing industries impact our welfare while at the same time provide some practical circular economy tools for addressing issues within these industries at multiple levels. Further iterations of the framework could include attempting a nested approach as proposed by

Elliott et al. (2017), whereby the framework is applied to socio-ecological systems in the same geographical area to assess how they interact, and react to, changes in the Norwegian system.

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Chapter 3
Developing a Circular Economy for Fishing Gear in the Northern Periphery and Arctic Region: Challenges and Opportunities

Neil A. James

Abstract There is growing concern regarding the extent and impact of marine litter waste. One particularly troublesome ocean waste fraction consists of abandoned, lost, or discarded fishing gear, including fishing nets. The relentless increase of marine litter is particularly pertinent to countries of Northern Europe and the Arctic region, which currently have limited business opportunities and associated supply chains capable of recycling or reusing this material. In this chapter, we outline the difficulties and opportunities in establishing a circular economy for fishing nets in Northern Europe and the Arctic, with a focus on experience and successful practices established through transnational and collaborative projects.

Keywords Circular economy · Sustainability · Fishing gear · Northern Europe · Arctic · Remote and rural regions

3.1 Introduction

Marine plastic pollution is vast, ubiquitous, and increasing across the globe (Jambeck et al. 2015; Borrelle et al. 2020; OECD 2022). In the environment, plastics have been shown to cause harm to a wide range of wildlife (Kühn et al. 2015), whilst the breakdown of plastics into smaller pieces poses a threat to human health, with plastics presence found in breast milk, infant faeces, infant milk formula, and in the placenta (Ragusa et al. 2022; Liu et al. 2023). Marine plastics are causing a range of negative ecological and social impacts, whilst the annual economic impact has been estimated at up to $33,000 per tonne of marine plastics (Beaumont et al. 2019). Meanwhile marine plastics have been cited as a potential planetary boundary threat

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in need of urgent prevention and management (Vegter et al. 2014; Villarrubia-Gómez et al. 2018).

Fishing nets, and associated gear, are one of the most harmful types of marine plastic debris (Wilcox et al. 2016; Gilman et al. 2021), whilst simultaneously it has been suggested that fisheries themselves are one of the most vulnerable sectors in terms of the impact of plastics, with productivity, profitability, safety, and viability at risk (Beaumont et al. 2019).

3.2 Northern Periphery and Arctic Region

The Northern Periphery and Arctic (NPA) region comprises locations in northern Europe and the Arctic, specifically the whole of Greenland, Iceland, and the Faroe Islands, together with portions of Ireland, Norway, Svalbard, Sweden, and Finland. Until recently, it also included parts of Scotland and Northern Ireland, and we include these regions in this chapter (Fig. 3.1), as they were included in several relevant and recently completed projects funded by the Northern Periphery and Arctic Programme, part of the European Territorial Cooperation Objective (Interreg), a cooperative funding mechanism of the European Regional Development Fund.

The region is characterised by a high proportion of remote and rural areas with relatively low population density and has many important fishing grounds, ports and operations. The capital cities of Ireland, Scotland, Norway, Sweden, and Finland are not included within the region, although Reykjavik (Iceland), Nuuk (Greenland), and Tórshavn (Faroe Islands) are included. Consequently, the NPA region has relatively fewer businesses and recycling infrastructure compared to other parts of Europe. The urban centres that are present in the NPA region are, by definition, remote from large towns and cities. Larger distances and travel times pose a barrier in connecting individuals and business, with passenger and freight transport in some instances limited to ferries, or airplanes. In Greenland, there are no roads that connect towns, and therefore transport is either by helicopter or airplane, by dog and sled, or by sea in the summer.

3.3 The Circular Economy

The traditional linear economy, or *take-make-dispose* model, is widely considered to be more damaging to the environment, with lower resource sustainability than a circular economy (Sariatli 2017). A circular economy can be considered a system where waste has been *designed out*, with resources used for as long as possible. The Ellen MacArthur Foundation (2022) considers the circular economy to be designed to: (1) eliminate waste and pollution, (2) circulate products and material at their highest value, and (3) regenerate nature. Reducing waste and the consumption of resources can result in lower energy requirements and generate jobs and businesses

Fig. 3.1 Map showing the countries, and portions of countries within the northern periphery and Arctic region. Created by the Circular Ocean project

(Stahel 2016). By definition, a circular economy is one that has enhanced sustainability, and/or where the life of products is extended and resources used through more than one life, thereby giving increased circularity. There has been increased awareness of the issues relating to the circular economy, circularity, and sustainability, with notable progression by high-profile companies. Indeed, attention of these terms is reflected in internet searches, with data showing increased global relative search interest over the last 10 years (Fig. 3.2).

Similarly, public awareness and interest in marine plastics has also increased during this time period (Fig. 3.3).

3.4 Quantifying End-of-Life Fishing Nets and Ropes

Fishing nets and ropes may be abandoned, lost, or otherwise discarded, at sea, ultimately sinking to the sea floor, or deposited on shorelines by tides. Alternatively, fishing nets and ropes can be stored, collected, or dumped on land, for instance at

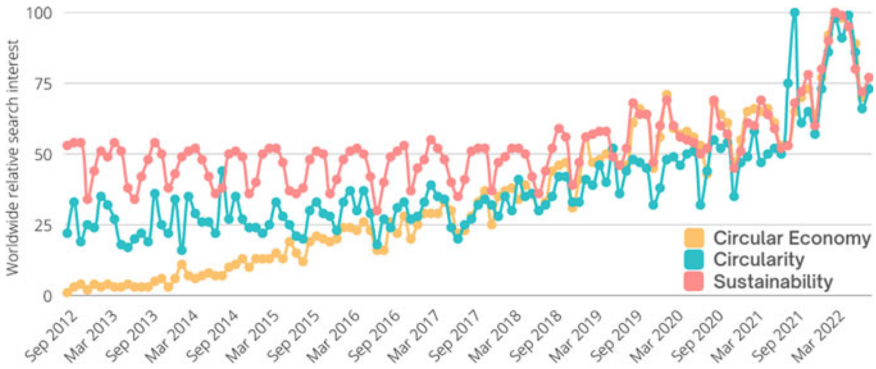

Fig. 3.2 Global relative interest in three search terms, Circular Economy, Circularity, and Sustainability from Google Trends over time. Numbers represent search interest relative to the highest point on the chart, from 1 September 2012 to 31 August 2022

Fig. 3.3 Global relative interest in two search terms, Ocean plastic, and Marine plastic from Google Trends over time. Numbers represent search interest relative to the highest point on the chart, from 1 September 2012 to 31 August 2022

ports. For there to be an effective and sustainable sector reusing and/or recycling fishing nets, it is imperative that there are accurate data regarding the amount, type, and distribution of fishing nets. However, there are fundamental data gaps regarding these basic metrics. For instance, accurate estimates regarding the amount (mass or volume) of abandoned, lost, or otherwise derelict fishing gear (ALDFG) are currently lacking, both globally and regionally. An often-quoted figure is that approximately 640,000 tonnes of fishing nets enter the oceans each year. However, this figure is problematic, as it seems that it cannot accurate be traced back to its original source (Richardson et al. 2021). In a press release by UNEP (2009), it states that 10% of marine litter is in the form of fishing nets and rope:

> The report estimates that abandoned, lost or discarded fishing gear in the oceans makes up around 10 percent (640,000 tonnes) of all marine litter. Merchant shipping is the primary source on the open sea, land-based sources are the predominate cause of marine debris in coastal areas.

The figure of 640,000 tons is arrived at by using an older estimate of plastic debris entering global seas each year (6.4 million tonnes), and multiplying by 10% (the proportion inappropriately said to represent abandoned, lost, or discarded fishing gear). However, the report itself (Macfayden et al. 2009) states:

> Attempts at broad-scale quantification of marine litter enable only a crude approximation of ALDFG comprising less than 10 percent of global marine litter by volume, with land-based sources being the predominate cause of marine debris in coastal areas and merchant shipping the key sea-based source of litter.

Therefore, the estimate provides a figure of less than 10% of marine litter comprised of fishing nets and ropes, but in the unit of volume. Given the mix of units and the discrepancy between press release and report itself, it appears there is little basis for the annual figures of 640,000 tonnes of fishing nets and ropes entering the oceans. Using information submitted to LITTERBASE (Bergmann et al. 2017), which has collated data from 1413 studies, the estimated proportion of all fisheries-related gear is 13.21%, with fisheries plastics and rope representing 10.7% of global marine litter.

To facilitate and support stakeholders interested and compelled to engage with a more circular approach to fishing gear management, we need a better understanding of material flow, especially at local and regional scales. There have also been alternative and more regionalised approaches to estimate the amount of fishing gear lost, repaired, and reaching end-of-life. Using a Local Ecological Knowledge approach involving detailed interviews with 114 fishers in Norway, Deshpande et al. (2019) determined estimates of annual rates of fishing gear disposal and found that the life span of fishing gear varied with type, with purse seine nets lasting the longest at just over 10 years, whilst trawl and gillnets has the shortest life spans with a mean of 2.8 and 2.1 years, respectively. These differences between fishing net type, reflect their methods and the associated risk of entanglement, abrasion or breaking. Consequently, a greater proportion of gillnets (33.1%) and trawl nets (25.1%) are disposed of annually, in comparison to purse seine nets (7.3%), although almost a third of long-line nets (30.8%) are also estimated to reach end-of-life each year. These estimates, at least in the setting and context of Norway, can provide an idea of the amount of material available for use by up/recyclers (30.8%). This approach could be replicated in regions across Europe, and more widely, to provide better estimates of the mass of fishing gear available for second-life. More accurate data are vital to enable the move to a more circular economy for fishing nets and ropes.

For fishing nets and ropes that do not reach end-of-life at harbours, port reception facilities, or recycling centres, there are alternative ways in which they may be located and quantified. The identification of marine plastics hotspots can enable and inform collection and recycling efforts. Organised and ad hoc beach cleans by volunteers can be valuable in not only helping to remove fishing nets and ropes from shorelines, but also in providing information regarding the rate of deposition, mass, and location of this debris. In the UK the charity, Marine Conservation Society organises beach cleans, and records data on the litter collected. Similarly, Nordic Coastal Clean-up (2022) is a network of 8 organisations across Greenland, Denmark, Norway, Sweden, the Faroe Islands, and Finland, who reported that 16.8% of items removed were fisheries-related debris in 2021, with the Nordic region said to comprise a greater proportion of this type than other regions. Similarly, hotspots may be identified through crowdsourcing, community/citizen science projects including LITTERBASE and Birds and Debris. LITTERBASE (Bergmann et al. 2017) collates and maps information on marine litter from published studies, whilst Birds and Debris (http://www.birdsanddebris.com), created as part of the Blue Circular Economy project (2018–2022), collects incidences of interactions between birds and debris, including entanglements and nest incorporation of predominantly threadlike debris such as sections of nets and rope.

An additional way in which plastics hotspots may be identified is through remote sensing, for instance via airplanes, drones, and satellite data (Goddijn-Murphy et al. 2018; Topouzelis et al. 2021). Remote sensing provides a significant future opportunity to identify hotspots of fishing nets and ropes, especially in more northerly regions including the Arctic, where population densities are lower and the regular or incidental monitoring, reporting, and removal of plastic litter are much reduced, and more costly.

3.5 Fishing Nets and Ropes in the Northern Periphery and Arctic Region

The logistical challenges of transport in the NPA region pose a particular barrier when developing a more circular economy for end-of-life fishing nets and ropes. For instance, in Sisimiut, the second largest town in the West of Greenland, fishing nets are accumulating in a local dump site, as there are no local recycling facilities and each municipality is responsible for their own waste management (Linneberg et al. 2021). Across Greenland, waste is either sent to local landfills or incinerated, with some hazardous materials and metals being exported to Denmark (Eisted and Christensen 2011; Papineschi et al. 2019). Transporting end-of-life fishing nets and ropes to Europe, for example Denmark, would have significant implications in terms of financial cost, carbon emissions, and political considerations. Remote-recycling challenges are seen across the NPA region, including the Faroe Islands, where there is an absence of a local recycling industry among the 18 islands with recyclables being transported to Europe (Papineschi et al. 2019). In Svalbard, material in dump sites is causing concern in terms of contaminants, including microplastics, leaching into the soil (Granberg et al. 2019). Waste from Longyearbyen, Svalbard, is transported to Norway for incineration (Granberg et al. 2019), whilst plastics in Iceland are largely sent to Sweden for processing (Papineschi et al. 2019).

If there is to be a significant move away from a *take-make-dispose* business model for fishing nets and ropes in remote regions, then local solutions, transnational coordination, or a combination of both, are needed. If local solutions are developed to recycle, or reuse end-of-life fishing nets and ropes, then this will likely be more sustainable than alternatives requiring significant transport. A so-called *Small Circles* approach, where physical distances are minimalised, has been suggested to be the preferred model towards sustainability in plastics recycling (Havas et al. 2022), but is particularly challenging in remote and rural regions.

Transnational coordination, whether through international agreements, or through businesses or non-governmental organisations (NGOs) operating across borders, can assist in developing economies of scale for fishing net recycling and reuse. Local end-of-life, or discarded fishing net availability may be unpredictable, or at low levels in isolated regions. Transnational collection schemes include businesses such as Nofir, based in Norway, which collects fishing nets across the globe for recycling, reuse, and energy recovery, and the KIMO Fishing for Litter programme, which supplies collection bags and disposal services for fishers who bring back waste fishing nets and other waste collected at sea, and operate in ports of Norway, Ireland, and UK. Such schemes are reliant on coordinated efforts and/or significant logistical operations to bring together significant quantities of fishing nets and represent a potential mechanism by which fishing net circularity is achieved. However, the large distances and associated carbon emissions involved with the transport of material provides a barrier towards sustainability.

Local solutions for fishing net recycling may come through innovation in technology and design. For instance, 3D printing offers the potential for individuals or businesses in remote and rural regions to use locally available plastic polymers to create new products (Hunt and Charter 2016). Due to the large volume of polymer waste generated by fishing nets and ropes, it is theoretically possible to convert these materials into value-added products using 3D printing. The use of polymers in 3D printing holds considerable potential as a localised production method, especially as the technology becomes increasingly accessible. The cost of purchasing cleaning equipment, shredders, filament extruders, and a fused filament fabrication 3D printer could be offset, if recycled plastic filaments can be made successfully from fishing nets and ropes. Alternatively, moulds may be created using fused filament fabrication 3D-printed tools, allowing products to be made using an injection moulder and filament with a higher melting point (Hunt and Charter 2016).

3.6 Engagement and Knowledge Sharing

Interdisciplinary engagement and knowledge sharing can be important in helping to drive innovation. As part of the Circular Ocean project, a ChemHack event was held during the 17th European Meeting on Environmental Chemistry (EMEC), Inverness, 2016. Its aim was to bring together expertise in the field of environmental chemistry to solve a challenge pertinent to the recycling of fishing nets and ropes (Boyd 2017).

The event provided a platform for participants to think, develop and cocreate eco-innovative solutions faced by the fishing industry. Anti-foulants are impregnated in fishing nets and ropes and cages to protect and extend the life of that equipment. However, these chemical treatments make the recycling of fishing nets, ropes, and cages problematic at the *end-of-life* stage. The challenge of the ChemHack event was to develop innovative solutions to *end- of-life* problems associated with contaminated fishing nets and ropes, specifically washing processes to remove anti-foulants and other chemical compounds impregnated into nylon fishing nets and ropes and cages. This included identifying processes to decontaminate the wastewater arising from the washing process and to extract copper compounds from fishing nets, ropes, and cages for recycling metals.

Local- and sector-specific knowledge can be essential in understanding barriers to the development of circular, more sustainable solutions, and to initiate and enable cooperation and coordination between different stakeholders. One method which can be effective in informing on concepts of the circular economy, sustainable development, and circular business models, whilst promoting collective strategic thinking are Scenario Exploration Systems (SES), also referred to as *Serious Games* (Whalen et al. 2018; Manshoven and Gillabel 2021). The Circular Ocean project used an SES in Ireland and Iceland to explore the issue of recycling fishing nets and ropes at a port area. The SES was created by the EU Policy Lab, part of the European Commission's Joint Research Centre, following a two-year foresight study on the future of eco-industries and eco-innovation in Europe to 2035. It deploys sustainable transition scenarios using a physical board. Invited stakeholders took the role of SMEs involved in recycling or reuse, fisheries agencies, harbour masters, and fishermen, with two scenarios, local self-reliance and shared circular strategies, explored. The exercise facilitated discussion, knowledge sharing, and the development of coordinated strategies, with key messages including:

- It is necessary for all stakeholders to work together to make a difference in this issue.
- Taxation will have to be adapted to improve the economics of recycling and reuse.
- Some regulatory interventions will be necessary to stop some detrimental practices.

3.7 Legislation and Policy

It appears that interventions through regulations will be a key driver to lessen the presence and impact of marine pollution and to ensure enhanced resource sustainability, and the development of more circular business models. Currently, there are a range of international agreements and policies relevant to the NPA region that are aimed at preventing or reducing marine pollution. These include MARPOL (International Convention for the Prevention of Pollution from ships), whilst the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (also called the London Convention, and updated via the London Protocol), United Nations Convention of the Law of the Sea (UNCLOS), Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Basel Convention), and Honolulu Strategy (for an overview see supplementary material in Linneberg et al. 2021). In addition, by 2025 Goal 14 of the UN 2030 Agenda for Sustainable Development is to:

> "Conserve and sustainably use the oceans, seas and marine resources for sustainable development", with a target to "prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" (UN 2017).

Within the NPA region, the OSPAR Commission, an intergovernmental convention aimed at protecting the Northeast Atlantic marine environment, has "Polluter Pays" as a guiding principle (OSPAR 2021). In addition, the OSPAR Convention's North-East Atlantic Environment Strategy 2030, sets out its strategic objectives, including S4.08 which states that:

> By 2025 OSPAR will develop and implement measures to substantially reduce marine litter from fishing and aquaculture gear, in collaboration with those sectors, as appropriate, and by 2027 will determine the need for, and where appropriate adopt, targets or other actions for the separate collection of end-of-life fishing and aquaculture gear coherent with relevant EU directives and the update of the OSPAR Regional Action Plan on Marine Litter.

Protection of Arctic Marine Environment (PAME), a working group of the Arctic Council, developed a Regional Action Plan on Marine Litter in the Arctic (PAME 2021). It sets out a suite of actions including those that aim to reduce marine litter from fisheries and aquaculture, cleaning Arctic coasts, and sustainable materials management in the Arctic environment. There are at least 5 actions which are especially pertinent to the collection and recycling of fishing nets and ropes, and can therefore assist the movement towards a more circular economy in the NPA region, including:

> Action 2: Support and promote gear marking, reporting, and recovery of ALDFG, as outlined in the FAO Voluntary Guidelines for the Marking of Fishing Gear.
>
> Action 3: Identify most commonly lost or discarded fishing gear in different areas of the Arctic, as well as where opportunities may exist to develop procedures for ALDFG prevention and reduction within the region.
>
> Action 4: Identify hot spot areas of ALDFG in the Arctic through mapping of known snagging sites or unsanctioned dumping grounds, in collaboration with relevant stakeholders.
>
> Action 7: Promote separate collection of end-of-life fishing gear and ALDFG in relevant ports to enhance its further recovery and preparation for reuse or recycling.
>
> Action 29: "Promote the development and design of materials for use in fishing gear that minimises impacts upon ecosystems or the environment from ALDFG".

Meanwhile, the European Commission adopted its Circular Economy Action Plan (CEAP) in March 2020, as part of the European Green Deal which supports sustainable growth. Together with the EU's Single-Use Plastics (SUP) Directive (European Union 2019), which includes an extended producer responsibility (EPR) scheme for fishing gear, to be implemented by member states by the end of 2024, with Norway, Iceland, and the UK also developing parallel policies. This legislation puts added responsibility onto producers in terms of covering the cost of separation, transport, and treatment of fishing gear plastics, and is therefore likely to result in an increased availability of reusable and recyclable material in the NPA region.

Following an agreement between UN member states to negotiate on a new global treaty on plastics pollution, there are ongoing and concerted efforts to develop a coordinated approach to a more sustainable and circular plastics economy. It remains to be seen whether an effective international, legally binding agreement can be agreed to reduce plastics production and pollution, how this is implemented in practice, and how this varies across countries and regions.

3.8 Conclusion

Increased awareness of the impact of marine plastics, in addition to current and impending legislation and strategies for reducing the presence and impact of ALDFG in the environment provide an impetus for the movement towards a more circular economy. If the impacts of fishing nets and ropes are to be mitigated it is imperative that there is a marked increase in the sustainability of these resources. Developing a circular economy for fishing nets and ropes in the NPA region is challenging, due to relatively low population density, large distances to recycling and business infrastructure, and the large coastlines which make monitoring and collection more difficult. However, a better understanding of the quantity, location, and flow of fishing nets and ropes, in addition to new recycling and upcycling opportunities, can be achieved through innovation and adaptation. Remote and rural regions, and in particular the fishing sector, are often accustomed to adapting to change and incorporating innovation. It is likely that an effective circular economy for fishing nets and ropes in the NPA region will only be achieved through a collaborative approach involving a broad spectrum of stakeholders. This will be important in the NPA region if fishing nets and ropes are to be managed sustainably, whilst exploiting opportunities for reuse, recycling, and upcycling.

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Part II
Solutions: Value Chain of Waste Fishing Gear

Chapter 4
Circular Business Models for SMEs in the Fishing Gear Industry

Sardar Wasi Uddin Al Ahmed, Richard Glavee-Geo, Siv Marina Flø Grimstad, and Markus Andre Hånes Engeseth

Abstract Recycling plastic materials including fishing nets, ropes, and components (FNRCs) through the business models of SMEs and microenterprises can ensure both economic and environmental benefits. The aim of this chapter is to explore how a circular business model for SMEs in the fishing gear industry can be realised and to provide increased understanding of the circular business model processes. The study examined the development of circular business models and practices of circularity by companies in the fishing gear industry. We applied a qualitative research design and developed frameworks to evaluate the practice of circularity. The qualitative analysis and findings of the cases provided unique insights on the level of circularity of SMEs within the marine plastic recycling value chain in the north-western part of Norway. The main outcome of this research was the proposed framework for a circular business model for the fishing gear industry.

Keywords Environmental concern · Recycling · Waste fishing gear · Circularity · Local innovation systems · Sustainability

4.1 Introduction

The world has awakened, understanding that the currently used *take-make-dispose* extractive industrial model of production is less efficient in resource utilisation. The concept of the circular economy wishes to move away from economic growth driven by the consumption of finite resources and design a model where what once was considered waste, is now seen as a resource (Kraaijenhagen et al. 2016). Whereas the traditional model of industry has a ceiling of growth, a circular business model is based on designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation 2020). The business model is a tool that describes the rationale of how an organisation creates, delivers,

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and captures value (Osterwalder and Pigneur 2010). Circular business models incorporate a triple bottom line approach, which consider a wide range of stakeholders' interests, including environmental and social issues (Bocken et al. 2014). A fundamental question for any eco-innovative company is how to deliver value to its customers in a way that is profitable and less resource intensive (Jensen 2018).

Fishing nets, ropes, and components (FNRCs) are often lost or discarded in the oceans, or sent to end-of-life collection, where only some of the material and components are recycled. The rest is either disposed of in a landfill, or by means of incineration (Deshpande et al. 2020). Ghost fishing gear comprise approximately 10% of the total marine litter, but is the major source of microplastics littering the oceans, and constitute 75% of all plastic litter in excess of 20 cm in size (Laville 2019). US national ocean service (National-Ocean-Service 2020) identifies typical sources of marine litter which includes: (i) littering, dumping, and poor waste management practices; (ii) storm water discharges; and (iii) extreme weather events (National-Ocean-Service 2020). The objective of this chapter is to explore, and to highlight how a circular business model for SMEs in the fishing gear industry can be accomplished. We provide an increased understanding of the circular business model processes that small- and medium-sized enterprises (SMEs) undertake using a case study approach. In the next section, we present the theoretical frame of reference derived from a review of the literature on circular economy and circular business models. This is followed by the methodological approach where we present the cases studied.

4.2 Theoretical Background

4.2.1 Circular Economy

The concept of circular economy is very innovative, timely, and novel (Ghisellini et al. 2016; Kraaijenhagen, et al. 2016). It provides an economic model where the main goals are to adopt sustainable economic growth, enhance global competitiveness, and generate jobs. For the circular economy to become mainstream, radical and systematic innovation is needed (Manninen et al. 2018). At present, most of the business modelling tools and methods lack at least some of the identified and needed elements for innovating business models in a circular economy. The traditional model of *Take—Make—Waste* causes many environmental problems that will eventually reach a sustainability dead-end as the earth's resources will be exhausted (Antikainen and Valkokari 2016). The circular economy offers extensive and exclusive business opportunities to the existing and new actors available in the economy (Ellen MacArthur Foundation 2020). In a circular economy, the closed loops consist of two supply chains: one is the forward chain and the other one is the reverse chain (Wells and Seitz 2005). In a reverse chain, a recovered product re-enters the forward chain (Wells and Seitz 2005). According to the Ellen MacArthur Foundation (2020),

> A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources.

Murray et al. (2017) defined circular economy as:

> an economic system wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output to maximise ecosystem functioning and human well-being.

Kraaijenhagen et al. (2016) states that:

> Circular economy is an economy in which stakeholders collaborate in order to maximize the value of products and materials, and as such contribute to minimising the depletion of natural resources and create positive and societal and environmental impact.

The main goal of the circular economy is to prolong product life cycles through various activities such as: repair, maintenance, reuse, redistribution, refurbishment, remanufacturing, recycling, cascading and repurchasing (Lüdeke-Freund et al. 2019). The Ellen MacArthur Foundation (2020) proposed an outline of the circular economy. According to this model, the circular economy consists of three major principles: firstly, preserve and enhance capital by controlling finite stocks and balancing renewable resource flows; secondly, optimise the use of resources by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles; and thirdly, foster system effectiveness by revealing and designing out negative externalities (Ellen MacArthur Foundation 2020).

4.2.2 Circular Business Model

A circular business model can be defined as the foundation of how an organisation creates, delivers and captures value with and within closed material loops (Mentink 2014). A Circular business model is actually one type of sustainable business model, and regarded as a subcategory of business models (Antikainen and Valkokari 2016). 'The idea of a circular business model is that it does not need to close material loops by itself within its internal system boundaries, but can also be part of a system of business models that together close a material loop in order to be regarded as circular' (Mentink 2014). According to Bocken et al. (2014), there are eight archetypes for the development of sustainable circular business models: maximise material and energy efficiency, create value from waste, substitute with renewables and natural processes, deliver functionally rather than ownership, adopt a stewardship role, encourage efficiency, re-purpose the business for society/environment, develop scale up solutions. It is important to emphasise that:

> Circular business models are by nature networked: they require collaboration, communication, and coordination within complex networks of interdependent, but all actors or stakeholders are independent and not influenced by one another. (Antikainen and Valkokari 2016).

The challenge of re-designing business ecosystems is to find the *win–win* setting that helps find a balance between the self-interests of involved actors and thereby influence and facilitate their actions in order to cooperatively shape the sustainable circular business model (Antikainen and Valkokari 2016). Osterwalder and Pigneur (2010) proposed a framework for sustainable circular business models based on the ideas and the structure of the business model canvas and other tools, and studies on the circular economy and sustainability. The framework includes the idea of continuous repetition with sustainability and circularity evaluation of the business model which consists of 3 levels: business ecosystem level, business level, and sustainability impact (see Fig. 4.1).

These features are needed for the purpose of gaining factual data about sustainability of the business model along with optimising the processes and understanding the dynamics of the processes required. For instance, change in one link in the supply chain may dramatically influence the whole model. The sustainability part of this evaluation can be carried out by using the evolving literature of life-cycle assessment tools. The circularity perspective focuses on visualisation of the model for the purpose of understanding the essential actors, the relationship among them, the cycle stages, and the flows of material and information. For example, three environmental strategies—closing, narrowing, and slowing the loop within circularity (Bocken et al. 2014; Kraaijenhagen et al. 2016; Lüdeke-Freund et al. 2019).

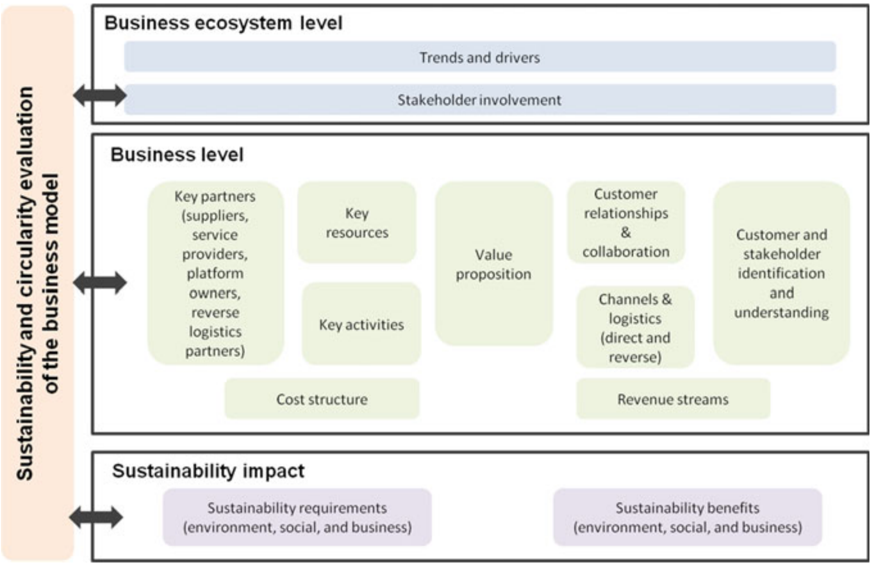

Fig. 4.1 Framework for circular business model
Source: Antikainen and Valkokari (2016)

4.3 Research Design and Methodology

Selecting a research methodology depends on the research paradigm and the objectives of the study (Guba and Lincoln 1994). In this study, we used an exploratory, qualitative, multiple case study. The major benefit of the qualitative approach is that it provides a depth and richness of data, which is difficult to attain through quantitative research (Voss et al. 2002; Yin 2011). A qualitative case study is a desirable research approach for realists whose goal is to describe and explain a phenomena, capturing the appropriate level of complexity (Bhaskar 2014). By using such a case study method, researchers can get a holistic view and explore social processes in rich and complex detail. In this process, contextual variables that affect actors' behaviour will be observed and identified (Lindgreen et al. 2020).

4.3.1 Case Selection

Case selection or sampling is an important methodological choice in case study research (Miles and Huberman 1994). Sampling in qualitative research involves two actions. The first action is to set boundaries that define aspects of the target case(s) that can be studied within the limits of time and budget. The second action is to create a sample frame that has a potential for uncovering, confirming, or qualifying the basic processes or constructs that underpin the study (Miles and Huberman 1994). Accordingly, we chose Norway as the research setting for two reasons; the first is the feasibility of obtaining rich qualitative data within time and budget constraints, the second is that the Blue Circular Economy (BCE) project's mission is to generate sustainable business opportunities in the Northern Periphery and Artic (NPA) region (Peck 2020), where Norway appears to have the biggest fishing industry (Charter 2017). Our study is based on five cases: two recycling firms which recycle plastics into raw materials, one firm which produces the recycled plastic materials, one firm which is trying to transition into using mainly recycled materials, and the last one is the customer of the firm which is trying to make the transition. Table 4.1 summarises the key characteristics of the selected cases, and Appendix 1 provides case profiles.

4.3.2 Data Collection and Analysis

Data analysis in case studies is carried out in two steps, the first of which is the within-case analysis. Here, the researcher documented how the data from the individual informants within each company were handled, with respect to how specific research topics were addressed. This is generally accomplished by coding, in which the raw data are converted or coded to understandable components, which can be more easily compared across informants (Eisenhardt 1989). A figure is presented,

Table 4.1 Overview of the case firms

Case number	Name of firm	Specialisation	Sourcing location	Customer segment	Market location
Firm # 1	Ørskog Plast Industri AS	Plastic production	Norway (Ålesund)	Construction industry	Scandinavia
Firm # 2	PLASTO AS	Plastic production	Norway (Åndalsnes)	Aquaculture industry	Global
Firm # 3	NOPREC AS	Plastic recycling	Norway (Ottersøy)	Recycled plastic manufacturers	Nordics
Firm # 4	REPLAST	Plastic recycling	Norway (Frei)	Recycled plastic manufacturers	Nordics
Firm # 5	AKVA Group	Aquaculture	Norway (Klepp)	Aquaculture operations	Global

which shows how the coding is done, and how themes and patterns within the data are identified using a coding scheme. The coding scheme itself is included. A table is included that shows how the data were interpreted and the coding of case-study interviews was developed. This coding and identification process could be supported by different qualitative research-based software (Lindgreen et al. 2020). In this study, semi-structured interviews with a set of open-ended questions were used to collect data. Different interview guides (Appendix 2) were prepared for the different categories of firms. Open-ended questions were used to create a dialogue and discussion with the interviewer. Because of the COVID-19 pandemic, all interviews were conducted through Skype. The questions were kept as short and specific as possible. Leading questions and questions with a strong positive and negative association were avoided. With permission, the interviews were recorded to avoid biased interpretations and conclusions. This allowed for more accurate transcriptions. After conducting and transcribing the interviews, the interviewees were given the opportunity to review the transcript and make any revisions if necessary. The analysis was performed in four stages: evaluation, examination, coding, and categorisation. NVivo, the software for qualitative data, was used to complete the whole process. NVivo facilitates handling a large amount of qualitative data in a very useful way (Zamawe 2015).

4.3.3 Data Validity and Reliability

To increase the validity of the findings and to reach a quantifiable consensus point of what characterises a circular business model for SMEs in the fishing gear industry, a Delphi study was performed. Delphi may be characterised as a method for structuring a group communication process, so that the process is effective in following a group of individuals to deal with a complex problem. To accomplish this structured communication, the following is provided; some feedback of individual contributions of information and knowledge, some assessment of the group judgement or view; some opportunity for individuals to revise views, and some degree of anonymity for the individual responses (Hallowell and Gambatese 2010). The techniques applied in Delphi are to achieve a single consensus upon an emerging topic area or subject for which there is a contradiction or indeed controversy from the Delphi expert panel (Day and Bobeva 2005). For this study, respondents were selected based on their participation in the 'Blue Circular Economy: Converting waste fishing gear nets into business opportunities' workshop held at NTNU in Ålesund on 27 November 2019. The questionnaire was sent to 23 participants. Their positions were Founder, Project Manager, Regional Manager, Sales Manager, Quality Manager, Business Advisor, Vice-Rector, Professors, Director, Scientific Assistant, and Researchers. Interview participants were excluded from the Delphi study. To ensure reliability of the data during triangulation phase, the analytical approach was based on categorisation and aggregation of themes, which were derived from the case interviews, and compared with relevant literature (Eisenhardt 1989). Before that, the initial findings derived from the primary data analysis were also compared with the basic features of circular business model developed by the Ellen MacArthur Foundation (Yin 2011).

4.4 Case Analyses and Findings

4.4.1 Plastics Material Flow: High Level of Circularity—Model 1

To show how different firms are interconnected as well as how plastics materials flow throughout the life cycle of the products, three models were developed. The models created were inspired by the Ellen MacArthur Foundation's conceptual model for circular plastics economy (MacArthur et al. 2016). In model 1 (see Fig. 4.2) plastic producing firms (e.g. Ørskog Plast Industri AS, denoted by firm #1 in model 1) use both recycled plastic materials as well as non-renewable virgin plastic materials in their production. Virgin plastic materials represent approximately 10% of the total plastic inputs, while recycled materials make up the remaining 90% of the materials. The firms use injection moulding as the method of production. If there is an error in the production phase and the product comes out flawed, the firms regranulate the products and reuse all materials again, with no wastage. The products are made for stabilising rebars for concrete construction, which means the products are sold to construction firms. When the firms have finished laying the concrete, depending on which stabiliser type they purchased, they either twist the product out of the concrete and dispose of it, or leave it standing in the concrete. If the product is left in the building, the product is not disposed of until the demolition of building. They were not involved in the disposal phase and did not know which method of disposal their customers used at the end-of-life their products. Whether the products end up incinerated, landfilled, or recycled, depends on which waste management station the

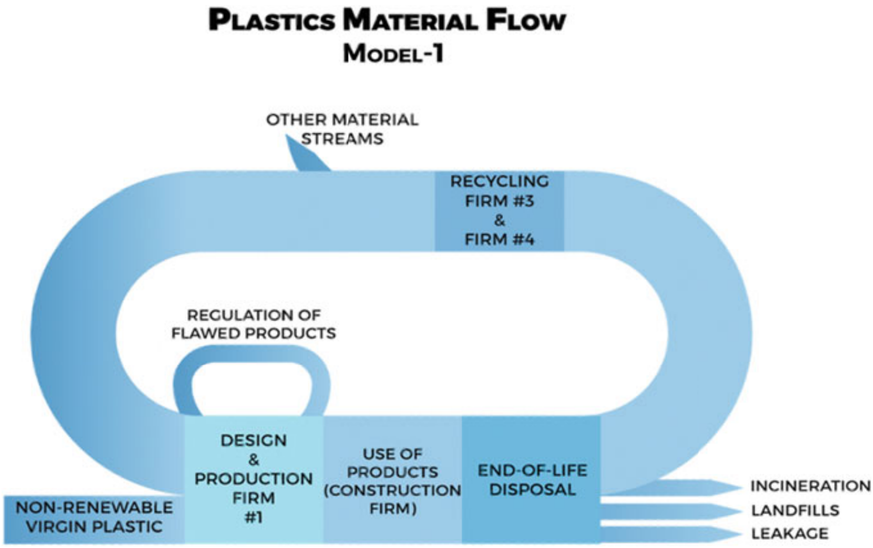

Fig. 4.2 Plastics material flow: high level of circularity—model number 1 (researchers' own model)

firm delivers to, as there are substantial differences in the handling of waste between regions. The assumption was that the products were disposed of by the local waste management stations, and it was supported by the interviews of Ørskog Plast Industri AS, who believed that it was the most likely method of disposal.

NOPREC and REPLAST AS (denoted by Firm #3 and firm #4 respectively in the model 1) are recycling firms, specialising in recycling plastics and collect plastic fractions. These firms are usually supplied plastic fractions from the waste management stations, which are not equipped to handle the recycling process. The waste management stations would otherwise landfill or incinerate the plastic materials, had the firms not been there as an alternative. The recycling firms receive plastic fractions which are defined or undefined. The defined batches are plastic materials which consist of the same plastic type. The undefined plastic batches are a collection of several different plastic types in one and the same batch.

As the recycling firms receive the plastic fractions, the first step of the process is to sort and clean the materials. Both firms have individually developed routines and technology for sorting the materials. The waste materials are sometimes also washed to remove pollutants from the plastic material fractions. When the materials are clean and sorted, the firms regranulate and process the materials, producing plastic pellets. These pellets are then ready to be used as inputs for plastic manufacturing. Both NOPREC and REPLAST AS can recycle nearly 100% of the plastic materials they collect. Pollution, poor sorting, and composite materials are still recyclable, but these factors do negatively contribute to the quality of the recycled plastic materials. As the recycled plastic materials are produced, the firms sell them to plastic manufacturers who are able and willing to use it in their production. Some of the materials are sold to plastic producers, which are also customers of both NOPREC and REPLAST AS, while the rest of the materials are sold to other plastic manufacturers. Plastic-producing firms use almost 90% recycled plastic materials as their input, which ensure a high level of circularity in practice.

4.4.2 Plastics Material Flow: Medium to Standard Level of Circularity—Model 2 and 3

There are other kinds of plastic producing firms (e.g. PLASTO AS, denoted by firm #2 in models 2 and 3) mostly used non-renewable virgin plastic materials in their manufacturing process at their early stage. For example, in 2019, PLASTO AS used mostly non-renewable virgin plastics material in their manufacturing process and they had a few pilot projects with plastic recyclers (e.g. NOPREC and REPLAST AS, denoted by firm #3 and firm #4 in the model 2 and 3), in which they were able to test if recycled plastic materials were viable alternatives. The firm wished to start using recycled materials in larger volume, but they needed consent from their main customers (e.g. AKVA Group, denoted by firm #5 in models 2 and 3) before they could do so.

The aquaculture firms have stringent standards for the quality of the equipment they use and have not yet granted permission for recycling materials being used in their equipment. In 2021, PLASTO AS and AKVA Group had come up an official agreement to use more than 40% recycling materials in their manufacturing process. By doing this, they have transformed themselves from the medium level circularity (see Fig. 4.2) to standard level circularity (see Fig. 4.3) in practice. These kinds of plastic-producing firms also use injection moulding to make plastic products. Most of the manual labour in the factory has been automated, meaning the products are never touched by human hands in production. If any products have any flaws during the production period, the firms regranulate the products and reuse the materials with no wastage.

The customers of these kinds of plastic producing firms purchase the products from plastic producers and then deliver these products as well as any other equipment needed, to aquaculture firms. The aquaculture firms operate the fish farms, and if any equipment is damaged, the plastics producing firms collect the equipment and repair it. When the equipment reaches end-of-life, plastic producing firms are called on. The plastic producing firms then regranulate the equipment on site. The materials are then brought to their own facilities. This is the case for most equipment, as the aquaculture firms are often obligated to document that they have been ‘responsible’ in their disposal of equipment. On a few occasions, plastic recycling firms are not called on to collect the equipment, it is directly sent to the waste management stations due to low landfill fee, where the equipment might be landfilled, incinerated, or sent to recycling firms. The equipment used by the fish farmers which has the shortest life span is the feeding tubes. Most feeding tubes use air for the propulsion of fish feed, which wears

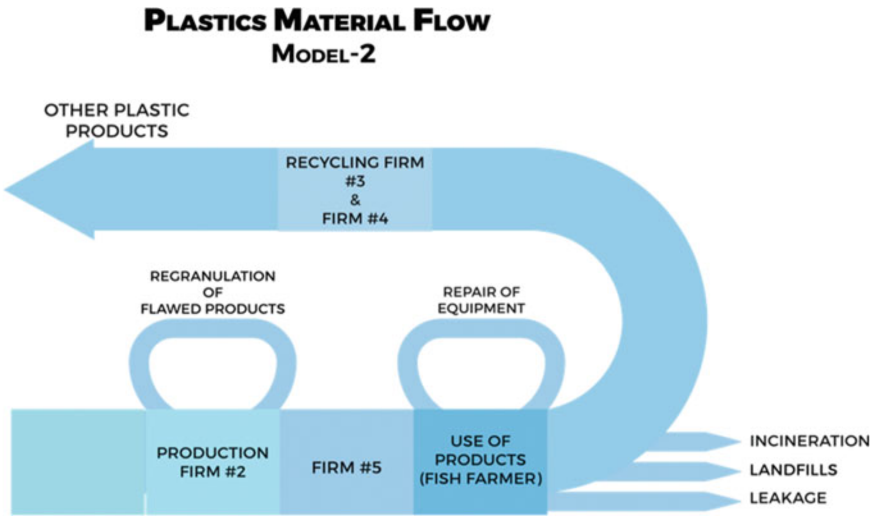

Fig. 4.3 Plastics material flow: medium level of circularity—model number 2 (researchers' own model)

down the plastic tube. Consequently, there is some leakage of microplastics during the lifespan of the tube. At the time of this study, the customers (e.g. AKVA Group) of plastic-producing firms were conducting a project to investigate and measuring the leakage. The case company has also developed a system (using tubes) that makes use of water for propulsion, which should cause less leakage and increase the lifespan of the tube.

The plastic materials end up at the facilities of plastic recycling firms through the transportation of the plastic fractions by the recycling firms, or by waste management facilities sending it to them. Once the plastic fractions are delivered at the facility, they are sorted and cleaned, and then made into small pellets. The product is then ready to sell to the plastic manufacturers, who use recycled plastic materials (this is represented by 'other plastic products' both in Figs. 4.3 and 4.4). Table 4.2 shows the summary of the findings.

4.5 Circular Business Model for the Fishing Gear Industry

Currently, there are a lack of frameworks for creating circular business models in the fishing gear industry. The current tools do not offer sufficient understanding for the changing business environment and the need for adjusting the current value chains. Besides, the impact of the circular business models should be evaluated through the value creation for all stakeholders (Antikainen et al. 2013). Through this study, a framework for a circular business model (Antikainen and Valkokari 2016; Costello

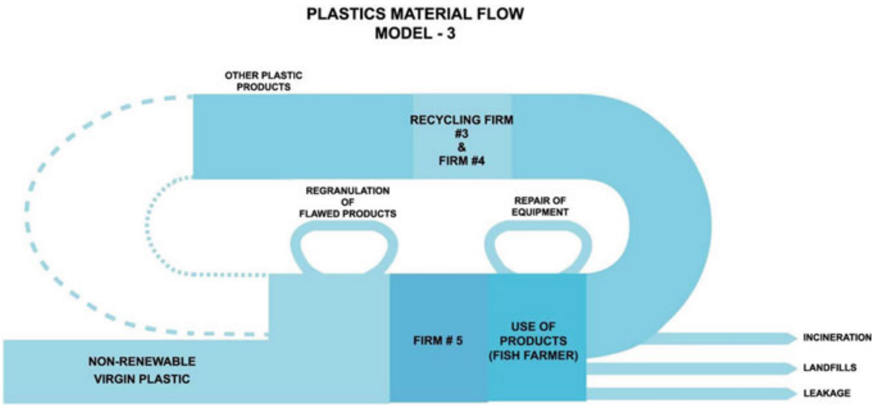

Fig. 4.4 Plastics material flow: standard level of circularity—model number 2 (researchers' own model)

Table 4.2 Plastic material flows in different levels of circularity

Features	*Model 1* (***HIGH*** *circularity in Plastic material flows)*	*Model 2* (***MEDIUM*** *circularity in plastic material flows)*	*Model 3* (***STANDARD*** *circularity in plastic material flows)*
Recycled plastics materials	Use ***high*** level of recycled plastics material s	Use ***low*** level of recycled plastics materials	Use ***medium*** level (almost 50%) of recycled materials
Non-renewable virgin plastics materials	Use ***low*** level of non-renewable virgin plastics materials	Use ***high*** level of non-renewable virgin plastics materials	Use ***proportionately low*** level of non-renewable virgin plastics materials
Method of production	Follow ***injection moulding*** as the method of production	Follow ***injection moulding*** as the method of production	Follow ***injection moulding*** as the method of production
Amount of wastage	***No*** wastage is available after production	***No*** wastage is available after production	***No*** wastage is available after production
Collaboration with recycling firms	***Yes***, have collaboration with several recycling firms	***Yes***, have collaboration with several recycling firms	***Yes***, have collaboration with several recycling firms
Practice of circularity	***High*** level of circularity ensured	***Medium*** level of circularity ensured	***Standard*** level of circularity ensured

and Osborne 2005) for the fishing gear industry is proposed. The framework (see Fig. 4.5) can be considered as a good way for communicating a business model to all related stakeholders.

4.5.1 Business Ecosystem Level

The problems and challenges in the fishing gear industry are threefold: environmental-, social-, and economically oriented (Peck 2020). There is an urgent need to reduce the environmental impacts from the fishing gear industry by using recycling and reusing techniques in the production systems, supply chain management, and logistics (Peck 2020). After identifying all the problems and challenges that the fishing gear industry face, it is essential to map out the involvement level among all stakeholders with each other (Lüdeke-Freund et al. 2019). The relationship with each stakeholder is expected to be trustworthy, direct, close, regular, transparent, and maintain good product quality (Ellen MacArthur Foundation 2020).

4.5.2 Business Level

Key resources involve the identification of physical, human, financial, natural, and technological capital or solutions needed by an organisation to carry out its operation. These resources can be acquired or developed by the organisation or its key partners (Osterwalder and Pigneur 2010). Sustainable and green business solutions, eco-innovation, blue circular economy, 3D-printing technologies, and injection moulding are considered as the key resources for the fishing gear industry (Jensen 2018). Upcycling FNRCs into sunglasses, socks, clothes, skateboards, toys and surfing and fishing accessories and repurposing FNRCs into bracelets, key rings, necklaces, dog leashes, bikes, garden accessories and mats are the most innovative and sustainable solutions of FNRCs of fishing gear industry and can be seen as the outcomes of its key resources (Charter 2018). A unique circular value proposition helps in accelerating the transition of a firm towards circularity and to overcome all the challenges (Antikainen and Valkokari 2016). The unique circular value proposition for the fishing gear industry is employing multiple life strategies for fishing gear with product life-extension, modular design, reuse, repair, refurbishing, and remanufacturing (Peck 2020). The growing awareness and extensive media coverage on environmental issues, for example climate change, environmental pollution, and the use of natural resources, as well as the increase in consumer consciousness, are the growing forces that encourage all types of industry, including the fishing gear industry, to restructure its current business model and its customer segments (Antikainen and Valkokari 2016; Kraaijenhagen et al. 2016; Mentink 2014). The fishing gear industry has three types of customers; producers or manufacturers, recyclers, and aquaculture cluster (Jensen 2018). To create a unique circular value proposition, defining the key resources is not enough; mapping out all stakeholders that can be influenced or have the capability to influence the industry as a whole is important (Daou et al. 2020). For the fishing gear industry this unique circular value chain consists of four parts; universities and research centres, business units (e.g. manufacturers, recyclers, waste management companies), government units (e.g. municipalities and authorities), and civil society organisations, associations, and volunteers (e.g. beach cleaning organisations).

Firms in the fishing gear industry could promote their brands and products through various channels, such as the firms' own websites; social media platforms like Instagram, Facebook, and Twitter; campaigns like TV or billboards; online advertising platforms like Google ads or YouTube ads; direct sale, local and international trade fairs, conferences, webinars, and seminars and so on (Peck 2020). Estimating the costs of activities and the amount of resources needed for the business operations, is certainly a major responsibility (Osterwalder and Pigneur 2010). The associated costs of the fishing gear industry can be divided into two parts: fixed costs such as capital investments, research and development, depreciation, administration, disposal cost, etc. and variable costs (e.g. maintenance, labour, marketing, promotional, lifespan costs etc.) (Peck 2020). The revenue streams of a business organisation refers to the different types of income and flows generated from the value created and delivered to the market (Osterwalder and Pigneur 2010). The revenue streams of the fishing gear industry consist of selling end-of-life fishing gear to recyclers, lease agreements, incentivised return and sharing resources/platforms (Peck 2020).

4.5.3 Sustainability Impacts

The discussion regarding environmental foresights and circular economy has received special consideration when the European Commission published an action plan for the circular economy in December 2015 (Manninen et al. 2018). Considering environmental issues and responses to the environmental challenges are equally important to the responses against economic and social challenges (Kraaijenhagen et al. 2016). Some of the environmental foresights for the fishing gear industry are environmental regulations such as the Extended Producer Responsibility (EPR) schemes (Peck 2020), an EC action plan for the circular economy (First Circular Economy Action Plan 2015) and the United Nations SDGs (Sustainable Development Goals 2015). Highlighting the social foresight is as important as identifying environmental foresight (Daou et al. 2020). One of the key challenges is designing business models in such a way that it enables the firms to capture economic value for itself and delivering social and economic benefits as well (Schaltegger et al. 2012). Also, identifying social foresights and impacts through a framework and translating them into a competitive advantage helps a firm to drive sustainability innovation forward (Lüdeke-Freund et al. 2019). Some identified social foresights for the fishing gear industry are: Consumers' awareness of environmental issues and the treatment of fishing gear, customers' attitudes, and trends towards environmental and eco-friendly products, introducing new products' portfolio from waste and new entrepreneurial spirit (Charter 2018). Business model innovation is the novel way of creating, delivering, and capturing value that is achieved through a change of one, or multiple components in the business model (Osterwalder and Pigneur 2010). It is apparent that radical innovations and disruptive business models are needed to

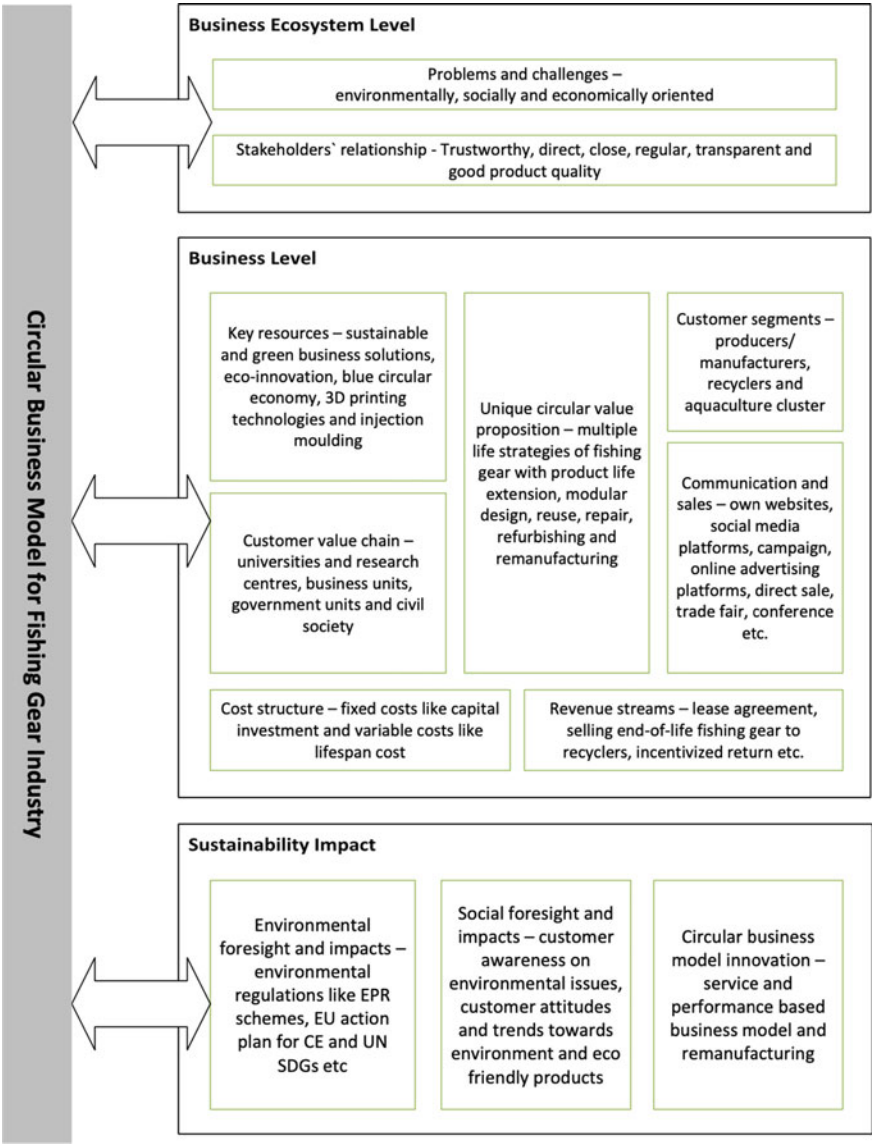

Fig. 4.5 Conceptual framework of circular business model for fishing gear industry. *Modified from* Antikainen and Valkokari (2016)

tackle current challenges and move towards the circular economy model (Boons et al. 2013). Service and performance-based business models and remanufacturing (Peck 2020) are the circular business model innovation for the fishing gear industry.

4.6 Conclusion

The objective of this chapter was to explore how circular business models for SMEs in the fishing gear industry can be achieved and to provide increased understanding of the circular business model processes of SMEs using the case study approach. The study applied a qualitative research design to explore the treatment of fishing nets, ropes, and components (FNRCs) in the context of circularity and therefore, developed a framework to evaluate the practice of circularity in the fishing gear industry. The findings from the case analyses provided unique insights on the level of circularity of SMEs within the marine plastic recycling value chain in the north-western part of Norway. Though the findings should be interpreted in the context of the limits inherent in qualitative research, the study sets the directions for future research.

Firstly, the study sample is limited to five Norwegian case firms; therefore, one should be cautious in generalising the findings. There might exist geographic biases in the conceptions of fishing gears and approaches towards circularity. The same is true for specific industry backgrounds. The criteria for the firms to be classified as SMEs was whether they had less than 100 employees (Iversen 2003). However, it could be an avenue for future research to use firms of different sizes and larger samples from other countries as well. Secondly, the findings are based on perceptions and understandings of the circular business model aspects when targeting SMEs in the fishing gear industry, which may restrict external validity. Thus, we invite future research to test our proposed models on firms from other industries. Such research can complement the findings of the study and offer a more nuanced and holistic understanding of the practice of circular business models for SMEs in other industries. Thirdly, although all types of players of the fishing gear industry (e.g. manufacturers, suppliers, and the customers) are included in the study, the complexity and degree of criticality of product portfolios are not accentuated. Therefore, caution should also be exercised in interpreting and generalising our findings. Finally, we encourage more research to continue regarding circular business models for SMEs in the fishing gear industry by focusing on the three levels; business ecosystem level, business level, and sustainability impact, which has been the central point and focus of the present study.

Appendix 1 Case Profiles

Case 1—Ørskog Plast Industri AS—Ørskog Plastindustri is one of the Scandinavia's leading manufacturers of plastic products for the construction industry. They produce among other things, reinforcement chairs, spacers, cones, and plugs. Their products are produced in recycled polyethylene / polypropylene (PE / PP). The company was established in 1986 and is located at Sjøholt in the Ålesund municipality of Møre og Romsdal, in the western part of Norway, approximately 40 kms from Ålesund city centre. The company is conducting their business in across Scandinavia and looking for agents or representatives to expand their business all over Europe. The contract details are: ØRSKOG PLASTINDUSTRI AS, Måsøyra 1, 6240 ørskog, Norway; telefon: 70 27 00 86, e-mail: post@oplast.no.

Case 2—Plasto AS—Plasto AS is another manufacturer of plastic products which started its journey in 1955. It is located in the city of Åndalsnes in the West of Norway. The company has around 40 employees. Most of the customers are based in Norway with several in the local area of Åndalsnes. However, through their customers' products, their high-end components are spread internationally. Up until the early 2000s, the company was dependent on the automotive company as a low-margin supplier to a car manufacturer. But financial difficulties resulted in a changed business model, going from standard components at low margins, to innovate and customized products at higher prices. At present, their strategy is centred on research-based innovation with special emphasis on networks and external collaboration. The company is renowned for its open attitude and willingness to commit resources to research and development (R&D) projects in collaboration with universities and research institutes. The contract details are: Raumavegen 43, 6300 Åndalsnes, Norway; telephone: T: + 47 71 22 01 00; e-mail: firmapost@plasto.no.

Case 3—NOPREC AS—In the summer of 2017, Norwegian Plastic Recycling AS (NOPREC) launched the brand-new granulation line at Matmortua. After testing and fine-tuning the plant, high-quality plastic raw material is now produced from discarded fish firms, feed bags and hoses from the aquaculture industry and ropes, plastic cans, and other plastic waste from the fishing industry. The facility is co-located with Containerservice Ottersøy AS on Matmortua. This makes it possible to control and track the waste from the time it is reported by the customer until it is transported out as plastic granules, finished recycled raw material. The company also run research and development (R&D) projects with small and large partners and want to contribute to driving the Norwegian circular economy forward by driving plastic waste from Norway back into Norwegian plastic production. Their contact details are: Matmortua, Foldavegen 6012, 7940 Ottersøy, Norway; telephone: + 47 743 97 333.

Case 4—Replast AS—Replast AS was established in 2017 as a project group, the company springs from a long-term vision of being able to recycle plastic waste where it is generated. The company recycles plastic in various formats. They work directly with manufacturers, collectors, municipalities, and private actors. The firm is also part of several research projects that will further, and improve, the qualities of reproduced raw materials within this industry. They work closely with several players and manufacturers to increase the quality and credibility of using reproduced material. This is something they believe is absolutely necessary for today's requirements for quality and volume to match manufacturers' needs in the future. The firm comes from the western part of Norway, and their contact details are - Replast AS, 114 Husøyvegen, Frei, Møre og Romsdal, 6520, Norway, Phone: + 47 413 99 540, E-mail: post@replast.no.

Case 5—AKVA Group—AKVA group is present in all markets with offices in Norway, Chile, Denmark, Scotland, Spain, Greece, Iceland, Canada, Australia, and Turkey. AKVA Group is a unique partner with the capability to offer both sea-based and land-based aquaculture operations with complete technical solutions and service. It is a global technology and service partner that deliver technology and services that help solve biological challenges within the aquaculture industry. The contact details of the company are: Plogfabrikkvegen 11, N-4353 Klepp stasjon, Norway, mail address: P.O. Box 8057, N-4068 Stavanger, Norway; phone: + 47 51 77 85 00.

Appendix 2 Interview Guide Questions Operationalising Circular Business Model Themes

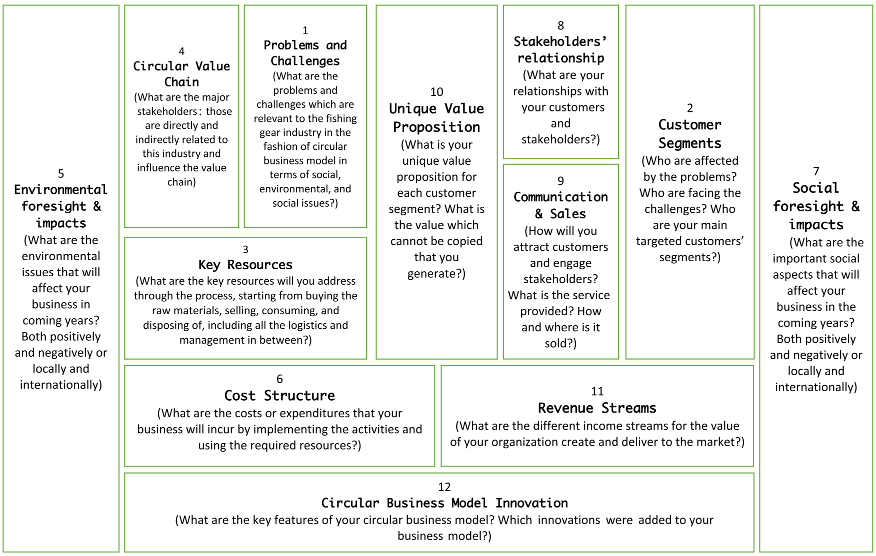

Figure: Researchers' own Circular Business Model Canvas for Fishing Gear Industry inspired by Osterwalder & Pigneur's business model canvas

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Chapter 5
Opportunities for Circular Business Models and Circular Design Related to Fishing Gear

Martin Charter

Abstract There is growing interest in circularity and fishing gear-driven emerging legislative, standards, NGO interest and other stakeholder pressures. At present, there has been little focus on new circular business models (CBM) or circular design of fishing gear. The chapter will overview fishing gear, highlight key legislation and introduce CBMs and circular design in this context providing: (i) description of fishing gear used for fishing, (ii) European Commission (EC) Single Use Plastics (SUP) Directive and the related Extended Producer Responsibility (EPR) legislation as it relates to waste fishing gear, (iii) opportunities for more circular business models (CBMs) from fishing gear and (iv) design strategies to the improve the product circularity of fishing gear (circular design).

Keywords Fishing gear · Circularity · Circular business models · Circular design · Extended producer responsibility

5.1 Introduction

This chapter focuses on Circular Business Model (CBMs) and circular design of fishing gear—two new concepts and issues for the sector. Essentially, producers and assemblers have produced a variety of fishing gear to catch fin-fish and shell-fish and issues related to circular economy are new to leadership teams and designers/developers. The growing awareness of circular economy worldwide amongst policymakers, civil society, business and academia is leading to a discussion over the need for a transition away from linear *take-make-waste* economy to a more circular economy. This is particularly being driven by the European Commission through its Circular Economy Action plans and the Sustainable Product Initiative. Circularity is impacting on the fishing gear sector through the development of EPR legislation and new European standards that are now being developed under the

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technical committee: CEN TC 466. Waste fishing gear in the world's oceans is a widespread and enduring problem globally. There is agreement on this fact, however, the size of the problem is fully not agreed on. One study suggests that 10% of all marine plastics are waste fishing gear (Macfayden et al. 2009), and the European Commission (EC) use a figure of 27% (by weight) of marine plastics being waste fishing gear (EC 2018). Another study suggests that 70% of floating macro plastics in the ocean gyres is fishing related (UNEP 2016; Eriksen et al. 2014). Fishing gear containing plastic poses a significant risk to marine ecosystems, biodiversity and human health: there are additional risks to marine-related economic activities including tourism and shipping.

There are essentially two categories of waste fishing gear[1]: end-of-life of fishing gear; and abandoned, lost or discarded gear (ALDFG) which is commonly known as *ghost gear* (EC 2008). End-of-life gear is often left in piles in harbour facilities due to the absence of a waste management plan for fishing gear, which means it often goes to landfill or incinerators as a final destination. Ghost gear is abandoned, discarded or accidentally lost fishing gear that fish or marine animal predators and scavengers can get caught and, typically, die as a result.

To tackle the marine plastics problem, the EC have passed measures to reduce the impact of certain plastic products in the marine environment through the Single Use Plastics (SUP) Directive (EU) 2019/904. This includes the reporting and monitoring requirements of fishing (and aquaculture gear) being placed on the market. The annual (calendar year) reporting period began on 1 January 2022. Reporting will need to be in place 18 months after the calendar year by each Member States of the European Union (e.g. by June 2024). The SUP Directive will place increased responsibilities on fishing gear producers and assemblers (that place plastic fishing gear on the market), and governments to improve the recovery, accountability and outcomes related to fishing gear within the context of a circular economy. EPR legislation will come into force on 31 December 2024. As indicated above, in addition, there are European standards that are being developed through a new technical committee: CEN TC466.

Research (Circular Ocean, n.d and CfSD, n.d) has indicated that there are a series of key points to be considered, when thinking about circular business models (CBMs) and circular design for fishing gear.

Economics

- Fishing operators work to very tight margins and do not want their fishing gear to fail
- Fishing gear can be expensive, with some individual fishing gear costing up to €200,000; however, some monofilament fishing nets are even more expensive

[1] "Waste fishing gear" is defined as: as any fishing gear covered by the definition of waste, including all separate components, substances or materials that were part of or attached to such fishing gear when it was discarded, including when it was abandoned or lost.

Manufacturing and assembly

- There is a range of scientific working groups that work on technical requirements for the development of fishing gear[2]
- Fishing gear is often assembled in Europe, for example, with polymers and components procured from suppliers in India, China and South Korea
- Fishing gear is generally made to order; therefore, there is often considerable dialogue between the fishers and fishing gear manufacturers and assemblers
- Customisation of fishing gear is common, with adaption based on individual experience of fishers, leading to a variety of co-design of fishing gear.

Design and development

- A complex and wide variety of fishing gear is used to catch finfish and shellfish in fresh water, saltwater and in aquaculture farms.
- New gear design and development requires technical trials and the construction of model fishing nets built to scale to take account of vessel size, engine types, fish behaviour and gear interaction.
- Design and development processes for fishing gear often appear to be based on senior people's knowledge and experience in fishing gear production or assembly rather than following a structured product design and development process, e.g. a stage-gate process that might be found in other market sectors.
- Fishing gear is typically repaired and modified by the fishers and/or sometimes by the fishing gear suppliers as part of "take back" contracts with fishers.

5.2 Fishing Gear

Fishing gear comprises a complex series of products used for active and passive fishing in addition to rearing or growing different types of finfish and shellfish. Fishing gear includes nets, ropes, components and peripherals. A significant proportion of fishing gear is produced from polymers, but metals, rubber and other materials are also used. The table below illustrates the variety of gear used for different types of fishing. This chapter uses the term waste *fishing gear* when referring to fishing nets, ropes, components and peripherals (FNRCPs).

Table 5.1 is an indicative classification of fishing gear used to catch finfish and shellfish. The table was compiled from multiple sources (Sea Choice n.d, MSC n.d and FAO 1990) and should be viewed as a indicative document for further discussion and research. There were three main challenges in compiling the table: lack of easily accessible information on the topic; many different terms used in the fishing sector that vary geographically as well as between policy, academia and industry; and

[2] There are scientific working groups that focus on technical issues related to fishing gear development including those within International Council for the Sea (ICES), Scientific, Technical and Economic Committee for Fisheries (STECF) and Food and Agricultural Organisation of the United Nations (FAO) [Working Group on Fishing Technology and Fish Behaviour (WGFTFB).

Table 5.1 Fishing gear category and corresponding gears

Type	Name	Active or passive	How the fishing gear are used	What the fishing gear are made of	Position in the ocean	Catch		Notes
						Finfish	Shellfish	
Nets	Trawls (Pelagic)	Active	Nets are towed by one or two boats (pair trawling)	A cone-shaped net with a closed "cod-end" to holds the catch	Midwater	Herring Hoki Mackerel		Specific mesh sizes, exclusion devices and acoustic deterrents prevents bycatch
	Trawls (Demersal)	Active	Nets are towed by one or two boats (pair trawling)	A framed cone-like net with a cod-end bag	Ocean bottom	Atlantic cod Rockfish Hake	Shrimp	
	Dredges	Active	Rigid structures rake the seabed to dislodge the catch into the net which is dragged over the sediment	A triangle iron frame with a front bar (with or without teeth). Has either fine nets or a metal collecting basket	Ocean bottom		Scallops Oysters Clams	Specific mesh sizes and escape panels prevents bycatch Highly regulated to prevent the loss of habitat
	Purse Seine	Passive	A vertical net "curtain" is placed in the water which traps the catch by drawing in the bottom of the net	Bottom-weighted nets	Midwater	Salmon Herring Tuna Mackerel		
	Danish Seine	Active	Nets are towed by one or two boats (pair trawling)	Tunnel shaped net	Ocean bottom	Tiger flathead Eastern school whiting		

(continued)

Table 5.1 (continued)

Type	Name	Active or passive	How the fishing gear are used	What the fishing gear are made of	Position in the ocean	Catch		Notes
						Finfish	Shellfish	
	Gillnets (stationary)	Passive	Nets are placed in the water (in a line, a circle, left drifting, or stationary) and entangle the catch	Wall or curtain of netting that hangs in the water—size of fish caught can be determined by the mesh size	Shallow water	Manitoba Whitefish Salmon		Attaches acoustic deterrents to nets to deter marine mammals
Hook and line	Longlines	Active	Lines are dragged behind boat	Long lines of baited hooks	All levels of depth	Swordfish Tuna Halibut Sablefish		Weights are placed on lines and use tori lines to prevent unintended interactions with non-target fish, seabirds and other marine life
	Bottom (demersal)	Active	Uses hooks to catch fish	Long lines of baited hooks	Ocean bottom	Halibut Rockfish Cod		

(continued)

Table 5.1 (continued)

Type	Name	Active or passive	How the fishing gear are used	What the fishing gear are made of	Position in the ocean	Catch		Notes
						Finfish	Shellfish	
	Pole and line (chumming)	Active	Creates the illusion of a school of prey fish by spraying water from the back of the boat and scattering small bait fish onto the sea surface	A hand-held wooden or fibreglass pole with a short line and barbless hook attached	Midwater	Tuna		
	Handlines, jigs and trolls	Active	Uses hooks to catch fish yet the lines are shorter than longlines and in the water for a shorter time	One hook to one fishing line	All levels of depth	Tuna, Swordfish Mahi-mahi Cod Haddock		
Traps	Pots Stow Bag nets Fixed traps	Passive	Stationary enclosed spaces with cone-shaped entrance tunnel that are laid on the seabed for 24–48 h then are hauled onto a boat for harvesting and re-baiting. Laid in strings (with traps attached to a long rope)	Consists of wood, metal, wire netting or plastic and rope	Ocean bottom		Lobster Crabs Shrimp and Sablefish	Mesh walls should be sized so that small fish can escape. Exclusion devices prevent larger marine animals becoming entangled

NB Fish Aggregating Devices (Fish aggregating devices are floating objects that are designed and strategically placed to attract pelagic fish (NOAA Fisheries n.d), https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-fish-aggregating-devices) are not included in this categorisation distinguishing between different types of fishing gear and fishing techniques is not always clear cut. It is recommended that further research is completed with input from gear technologists, industry experts and other stakeholders from the fishing community.

There is a significant variety of fishing gear used to capture finfish and shellfish with different requirements for the fishing gear dependant on the finfish and shellfish targeted. Comprehensive lists of gear have been difficult to find; however, the need for such categorisation is now being driven by legislative and standards development in Europe. In addition, there are different polymers used for different types of gear. The focus historically purely on the function of the gear rather than what materials they were made from.

5.3 Legislative and Standards Development in Europe

The development EPR legislation in Europe by the EC is now leading to emerging discussion over circular economy in the fishing gear sector. Whilst most producers of fishing gear will focus on compliance, a number are likely to be interested in new circular business models. In addition, to the legislative development new European standards are now being taken forward by CEN through TC 466 that includes guidance for stakeholders on circular design and circular business models (see later section).

The EPR legislation embedded within the Single Use Plastics Directive (SUPD) aims to tackle the many challenges posed by waste and end-of life fishing gear made from plastics. The SUPD is based on the "Polluter Pays" principle: the aim is to make fishing gear producers and/or assemblers responsible for the end-of-life phase of fishing gear by taking on the costs of managing the products' waste streams. Prior to implementation of the EPR there are requirements to collect and report data on fishing gear placed on the market and on waste fishing gear (containing plastic) collected in Member States. In addition, implementation of the Port Reception Facilities (PRF) Directive will mean collection infrastructure will need to be set up for waste and end-of-life fishing gear. EPR will seek to increase the collection rate of waste and end-of-life fishing gear, thus reducing disposal at sea as well as disposal by landfilling and incineration, and the associated environmental and economic impacts of marine plastics.

Under the SUPD, member states will need to bring into force laws, regulations and administrative provisions to enable the introduction of EPR for fishing gear by the 31st December 2024. Member states will be able to design and implement tailored legal, administrative and economic instruments to create local solutions at ports and/or within fishing communities.

In 2027, the EC will evaluate the SUPD and may include new legislative proposals or binding collection targets related to the EPR of fishing gear.

Under EPR, member states will have the flexibility to develop EPR schemes in consultation with stakeholders including producers and assemblers of fishing gear, fishers, recyclers, SMEs, entrepreneurs, co-operatives or social enterprises.

5.4 European Standards Development: European Committee for Standardisation (CEN) TC466

5.4.1 Background

A Standardisation request M/574 (COMMISSION IMPLEMENTING DECISION) related to circular design of fishing gear in support of Directive (EU) 2019/904 was submitted by the Directorate-General for Maritime Affairs and Fisheries (DG MARE) to CEN in November 2019. In November 2020, CEN established a technical committee—CEN TC 466—to progress standards development related to circular design, circular business models (CBMs) and recyclability of fishing gear as highlighted in M/574 (CEN 2020). The secretariat for the CEN TC 466 is provided by the NEN (Dutch standards body). The deadline for publication of the standards is May 2024, but NEN has applied for an extension to December 2024 to align with legislative development. As at March 2022, seven standards are being developed under three working groups (WGs), convenors of the WGs have been appointed and writing of the text has now started. Of note, is the secretariat of WG2—that is developing guidance on CBMs—moved to CENTEXBEL[3] in January 2022.

5.4.1.1 Scope

The scope of CEN TC 466 is standardisation in the field of circularity and recyclability of plastic-based materials in fishing gear and aquaculture equipment. Excluded is standardisation work concerning fish processing, fish packaging, fish food products and general work on materials and equipment covered by other CEN technical committee.

[3] Centexbel is an institution recognised by the application of the Royal Decree of January 30th, 1947 (a.k.a. "Law De Groote"). Its mission is to promote research and technological development with the intention of enhancing the cost-effectiveness, quality and production capacity of the Belgian textile industry.

Table 5.2 CEN TC 466 working groups (WGs)

WG 1: Technical requirements of circular design of fishing gear (CDFG)
1. Technical requirements of CDFG
WG 2: Environmental and circular requirements for fishing gear and aquaculture equipment
1. Environmental requirements of CDFG (part 4)
2. Circularity requirements of CDFG (part 5)
3. Circular business models for fishing gear and aquaculture equipment (part 6)
WG 3: Guidance on implementing CDFG
1. The standard on the CDFG (part 1)
2. Principles and user manual of CDFG (part 2)
3. Digitalization of gear and components (part 7)

5.5 Circular Business Models (CBMs) and Circular Design

Growing awareness of Circular Economy opportunities, EPR legislation and standardisation activities may encourage fishing gear producers to explore new CBMs, e.g. reuse, modular design, leasing, etc. and start to integrate circularity in gear design and development. Further discussion of CBMs related to fishing gear can be found in the next section.

Extending the life of fishing gear—through repair—is already commonplace amongst fishers but not reported or monitored. For example, fishers in British Columbia, Canada, often take salvageable and reusable parts of old fishing nets (that would otherwise have been discarded) and use them to patch up their current, serviceable fishing nets.

The implementation of the PRF Directive will mean that infrastructure for the regular collection of waste and end-of-life fishing gear in all European Union (EU) member state harbours and ports will need to be set-up, which will potentially create a market for 2nd life polymers and other materials. PRF Directive and EPR in EC member states and outside the EU, e.g. in Norway and UK, could also become a trigger for innovative solutions for start-ups, SMEs, entrepreneurs, co-operatives and social enterprises:

- Ports, coastal cities and towns, and fishing communities could establish initiatives to support local SMEs in the reuse, upcycling, repurposing and recycling of waste fishing gear to tap in the national targets for a circular economy
- Centralised collections might be established to facilitate public–private partnerships to undertake larger scale repair, servicing, remanufacturing and recycling activities
- Solutions need not be small scale and/or artisan. They could be industrial scale within a local circular economy model.

The implementation of EPR could result in the development of new products, new businesses and jobs, for example, by:

- Using recycled plastics from fishing gear to produce pellets (using mechanical recycling) for use in injection moulding of products, e.g. sunglasses, skateboards, toys, surfing and fishing accessories
- Using recycled fibres using the de- and re-polymerisation (chemical recycling) of nylon fishing nets to produce socks, clothes, swimwear, carpet tiles, etc
- Repurposing of fishing gear into bracelets, keyrings, necklaces, dog leashes, bike, garden accessories and mats.

In 2018, The Centre for Sustainable Design ®[4] (CfSD) at UCA Business School completed research into commercial products produced from recycled plastics, e.g. pellets from fishing nets, or through the re-use of fishing gear or materials. It indicated that the number of commercially available products was limited at the time of publication (Charter et al. 2018). There are indications that the number of commercialised products has increased, but total numbers are still small.

Informal discussions with fishing gear manufacturers have indicated that the product design and development processes operated by fishing gear producers and/ or assemblers are often not formalised; and formal product design and development training, tools and methodologies are less likely to be used in the sector compared to many other market sectors. Therefore, at present, ecodesign and more specifically circular design strategies, processes and tools are unlikely to be implemented by fishing gear manufacturers and assemblers, unless there are external drivers, e.g. from customers (fishers) and/or there are policy drivers. One gear technologist indicated that he had used specialist computer-aided design (CAD) software to design fishing gear, but the current CAD software did not include any environmental modules. Environmental modules provide guidance on design strategies to reduce product-related environmental impacts, e.g. design for modularity, design for repairability, design for dismantlability, etc. This is reinforced by unpublished cross-sectoral research completed by CfSD, that indicated that few CAD tools have incorporated environmental modules to date and none have integrated product circularity modules.[5] Further research needs to be completed in this area.

[4] The CfSD has built world-class knowledge and expertise of sustainable innovation and product sustainability. The Centre research, develops and disseminates understanding of present and future sustainability impacts and solutions related to innovation, products, technologies, services and systems through projects, training, events, networks and information.

[5] Findings relate to unpublished research completed on product circularity and design tools within EC funded ORIENTING project (ORIENTING, n.d).

When implementing ecodesign[6] (or, more specifically, circular design) and CBM-related fishing gear, several key issues need to be considered:

- Functionality: The design of fishing gear should target specific fish, the respective water environment conditions and fishing techniques[7]
- Cost: Fishing operators work to tight margins and global prices for catches fluctuate
- Customisation: The design of fishing gear needs to be tailored to a fishing method and fishing operator activity such as those outlined in (see Table 5.1a Fishing Gear Category and Corresponding Gears and Table 5.1b Indicative classification of Fishing Gear)
- Material selection: Fishing gear needs to survive harsh conditions. Fishing nets and ropes are therefore typically made from nylon, polypropylene and polyethylene (polymers) which are either braided or twisted.[8] Newer plastics, such as Dyneema®[9] has been developed to improve the efficiency and productivity of fishing or to increase the lifespan of the fishing nets and ropes. However, these advanced technical materials raise additional challenges at end-of-life (Plastix n.d).
- Failure modes and effects: Key failures come from tearing and stretching. Durability is key but depends on external factors that cannot be overcome through design, e.g. entanglement of nets in ocean debris, sabotage from competing fishing operators, destructive fishing practices or unskilled fishing operators.

5.5.1 Circular Business Models

Thinking proactively about the development of CBMs for fishing gear amongst producers/assemblers is a new area. It has been primarily fishers (customers) that have been involved in product life extension through repair, but some producers have explored take-back model where they will repair fishing gear and return to fishers.

Below are existing and potential CBMs that might be considered by fishing gear stakeholders: see Tables 5.2 and 5.3. The classification of CBMs is based on Clause 6 ("Guidance on enabling mechanisms and business models") in BS8001:2017 (bsi 2017)—Framework for implementing the principles of the circular economy in organisations—that was further developed to focus on fishing gear in a chapter by Charter and McLanaghan in *Designing for the Circular Economy* (2018). A report

[6] "Ecodesign is the systematic approach which considers environmental aspects in the design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product" (IEC 2019; ISO 2020).

[7] Fishing gear is being increasingly designed to avoid bycatch of unwanted fish through excluders or specific designs.

[8] Fishing lines may be constructed from multiple polymers for specific purposes, e.g. weighted ropes with metal cores.

[9] Dyneema ® is a brand name for rope that uses ultra-high molecular weight polyethylene.

further developed the original thinking, and this is highlighted in Tables 5.2 and 5.3 (Charter et al. 2020).

Table 5.2 highlights existing CBM practices and potential additional opportunities that may be becoming more relevant, particularly given current trends and policy changes. The table highlights potential models related to customisation, e.g. production on demand, product life extension, facilitated reuse and modular design. With emergence of EC legislative recycling requirements from EPR and new CEN guidance standards on circular design, it is likely that these options may be considered with modular design perhaps being a less complex strategy to adopt.

Table 5.3 identifies new CBMs and outlines opportunities and threats. It considers the stakeholders owning and implementing the business model, the opportunities provided by the models, and threats that could hinder the models' introduction. The EC EPR legislation will drive potential opportunities for CBMs, some will be more complex and require, significant organisational change and other will require primarily adaption of design and development processes. Some of the key challenges associated with implementing CBMs will be the change of mindset associated with

Table 5.3 Summary of key targets and dates related to the SUP and PRF Directives

Year	Description
27/06/2019	Entry into force of the revised Port Reception Facilities (PRF) Directive
02/07/2019	Entry into force of the SUP Directive
03/07/2020	Entry into force of implementing acts laying down the format for reporting data on fishing gear (containing plastic) placed on the market and waste fishing gear collected[a]
21/01/2022	Entry into force of implementing acts for PRF Directive[b] that requires the provision of collection facilities for passively fished gear, including ALDFG and "end of life" fishing gear
2022	Member states need to collect and report data on fishing gear placed on the market and on waste fishing gear (containing plastic) collected in the Member State. This will need to be completed annually
2024	Member states will need to report the data and information collected electronically within 18 months of the end of the reporting year for which they were collected (first reporting year: 2022)
31/12/2024	Member states to have established EPR schemes for fishing gear (containing plastic)
07/2027	EC completes an evaluation of the SUP Directive—if appropriate, the EC will propose binding collection targets for waste fishing gear following a study of the feasibility of establishing such binding targets

[a] The Commission Implementing Decision laying down the format for reporting data and information on fishing gear placed on the market and waste fishing gear collected in Member States and the format for the quality check reports was adopted on 31st May 2021. Please see the link here: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2021.211.01.0051.01.ENG&toc=OJ%3AL%3A2021%3A211%3ATOC

[b] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R0089&from=EN

circularity thinking, potential development costs, e.g. reverse logistics, new collaboration with fishers (and other stakeholders) and (re)training of producer's design/development teams.

Strategies related to—and aimed at improving the business and product circularity of fishing gear—are embedded in the respective tables. The tables have been designed to initiate discussion.

Many of the CBMs outlined in Tables 5.2 and 5.3 are a potentially disruptive and a radical departure from the "business as usual" in the industry. Therefore, any implementation of these CBMs would require extensive research, piloting and testing (Tables 5.4 and 5.5).

5.5.2 Ecodesign

CEN 466 has now started standardisation activities related to the circular design of fishing gear as part of new EC activities covering a variety of other sectors including energy-related products and textiles. At present, ecodesign or more specifically circular design is a new issue for the fishing gear sector. 80% of a product's environmental impact is determined at the design and development stage (Smallpiece Trust 1989). However, this figure should be treated as a "rule of thumb": the important point is that consideration of environmental issues at the design and development stage is essential to improve product-related environmental performance throughout the lifecycle of fishing gear. Ecodesign is a process to reduce product-related environmental impacts in design and development and has been practised by leading companies in other industry sectors—outside of the fishing gear—since the 1990s. Other terminology is used worldwide that is equivalent to ecodesign and includes environmentally conscious design (ECD), design for environment (DfE), green design and environmentally sustainable design. The term ecodesign is used below and throughout this report.

Two international standards on ecodesign have been published: IEC 62430:2019 and ISO 14006:2020.

> Ecodesign is the systematic approach which considers environmental aspects in the design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product
>
> (IEC 62430:2019 (IEC 2019) and ISO 14006:2020 (ISO 2020))

As indicated previously, informal conversations amongst fishing gear producers and assemblers indicated that (fishing gear) design and development often seems to be an informal process based on personal experience and learning of company leaders—rather than formalised design and development process as typically seen in other market sectors. In addition, dialogue has also indicated that neither ecodesign or more specifically circular design has been practised in (fishing gear) design and development. There needs to be further research into this area.

Table 5.4 Existing circular business models and additional opportunities

Circular economy business model	Existing practices	Additional opportunities
Produce on demand (made to order and custom made)		
Producing a product or providing a service only when customer demand has been quantified and confirmed	Fishing gear is often custom made to the needs of individual fishing operators based on their fishing practices	Emerging digital production technologies (e.g. adopted from textile industry) could reduce production times and costs while increasing customisation potential Adopt ecodesign strategies to reduce resource consumption across products' life cycle Combine with other CBMs for additional revenue streams e.g. re-use, repair, remanufacturing and reconditioning
Product life-extension		
New products designed for a long lifetime (durability)	Producers provide fishing operators with a fishing net plan as well as repair patches. Durable materials such as Dyneema® are becoming more common, increasing the lifespan of the fishing gear	Combine with other CBMs for additional revenue streams. Examples: refurbish, repair, remanufacturing and reconditioning services. Combine with modular design and ecodesign strategies to facilitate high quality and commercially viable reuse Adopt ecodesign strategies to reduce resource consumption across products' life cycle
Facilitated reuse		
Reuse with or without repair/ upgrade (supplied, either free of charge or resold)	Producers and fishing operators frequently reuse many of the components of fishing gear such as weights and buoys	Reuse of complete fishing gear systems is high unlikely due to their customised nature. However, there is potential for greater reuse of key components of fishing gear than currently taking place. Commercialising reusable components could be undertaken by the fishing operators, producers, centralised/localised market brokerage and storage or a separate reuse network Combine with other CBMs for additional revenue streams. Examples: refurbish, repair, remanufacturing and reconditioning, recycling, downcycling, upcycling and repurposing or circular business models (e.g. modular design, product life extension) and ecodesign strategies to facilitate high quality and commercially viable reuse
Product modular design		
Products designed to be modular so that components are updated	Fishing gear can be produced so that key components can be easily removed and replaced	Combine with other CBMs for additional revenue streams. Example: repair, remanufacturing and reconditioning Combine with other CBMs (e.g. product life extension) and ecodesign strategies to facilitate high quality and commercially viable reuse

Table 5.5 New circular business models' opportunities and threats

Business models	Opportunities	Threats
Incentivised return		
Incentivises customers to return used/unwanted items to the producer. The producer then either recycles materials or remanufactures the product	Enables producers to meet upcoming SUP and PRF Directives without paying additional EPR fees. This could: • Facilitate an increase in repeat orders for the producer when combined with take back discounts or a deposit scheme • Increase the collection rate of fishing gear thus reducing illegal dumping at sea • Increase the likelihood of fishing gear entering circular resource flows if combined with reuse, remanufacturing and recycling, especially if producers can commercialise circular business models	Producers could incur additional costs due to extra logistics demands, sales discounts or labour and storage demands to handle returning used fishing gear To ensure fishing gear enter circular resource flows producers will require additional resources to undertake diagnostics to assess retainable value

(continued)

Table 5.5 (continued)

Business models	Opportunities	Threats
Lease agreement		
Leasing access to a product/service and not selling ownership. This can be on a business to business (B2B) or business to consumer (B2C) basis. In general, an "operating lease" model is likely to be best suited for product service system models in the context of a circular economy, because ownership of the asset is retained by the lessor and can be combined with service or performance-based business models	Enables fishers' access to consistent high quality fishing gear with lower capital investment and potentially a lower lifespan costs when taking depreciation, maintenance and disposal/replacement costs into account. Because the fishing operators lease fishing gear from the producers and pay a regular fee for their use, repair and replacement guaranteeing, they will also have a suitable fishing gear available for use Enables producers to retain ownership of fishing gear enabling them to: Ensure fishing gear are returned at end-of-life to meet SUPD requirements Increase profit from individual fishing gear by product life-extension, modular design, reuse, repair, refurbishing and remanufacturing Obtain additional revenue streams by selling end-of-life fishing gear to recyclers	Requires resources (capital investment) to transfer producer's accounting (upfront sales profit) and sales (bonuses) practices from one-off sales to leasing Fishing operator cash flows, grants, accounting (depreciation) could hinder monthly payments Service contract will require legal clarity on responsibility/liability disputes between producers and fishing operators on maintenance/repair/handling/training etc. Producers underwrite liability of uncontrollable damages, entanglements or misuses etc. which could reduce profitability Insurance will be needed because if the fishers mishandle or don't repair the gear, the producer may face the return of degraded products at the end of the lease Culture and perception of control through ownership amongst fishing operators could result in a low uptake

(continued)

Table 5.5 (continued)

Business models	Opportunities	Threats
Sharing platforms/resources		
Shared access or "collaborative consumption" among users, individuals or organisations, but where some form of transactional arrangement (which could be financial) is provided. Enable increased utilisation rate of products and services by making possible shared use/ownership among consumers. Enabling customers to access a product, rather than owning it outright, and use it only as needed	Enables small scale fishing operators to gain additional revenue streams by renting out their irregularly used, underutilised or port-based fishing gear Enables small scale or start-up fishing operators to reduce costs, removing capital investment by paying per use for irregular used or port-based fishing gear Opportunity for a digital platform to generate revenue (on a % of rental prices) for providing intermediate services between parties, thus reducing the risks to fishing operators Opportunity for a community co-operative to rent port-based fishing gear or end-of-life treatment equipment to local fishing operators	Requires open, collaborative and highly trustful industry culture, which may be a significant challenge in a competitive commercial fishing industry Requires legal clarity on who takes responsibility for incorrect use, maintenance and damages Sharing platforms have potential in regional, artisanal small-scale fisheries where harbours are not too far from each other. It is unlikely to work for industrial fleets who spend weeks to months at sea at a time
Peer to Peer (P2P) lending		
P2P lending of products/services is mainly between members of the public or between businesses, but where no direct financial transaction occurs, or income is secured For B2B lending, business benefits might include reduced costs over directly sourcing the products/services concerned	Enables fishing gear producers to reduce costs by substituting virgin raw materials with recyclate, especially if the producer retains ownership of fishing gear through enacting lease agreements, performance-based pay and incentivised return Additional revenue stream for fishing operators to sell used fishing gear Opportunity for start-up either for collection or recycling used fishing gear	Requires open, collaborative and highly trusting industry culture which may be a significant challenge in a highly competitive commercial fishing industry Requires legal clarity on who takes responsibility for incorrect use, maintenance and damages Challenges could arise if fishing gear is required at the same time, e.g. fishing is tidal based in small ports

(continued)

Table 5.5 (continued)

Business models	Opportunities	Threats
Refurbish, repair, remanufacture and recondition		
Product gets a next life after remanufacturing: the process of restoring the product or part functionality to "as-new" quality; facilitated by design for disassembly. Enables the fishing gear producer to put the products back into the market to earn a second, or subsequent income, from a second or subsequent user	**Refurbish:** aesthetic improvement of a product, component or material, which might involve making it look like new, with limited functionality improvements. Opportunity for a port-based cleaning services by co-operatives or social enterprises Enables fishing operators to reduce fishing gear replacement costs **Repair:** returning a faulty or broken product, component, or material back to a usable state. While some fishing gear producers provide repair services, that are either port-based or at their facilities, and the majority of fishing operators self-repair there fishing gear there is an opportunity for a more joined-up approach to repair in the sector **Recondition:** return of a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure. Opportunity for port-based or centralised remanufacturing services by co-operatives or social enterprises **Remanufacture:** return a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product. Opportunity for additional revenue streams for producers if combined with other circular business models such as product life-extension, modular design, lease agreement, performance-based pay and incentivised return. Enables fishing operators to reduce costs with lower priced fishing gear	**Refurbish:** Low market demand could reduce the potential to cover operational costs. Will require quick turnaround to tie in with fishing operator's downtime **Repair:** Labour intensive work could make repair and reconditioning costs not viable. Will require quick turnaround to tie in with fishing operator's downtime. This could also be a source of additional income for artisanal fishers as they know how to deal with and repair fishing gear **Remanufacture:** Resource-intensive work could increase costs beyond the price of new fishing gear e.g. inspection, storage, disassembly, restoration and replacement of components, testing etc. Hindered by material degradation especially on plastic components Low and sporadic rates of used fishing gear collection could result in an unreliable supply chain

(continued)

Table 5.5 (continued)

Business models	Opportunities	Threats
Recovery of secondary raw materials/by-products		
Creating products through secondary materials from recovered waste	Recycling (closed loop): material is broken down to its chemical components, reproduced and manufactured into the same product, i.e. fishing gear. Enables producers to reduce costs by substituting recyclate with virgin raw materials, especially if the producer retains ownership of fishing gear through enacting lease agreements, performance-based pay and incentivised return. Additional revenue stream for fishing operators to sell used fishing gear Opportunity for start-up either for collection or recycling used fishing gear	Challenges include: Material degradation, irregular collection rates, material toxicity, contamination from salts, moisture, ultraviolet (UV) light, oil spills, chemicals etc. Labour intensive disassembly and material separation High capital investment and operational costs of recycling often cannot compete against low virgin raw materials costs High risks of producing a lower grade material that's not fit for the required performance Unrealistic potential for perpetual recycling due to material entropy Increased costs and red tape required to obtain waste licences to collect, transport and recycle waste fishing gear Large mix of material types
	Downcycling (open circular loops): material is broken down to its chemical components, reproduced and manufactured into the any product i.e. low-grade plastic products like street bollards. Opportunity for a port-based start-ups or centralised system to downcycle fishing gear into low grade fishing related products, e.g. crates, labels etc. Additional revenue stream for fishing operators to sell used fishing gear	

(continued)

Table 5.5 (continued)

Business models	Opportunities	Threats
	Upcycling (open circular loops): material is broken down to its chemical components, reproduced and manufactured into products, e.g. high-grade plastic products such as performance running shoes. Opportunity for port-based start-up or centralised system to upcycle fishing gear into new products, e.g. sunglasses, socks, clothes, footwear, carpet tiles, skateboards, toys and surfing and fishing accessories, etc. Additional revenue stream for fishing operators to sell used fishing gear	
	Repurposing (open circular loops): components are disassembled, and individual materials treated and reformed into new products e.g. keyrings and bags made from fishing nets and ropes. Opportunity for port-based start-up or centralised system to repurpose fishing gear into new products, e.g. bracelets, keyrings, necklaces, dog leashes, bike, garden accessories and mats etc. Additional revenue stream for fishing operators to sell used fishing gear	Challenges include: material degradation, irregular collection rates, material toxicity, contamination from salts, moisture, UV light, oil spills, chemicals etc. Labour intensive disassembly and material separation

Also as indicated previously, EC DG MARE was tasked in the Circular Economy Action Plan in 2015 with initiating European standards development related to circular design of fishing gear. A mandate was delivered to CEN in 2019 and TC466 has been established to take forward standards development. There are three of the key areas for standard development: circular design; CBMs; and recyclability of fishing gear (see earlier section on CEN TC466).

As indicated above, ecodesign and circular design are new concepts in the fishing gear sector. However, there are indications that R&D in circular design of fishing gear is starting. For example, Sotenäs Marine Recycling Centre (SMRC) and its partners have initiated a R&D project related to the circular design of fishing gear (see Chapter 10).

There appears to be a lack of awareness and understanding of the principles of lifecycle thinking that is embedded in ecodesign within the fishing gear sector. As fishing gear is a materials-based product, e.g. non-energy using in the *use* phase, the biggest product-related environmental lifecycle impacts are likely to be associated with the procurement of the materials in the supply chain, e.g. polymers and metals, and waste at the end-of-life. However, fishing gear is often repaired many times by the fishers (in the *use* phase of the gear) despite a lack of 'design for repairability' being included in design and development.

Effective implementation of ecodesign (and within it, circular design) requires increased awareness and understanding of a life cycle perspective that might consider designing for product life extension, e.g. "multiple lives" of fishing gear. However, designing more circular fishing gear will include a range of additional considerations that include:

- Identifying potential trade-offs between material durability and circular material loops such as recyclability
- Assessing commercial viability of using reusable components, given the labour-intensive nature of fishing gear assembly and disassembly, and the unpredictable supply of waste or end-of-life fishing gear
- Determining key components to *make (fishing gear) modular* without impacting on fishing gear performance.

As Circular Economy becomes an increasingly important policy driver in the sector, it will be important—from an environmental and economic standpoint—to extend the life of and retain the value of fishing gear in economic and social systems. Therefore, designing for the *closed loops,* e.g. producers and assemblers developing and implementing *take back* systems for fishing gear to enable the repair and refurbishment of fishing gear will increase. Where *closed systems* do not exist, extracting value from fishing gear in the *open loop* may emerge as entrepreneurs start to see business opportunities (Bakker et al. 2018).

From a product circularity perspective, a key consideration in fishing gear (product) design and development should be how to proactively *design for product life extension* e.g. repairability, durability, etc. Materials recycling should be considered as the final end-of-life stage of fishing gear lifecycle. In this context, product circularity should be thought of as a process to design and develop fishing gear, as a product/service, to retain the value in fishing gear for as long as possible in economic and social systems.

Thinking about *closed loop* design might lead to contracts between, fishing gear producers and assemblers, and fishers, where the fishing gear is sold as a service rather than as a physical product with, for example, take-back, and repair and modification services built into contracts. Proactive *open loop* design will mean that fishing gear in its 2nd life is designed to be reused in different applications outside of the fishing sector. Such proactively designed systems do not exist at present. Products produced from waste fishing gear in the *open loop* are generally not part of a designed system, as such, with the fishing gear collected and/or procured by designers and entrepreneurs, as end-of-life waste materials from the fishing system. For example, (Verdura n.d) re-uses sections of fishing nets for shoes, (Bureo n.d) recycles polymers from fishing gear into pellets for injection moulding into various products including skateboards, and (Fishy Filaments n.d) turns polymers from fishing gear into filament for 3D printing.

There is a diversity of materials (polymers, metals, rubbers, etc.) that are used in the current design and development, production and/or assembly of fishing gear. Simplifying the types and number of the materials used in the development of fishing gear will enable more effective recycling at end-of-life when product life extension or reuse options are no longer feasible.

There will need to be awareness-raising of the business and environmental benefits of ecodesign (and circular design) targeted at fishing gear producers and assemblers. In addition, new education and training courses will need to be established to help the designers and developers of fishing gear think through design strategies related to improving the product circularity of fishing gear. Tailored grant aid and financial support will also be needed to help increase awareness, understanding and build skill sets within the industry.

As Circular Economy policy increasingly emerges and EPR for fishing gear is implemented in European member states and elsewhere there will be a need to develop improved chemical and mechanical recycling infrastructure, as at present there is only one significant chemical recycler—Aquafil who produce (Econyl, n.d) fibres—and one mechanical recycler—Plastix Global (Plastix, n.d) who produce pellets—in Europe, that specialises in the regeneration and/or recycling of polymers from end-of-life fishing gear.

Implementing EPR in Europe will require all stakeholders to rethink the present way that fishing gear is produced and used through to the final end-of-life once product life extension and reuse has been exhausted. This will take time and money. It will also require significant cultural change and capacity-building amongst all key stakeholders in the fishing gear lifecycle and system. EPR will mean that there will also be the need to be "systems design" of collection, sorting, reuse and recycling of end-of-life fishing gear at regional and national levels.

It is currently unclear how EPR for fishing gear will be implemented in member states. The EC has not clearly set out the methods for calculating a producer EPR fee, and has not, so far, established minimum collection or recycling rates. This may change after the initial evaluation of the SUPD in 2027.

To fully address opportunities and challenges, there will be a need to bring together direct and indirect stakeholders in ports and related coastal areas (from fishing sub-systems) with stakeholders from the business and innovation sub-systems in ports and related coastal areas. Experience from Blue Circular Economy (BCE) stakeholder workshops organised by The Centre for Sustainable Design ® in Ålesund, Norway, and Galway, Ireland indicated the prime benefit of such events was to facilitate networking between role players who had never previously met, stimulating new connections, thinking and perspectives in those regions.

EPR and an increase in Circular Economy practices could result in waste fishing gear being *harvested*, e.g. cleaned and stored into materials banks—presenting an opportunity for start-ups, SMEs, entrepreneurs, co-operatives or social enterprises to develop new products (e.g. clothing) from the materials, new services (e.g. training, cleaning, repair) and new business models (e.g. rental of fishing gear). Combined with advances in technology (e.g. 3D printing) and tapping into local innovation systems, the possibilities could be substantial. Lessons should be learnt from existing leading-edge initiatives, e.g. Sotenäs Marine Recycling Centre in Sweden (see Part III, Chap. 10).

However, not all fishing gear will be reusable and/or recyclable and there is a need to classify and then manage degraded and contaminated gear, materials, components and peripherals. This may highlight further new opportunities for a start-ups or existing businesses. *Green* public procurement could be used by local authorities (that host ports and harbours) to kick-start the demand side and stimulate innovation—for example, incentivising the reuse of waste fishing gear in the *open loop* in building and construction products in coastal areas.

Systems will also need to set up to tackle the significant backlog of fishing gear that needs to be recycled and/or disposed of. There is abundance of usable gear in regional harbours, but unless there is a demand or incentives for repair is unlikely that gear will move back into use.

There is a need to change the mindset from thinking about waste and end-of-life fishing gear to maximising the value in fishing gear, components and materials for as long as possible in economic and social systems. This change in approach will require all key stakeholders to buy into a more holistic strategy that utilises products-services-systems (PSS) strategies, as well as *systems design.*

5.6 Conclusion

National Circular Economy policy development is increasing in Europe, and EPR and the CEN standards on the circular design, CBMs and recycling of fishing gear will come into force in 2024. These developments are likely to present significant challenges for the sector but may highlight new opportunities for the development of new CBMs and ecodesign (including circular design) of fishing gear across its life cycle. In addition, this may present opportunities for further development of products re-using fishing gear and using recycled polymers from waste and end-of-life fishing gear in new applications within or outside of fishing sector. However, at present, the number of commercial products developed in the *open loop* is limited.

Stakeholders benefiting from changes in the sector are likely to include start-ups, recyclers, SMEs, entrepreneurs, co-operatives or social enterprises focused on new opportunities related to development the recycling infrastructure through European member states, as well as those involved in converting waste and end-of-life fishing gear into products.

To ensure long-term benefits, the fishing gear sector should, ideally, adopt a joined-up, Europe-wide strategy and not just focus on a country and/or regional level approach—although regional and local plans will need to be developed as this is where issues will need to be tackled. It is also recommended that the fishing gear sector—working with other stakeholders—develops a clear vision, strategy and action plan that addresses circularity and EPR. The implementation of EPR in Member States and elsewhere could become a trigger for innovative solutions—including start-ups, SMEs, entrepreneurs, co-operatives and social enterprises focused on more circular solutions for the fishing gear sector. However, there will need to develop new systems to expand recycling systems within Europe related to EPR and to build knowledge around the ecodesign (and more specifically circular design) of fishing gear. Utilising best practice and lessons learnt from initiatives that have already progressed thinking and practice, e.g. Sotenäs Marine Recycling Centre (SMRC) and Steveston Harbour Authority in Canada will be essential. A key lesson learnt from these case studies is to include fishers in discussions from the start. The new business models, design strategies and innovation presented in this chapter provide a useful starting point for stakeholders to consider the next steps in tackling waste and end-of-life fishing gear.

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Chapter 6
Quadruple Helix Relational Approach to Recycling Fishing Nets: Cluster Development in the Norwegian West Coast Region

Hajnalka Vaagen and Arron Wilde Tippett

Abstract The study presented in this chapter takes the quadruple helix relational perspective to develop a regional innovation cluster for fishing nets recycling and upcycling. A multi-method approach is proposed—triangulating cluster development approaches with the quadruple helix model of innovation and organisational network analysis—to explore clustering abilities by network structures that promote linkages for well-organised circular value chains, regional innovation processes, brokerage of innovative ideas and other cluster-related structures, and relational patterns.

Keywords Cluster · Quadruple helix · Organisational network · Fishing nets · Circular value chain

6.1 Introduction

Pollution from fishing vessels and installations is recognised as one of the most serious environmental threats globally, with 46% of the Great Pacific Garbage Patch made up of fishing nets (Lebreton et al. 2018). The International Maritime Organisation IMO's Marine Environment Protection Committee (2021) has developed regulations and recently launched its strategy to reduce marine plastic litter (IMO 2021). However, many seaports are neither equipped with the necessary infrastructure nor technology, nor operational capabilities to receive, sort, store, and treat this type of waste (Deshpande and Haskins 2021). Businesses engaged in recycling-upcycling

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activities are also relatively few in number, as compared to the amount of recyclable waste, and most of them are in their early product and technology development phase, with rather immature value chains. To facilitate the development of specialised knowledge and technological capabilities needed, to solve the marine plastic litter problem, new stakeholder constellations and coordination between original equipment manufacturers, operators, and innovators are needed, as well as coordination with governmental units (Kalverkamp 2018).

Circular supply chains to transform discarded fishing nets into new business opportunities (i.e. new marketable products) are expected to lead to solutions that increase the circulation of raw materials and that hinder the waste from entering the ocean. Innovation and entrepreneurship are recognised as driving forces for circular supply chains and corresponding business models (Charter 2018; Iglesias-Sánchez et al. 2016), with collaboration with external actors and trust-based engagement as facilitators of the development of new capabilities to innovate through such models (Vildåsen 2018); e.g. collaboration between industry and academia helps to develop new internal competencies and sharing of early research results, and experience accelerates the development process and the adoption of circular business models. Collaboration with governmental units helps to spread circular economy research by providing financial support that facilitates industry-academia collaboration. These relational benefits are leading to the triple helix model of innovation (Etzkowitz and Leydesdorff 1995), as an approach to better understanding interactions between businesses, universities, and governmental units that may facilitate new business opportunities from fishing nets recycling. The sociocultural dimension of marine plastic litter suggests that innovations in this direction are also to be anchored in the needs and feedback from civil society (e.g. end-users, consumers, non-governmental organisations, and volunteers for beach cleaning). The quadruple helix, as an enhancement of the triple helix to also include civil society (Carayannis and Campbell 2009; Höglund and Linton 2018), puts the relational aspect between the three initial helices into the larger sociocultural context (McAdam and Debackere 2018; Nordberg 2017).

Against this background, the chapter at hand discusses how *the quadruple helix as a network of relations* can be applied to facilitate the development of a regional cluster for new business opportunities from reuse and recycling of discarded fishing nets. The Norwegian West Coast region already has strong cultural traditions for trust-based and reciprocal networking and clustering for technology-driven innovation and entrepreneurship, in the marine and maritime businesses. Long shipbuilding traditions and cutting-edge technology, coupled with global operations, ensured access to the fastest-growing markets (e.g. aquaculture, cruise, exploration), with flexibility and responsiveness to market changes and societal challenges as important enablers of the competitive advantage for cluster members (Hansen et al. 2020; Vaagen et al. 2016), and for the region at whole. Established relational and innovation capabilities, as well as regional specificities, are hence a valuable source of learning for new cluster initiatives, such as the one at hand. Cultural factors play a critical role in innovation and entrepreneurship, as these are stable over time due to shared values, norms of behaviour, and beliefs that also define the identity of people and organisations in the region (Ranga and Garzik 2015).

The network view of quadruple helix relations led us to the investigation of organisational (social) network analysis as a potential theoretical approach and methodology to study the relational properties that facilitate knowledge transfer, learning, combined resources, innovative ideas, and cooperation in the emerging cluster. Network theory provides an answer to how individuals (humans or organisations) can combine to create well-functioning systems and societies and provides explanations for different social phenomena, from individual creativity to corporate profitability (Borgatti et al. 2009). For a review of the network analysis in social sciences, with basic assumptions, goals, and explanatory mechanisms, see Borgatti et al. (2009), and for a discussion of its application in cluster development programmes, we refer to Pietrobelli and Giuliani (2011).

The research foundation is, as such, developed by triangulating cluster development approaches with the quadruple helix and organisational network analysis. The literature leading to the research foundation is reviewed in Sect. 6.2. The methodological approach is given in Sect. 6.3, with preliminary results in Sect. 6.4, and conclusion with future research directions in Sect. 6.5.

6.2 Theoretical Background

6.2.1 Clusters

Cluster policies aim to promote collective processes of growth and innovation in a regional area. These share at least three aspects that are also relevant for the discussion at hand (Pietrobelli and Giuliani 2011). First, they target a group of actors that are typically (but not necessarily) localised in a geographically bounded area. Second, clustering programmes are tailored to industry specificities and maturity, the stage of the cluster lifecycle, and regional characteristics. Third, cluster policies are grounded in one of two ideas, to search for higher innovation or to search for more efficiency in production; both of which are best achieved when firms collaborate and share resources. The latter suggests that a central principle of many cluster policies is the promotion of linkages and networks.

Efficient networks are recognised as social processes involving the interaction, cooperation, and alliance of different actors (Freeman 1991; Powell et al. 1996), with clear advantages to access resources, reduce information asymmetries, improve information quality, enable higher bargaining power, strengthen the lobbying power, enable firms to upgrade their capabilities, and generate innovative ideas. That said, conventional cluster programmes target general groups of actors and often stop at the level of identifying individuals in major categories in the cluster (Ketels 2013), e.g. suppliers of raw materials, designers, and clients. Key concepts like networking, connections, and linkages are often measured by aggregated indicators that only capture the connections between general categories but fail to account for the diversity of connections between individuals within each category. E.g. within the group of fishing nets, suppliers may be individuals with leading roles in R&D activities for recycling, shaping the cluster future. Macro-level clustering approaches cost-effectively account for the presence of collaborative networks and are justifiable by practical motivations. However, aggregated network measures may hide more than they reveal (Pietrobelli and Giuliani 2011), a general property of average values.

Furthermore, conventional cluster policies focus on strengthening existing networks rather than creating new ones, building on established regional economic performance and evolution (Ketels 2013). This makes it challenging to study innovation and entrepreneurship, as the main drivers of innovation-driven economies like the Nordic countries (Bosma and Levie 2010; Porter and Lopez-Claros 2004). Efficiency-driven economies, with a primary focus on growth and economic development, also increasingly turn to strengthen the private sector and develop public incentives for the development of the economy. Thus, entrepreneurship is important for the development of a country (Martínez-Fierro et al. 2016), and the entrepreneur is the best changing agent (Acs and Amorós 2008; Bosma and Levie 2010). As such, clustering approaches for the scope at hand must also capture the innovation and entrepreneurship capabilities.

6.2.2 Quadruple Helix

Innovation, entrepreneurship, and economic growth are directly related. Countries that achieve an increase in innovation and entrepreneurship also achieve higher rates of economic growth (Galvão et al. 2017). Galvão et al. (2017) apply the four dimensions of the quadruple helix model to propose a theoretical framework for entrepreneurship as a tool for economic development. The quadruple helix, extended from the triple helix (Etzkowitz and Leydesdorff 1995) to bridge the gap between innovation and civil society, emphasises the societal responsibility of universities besides their roles in education and research, and the need for tight interactions with industries producing commercial goods, governments regulating markets and providing financing, and the civil society (e.g. end-users, consumers, media, other). The quadruple helix claims that under the triple helix, the emerging technologies and innovations enabled by these do not always match the demands and needs of society, thus limiting their potential impact (Volpe et al. 2016). The fourth helix is defined as:

> A collective entity formed by individual users living on a territory and interacting with university, industry, and government as customers, citizens, or members of a community in order to contribute to build new innovation paths which are able to promote the socio-economic growth of the territory. Civil society demands that innovations are made according to its needs, releases feedback on products and services (and on their innovation value), and provides its own contribution in terms of knowledge, inventiveness, and creativity. Civil society is constantly interacting with the other three helices as a result of enabling technologies for information and communication which make social inclusion possible in real time and at low cost (Volpe et al. 2016).

In summary, the quadruple helix model is seen as a network of relations where public and private organisations interact in a value-creating process. It is also the approach the European Union intends to take for the development of a competitive knowledge-based society (Volpe et al. 2016). As interactions increase within this framework, each component evolves and adopts characteristics of the other institution, leading to hybrid organisations that facilitate entrepreneurship and innovation (Champenois and Etzkowitz 2018). Hybrid organisations, such as science parks, incubators, and catapult centres, act as a catalyst between actors in the quadruple helix network. One of the practical instruments of the triple and quadruple helix models is innovation clusters, with Silicon Valley as the most known cluster for new technologies and industries (English-Lueck 2017; Etzkowitz 2012).

To measure what the four helices represent in terms of economic development, multiple variables, and factors of influence are proposed (Carayannis and Campbell 2009; Etzkowitz and Leydesdorff 1995; Galvão et al. 2017). The transfer of specialists between university and industry measures knowledge transfer. Interactions between governmental units and universities depend on the government's policy on higher education and the strategic demands. The government, as the main source of funding, has a high influence on universities. Government and industry relations depend on the government's strategy towards specific markets. The key roles of the government in its interaction with industry are to regulate specific markets and to establish intellectual property law and its enforcement. Further, Galvão et al. (2017) show that innovation-driven economies exhibit greater relevance in the industry and government dimensions, with variables of high influence, 'R&D transfer' and 'financing for entrepreneurs'. The authors propose that a strong link between government and industry suggests strong R&D transfer from universities according to the needs of industry and government, which is important for innovation.

6.2.3 Critiques of the Triple and Quadruple Helix Models and Call for New Perspectives

The importance of collaboration in a quadruple helix puts the relationship aspect between the four helices in focus. This resulted in quadruple helix research from different perspectives, from supply chain to regional innovation management. However, studies take a macro-level perspective, fail to account for the micro-level relational specificities and value-creating activities through these relations, and consequently, also fail to assess the economic value generated by these relations (Hasche et al. 2020; Höglund and Linton 2018; McAdam and Debackere 2018; Miller et al. 2018). Examples of questions that are relevant in innovation management, but difficult to address on a macro-level, are as follows: 'who do we need to involve to generate innovative ideas, and who will help to implement these? Who are peripheral actors that represent untapped expertise and how to proactively involve them so that new connections for generating creative ideas can emerge? Who are the information brokers'? To answer these questions, research into individual relational perspective and the combined resources and activities such relations enable is needed (McAdam and Debackere 2018). Cunningham et al. (2018) emphasise the need to better understand the micro-aspects of relationships, to enhance knowledge of the dynamic relationships that arise between individual stakeholders, synergies between relations, collaborations, coordinated environments, and value-creating activities.

The micro-level relational perspective of innovation is supported by social science research, highlighting that innovation is generated by creative 'individuals', embedded within a network of interdependent ties (Simonton 2013) and that creativity lays at the nexus of the individual and the larger sociocultural context (Cattani and Ferriani 2008; Csikszentmihalyi 1997, 2014). Organisational network analysis from social sciences is a theoretical and methodological approach that proves valuable to uncover the micro-level relational aspects of networks. It is a research perspective based on the assumption that relationships amongst interacting actors (organisation or people level) are important in explaining their nature, behaviour, and outputs. The ONA facilitates quantitative or qualitative analysis by describing features of a network either through numerical or visual representations. ONA has been proposed as appropriate for cluster development (Pietrobelli and Giuliani 2011; Giuliani 2011), but practical applications are few. Examples are found in Breznik (2016) and Woods et al. (2019). The latter points to the position of a firm within the network of a low-technology cluster as important for new product development innovation. Further, firms occupying central network positions by their connection to many other members of the cluster, typically demonstrate greater innovation capabilities. Size, absorptive capacity, and managerial orientation are factors highlighted to influence a firm's network position in a cluster.

6.3 Methodology and Context of Analysis

6.3.1 Methodology

Organisational network analysis (ONA) is chosen as the methodology to explore regional cluster development abilities, to better understand where and what collaborative efforts are present, and what connections are needed to be strengthened or enabled, to stimulate cluster development. The selection of ONA suggests a move towards systems of relations of intertwined actors. The network of connections that enable quick transfer of innovative ideas, information and resources, and norms of behaviour within these networks (i.e. trust, obligations, and risk behaviour) provides the motivation to combine resources and generate solutions to emerging problems. Trust is a relational dimension of the social capital and is connected to the motivation to share and combine information and knowledge but also to the extent of resource exchange and product innovation (Tsai and Ghoshal 1998). Recall from Sect. 6.1

that capabilities needed to innovate through circular models is likely to arise in trust-based collaboration networks with external actors (Vildåsen 2018). Further, research shows that information exchange in a network is not random, but people and organisations seek advice from those they trust, although more qualified ones may be available (Casciaro and Lobo 2005). Therefore, the way actors are connected within a network structure says much about available resources and innovation potential (Burt 2004; Marsden 1990).

The ONA approach generates an understanding of the advantages and disadvantages of different network positions and structures in the cluster. These may differ from context to context. One structure of relevance for cluster development is *the promotion of linkages for regional innovation processes*, e.g. linkages between government and industry may strengthen R&D transfer from universities according to the needs of the industry and government (Galvão et al. 2017). The desired output for regional innovation processes may be *local cliques* connected by a few ties, to facilitate the sharing of creative ideas and high-quality knowledge, thus generating opportunities for innovation (Pietrobelli and Giuliani 2011). A second output may be 'core-periphery' structures with a core of densely connected actors and a periphery of few connections brokering new ideas from external actors (Cattani and Ferriani 2008). Too many connections can also be detrimental for innovation, and cluster development initiatives may focus on promoting connections only amongst partners that have something valuable to share. Avoiding redundant ties is, hence, important, and building connections with external actors (*small worlds*) and promoting diversity (*structural holes*, *brokerage*) are desirable to generate new ideas and creative outputs. Technological gatekeepers, as actors who acquire knowledge from outside cluster boundaries and contribute to technology diffusion within the cluster, are important for the growth of industrial and technology-driven innovation clusters (Giuliani 2011).

A second network structure with advantages to cluster development is *the promotion of well-organised regional value chains.* The desired network output may be a *hierarchical structure*, coordinated by one or few leading firms, orchestrating the local value chain and connecting it to markets and other stakeholders. Cluster development initiatives may, therefore, focus on selected connections and on increasing the centrality of some of the leading firms, whilst leaving others (for example, suppliers that only need to connect to their key customers) in less central positions.

6.3.2 Context of Analysis

Motivated by the dominant cluster development practices in the Norwegian West Coast region—i.e. facilitating well-functioning manufacturing value chains in the maritime and marine businesses—the clustering initiative at hand takes the *generic circular value chain* starting approach for fishing net recycling and upcycling (see Fig. 6.1 for illustration). The current value chain demonstrates a well-functioning forward stream of fishing rope manufacturing and operations systems, and a less mature reverse stream with missing connections, but also with a few leading actors

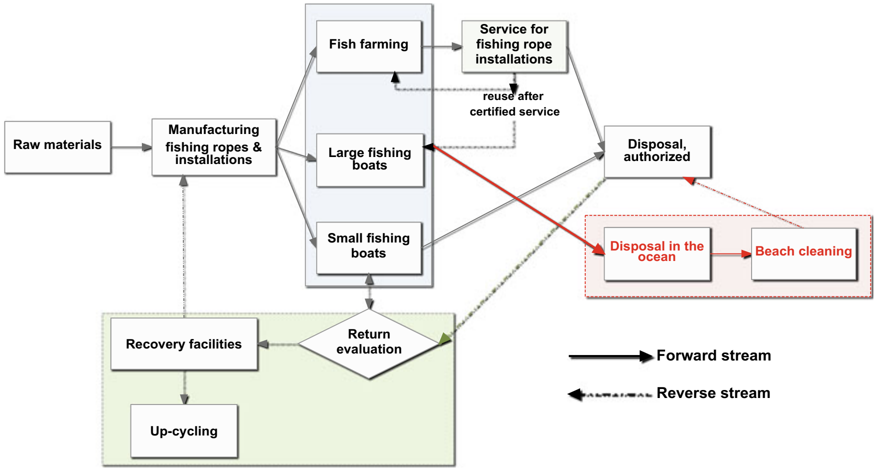

Fig. 6.1 Generic circular supply chain for fishing nets recycling and upcycling

potentially shaping the future of the reverse chain. Disposal of marine debris is regulated by IMO in order to facilitate a reverse stream from fishing boats and from service companies of fishing rope installations. However, many seaports are lacking facilities and competencies to handle disposed fishing nets, and a large share of fishing gear is discarded, lost, or abandoned in the marine environment (also known as 'ghost fishing'). These deficiencies necessitate new collaboration links, e.g. between authorities and aquaculture businesses to develop infrastructure for waste collection, sorting, and registration. Other connections of relevance are between volunteers cleaning up beaches and governmental units, in order to incentivise, formalise, and compensate volunteer work. Furthermore, collaboration paths between new businesses and governmental bodies are needed to enable flexible financing for entrepreneurs to develop new regulations and quality standards of recycled-upcycled products, to avoid inferior new products and unfair pricing, and to boost competition. Finally, the collaboration between academia and industry is also needed (e.g. by research projects and entrepreneurial education) for new product development from recycled fishing nets and for circular business models to be adopted by SMEs.

To enable these relations beyond supply chain collaborations to develop and deliver a product or service to a customer, the generic supply chain network is extended following the quadruple helix, to also include stakeholders from *government*, *academia*, the *civil society*, as well as *hybrid institutions* (such as science parks and incubators) that connect different actors and act as a catalyst in the network. The list of actors within the four helices makes up the early-phase cluster network, which stands as a basis for explorative ONA studies.

6.4 ONA Research Design, Data Collection, and Preliminary Results

An inter-organisational ONA research design is applied with relational data collected to enable mapping and visualisation of collaboration networks in the quadruple helix, as defined in Sect. 6.3. Relational data are collected by asking actors about their contact with other actors in the network; each respondent is asked to select individual organisations from a list. This differs from other approaches, as it asks about relationships between identifiable actors, and not between general categories or groups of actors. The respondents then categorised each connection with respect to the frequency of contact during the last year, measured by Likert scale. Organisational network visualisation and analysis tools used are UCINET NetDraw 2.178. The network underlying the data collection counts 69 organisational units. The aim is to explore current clustering abilities and to use the results to stimulate further cluster development and policy design activities.

6.4.1 Preliminary Results

Based on the questionnaire responses, the networks were constructed to visualise the relations in the preliminary cluster, the individuals' centrality in the network (defined by the number of direct ties one actor has with others in the network) with advantages for easy access to information, knowledge and resources, distance between nodes, and other important network measures. The network graphs are defined by nodes and the relations between the nodes. To rigorously treat anonymity, the major ethical issue embedded in network research design, outputs are presented by conventional versions that illustrate specific concepts, and participants (nodes) are presented by numbers and the helix vector they belong to.

The full network with frequent connections between individuals is visualised in Fig. 6.2. University is presented by blue circular nodes (7 actors), industry by red rectangular nodes (36 units), government by black triangle nodes (12 actors), and the civil society by green diamond nodes (13 actors). It is a dense network with few actors occupying central positions in the network (indicated by the node size). By zooming into the subnetworks of the four helices and into the ego-networks of central actors, structures of relevance for cluster development are detected. Two examples are given below, to illustrate central concepts for the promotion of value chains and innovation linkages.

Example 1 Looking at the industry subnetwork in Fig. 6.3, a *small world* with nodes (10, 13, 16, 22, 35) is detected (as highlighted). There, node 10 is a waste management company, node 13 is a recycling-upcycling manufacturer of discarded fishing nets into new raw materials, node 16 is a leading regional manufacturer and recycler of plastic products, node 22 is a fishery association, and node 35 provides consultancy for ocean plastic waste cleaning, recycling, and innovation activities.

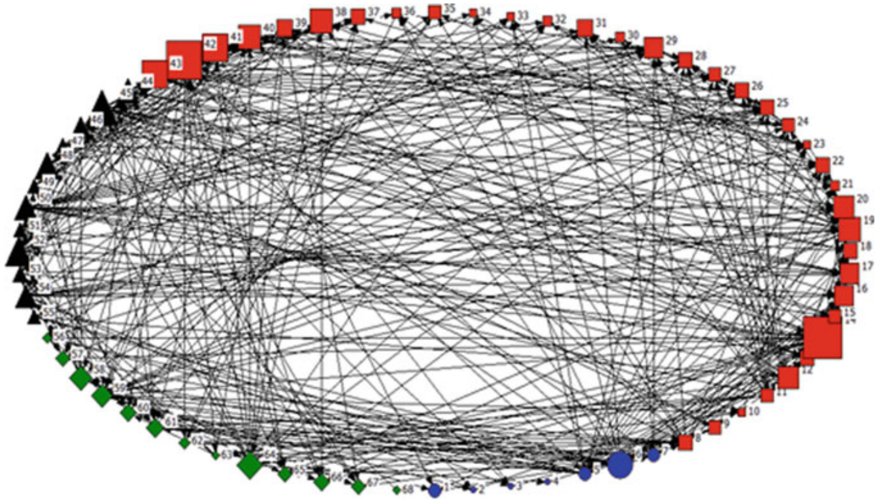

Fig. 6.2 Full cluster network

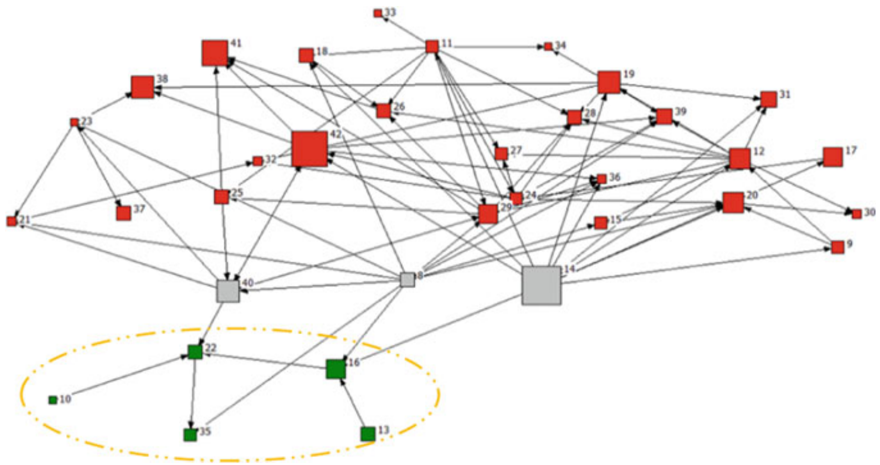

Fig. 6.3 Industry subnetwork. The 'small world' of nodes 10, 13, 16, 22, 35 (highlighted) connects to the network by a) value chain relations (nodes 8 and 14) and b) innovation processes (node 40)

This 'small world' connects to the industry subnetwork by two distinct structures: (i) *value chain relations* driven by the core activities of node 8, a leading recycling company of fishing rope nets, and node 14, a leading producer of fishing nets and equipment; and (ii) *innovation processes* through node 40, which is a hybrid organisation with incubator role for innovation in the marine and maritime industries. Node 40 connects complementary businesses by facilitating the transfer of new knowledge and innovative ideas; hence, important for innovation in the cluster. The *small world*

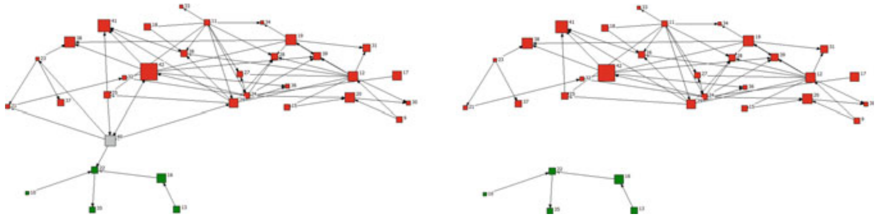

Fig. 6.4 Industry subnetwork with and without node 40, which is an influencer for promoting linkages for regional innovation

nodes, the connector nodes, and the remaining of industry nodes, are differentiated by colour. Node size reflects actor centrality in the full cluster network.

In organisational network theory, a gap between two groups of actors with complementary resources and information is known as a *structural hole* (Burt 2004). When the two groups of actors are connected by a third actor, the gap is filled, creating important advantages in terms of information and knowledge brokerage. According to Burt (2004), competitive advantage and early access to key information is a matter of access to structural holes. The concept is illustrated by Fig. 6.4, where the supply chain connector nodes from Fig. 6.3 (8 and 14) are removed. The connector node 40, an incubator to promote innovation, is illustrated on the first network and removed on the second one, to illustrate the structural hole. The results suggest node **40** to be an influencer, *important for the promotion of linkages for regional innovation processes.*

Example 2 The *promotion of well-organised regional value chains* is highlighted as a second network structure with advantages to cluster development. These relations are studied by the ego-network of leading industrials, such as node **14**, a leading producer of fishing rope installations. Its ego-network is visualised by the circle layout in Fig. 6.5, where 'own' supply chain members are presented by the rectangular industry nodes, connection to governmental units by links to triangles, to university and research institutions by links to circles, and to the civil society by links to the diamond nodes. The right side of Fig. 6.5 illustrates the supply chain subnetwork, with connections driven by economic transactions. Node size indicates actor centrality in the full network in Fig. 6.2, suggesting node **14** to be a *central player coordinating its value chain and connecting it to other actors in the cluster*. We also see that node 14 connects to multiple university nodes, highlighting R&D collaboration and knowledge transfer. University relations do not directly and immediately affect supply chain activities, but these facilitate the transfer of knowledge and innovative ideas and are expected to affect the cluster network in the long run.

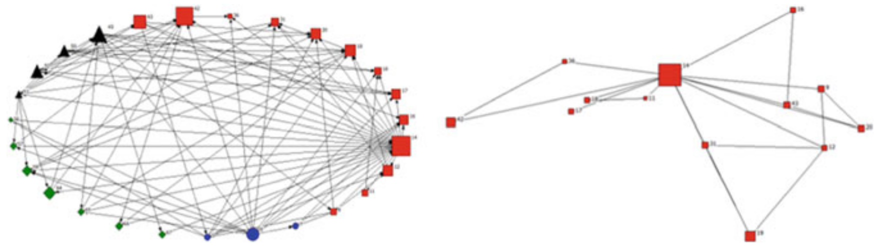

Fig. 6.5 Ego-network of industry node 14, with all quadruple helix relations on the left side, and only industry nodes on the right side of the figure

6.5 Conclusion

The research presented is a regional cluster development initiative through the relational lenses of the quadruple helix model of innovation. The aim was to explore current clustering abilities and stimulate further research about cluster development to solve the marine plastic litter problem. The cluster is in its early development phase, with established actors for regular operations, but with few innovators taking initiator roles to develop upcycling value chains. Thus, the network as an early-phase cluster suffers from the deficiency imposed by insufficient reverse-chain relations. Future clustering activities will therefore need to zoom into the value-creating reverse and circular activities of actors with influential roles and also zoom into policy-oriented decision-making paths leading to sustainable circular solutions. This is needed to increase cluster maturity by further identifying and connecting actors of influence and to uncover network strengths and weaknesses where further clustering activities are needed.

As a final point, cluster evaluation by ONA provides intermediate outputs where the value of networks is determined by network size and strength and relational characteristics (such as trust and brokerage of innovative ideas). These studies are to be complemented with knowledge of the economic value the firms draw from these relations and an understanding of the economic and societal benefits of a particular policy. This is needed to legitimate further networking actions in a particular direction and to assess the learning on how to make future projects for fishing net recycling more effective, by understanding what factors or mechanisms are held responsible for a policy's success.

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Chapter 7
Life Cycle Assessment of Fishing and Aquaculture Rope Recycling

Arron Wilde Tippett

Abstract In this chapter, we assess the environmental footprint of the production of recycled plastic granulate made of waste ropes from the fishing/aquaculture industries. The end-of-life treatment of waste fishing and aquaculture gear is an important factor in solving the marine plastic crisis. The improvement of waste management on land is thought to be one of the key strategies for tackling marine plastic challenges. Moreover, in terms of the circular economy, recycling is viewed as a more desirable end-of-life treatment than incineration and landfilling. Meanwhile, it is important to understand the environmental impacts of recycling processes to avoid problem shifting. The publication of environmental impact data on the recycling of fishing/aquaculture gear can assist policy makers and waste managers, amongst other stakeholders, in making decisions about end-of-life treatments. Life cycle assessment (LCA) is a standardised methodology for the assessment of the environmental impacts of a product across its full life cycle, from raw material acquisition through to end-of-life phases. In this chapter, we perform an LCA of fishing and aquaculture rope recycling. We begin with the acquisition of waste polypropylene/polyethylene (PP/PE) ropes from the fishing and aquaculture industries, move to the production of recycled granulate and end with delivery to the customer. We assess the environmental footprint of 1000 kg of PP/PE granulate across a range of impact categories, including global warming potential (GWP), acidification potential (AP), and eutrophication potential (EP). The core processes account for 40% of the total GWP emissions with the upstream and downstream processes accounting for 30% of the emissions each. A critical contributor to GWP emissions from PP/PE rope recycling comes from diesel production and consumption across the product life cycle. Finally, the global warming potential, acidification potential, and eutrophication potential of recycled PP/PE are significantly lower when compared to virgin PP and PE.

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Keywords Life cycle assessment (LCA) · Recycled fishing gear · Recycled aquaculture gear

7.1 Introduction

The global demand for protein and nutrition is driving the expansion of fishing and aquaculture industries across the globe (Hicks et al. 2019). The predicted doubling of the demand for fish by 2050 (Naylor et al. 2021) raises concerns about the sustainability of the expansion of the aquaculture and fisheries industries (Costello et al. 2020). The aquaculture and fisheries industries are heavily reliant on plastic equipment to house, feed, and capture fish. The volume of fishing and aquaculture gear lost to the environment is of particular interest due to the damaging effects they can have on individual species and ecological systems (Macfadyen et al. 2009). Economic losses are also evident through the loss of potential fisheries and the entangling of gear with propellers as well as other mechanisms. Large economic investments in fishing and aquaculture gear mean that losses to the natural environment often occur by accident. However, it is believed that gear is also purposefully lost to the environment to avoid costly port reception facility waste fees (Sherrington et al. 2016). A recent study by Deshpande et al. (2020) estimated that 380 tonnes of fishing gear from Norwegian fishers enter the sea each year. Fishing and aquaculture gear recyclers around Europe have begun to take up the challenge and have started to produce recycled plastic granulate for use in a range of products. However, it remains important to ensure that the environmental impact of waste plastic recycling is calculated to provide a benchmark for comparison with both virgin plastic production and other types of end of life treatments. Life cycle assessment (LCA) is an internationally recognised and standardised methodology for the environmental impact assessment of products and product systems (European Commission 2010). In this chapter, we will be estimating the environmental impacts of recycling fishing and aquaculture plastic rope using data from a case company in Norway.

7.2 Methodology

The environmental impacts related to the recycling of fishing and aquaculture rope are analysed using the standardised life cycle assessment method (LCA) (ISO 2006). The LCA methodology consists of four phases, as per ISO 14040 (ISO 2006). The first phase is setting the goal and scope of the study. This consists of defining the system boundaries and the declared unit. The second phase is the life cycle inventory (LCI), whereby all of the inputs and outputs of raw materials and energy to each individual process within the production life cycle are accounted for. The third phase is the life cycle impact assessment (LCIA), which involves calculating the environmental impact of each input and output flow throughout the production life cycle. The final phase is interpretation, which consists of analysing the data from the LCA using various visualisations. A detailed description of the LCA methodology is freely available from the European Commission (2010). In this study, the Gabi ts software was used to carry out the LCA with raw annual data collected in 2020 (for the production year 2019). Raw data was collected directly from the case recycling company using a mixture of meetings and data collection sheets. The processes used in the LCA and the final impact assessment were also validated by the case company before being included in this chapter.

7.2.1 Goal and Scope

The objective of this LCA is to estimate the environmental impacts related to the recycling of waste PP/PE fishing and aquaculture ropes into PP/PE granulate. PP/PE (polypropylene/polyethylene).

Case Company

Our case company is a plastics recycler based in Norway. The company is engaged in recycling plastic from both the fishing and aquaculture industries. They recycle PP/PE ropes from the fishing and aquaculture industries industry. Our goal is therefore to estimate the environmental impacts of recycling PP/PE from the fishing and aquaculture industry.

Declared Unit

The declared unit is the production of 1000 kg of recycled polypropylene/polyethylene (PP/PE) granulate from waste fishing/aquaculture rope. PP/PE granulate is used to replace virgin plastics in the manufacture of plastic products across a wide range of industries, from the furniture to the construction industry.

System Boundaries

The system boundaries are set at the point of collection of the waste plastic fishing/aquaculture rope (upstream processes) and include all processes relating to the processing of the fishing/aquaculture rope into new plastic granulate (core processes) and the delivery to the customer (downstream processes), as shown in Fig. 7.1. The system boundaries do not extend to the initial production of the PP/PE rope or to the use of the plastic granulate by downstream customers. The boundaries are set in order to compare recycled plastics to virgin plastics. Processes included in the study are listed and explained, as well as the way in which data was collected, in Table 7.1.

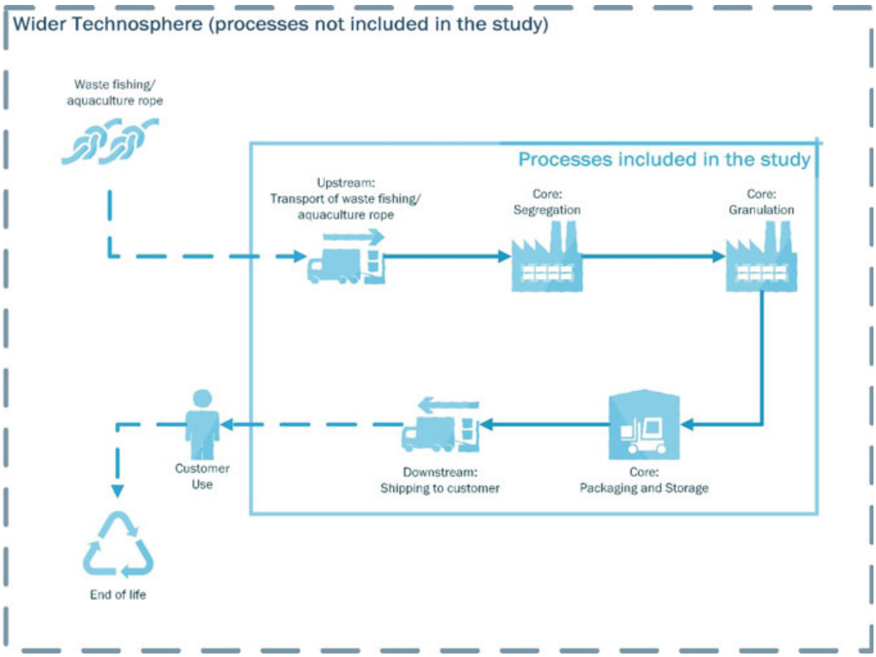

Fig. 7.1 System diagram of recycled PP/PE granulate production from waste fishing/aquaculture rope

7.2.2 Life Cycle Inventory

Foreground data on the upstream, core, and downstream processes for the year 2019 was obtained directly from as the case company in 2020 using data collection sheets and meetings/interviews. Background data was chosen from the Gabi Sphera database.

7.2.2.1 Life Cycle Impact Assessment

The environmental impact of the production of plastic granulate from waste fishing/aquaculture rope was obtained using categories from the CML 2001 characterisation model, as shown in Table 7.2. CML 2001 was chosen as it is a well-established, widely used, and scientifically supported method operationalizing the ISO 14040 standard series (European Commission 2010). CML 2001 uses characterisation factors developed from peer reviewed scientific literature, such as those found in the reports from Intergovernmental Panel for Climate Change (IPCC).

Table 7.1 Processes included in the Life Cycle Assessment of recycled PP/PE granulate production from waste fishing/aquaculture rope

Upstream	Transport	Truck with trailer used to collect waste fishing/aquaculture rope. Case company communicated that all of their trucks are Euro 6 or better and specified the tonnage, therefore the Gabi Truck Process GLO: Truck-trailer, Euro 6, 34–40 t grow weight/27 t payload was used (see Table 7.4)
Core	Segregation	Specific data collected on the mass of waste rope, that could not be recycled due to chemical coatings, and the waste management used for end of life. A generic data set from Gabi was utilised to model this process, EU-28: Plastic waste on landfill ts. The Gabi Truck Process GLO: Truck-trailer, Euro 6, 34–40 t grow weight/ 27 t payload was used for transport to the landfill site
	Forklift	Specific data was collected from the case company for the diesel used to move waste fishing/aquaculture rope around the factory. A proxy data set for the forklift process was used for diesel consumption, truck Euro 6, up to 7.5 t gross weight
	Granulation	Specific data was collected from case company on the electricity required to shred and granulate fishing/aquaculture rope waste. The generic Gabi data set was utilized to model this process, NO: Electricity grid mix ts
	Water for cleaning shredded material	The volume of water used to clean material is specific data collected from case company. The Gabi process used to model this was the EU-28: Process water ts
	Wastewater treatment	The volume of water going to the wastewater treatment plant was assumed to be the same as the water input to the system. The Gabi process used to model this was the EU-28: Municipal wastewater treatment (mix) ts
	Waste production	Specific data was collected on the mass of waste produced by case company during the granulation phase and the type of waste management used for end of life, which was incineration. A generic data set from Gabi was utilised to model this process, EU-28: Waste incineration of plastics ts
	Storage	Plastic granulate should be stored at a temperature of 21 °C in order to keep it dry. The excess heat from the granulation machine is used to maintain the temperature at case company, reducing the need for additional heating sources and thus additional processes in this system
	Forklift	Specific data was collected from the case company for the diesel used to store the new granulate at the case company's facility. A proxy data set for the forklift process was used for diesel consumption, truck Euro 6, up to 7.5 t gross weight (see Table 7.4)
	Packaging	Specific data was collected from case company on the type, mass and number of storage bags used to store each 1000 kgs of granulate. The generic data set from Gabi, EU-28: Polypropylene fibers (PP) ts was used to model this process. Transport from the bag production facility to the case company was assumed to be a GLO: Truck-trailer, Euro 6, 34–40 t gross weight

(continued)

Table 7.1 (continued)

Downstream	Delivery to customer	Truck with trailer used to deliver the recycled PP/PE granulate to the customer. The case company communicated that all of their trucks are Euro 6 or better and specified the tonnage, therefore the Gabi Truck Process GLO: Truck-trailer, Euro 6, 34–40 t grow weight/27 t payload was used (see Table 7.4)

Table 7.2 Impact categories modelled in the Life Cycle Assessment of recycled PP/PE granulate production from waste fishing/aquaculture rope

Impact category	Unit (expressed per declared unit)
Global warming potential, GWP	Kg CO_2-equiv
Acidification potential of soil and water, AP	Kg SO_2-equiv
Eutrophication potential, EP	Kg PO_4-equiv
Abiotic depletion potential—elements	Kg Sb-equiv
Abiotic depletion potential—fossil fuels	MJ, net calorific value
Net use of freshwater	m^3 eq
Hazardous waste	Kg
Non-hazardous waste	Kg
Total use of non-renewable primary energy resources (PENRT)	MJ
Total use of renewable primary energy resources (PERT)	MJ

Global Warming Potential (GWP)

Global warming or climate change is a global problem resulting from the infrared radiative forcing effects of greenhouse gases. Global warming potential in life cycle assessment is measured in kg CO_2-equivalent or carbon dioxide equivalents. Average temperature rises across the globe as a result of greenhouse gas emissions can be viewed as an exogenic pressure as, although emissions may be the result of local activities, the consequences from those emissions are at a global level.

Acidification Potential (AP)

Acidification is also a global problem resulting from the emissions of acid compounds from human activities. Acidification in life cycle assessment is measured using emissions kgs of SO_2-equivalent, or sulphur dioxide equivalents. Acidification of our oceans leads to the reduction in the productivity of low trophic level organisms, such as plankton and shellfish. These reductions have a knock-on negative effect on fish stocks, which feed on these smaller organisms. Acidification can also be thought of as an exogenic pressure, as it is a global problem which will have impacts locally.

Eutrophication Potential (EP)

The emissions of phosphates and nitrates from activities on the land lead to run off of these nutrients into water bodies causing eutrophication, or the enrichment of water bodies with nutrients. The productivity of plant species, such as algae, in water bodies, is limited by the concentration of key nutrients, such as nitrogen or phosphorus. Eutrophication releases plant species from this limitation and results in algal blooms which can ultimately create dead zones for other species below the hyperproductive algae. Eutrophication is measured in kgs of NO_3-equivalent emissions, or nitrate-equivalent emissions, and can be viewed as an endogenic pressure since these emissions have an effect on the local system.

Abiotic Depletion Potential (ADP Elements)

The depletion of minerals throughout the life cycle of a product is measured using the ADP elements impact category. It is important to understand whether a product system is depleting mineral resources, particularly rarer ones. Rare minerals have a higher weighting in LCA than more common minerals.

Abiotic Depletion Potential (ADP Fossil)

The depletion of fossil (carbon–hydrogen–oxygen) compounds is measured in terms of energy content lost. Production systems which rely heavily on fossil fuels, such as diesel fuel, perform poorly with this impact category.

Hazardous Waste Disposed (HWD) and Non-hazardous Waste Disposed (NHWD)

Hazardous waste can be defined as any waste (solid, liquid, or gas) which has a harmful effect on either humans or the environment.

Net Use of Freshwater (FW)

The volume of freshwater used in industrial processes is of global concern due to issues with water scarcity.

Total use of non-renewable primary energy resources (PENRT) and total use of renewable primary energy resources (PERT)

The energy demand of industrial processes is of interest as it is used as a proxy for the efficiency of a production system.

7.2.2.2 Sensitivity Analysis

Transport is one of the key activities in both upstream and downstream processes within a recycling company's production system. The sensitivity analysis focussed on adjustable parameters related to this process. Sensitivity analysis was performed on all free parameters within the Truck-trailer, Euro 6, 34–40 tonne/27 tonne payload truck data set from Gabi. This data set has 9 free parameters which can be manipulated

Table 7.3 Adjustable, free parameters available in the Gabi sphera Truck Processes, GLO: Truck-trailer, Euro 6, 34–40 tonne/27 tonne payload ts. PPM (parts per million)

Parameter	Data type	Value
Cargo	Case company specific data	1000 kgs
Distance	Case company specific data	7765 km
Payload	Gabi generic default data	27 tonnes
PPM sulphur in diesel fuel	Gabi generic default data	10
% of biogenic C in fuel	Gabi generic default data	5%
% of motorway driving	Gabi generic default data	70%
% of rural driving	Gabi generic default data	23%
% of urban driving	Gabi generic default data	7%
Utilisation	Gabi generic default data	61%

by the user. Since a variety of specific data and generic data was used to model truck transport, it is important to understand where sensitivity within the model exists. The sensitivity of each parameter was assessed by keeping all parameters, apart from the one under assessment, at the default value (Table 7.3). Sensitivity was measured by recording the carbon dioxide equivalent emissions as a result of parameter alternations as the output.

7.3 Results

7.3.1 Life Cycle Inventory

The foreground data was collected from the case company in 2020. The inventory data points are normalised to the production of 1000 kg of recycled PP/PE granulate, as per the declared unit. The data is shown in Table 7.2. Data was collected for the case company's production year 2019. In 2019, the case company collected 642,990 kg of PP/PE ropes from 18 sites (aquaculture, fishers, and waste management companies) ranging from 3.2 to 1421 km distance from their processing site. All PP/PE ropes collected by the case company were segregated into those that can be recycled and those which have to be sent to landfill due to contaminants in rope coating treatments. 10% of all PP/PE ropes collected by the case company in 2019 were sent for landfill. The segregation process also consumes some diesel due to the

Table 7.4 Inventory of foreground data used in the Life Cycle Assessment of recycled PP/PE granulate production from waste fishing/aquaculture rope

	Inventory of foreground data	Per 1000 kg recycled PP/PE
Upstream	PP/PE rope collected	1122 kgs
	Collection transport distance (2019 total)	27,126 km
	Collection sites in Norway (2019 total)	18
	Number of pickups (2019 total)	63
Core	PP/PE rope sent for segregation	1122 kgs
	PP/PE rope sent for landfill	112 kgs
	Distance to landfill	185 km
	PP/PE shredded rope sent for granulation	1010 kgs
	Electricity usage during granulation	345 kw
	Freshwater usage during granulation	100 litres
	Recycled PP/PE granulate produced	1000 kgs
	PP/PE granulate waste sent to incineration	10 kgs
	Distance to incinerator	275 km
	Diesel consumed by forklift	8.83 litres
	Number of PP bags (1600 litres)	1
Downstream	Distance to Norwegian customers (2019 total)	6646 km
	Delivery sites in Norway (2019 total)	7
	Number of drop-offs (2019 total)	10

use of forklifts to move material around the facility. Once segregated, the ropes are fed into the electric granulation machinery which shreds, cleans and granulates the PP/PE. The granulation process requires both electricity and freshwater and results in around 1% loss of waste material which is sent to a local incineration plant. The heat from the granulation machinery is used to heat the storage space housing the recycled PP/PE granulate. Each tonne of material is stored in PP bags which are moved around using a diesel-powered forklift. The case company has customers around Norway and Europe. In this study, the focus was on Norwegian customers who were located at a distance between 527–1842 km from the case company's facility (for the full inventory, see Table 7.4).

7.3.2 Life Cycle Impact Assessment

The environmental impact of the production of 1000 kg of recycled PP/PE granulate from fishing/aquaculture ropes was conducted across a range of impact categories. The results of the impact assessment are found in Fig. 7.2. The core activities account for the majority of environmental impacts with the upstream and downstream, collection and delivery, processes contributing a similar proportion to one

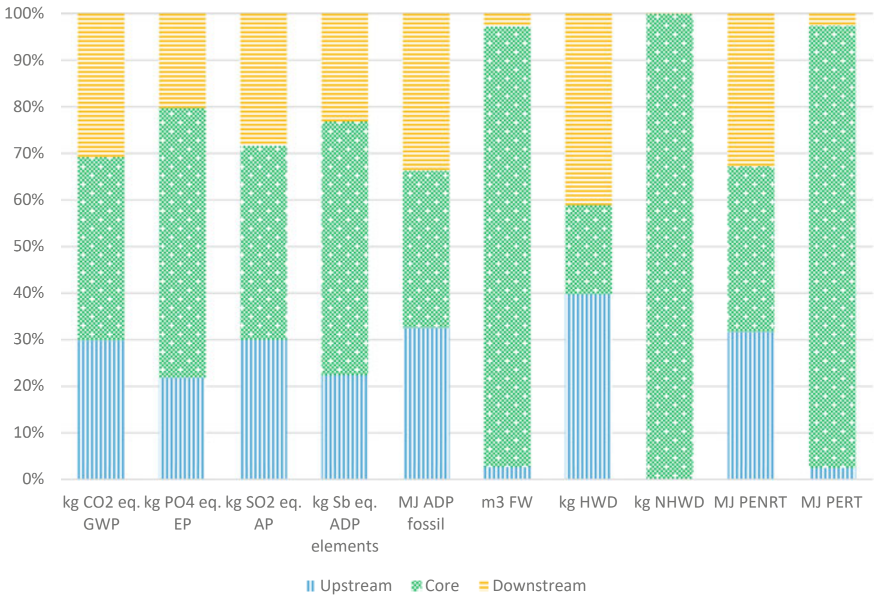

Fig. 7.2 Environmental Impact Assessment of the production of 1000 kgs of recycled PP/PE granulate from waste fishing/aquaculture rope in Norway GWP = Global warming potential, AP = Acidification potential, EP = Eutrophication potential, ADP = Abiotic depletion potential, FW = Net use of freshwater, HWS = Hazardous waste disposed, NHWD = Non-hazardous waste disposed, PENRT = Total use of non-renewable primary energy resources, PERT = Total use of renewable primary energy resources

another. This distribution of impacts across the upstream, core and downstream activities is observed for the majority of impact categories. A different pattern is observed for the the net use of freshwater (FW), non-hazardous waste disposed (NHWD) and the total use of renewable primary energy resources (PERT) whose impacts can be contributed mostly to core activities. A key contributor across the life cycle of the entire product system is diesel production and consumption. Diesel is used for both transport processes, collection and distribution, and core processes, such as the use of a forklift to transport waste ropes and granulate around the recycling facility. The production of 1000 kg of PP/PE granulate requires just 31 kg of diesel and the environmental impacts related to the production and consumption of this diesel makes up 74% of CO_2-equivalent emissions. The contribution of each life cycle phase to multiple environmental impact categories is discussed further below.

Global Warming Potential (GWP)

The carbon equivalent emissions for the production of recycled PP/PE from fishing/aquaculture ropes were estimated to be 184 kg CO_2-equivalents. Core processes account for 40% of GWP emissions (73 kg CO_2-equivalents) with upstream and downstream transport processes both contributing 30% (55 and 57 kg CO_2-equivalent emissions) each. The main contributor across all three phases of the life cycle is diesel production and consumption, with 14 kg and 123 kg CO_2-equivalents emitted by each process respectively. The collection of the ropes using heavy trucks, the use of a forklift to move waste ropes and recycled granulate around the recycling facility and the delivery of the granulate to the customers all require diesel fuel and thus contribute to the majority of the GWP emissions.

Net Use of Freshwater

The use of freshwater for the production of recycled PP/PE from fishing/aquaculture ropes was estimated to be 2.69 m^3 with the majority of water, 2.55 m^3 being used in the core granulation process at the case company's facility. The upstream processes account for 0,07 m^3 freshwater us whilst the downstream processes account for 0.08 m^3.

Eutrophication and Acidification Potential

Eutrophication and acidification potential emissions are greater for the core processes of the case company's production system. Each of the upstream and downstream phases contributed 0.01 kg PO_4 equivalent eutrophication emissions and 0.05 kg SO_2 equivalent acidification emissions whilst the core processes contributed 0.03 and 0.07 respectively. Diesel production and consumption bears the responsibility for these emissions in the upstream and downstream phases whilst the landfilling of 112 kg of waste ropes is responsible for 2.13 kg PO_4 equivalent and 2.15 kg equivalent SO_2 emissions.

Abiotic Depletion Potential

The recycled PP/PE production is attributed to very little consumption of minerals or metals resulting in low impacts in terms of total abiotic depletion of elements of 0.00002 Kg Sb equivalent across all life cycle phases. 2249 MJ of fossil fuels are depleted throughout all life cycle phases of the production system. Diesel consumption across all phases is the main contributor to the depletion of fossil fuels with 81% depleted during this process.

Waste

Waste production can mainly be linked to the core processes. The case company produce around 122 kg of non-hazardous waste during their production processes, which is either landfilled or incinerated. Hazardous waste from the production system stands at 0.0001 kg with diesel production the main contributor.

Total use of non-renewable primary energy resources (PENRT) and total use of renewable primary energy resources (PERT)

The use of non-renewable energy resources (PENRT) is evenly spread across the upstream, core and downstream processes (736, 824 and 761 MJ respectively). In contrast, the total use of renewable resources (PERT) is associated primarily with core processes (1619 MJ), specifically electricity production in Norway, whilst the upstream and downstream processes only use 43 and 44 MJ of renewable energy respectively.

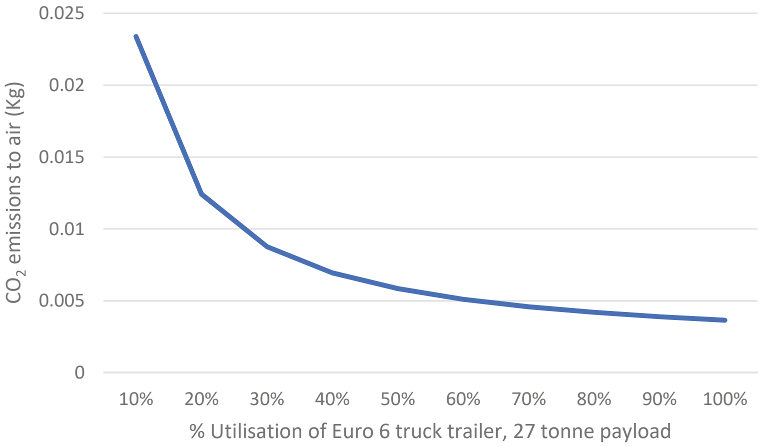

Fig. 7.3 Effects of variation in % utilisation of Euro 6 truck trailer (27 tonne payload) ts data set on CO_2 [Inorganic emissions to air] (kg)

7.3.2.1 Sensitivity Analysis

Sensitivity analysis was performed on greenhouse gas emissions to utilisation, and mass carried/payload is highly sensitive at lower values and less sensitive from around 55% utilisation, as shown in Fig. 7.3. High emissions associated with low utilisation rates are an issue for companies with a focus on transport and should be addressed accordingly. Increasing utilisation rates from 10 to 70% can have an almost fivefold decrease in greenhouse gas emissions from transport.

7.4 Discussion and Conclusion

The main contributor to the environmental impact of the PP/PE recylate production system is the production and consumption of diesel across the life cycle phases. The use of landfill for end-of-life treatment has impacts in terms of eutrophication and acidification, whilst global warming emissions are dominated by the consumption of fossil fuels. The geography of Norway, with its long, winding coastline results in large transport footprints for companies involved in logistics, particularly those interacting with the fishing and aquaculture sector. However, European and International targets to reduce emissions from trucks by 2030 and eliminate emissions by 2050 paint a positive picture of the future for this type of production system, particularly if core processes are also driven by renewable electricity sources.

The PP/PE recyclate production is favourable in terms of environmental impact to the production of virgin PP and PE (Plastics Europe 2014a, b), as seen in Fig. 7.4. The

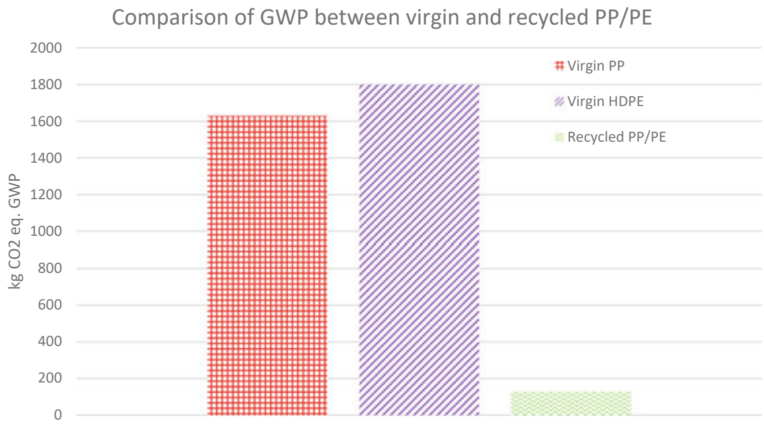

Fig. 7.4 Comparison of kg CO_2 equivalent emissions from the upstream and core production phases of virgin PP, virgin HDPE and recycled PP/PE granulate from fishing/aquaculture gear

production of recycled PP/PE granulate emits between 7 and 8% of the CO_2 equivalent emissions attributed to the production of virgin HDPE and virgin PP for upstream and core processes.

In this chapter, results from a life cycle assessment of recycling PP/PE from waste fishing/aquaculture gear have been presented. Data and models built to perform the assessment are based on technologies and practices in a Norwegian context. When assessing the carbon footprint, results show that PP/PE recycling following the upstream, core, and downstream processes included in our study largely depend on transportation, for in-house processes as well as collection and delivery. The transportation distance, selection of energy carriers, utilisation rates, and speed all contribute to the total greenhouse gas emissions from transport. Some of these conditions could also vary both spatially and temporally. For instance, recyclers located closer to their customer base would, all other things being equal, have a lower fuel consumption and thereby reduced greenhouse gas emissions from transport. Local market conditions, such as supply volumes and frequencies, could also impact utilisation rates. Recyclers operating with larger volumes and higher utilisation rates would also have a lower greenhouse gas emission per declared unit than the results of our study. This may also vary over time. When an extended producer responsibility scheme (EPR) for fishing gear is introduced, European countries will need to establish infrastructure to manage obsolete gear. This could make the collection and distribution of obsolete gear more efficient and predictable, enabling recyclers to reduce the impact of transport logistics.

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Chapter 8
Engaging Volunteers as Experts in Data-Driven Research Projects and a Circular Economy: The Case of PlastOPol

Christina Carrozzo Hellevik and Paritosh C. Deshpande

Abstract Beached plastic litter is a global concern and is also an important source of data for research to improve our understanding of the extent and the main sources of the problem. Digital tools can help both in making the data registration process easier for *citizen scientists* and in processing the information and displaying it visually to decision makers. However, we argue that it is also vital to include the local ecological knowledge of both volunteers and semi-professional beach-cleaners. In this chapter, we summarise the main challenges in modelling plastic behaviour in the seas together with some of the best tools available to date. We then highlight how volunteers can contribute to testing and refining the tools. We exemplify this point through the case of the PlastOPol project and derive implications for mitigation and prevention measures.

Keywords Local ecological knowledge · Marine plastic pollution · Spatio-temporal models · Litter · Debris

Background

8.1 The Issue of Marine Litter

Marine litter is defined as any persistent manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment and is listed amongst the major perceived threats to biodiversity (Gall and Thompson 2015). Plastic dominates the litter items on a global scale with scientific studies

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estimating that a staggering 8–13 million tonnes of plastic pollution which enters the oceans annually from land as a result of waste mismanagement (Jambeck et al. 2015). Plastic debris is of particular concern due to its abundance, and its persistence in the environment, which makes it a ubiquitous category of marine debris. One of the key indicators of abundance, composition, and trends of litter in the marine environment is the amount found on beaches as these act as a key pathway for litter to enter in the oceans due to mismanagement (Haarr et al. 2020).

In 2010, the European Union's Marine Strategy Framework Directive recommended the goal of measurable reductions in marine litter in the European region by 2020. Similarly, the OSPAR Commission has set down objectives for the reductions in, and monitoring of, marine litter in the North East Atlantic region (Ospar Commission 2014). In order to reach the targets set by the OSPAR and EU's Marine Strategy framework, coordinated efforts are essential from preventive waste management to mitigative measures for waste removal in the region. Citizen and volunteer-driven beach cleanups are considered an effective mitigation strategy for both raising awareness about the problem and for removing, and thereby reducing, the number and quantity of litter items entering the ocean ecosystem. However, robust time series of quantitative and representative beach litter data are generally not available, in large part due to the high cost and logistical challenges associated with collecting such data (Haarr et al. 2020).

8.2 Challenges in Harmonising Data from Citizen Science

Volunteer beach-cleaners often record their findings on apps or Web portals. Some of these apps and portals include Pelletwatch; Debris Tracker; Clean Swell; Shoreline Cleanup; Birds and Debris. The challenges of relying on beach cleanup data include issues of accessibility that limit geographical coverage, the difficulty in characterising and classifying the litter in its various states of decomposition and the extra time it takes for volunteers to record their information.

As prevention of plastic pollution entering the marine environment is still the most effective way of tackling the problem, source identification is also a main concern (Falk-Andersson et al. 2020). Technological tools to record and simulate plastic flows can assist in dealing with these challenges. Identifying sources of marine plastic pollution is the focus of research projects around the world; however, to this day, they are still in their infancy and their accuracy and level of detail are disputable. Indeed, models are a simplification of a real phenomenon that allow thinking about the phenomenon in question. Models help identify patterns, and better understand the implications of the phenomenon. Spatio-temporal models such as those simulating plastic flow patterns in water systems can be based on physical parameters and/or on existing data from real floating objects.

Three main challenges arise in the attempt to model plastic behaviour at sea.

Firstly, the complexity of the hydrological system and underwater topography is very high. Weather is changeable and will influence drifts and currents, wave height and direction, not to mention influx of fresh and brackish water from rivers and streams. Larger scale ocean circulation systems are better understood; however, there can be variation from models due to changes in water density from inputs of freshwater from melting ice as a consequence of climate change. Moreover, the behaviour of litter may be strongly influenced by the topography of the continental shelf, which is not always mapped accurately. There are many knowledge gaps in our understanding of the conditions in which litter objects float, sink and get beached, and potentially re-enter the marine environment. The practical challenges of carrying out research in marine environments make data collection and precise mapping very costly. In principle, it is possible to build models without reference to physical parameters, by using machine learning on particular datasets. However, this kind of approach requires very large datasets to train the models and identify an adequate pattern in the data. If data are lacking or biased (Mehrabi et al. 2021), this will be reflected and even exacerbated in the model, and its accuracy and usefulness will be undermined.

The second challenge is related to the complexity of plastic as a material. As highlighted in Chaps. 1 and 3, the way in which plastic particles flow is dependent on their size, weight, density, and shape, which in turn is dependent on the particular composition of the plastic polymer (Steer and Thompson 2020). Their size changes over time according to their decomposition rate, which itself is dependent on the polymer type and exposure to weathering. When modelling their flow patterns, we distinguish macroplastics (over 5 mm) from microplastics (5 mm or less; Steer and Thompson 2020). The porosity of plastic particles makes them prone to colonisation by viral and bacterial communities, creating a biofilm or plastisphere (Amaral-Zettler et al. 2020). These pathogens, together with pollutants such as heavy metals (see Chap. 11) act as *hitch-hikers* (Brennecke et al. 2016; Kirstein et al. 2016) and affect the particles' mass and density and by extension their buoyancy (Khalid et al. 2021). Attempts have been made at modelling the spread of microplastic (e.g. Huserbråten et al. 2022) based on the previous efforts to model the spread of salmon lice around fish farms in Norwegian fjord systems. These models are called particle dispersion models and work by standardising particles to a single size, shape, and weight, close to the ones of salmon lice, and by simulating a known current system. The particles are then shown to follow the currents and disperse into the sea. There are many issues with this type of model, one of which is the lack of verification, or ground-truthing and, as previously mentioned, the diversity of shapes and composition of plastic particles.

The third challenge consists in an overall lack of data. Despite the many apps and Web portals available worldwide for registering images and information about the litter found, this is most often restricted to beached litter. There are exception to this as some projects have focused on plastic accumulating in remote areas (de Vries et al. 2021). Other projects have attempted to map litter on the ocean floor (Buhl-Mortensen and Buhl-Mortensen 2017), and georeferenced images and videos exist and can be requested for analysis. However, to build comprehensive knowledge of how plastics behave at sea, making their way through the water column, carried by currents, nutrient upwelling, and eventually ending up on shorelines or at the bottom of the sea, would require tagged objects that continually send signals on their journey. This is technologically challenging and costly, not to mention that it is ethically questionable to add even more plastic into already saturated oceans (Huserbråten et al. 2022). Drifter programmes exist, such as NOAA's global drifter programme, and were used in the PlastOPol project to try and make sense of flow patterns; however, it is far from enough to gain an understanding of such a complex environment.

The challenges mentioned above point to the need to include other sources of information than raw data and models. It can be useful to include knowledge from people familiar with an environment and with the litter. Volunteers working with the beach and ocean cleanup programmes develop knowledge about the characterisation, flow patterns and even the origin of the litter. This knowledge is often not picked up in the apps or portals they use to record their findings (Falk-Andersson et al. 2020). This type of knowledge can be compared with the concept of local ecological knowledge (LEK) defined in Chap. 14. There is a worldwide recognition that LEK is being lost or under-recorded (Zukowski et al. 2011). Similarly, citizen science data are often not used to their full potential, sometimes because of a lack of contact between researchers and the volunteer community (Falk-Andersson et al. 2020). We argue that the knowledge built-up by volunteer beach-cleaners is comparable to local ecological knowledge, and that volunteers should be included as experts in research and development projects involving marine litter.

This chapter will address the following research questions:

R.Q.1. How can we best utilise volunteers' efforts and harmonise the knowledge collected by them during the beach cleanup projects?

R.Q.2. What tools can be used to effectively engage the volunteers and collect valuable information for developing evidence-based mitigation strategies for marine litter?

Here, we illustrate the use of the digital tool for mapping marine litter across the case area of Møre and Romsdal including Ålesund, Norway. The case study presents the need for digital tools and its applications to harmonise volunteers' data and its potential applications in scientific studies. In Sect. 8.3, we will start by defining the theoretical framework and the concept of local ecological knowledge and citizen science. In Sect. 8.4, methods, we will present the PlastOPol project and the digital tool developed. We will also outline the profile of some typical volunteers around the coasts of Norway. The findings from the project and the tools will be elaborated in Sect. 8.5. Finally, the limitations and way ahead in utilising citizen science in managing marine litter will be discussed in Sect. 8.5.3 and limitations in Sect. 8.5.4.

8.3 Theoretical Framework

8.3.1 Local Ecological Knowledge

Engaging volunteer beach-cleaners in research projects should be carried out thoughtfully. Literature about LEK highlights it as very valuable and important, especially in the context of natural resource management, for example, fishing and other forms of harvesting (Ruddle 2000). In this context, Ruddle describes it as sophisticated, empirical, risk-based, still-evolving knowledge arranged against a set of principles and institutions that might be different to the mainstream ones (2000). It can be argued that beach-cleaning, as a form of nature conservation, mitigating impacts on wildlife and natural resources, also falls in that category.

LEK and citizen science have been linked in the context of climate change research by Reyes-García et al. (2020). The point that Ruddle makes is the urgent need to capture precious local knowledge, whilst at the same time, showing respect for the knowledge-bearers and avoiding stapling our 'utilitarian' values and merely extracting data and information out of them. In order to achieve this, it is essential to understand the values and motivations of the volunteers, and we argue, what their working conditions are, in order to best approach this exchange.

8.3.2 Citizen Science

The term citizen science is used to refer to scientific projects that involve non-professional scientists in the scientific enquiry (Silvertown 2009). In research projects, non-academic stakeholders tend to be regarded merely as sources of data, either passive or active, following the recent term 'crowdsourcing' (Wiggins and Crowston 2011). Some research projects involving civil society, also called 'citizen science projects', are moving away from this trend, following Schrögel and Kolleck's model (2019) and enabling participants to contribute more meaningfully to research and policy development and learn from the process (e.g. Oturai et al. 2022). There are many benefits in using citizen science data including a wider geographical span covered, lower financial costs, and carbon emissions from using local volunteers, increased environmental awareness of volunteers (Rayon-Viña et al. 2019). In the case of marine litter including abandoned, lost, and otherwise discarded fishing ear (ALDFG), volunteer beach-cleaners often register their findings using apps or Web portals, hoping their efforts will inform policy development to mitigate marine plastic pollution. Studies have shown that citizen science project-based data had as high standards as data collected using more classical scientific methods (Falk-Andersson et al. 2020). As an added benefit, research has shown transformational change in the volunteers taking part following increased awareness, understanding of the mechanisms of plastic pollution and of its drivers and impacts (Wyles et al. 2017; Rayon-Viña et al. 2019).

So how should we engage with these volunteers and benefit from their invaluable knowledge, whilst giving something back? How can research projects on marine plastic and ALDFG effectively drive a positive change? These questions, and the ambition of modelling plastics flow patterns, were the springboard for the PlastOPol research project.

8.4 Methods: The Case of the PlastOPol Research Project

Through the PlastOPol project, two tools were developed, one aimed at volunteers, and one at local policy-makers.

The first tool is a spatio-temporal visualisation of the litter collected between 2013 and 2021 in the region of Møre and Romsdal and a prediction model for 2022. The data are represented in the form of circles of different sizes and different shades of red according to the weight recorded in the Ryddenorge portal (Bli med | Aksjoner—Rydde (ryddenorge.no) as seen in Fig. 8.1. The objective is to create an at-a-glance impression of where the hotspots are in the region to support decision-makers on in identifying areas to allocate resources for waste management and cleaning activities. The visualisation also offers the possibility to filter only litter from fisheries.

The second tool consists in a model that detects litter objects in photos, which is itself embedded in an app that can also work offline. This constitutes a feat of technology as it requires compressing very large infrastructures into portable devices

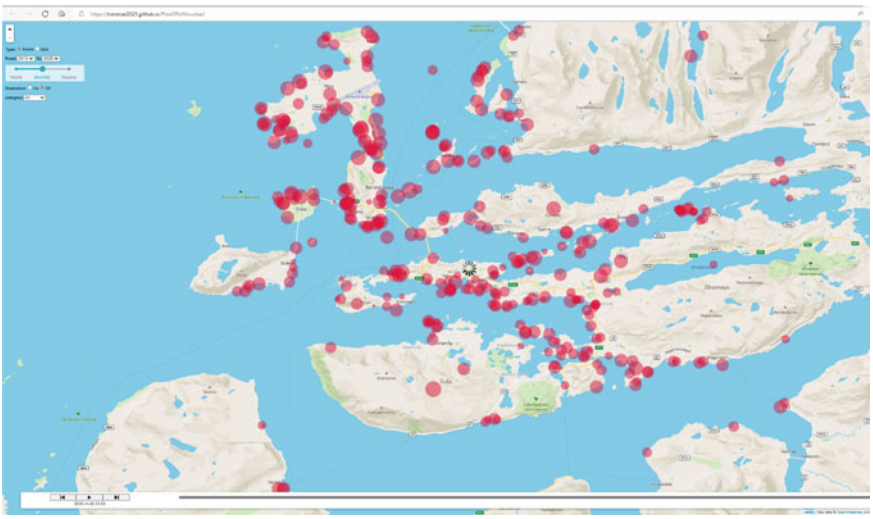

Fig. 8.1 Interactive visualisation platform displaying the marine litter collected by volunteers in Møre and Romsdal cumulatively between 2013 and 2021 as recorded on Rydde, developed as part of the PlastOPol project

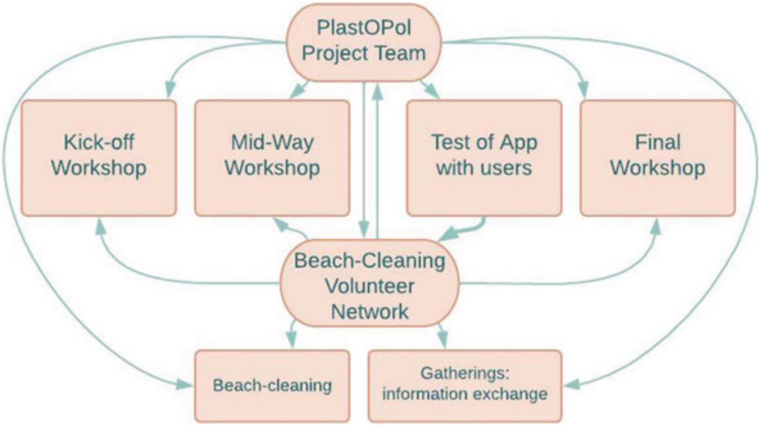

Fig. 8.2 Model conceptualising the collaboration between the PlastOPol project team and the beach-cleaning volunteer network

(Córdova et al. 2022). The implications are that such a model can be used in remotely operated devices such as drones or underwater cameras or by volunteers on their mobile phones.

For this tool to be useful to its users, it was important to understand their needs and working conditions. This was achieved through observation, by including the volunteer networks as reference group in the project and to all three workshops, by joining some of the network's own activities, and by testing the tools with the volunteers out in the field. In addition, their experience of marine litter hotspots was used to calibrate and validate the prediction model, and the app was tested in the field with the volunteers on several occasions and problems fixed along the way. A diagram to illustrate the collaboration with the volunteers is presented in Fig. 8.2.

The results of these tests and observation are explained in the next section, where we define a profile of coastal cleanup volunteers and discuss the implications for involving them in research projects and ultimately, in preventive measures.

8.5 Results

8.5.1 Towards Building a Profile of Coastal Cleanup Volunteers in Mid and Northern Norway

We go beyond the *enviro-leisure activism* model used by Power (2022), and instead, build on the concepts of civic ecology and environmental stewardship proposed by Jorgensen et al. (2021). We present a profile of organised, dedicated and well-trained volunteers on the West coast of Norway (see Chap. 4), as these form a particularly large community. Indeed, these volunteers form networks or communities with various degrees of organisation. In some cases, they receive payment for their work from the Environmental Agency or the Norwegian Retailer's Environment Fund (in Norwegian: Handelens Miljøfond), in which case we refer to them henceforth as semi-professional.

Through their networks and communities, volunteers gather and provide each other with moral, logistical, and other practical support, and, most importantly, share information. Such information includes what types of litter are most commonly found, what areas need attention, what sort of waste collection arrangements exist, or what the potential origin of the litter might be. Hypotheses about the sources of the litter are often supported by local knowledge and evidence such as labels with a company name or other signature, particular types of ropes used by the fishing or aquaculture industries, polystyrene boxes for frozen fish, etc.

In addition to being knowledgeable about the nature of the litter they collect, volunteers often develop an understanding of physical parameters in the areas they clean, such as microclimatic conditions, currents, topography, and tides. To the point that they may be able to predict what a storm will bring (Neis 1992). Indeed, strong weather events such as storms, hurricanes, floods, and tsunamis (Pelamatti et al. 2019; Murray et al. 2018) have been documented to contribute to a surge in marine litter, particularly of large items.

Volunteers are, by definition, highly motivated as they conduct activities without or with little monetary reward. They often brave harsh weather and prioritise beach-cleaning over other more hedonistic activities. Semi-professional beach-cleaners often start as volunteers, before becoming so engaged and committed to their patches and surroundings that they turn to sources of funding to be able to dedicate more time to the activity. They are often motivated by ideals, which could be simply: having a clean beach to enjoy, or more abstractly: removing plastics from an environment to protect local wildlife or to make a better world for their children and future generations. In many cases, they will develop relational values (Chan et al. 2018) with one or several places they visit repeatedly, whether consciously or not, and grow to care more and more about the changes in that area.

Another characteristic of the West coast of Norway is the number of small islands and remote island communities. In these cases, volunteer beach-cleaners are often strongly embedded in their local societies. They will be aware of plastic leakages reported to the authorities and will help mitigate any impact. Anonymity may be the preferred course of action to follow GDPR regulations and prevent possible conflicts of interest when reporting.

8.5.2 Benefits of Using Digital Tools and Engaging Actively with Volunteer Communities

Our interactions with the volunteer networks and participation in the cleanup activities revealed that improved digital tools can facilitate the work of volunteers, by streamlining or even automating the registration process. Indeed, frustration over clunky Web portals or malfunctioning apps, or worse, paper forms that get wet or fly away in the storm, may discourage the volunteers from submitting their data.

The collaboration experience was extremely positive, and the impression is that the volunteers cannot only help test the tools but also act as champions for their adoption by the community if they think it adds value to their work. In the case of PlastOPol, basic bugs were detected in the app when used in the field as well as the need for shorter pathways to the recording of the information so as to avoid unnecessary time spent on a phone rather than picking up litter. As the app is still being piloted and improved, we are unable at this stage to provide numbers of volunteers who have adopted it. In the cases where research is carried out at a more policy-oriented/ innovation level, the volunteers can bring insights on why, where, and in what way waste management is lacking, what incentive orders are needed from the government or what policy should be put in place.

Implications for Research: Working Towards a Practice-Enlightened Tool Development

Academics may tend to pursue what they consider 'interesting questions', advance knowledge about how or why a certain phenomenon occurs. In the field of data science, they might, to use an old cliché, develop an entire system from 'the comfort of their armchair'. These systems and models therefore often do not consider the ways in which an activity is practised or what the needs are for the activity to be carried out successfully and more efficiently. To give a concrete example: a scientist may not be aware of the bias embedded in the data they are looking at; e.g. that the locations reflect where the volunteers go repeatedly for various reasons and are not necessarily representative of the true distribution of marine litter. It is, therefore, essential to understand the activity that a tool is meant to support and even engage in it to experience the different stages at which the tool might come in useful or be redundant. A subtle balance has to be struck amongst the interests of all partakers in the project. Science and technology should be developed but scientists should be challenged to incorporate their end-users in the design (Demirel 2020). In other words, a translator or interpreter should act as a pivot in order to find a common language and interest for the sake of the project's success.

On the other hand, volunteers will often commit their time and travel distances to attend workshops and seminars on the topic they feel passionate about if they think that a positive outcome is likely. Not delivering and inviting them as a mere box-ticking exercise should be discouraged not only on ethical grounds but also to avoid participation fatigue. A respectful communication should be established, where the volunteers feel that their knowledge is valued, and that their inputs are truly incorporated in the research and tool development.

Science and Digital Tool Development for Transformational Change

Information and communication technology (ICT) and research projects in general can bring something to the political agenda. They can provide a platform for the expert knowledge of volunteers to have a voice, to inform, and contribute to data collection and decision-making. Spatio-temporal visualisation models have the potential to summarise years of scattered efforts into powerful images and provoke reactions. Longitudinal studies using digital tools will generate robust datasets that can be used for image or pattern recognition that would further aid in predictions of sources, abundance, characterisation, and transport of typical litter items. These tools can then assist local and regional policy-making on marine litter prevention.

8.5.3 Using Citizen Science for Preventive Strategy Making

As previously established, preventive strategies are more holistic and effective in battling the marine litter problem than mitigation measures. Indeed, the following debates regarding the collection and removal of marine litter including ALDFG have arisen, to which volunteer and semi-professional beach-cleaners can provide valuable insights through their practical experience in the field.

> As plastics that have been exposed to weathering for years become brittle to the touch or handling, to what point should we strive to extract plastics from a given environment?

This question has attracted attention at national level in Norway and points to the difficulty of handling microplastics and our lack of understanding of the overall effects of leaving plastic in the environment, when compared to handling it for removal. There is no simple answer to this question, and there is widespread scepticism about the benefit of large-scale cleanup operations including complete habitat overturn to remove *macrolitter* from the soil or ocean floors (Buhl-Mortensen and Buhl-Mortensen 2018). However, some industry-led stakeholders may think otherwise and be of the opinion that it is a good idea to involve large machinery and extract entire layers or soil and sediment, even to the detriment of invertebrates and other members of the local fauna and flora.

A second question that divides the community is:

> What is the mass of various plastic polymers collected from the beach clean-up programmes? And how can recordings of beach clean-up be more effective for generating evidence for effective policy making?

The volunteer-based beach cleanup programmes conducted by authorised agencies in Norway typically follow OSPAR regulations to document the retrieved litter items (HN Rent 2021). Although OSPAR guidelines provide a uniform framework for classifying the retrieved items, it only allows users to record the findings based on the size and number of the collected litter. Such a classification approach misses recording the other essential details, such as the quality of the retrieved litter its mass. The lack of mass-based data on collected litter is highlighted as one of the significant limitations in developing a holistic understanding of the mass flows of plastic items across their life cycles (Deshpande et al. 2019). The product mass flows across their life cycle stages are vital for developing preventive strategies for sustainable and circular management of end-of-life products.

The inclusion of these qualitative and quantitative dimension in volunteer recordings may lead to building critical knowledge base for preventive strategies such as polluter pays, extended producer responsibility, or developing sustainable strategies for circular economy in the region.

8.5.4 Limitations

Although volunteers expressed high hopes about the technological achievements of the project, a few issues remain to be addressed. Indeed, to avoid duplication, the current national database and the PlastOPol app should be merged or at least made to communicate with existing national reporting systems; the app should be more user-friendly to really make the registration process easier, and the object detection model's accuracy should be improved through repeated use of the app. This is a work in progress and we still hope to make the tools publicly available and free.

Secondly, although technology can bring publicity to an issue and even push it to the political agenda, there are currently no legal tools to deal with the problem of marine plastic pollution and assign budget and staff at municipality level. This therefore remains, to this day, an idealist issue, and volunteers and school children will continue to bear the brunt of the cleanup process.

8.6 Conclusion

When envisioning research projects and a circular economy, the volunteers will be a keystone agent on several fronts. Their knowledge of the litter hotspots can allow informed remediation efforts enabling material to be reintegrated into the value chain. Meanwhile, local knowledge of volunteers can help identify potential sources of plastic leakage into the environment and thereby inform preventive measures. One could imagine creating a bridge between the different stakeholders to not only recover lost items, but most importantly to avoid the plastic from being discarded in the first place. Indeed, the different local businesses could be connected, and new loops created based on the information gathered by the volunteers.

With their knowledge of local stakeholders and flow patterns of the litter, they could, if engaged honestly, play a crucial part in pointing at all the disjointed ends of the current non-circular system, highlighting areas and stakeholders where there is potential for collaboration and reporting non-compliance to the law. A great incentive for them will be to see a reduction in the amount of litter in the environment they know so well.

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Chapter 9
The Role of Non-profit Organisations (NGOs) in Value Creation: Lessons from the Recycling of Fishing Gear in Norway

Richard Glavee-Geo, Sardar Wasi Uddin AI Ahmed, Arron Wilde Tippett, Siv Marina Flø Grimstad, and Mark Pasquine

Abstract Value chain collaboration and volunteering by non-governmental organisations (NGOs) are success factors that enhance fishing gear recycling. Using multiple cases of NGOs from the Norwegian value chain of recycled plastic fishing gear, we highlight the role of NGOs in fishing gear recycling through collaborative partnerships with small- and medium-sized enterprises (SMEs). The Blue Circular Economy (BCE) project provided us with the opportunity to understudy and highlight this contextually rich phenomenon. Our study shows that sustainable value creation can be achieved through marine plastics recycling, value chain collaboration, volunteering initiatives/operations, and local innovation system (LIS) leading to new process, service, and product development. The chapter provides increased understanding of the role of NGOs within the value chain. Value chain collaboration between SMEs and NGOs stimulates innovation in the local environment (LIS) and within the industry. Collaboration drives the innovation process and enhances recycling of marine plastics. Marine plastics with a focus on waste fishing gear recycling can lead to sustainable value creation. NGOs therefore occupy a key position in the value chain not only for advocacy, but also for value creation.

Keywords Value creation · Volunteerism · Marine plastics · Fishing gear recycling · NGO-SME collaboration · Not-for-profit · Stakeholder engagement · Innovation potential · Innovation system · BCE project

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List of Abbreviations

BCE	Blue Circular Economy
CSR	Corporate social responsibility
MPP	Marine plastic problem
MPR	Marine plastics recycling
NGO	Non-governmental organisations
NPA	Northern Periphery and Arctic area
NPD	New product development
SME	Small- and medium-sized enterprise

9.1 Introduction

Partnerships between for-profit firms and social organisations can lead to shared value that both increases societal well-being and is profitable (Menghwar and Daood 2021; Porter and Kramer 2011). One form of shared value is the creation of sustainable value. Sustainable value creation means the greening of the value of the supply chain, producing more environmentally friendly or eco-efficient products, providing consumers with information, and creating awareness about sustainable consumption through advertising, marketing, and product information (Chatain and Plaksenkova 2019; Kong et al. 2002). Sustainable value creation faces unique challenges to each of the economic sectors like public, private, or non-profit organisations, to manage resources strategically, offer new solutions, and manage costs (Bryson 2018; Cabral et al. 2019; Koster et al. 2019). Non-governmental organisations (NGOs) have a critical role in sustainable development, especially in their partnership with key stakeholders, in serving the needs of individuals and communities (Austin 2000; Kong et al. 2002). Worldwide many of the NGOs are developing a more sophisticated understanding of environmental issues, based on sound scientific research, and are developing effective strategies to solve environmental problems through strategic collaborations or partnerships.

The twenty-first century has seen increased interdependency amongst stakeholders in finding solutions to the world's pressing environmental and social problems. Cross-sector collaboration amongst public, private, and non-profit organisations is intensifying day by day (Austin 2000; Haack et al. 2012). The role of NGOs as watchdogs of large cross-sectoral collaboration and their advocacy role in developing good practices are well established in the literature (Valente 2012; Van Cranenburgh et al. 2013). However, little is known about how NGO interactions and collaboration with SMEs can be sources of value creation. The literature on marine plastics pollution is generic and not related directly to fishing gear recycling and the role that NGOs play in the intervention process. Hence, this chapter seeks to explore interactions and collaborative initiatives between NGOs and other key stakeholders, in the context of the recycling of fishing gear in Norway. Using multiple cases, we seek to explore the following research question: *how are NGOs accelerating plastics recycling and promoting sustainable value creation in the fishing gear industry in Norway?* Through this study, we identify the salient success factors, processes, and procedures by which NGOs influence value creation in the industry.

Our analysis identified value chain collaboration and volunteering initiatives and operations by NGOs as success factors that enhance marine plastics recycling. In this chapter, we use 'non-profit' organisation (NPO) and 'non-governmental' organisation (NGO) interchangeably with the same intended meaning and purpose. Value chain collaboration between SMEs and NGOs stimulates innovation, process, and new product development within the industry. Collaboration drives the innovation and new product development process and enhances recycling of marine plastics. Increased collaboration amongst actors within the value chain also enhances volunteering initiatives and operations of the NGOs. Sustainable value creation is achieved through marine plastics recycling, value chain collaboration, volunteering initiatives and innovation, and new product and process development (through local innovation system). These processes and factors provide increased understanding of the role of NGOs within the value chain. NGOs' roles go beyond volunteering operations and can be sources of new ideas, testing of new processes, development of new products and services, and catalysts for innovation. NGOs therefore occupy a key position in the value chain not only for advocacy but also for value creation. In the next section, we present the theoretical frame of reference for the study through a review of the literature. This is followed by a description of the research design and methodology; then, a discussion of the findings and finally some concluding remarks is made.

9.2 Literature Review

9.2.1 Strategic Value Chain Collaboration: A Stakeholder Theory Approach

The collaboration between business organisations and non-governmental organisations is no longer restricted to philanthropy and charity but has demonstrated extended diversity in recent decades, with a range of coalitions addressing environmental issues and codes of conduct (Arya and Salk 2006; Austin and Seitanidi 2012). In the context of increasing public awareness and active participation towards environmental issues, emerges new expectations from both business entities and non-governmental organisations to come closer and initiates new strategies through collaboration (Jamali and Keshishian 2009). In addition, the convergence of political, social, and economic pressures from all sides has been accelerating these types of collaboration to a greater extent (den Hond et al. 2015). The search for new resources, opportunities, and more effective organisational approaches is bringing non-governmental organisations and business corporations together (Harrison et al. 2001; Shumate et al. 2018).

These collaborations are also emerging day by day because businesses are increasingly re-evaluating their traditional business models and seeking new strategies of engagement with their communities that will have greater economic relevance and higher social and environmental impact (Baur and Schmitz 2012; Rivera-Santos et al. 2017). Consequently, more corporate executives have been willing to consider an alternative perspective to strategic management, integrating both social and environmental responsibilities, and this has been paralleled in turn by proliferation of non-governmental organisations seeking to promote more ethical and socio-environmental responsible business practices (Dhanani and Connolly 2015; Guay et al. 2004).

Modern stakeholder theory was first introduced and best described as a conceptual model by Freeman (1984). He explained that firms must go beyond merely maximising shareholder value to address the interests of their stakeholders, who can influence or are influenced by the organisations' purpose (Freeman 1984, 2004). Shareholder value is the value delivered to the equity owners of the firm due to management's ability to increase sales, earnings, and cash flow, which leads to an increase in dividends and capital gains for the shareholders (Hayes and Scott 2021). Financial economists contend that, when the corporate enterprise maximises shareholder value, everyone—workers, consumers, suppliers, and distributors—will, as a result, be better off (Lazonick and O'sullivan 2000, p. 27). Stakeholders are seen as contributing to the firms' resource-creating capacity holders. Stakeholders are also considered as potential beneficiaries and risk bearers as well (Post et al. 2002). Ayuso et al. (2014) show that stakeholder theory can relate to the literature of corporate social responsibilities broadly and corporate sustainability within this. The theory provides a suitable theoretical framework for analysing the relationship between the business community and society and shows a win–win direction for both entities (Cordeiro and Tewari 2015). To turn corporate social responsibility (CSR) into a business objective, may perhaps best be achieved by the transformation of intangible social and environmental issues, into tangible stakeholder interests (Dmytriyev et al. 2021). Reflecting this, scholars have explicitly begun to apply stakeholder theory in the real-life context. This has largely been done by examining stakeholder pressures on business organisations, to adopt proactive environmental planning, strategies, and action plans through innovations that they hope will result in improved environmental performance (Freeman et al. 2021). To describe how stakeholders, including regulators, customers, and activists such as non-governmental organisations, research institutes, local authorities, and industry associations, impose institutional pressure on the governing bodies of the business organisations, which were probably the first attempt to introduce a framework using stakeholder theory (Delmas and Toffel 2004, 2008, 2010). Our study presents a conceptual framework focussing on SMEs-NGOs collaboration that generate value from the recycling of marine plastics in Norway.

9.2.2 Sustainable Value Creation: A Dynamic Capabilities Approach

Business models for sustainability are considered a mechanism for business organisations to create synergies amongst economic, environmental, and social values which consequently leads to sustainable value creation (Evans et al. 2017; Surie and Ashley 2008; Zott et al. 2011). Despite the burgeoning literature on sustainable business models (SBMs) and sustainable supply chain management; very few introduce how different supply chain business models institutionalise situational logics and related power relations, and how these business models impact on sustainable value creation (Lüdeke-Freund 2020; Muñoz and Cohen 2018; Tregidga et al. 2013). Dynamic relationship enables sustainable value creation and resolves sustainability related trade-offs (Brennan and Tennant 2018). Value is created when tangible factors of production like processes, business models, products, services, and infrastructure are brought into specific combinations with ideas of sustainability impact and sustainability values (Esch et al. 2019; Roome and Louche 2016). Sustainability value has recently been considered pivotal to sustainable business model innovation (BMI) (Ordonez-Ponce et al. 2021).

Cultural resources are important to lead sustainable value creation (Esfahbodi et al. 2016), which are ideologically conditioned on how structural resources may be utilised and effect their diffusion into society (Maas and Rosendaal 2016; Panapanaan et al. 2016). There is an inherent connection between the societal aspirations of sustainability and firm-level goals (Pitelis 2013). Trade-offs will always occur when organisations promote their own economic growth at the expense of environmental and social goals (Sewchurran et al. 2019). This trade-off demands an equal combination of cultural and structural resources and results in some aspects of the triple-bottom line approach (Hahn and Figge 2011; Pagell and Shevchenko 2014).

Conceptual Model

The dynamic capabilities theory is an extended application of the resource-based view (RVB) of the firms (Barney 2001). Teece et al.'s (1997) 'dynamic capabilities and strategic management' study puts forward the dynamic capabilities' perspective as an extension of the resource-based view of the firm (Arranz et al. 2020). 'Dynamic capabilities' are defined as the firms' abilities to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments (Teece et al. 1997). Eisenhardt and Martin (2000) considered the dynamic capabilities as a set of specific and identifiable processes such as product development, strategic decision making, and alliances (Eisenhardt and Martin 2000). Dynamic capabilities are foreseeable behavioural patterns through which the organisations manage their resources with the objective of obtaining success (Nelson and Winter 2002). Therefore, dynamic capabilities enable organisations to develop innovation and encompass the management of capabilities and resources of all functions of firms, with the final objective to achieve a competitive advantage (Teece 2007; Zahra et al. 2006). In addition to our use of the stakeholder theory as the foundation for the collaborations

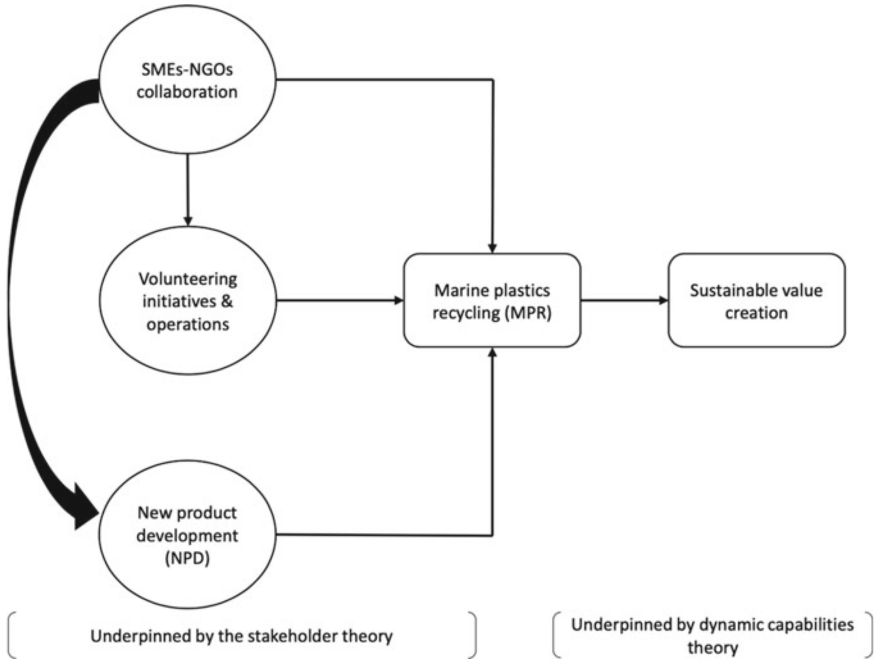

Fig. 9.1 Conceptual framework of the study

we explore between NGOs and SMEs, we also highlight the role of dynamic capabilities. Based on the relationships discussed above, a conceptual framework showing all constructs is shown in Fig. 9.1. This model serves as a guide for the data collection and analysis.

9.3 Research Design and Methodology

The selection of research methodology depends on the research paradigm and the objectives of the study (Guba and Lincoln 1994). The study's design is explorative and qualitative. We used multiple case studies in order to provide new insights and to help increase our understanding of the issues at stake. The major benefit of the qualitative approach is that it provides a depth and richness of data, which is difficult to attain through quantitative research (Voss 2010; Yin 2011). The qualitative case study is a desirable research approach for realists whose goal is to describe and explain phenomena, capturing the appropriate level of complexity (Bhaskar 2014). By using a case study method, researchers can get a holistic view and explore social processes in rich and complex detail. In this process, contextual variables that affect actors' behaviour can be observed and identified (Lindgreen et al. 2020).

9.3.1 Case Selection

Case selection or sampling is an important methodological choice in case study research (Miles and Huberman 1994). Sampling in qualitative research involves two actions. The first action is to set boundaries that define aspects of the target case(s) that can be studied within the limits of time and budget. The second action is to create a sample frame that has a potential for uncovering, confirming, or qualifying the basic processes or constructs that underpin the study (Miles and Huberman 1994). Accordingly, we chose Norway as the research setting for two reasons; the first is the feasibility of obtaining rich qualitative data (e.g. through interviews) within the time and budget constraints, the second is that the Blue Circular Economy (BCE) project's mission is to create sustainable value in the fishing gear industry in the Northern Periphery and Artic (NPA) region (Blue-Circular-Economy 2020; Charter 2020), where Norway appears to have the biggest fishing industry (Charter 2017). The BCE project provides a rich and highly contextualised phenomenon that we seek to explore. The case study approach helps build a picture of the context that the phenomenon is embedded in and is appropriate for describing actors, structure, and agency relations taking place through social interaction (Yin 1994). Our study is based on six cases—all are non-profit organisations, both local and international, and have their operations in Norway. All the key informants interviewed for the study belong to organisations that are part of the network 'Marine litter Møre and Romsdal' (Nettverk Marin Forsøpling Møre og Romsdal) whose activities are funded by the Norwegian Retailers' Environment Fund (Handelens Miljøfond) and the Norwegian Environment Agency (Miljødirektorat). Table 9.1 summarises the key characteristics of the selected cases, whilst Table 9.2 showcases some of the key actors in the Norwegian plastics value chain.

Table 9.1 Overview of the case firms

Case	NGO	Type of operation	Location (origin)	Funding source
1	Plastpiratene	Beach cleaning	Lepsøya (Norway)	Sponsors and partners
2	Rydd Møre	Beach cleaning	Ålesund (Norway)	Sponsors and partners
3	Nordic Ocean Watch	Beach cleaning	Oslo (Norway)	Sponsors and donation
4	Visjon AS	Research and consultancy	Valderøya (Norway)	Partners and consultancy fee
5	World Wildlife Fund: WWF	Wilderness preservation and environment safety	Gland (Switzerland)	Sponsors, partners, and donation
6	Runde Miljøsenter	Research institution	Runde (Norway)	Sponsors and partners

Table 9.2 Overview of recyclers and manufacturers

ID	Firm	Type of operation	Location (origin)	Value chain role
1	Noprec	Recycling	Ottersøy (Norway)	Key actor
2	Containerservice	Waste management and logistics	Ottersøy (Norway)	Supporting role
3	Plasto	Manufacturer	Åndalsnes (Norway)	Key actor[a]
4	Partnerplast	Manufacturer	Åndalsnes (Norway)	Key actor[a]
5	Ørskog Plast Industri	Manufacturer	Ørskog (Norway)	Key actor

Note [a]Though focus is on SME-NGO interactions, a few of the firms are medium–large-sized organisations

9.3.2 Data Collection and Analysis

Data analysis in case studies is typically carried out in two steps, the first of which is the within-case analysis (Ayres et al. 2003). The researcher documents how the data from individual respondents within each organisation were handled, with respect to how specific research topics were addressed. This is generally accomplished by coding, in which the raw data are converted or coded to understandable components, which can be more easily compared across respondents (Eisenhardt 1989). This coding and identification process could be supported by different qualitative research-based software (Lindgreen et al. 2020). In this study, semi-structured interviews with a set of open-ended questions were used to collect data. Observations, BCE workshop interactions, and Webpage documents were sources of secondary information collected from the recyclers and manufacturers. Six interviews were conducted with the NGOs (see Table 9.1). A standardised semi-structured interview guide (see Appendix) was used, though the interviews were flexible, and interviewees were allowed to present deeper insight into the issues under consideration. Whilst in some instances, follow-up interviews were conducted to clarify issues. Open-ended questions were used to create a dialogue and discussion with the interviewer. Because of the COVID-19 pandemic, all interviews were conducted through Zoom. The questions were kept as short and specific as possible. Leading questions and questions with a strong positive and negative association were avoided. With permission, the interviews were recorded to avoid biased interpretations and conclusions. This allowed for more accurate transcription of the interviews. After conducting and transcribing the interviews, the interviewees were given the opportunity to review the transcript and make any revisions if necessary. The analysis was performed in four stages: evaluation, examination, coding, and categorisation. The software used for analysing qualitative data was NVivo. NVivo facilitates handling a large amount of qualitative data in a very useful way (Zamawe 2015) and was useful in identifying the key issues and organising the data into the themes underlying the data structure as shown in Fig. 9.2.

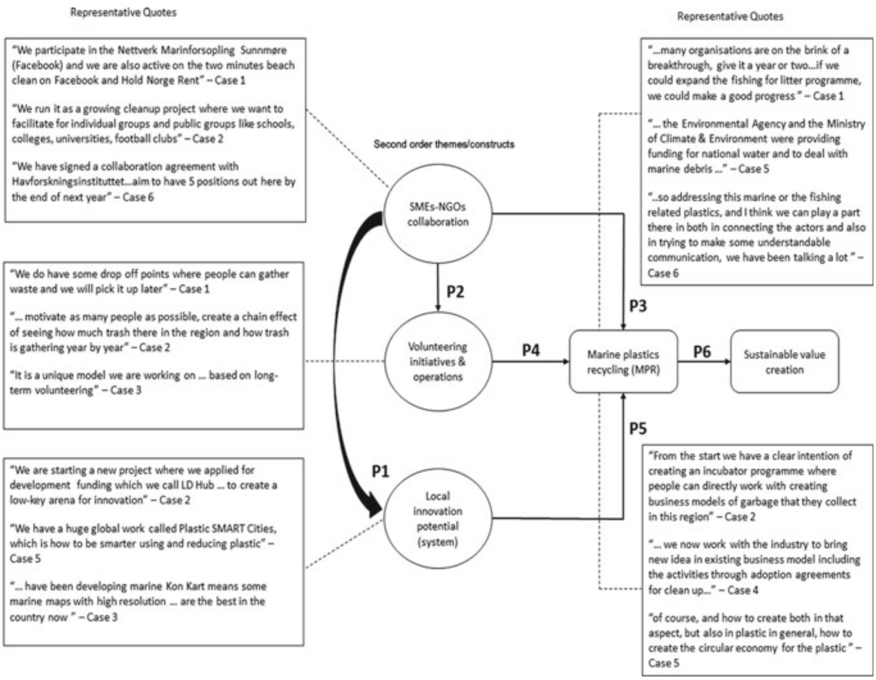

Fig. 9.2 Proposed conceptual framework and data structure

9.4 Findings and Discussion

Innovation is the successful exploitation and commercialisation of new ideas. It is far more than the common perception that innovation is only about new ideas or research and development (R&D). Innovation can cover processes, technology, organisation, and marketing, in the development and commercialisation of novel products and services providing value to customers. Innovation can occur at four main levels (technologies/products/services; process; organisational; business). Innovation includes but is not restricted to the ideas and research stages of the innovation cycle, or to novel technology alone, although these are core elements, innovation includes 'low tech' and is not restricted to 'high tech' technologies (Clark and Charter 2007). Similarly, eco-innovation is described as the process of developing new products, processes, or services which provide customer and business value but significantly decrease environmental impact (Clark and Charter 2007; Fussler and James 1996). The literature review and our six cases provide the insights associated with the role of non-profit organisations to create sustainable value through marine plastic recycling in the fishing gear industry. Based on these insights, a conceptual framework is proposed to delineate stakeholders' interests through strategic collaboration amongst them, which leads to marine plastics recycling (MPR) and creates sustainable value through the best utilisation of dynamic capabilities of the organisations.

Figure 9.2 presents the framework and explains the relationship amongst the proposed propositions which are discussed below. We define strategic value chain collaboration as an external form of collaboration between small- and medium-sized enterprises (SMEs) and non-governmental organisations (NGOs) which simultaneously introduce economic, social, and environmental success for the involved parties and therefore increase public awareness and active participation towards sustainability (Arya and Salk 2006; Austin and Seitanidi 2012). These types of collaborations have been on the rise as most organisations are increasingly re-evaluating their traditional business models and looking for new sustainable options (Baur and Schmitz 2012; Rivera-Santos et al. 2017). For example, in our case study, we observe a good number of clean-up projects are accomplished through collaboration. A key informant of one of the beach cleaning cases stated, '*… we run it as a growing clean-up project where we want to facilitate for individual groups and public groups like schools, colleges, universities, football clubs*' (Case 2). This type of collaboration also accelerates local innovation systems (with the possibility of new product, process, and service development) strategies in the fishing gear industry as well. For example, another informant of an NGO said, '*… we are doing a huge global work called Plastic SMART Cities, which is how to be smarter using and reducing plastics*' (Case 5). Accordingly, the following proposition is suggested:

Proposition 1 *Value chain collaboration between non-governmental organisations (NGOs) and small- and medium-sized enterprises (SMEs) stimulates innovation and enhances the local innovation system (leading to new product, process, and service development).*

From our field study, we observed examples of value chain collaboration between SMEs and NGOs. In addition, we visited the NGOs to observe at first-hand how they conduct their operations. From these observations and from the data analysis, their role in volunteerism and activism to deal with the fishing gear pollution problem was insightful. The data analysis shows the dramatic impact of the activities of the NGOs, regarding marine plastics recycling. Our analysis shows that the NGOs have strong and common motivations (for example, social and ethical responsibilities to our world) and make use of a range of communication platforms (for example, different online platforms). NGOs are actively involved in fund-raising initiatives (for example, sponsorship, partnerships, donations, and government funding). NGOs have a range of sources for funding their operations. Collaborations between NGOs and SMEs are reliable sources of funding, both locally and internationally. NGOs and SMEs enter into partnerships where funds flow from the SMEs to NGOs and in return, new product and process development ideas, community engagement and reputational advantages, flow to the SMEs and the local environment. SMEs want to be seen to be contributing to both the environmental and social needs of the community through collaboration with the NGOs. Our analysis also shows that NGOs use a variety of platforms to engage with their stakeholders and the public. Social media, for instance Facebook and Instagram, are playing an important role in this regard. The key informant of an NGO stated, '*…more or less all the clean-up stuff we do, we do in cooperation with the different organisations. And so, it's not that* *common that we do it by ourselves, but we do it together with other beach cleaning organisations in order to both have a big impact when it comes to actual cleaning itself and social media is great means of communication for us*' (Case 5). Thus, we posit the following proposition:

Proposition 2 *Value chain collaboration between non-governmental organisations (NGOs) and small- and medium-sized enterprises (SMEs) promotes volunteering initiatives and operations.*

The stakeholder theory (Freeman 1984, 2004) provides a suitable theoretical framework for understanding the interactions and relationships between an organisation and its stakeholders. The theory highlights the successful consequence between business organisations and society and shows a win–win situation for both entities (Cordeiro and Tewari 2015). It paves the way of turning corporate social responsibility into business objectives through the transformation of intangible social and environmental issues into tangible stakeholders' interest in the best way (Dmytriyev et al. 2021). Plastics are essential and ubiquitous materials in our daily lives and address numerous societal challenges. Cumulative production of plastics now exceeds 8000 million metric tonnes, of which approximately 9% has been recycled, 12% incinerated, and 79% accumulated in landfills of the natural environment (Pravettoni 2018).

With the exception of concrete and steel, plastics are now the most common manmade material (Carney Almroth and Eggert 2019). In every year, more than 10 million tonnes of plastics enter the ocean annually (Jambeck et al. 2015), and more than 80% of marine litter are plastics ('European Parliament' 2019; Geyer et al. 2017). If the trend continues, the amount of plastics making its way into the oceans is set to double from 2010 to 2025, rising from approximately 8 million metric tonnes in 2010 to 16 million metric tonnes in 2025 (Jambeck et al. 2015; Pravettoni 2018). There are different types of plastics polymers, but the market and the litter found in the marine environment are dominated by six substances: polypropylene (PP), polyethylene (PE), polyvinylchloride (PVC), polyurethane (PUR), polyterephthalate (PET), and polystyrene (PS), which together comprise approximately 80% of total plastics production ('Plastics Europe' 2017). Not all plastics are equally problematic. Beach, ocean, and river litter surveys show that certain plastic products and materials are more likely to enter the environment than others, with about 50% of items found, and are single use plastic items (Addamo et al. 2017). These are commonly used products that are difficult to recycle, easily littered, and often made of low-density plastics polymers, which means they often float (Willis et al. 2018).

To combat these issues, there is an increase in policies that target specific types of plastic waste (Carney Almroth and Eggert 2019). In this study, we mainly focus on understanding how strategic collaboration between SMEs and NGOs can impact on recycling marine plastics, more specifically, lost or discarded fishing gear made of plastic. NGOs have been playing an essential role in recycling marine plastics, particularly in their partnership with key stakeholders such as SMEs, and in serving the needs of individuals and communities. As one of our informants of one NGO stated, '…*the Environmental Agency and the Ministry of Climate and Environment were providing funding for national waters and to deal with the marine debris…they were the ones getting funding from them, and for that amount of money that we were providing for the different kinds of activities, for instance; having beach clean-ups, having underwater clean-ups, participating, and building on the national beach clean-up, they do a lot of policy works that we did to get marine plastics on the agenda for and for different politicians in Norway … and we also contributed to challenging all the different political parties in Norway to a zero-tolerance vision for plastics, that was in 2017 at RNC in August*' (Case 5). Many of these NGOs are developing a more sophisticated understanding of marine plastics problem (MPP) based on sound scientific research through the collaboration with universities and research institutes. Another informant said, '…*so addressing this marine or the fishing related plastics, and I think we can play a part there in both in connecting the actors and also in trying to make some understandable communication, we have been talking a lot about that*' (Case 6). In the study's context, we observed SME-University/Research-NGO collaborations. Collaboration between SMEs and universities (e.g. NTNU), research institutes (e.g. SINTEF, Møreforsking) and NGOs were observed and noted. The informant from the environmental centre (Case 6) said, '…*we work with the science, with the research and then we have the visitor centre and it's about communication to the public and where people can come in and learn about birds and the oceans and the global nature and plastics and we work in both places*'. These collaborations are geared towards the development of effective strategies to solve environmental problems such as marine pollution. Based on the empirical evidence and theory, we propose:

Proposition 3 *Value chain collaboration between non-governmental organisations (NGOs) and small- and medium-sized enterprises (SMEs) enhances marine plastics recycling.*

Proposition 4 *Volunteering initiatives and operations by the non-governmental organisations (NGOs) enhance marine plastics recycling.*

Proposition 5 *Local innovation potential (system) can enhance marine plastics recycling.*

Cultural or structural resources like strategic partnerships between SMEs and NGOs are very important to lead sustainable value creation (Esfahbodi et al. 2016). These resources help apprehend societal aspirations of sustainability and the aspects of triple-bottom line approach (Hahn and Figge 2011; Pagell and Shevchenko 2014; Pitelis 2013). Dynamic capabilities of an organisation lead new product development strategies and networking (Eisenhardt and Martin 2000). Our informant from Case 4 said, '…*we now work with the industry to bring new ideas in existing business models including the activities through adoption of agreements for clean-ups*'. The informant from Case 2 said, '…*from the start we have a clear intention of creating an incubator programme where people can directly work with creating business models of waste that they collect in this region*'. And finally, the informant from Case 5 stated,

'*…of course, and how to create both in that aspect, but also in plastic in general, how to create the circular economy for the plastic*'. Based on our findings, the dynamic capabilities of both SMEs and NGOs are helping them to leverage social capital achieved and developed via networking and value chain collaboration. Consequently, these interactions and collaborations accelerate marine plastic recycling initiatives which furthermore can enhance value creation sustainably. Hence, we posit that:

P6. *Marine plastics recycling can lead to sustainable value creation.*

9.5 Summary

Based on the review of the literature, we developed a conceptual framework (Fig. 9.1). We further demonstrate empirically how the data structure (Fig. 9.2) justifies the proposed framework. Our data structure shows the link between value chain collaboration and volunteering by non-governmental organisations (NGOs). Our data structure shows thematic analysis that focussed on the innovation potential that is stimulated from the collaborations and interactions. Innovation systems are known to structure firm processes (Rantisi 2002): it channels the process by developing a specialised labour market, facilitating the linkages between key innovating actors and other groups in the industry and defining (and redefining) the use-values of commodities (Rantisi 2002). For example, case 2 states 'we *are starting a new project where we applied for development funding which we call LD Hub….to create a low-key arena for innovation*'. Hence, we appraised our initial model with a focus on the link between SME-NGO collaboration and new product development, to a focus on the local innovation potential (system) of the fishing gear recycling cluster in the North-West of Norway. The waste fishing gear recycling industry in the North-West of Norway is in its developmental stage and is supported by the well-developed and dynamic marine and maritime clusters. Knowledge spill-overs between the marine, maritime, and the waste fishing gear industry enhance the innovativeness of the clusters. Industrial district and regional innovation systems are closely related but capture different aspects of regional economic development. Given the 'nestedness' of a system in other systems, one regional innovation system can support several districts (and clusters). However, in some cases, districts (or clusters) may be considered as local innovation systems with independent innovation patterns (Muscio 2006). The waste fishing gear recycling industry despite being dependent on the marine and maritime industry has its own innovation peculiarities and features. Sustainable value creation can be achieved through waste fishing gear recycling, value chain collaboration, volunteering initiatives/operations, and the local innovation system (leading to new process, service, and product development). Value chain collaboration between SMEs and NGOs stimulates innovation in the local environment (local innovation system) and within the industry. Collaboration drives the innovation process and enhances recycling.

9.6 Conclusion

In line with Porter and Kramer's (2011) view that shared value can be created through business partnering with social organisations, this book chapter highlights value chain collaboration and volunteering by NGOs as success factors that enhance fishing gear recycling. Value chain collaboration between SMEs and NGOs stimulates innovation (possibly new product, processes, and service development) within the industry. Collaboration drives the innovation and process improvement and enhances recycling of marine plastics. Furthermore, fishing gear recycling can lead to sustainable value creation. This book chapter provided initial insights based on an explorative study.

Appendix

Interview Guide

- Organization/association (Date of establishment; What motivates its establishment?).
- Is the NGO a member of an umbrella organisation/association?
- Do you have a board? And do you have a charity number?
- How does the organisation/association raise funds?
- How important is the NGO's role in addressing the issue of marine plastic pollution?
- Which of the following stakeholders does the NGO interact with: Plastic producers? Waste Management (Logistics)? Port Authorities? Waste Management (Recycling)? Municipality? National Government?
- Please provide more insight on your interactions with these stakeholders.
- Please describe any interaction between the NGO and the SMEs, and other stakeholders involved in the fishing gear recycling value chain? Please, provide contact details.
- How does this interaction take place?
- How does this interaction influence your activities?
- Please tell us how you influence business/industry policies and strategies?
- What kind of interaction/relationships do you have with the SMEs?
- Who is the most important stakeholder you are dealing with?
- Please provide some more insight on how the NGO deals with this important stakeholder.

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Part III
Marine Plastics: Towards a Circular Economy

Chapter 10
Sotenäs Marine Recycling Centre in Sweden: A Case Study Related to Waste Fishing Gear

Martin Charter and Paul Whitehead

Abstract The chapter is a case study on the development of a Sweden's first recycling centre focussed on waste fishing gear and other marine plastics based in Sotenäs. Key to the development of the centre has been a longer-term vision and commitment from the local municipality and the fishermen's association. Working with partners across Sweden and locally, the centre has also developed an innovation testbed that is developing new test for polymers from waste fishing gear and aims launch new circular products. The chapter provides favourable learning for any organisation that will be tasked with establishing recycling infrastructure in relation to extend producer responsibility (EPR) requirements for fishing gear that will come into force across the European Union in 2025.

Keywords Fishing gear · Sweden · Circularity · Recycling · Circular design · Extended producer responsibility

10.1 Introduction

Waste fishing gear is now being recognised as a major contributor to marine plastic waste and is in the spotlight for European policymakers. Other drivers include increased media interest in marine plastic pollution, pressure group activity, new European standards related to circularity of fishing gear, and importantly a forthcoming European Commission (EC) Directive covering Extended Producer Responsibility (EPR) that will be implemented in December 2024 (Charter 2023). This means that the fishing gear sector will need to consider sustainability and specifically circularity of their activities.

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At present, the infrastructure for the recycling of fishing gear is limited worldwide with few established and scaled recyclers of fishing gear. This is a potential challenge in Europe with all member states and fishing gear producers needing to have schemes in place by January 2025.

This chapter is a case study focussed on the development of the Sotenäs Marine Recycling Centre (SMRC), Sweden. The case study was prepared based on interviews with key stakeholders involved in SMRC during 2021. Extensive research completed within the Circular Ocean (Circular Ocean n.d. and CfSD n.d) and the Blue Circular Economy (Blue Circular Economy n.d and CfSD n.d) projects and dialogue with the Global Ghost Gear Initiative (GGGI) indicated that current best practice in recycling fishing gear is very limited. SMRC emerged as an interesting case study from dialogue in expert workshops organised by DG MARE at European Commission. In addition to recycling of fishing gear, SMRC also provides testing services and aims to develop new circular products derived from waste fishing gear and other marine plastics through an innovation testbed—'Testbed Ocean Waste' (TOW). With the growing interest worldwide in tackling waste fishing gear and emerging EPR legislation in Europe, this case study provides an example of the development of recycling infrastructure for fishing gear. The chapter also includes lessons learnt and conclusions that will be of interest to an international audience.

10.2 Sotenäs Symbioscentrum (Sotenäs Centre of Symbiosis)

Sotenäs is a small coastal municipality with a strong fishing and marine culture. The town has a population of about 9000, which increases, through tourism, to more than 50,000 during the summer months. The municipality is located 122 km north of Gothenburg, Sweden.

In 2015, the Sotenäs Municipality in Sweden established the Symbioscentrum (Sotenäs Centre of Symbiosis) as an organisation to implement industrial symbiosis in Sotenäs. The goal was to apply industrial symbiosis principles to strengthen the local economy socially, economically, and environmentally through designing an integrated system that viewed waste as a potential opportunity and covered many different types of waste produced by the municipality including fishing gear.[1]

Symbioscentrum aims to develop synergies between industrial players involved in renewable energy, food production, aquaculture, algae production, marine technology and innovative products, upcycling waste heat, fish industry waste, and other wastes from the neighbouring sea to create jobs (many of them green), value-added products and processes, and improvements in material and energy efficiency in the region. The creation of new jobs and encouraging the setting up of new companies is a key part of the strategy (Fig. 10.1).

[1] Industrial symbiosis is the process by which wastes, or by-products of an industry or industrial process become the raw materials for another (Chertow 2000).

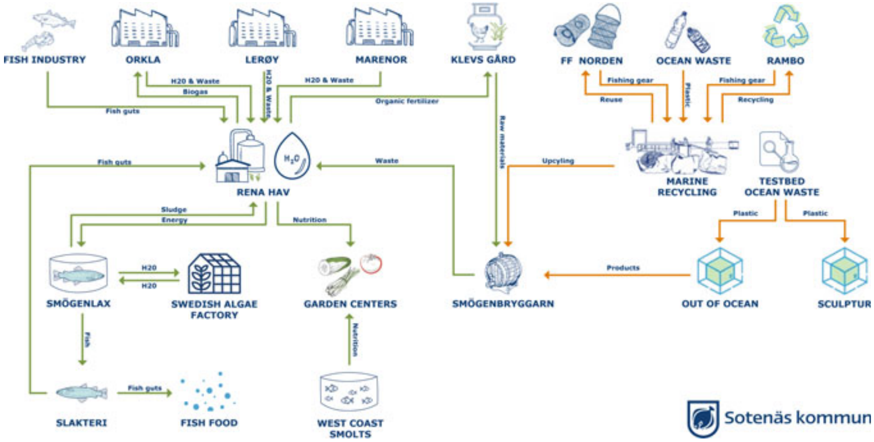

Fig. 10.1 Symbioscentrum system
Source: Sotenäs Symbioscentrum, Sotenäs Municipality, Sweden, 2022

10.2.1 Symbioscentrum's Vision

Symbioscentrum stated vision was to develop a system encompassing three core projects: (I) a biogas facility, (II) a wastewater treatment plant (WWTP) managed by Rena hav, and (III) recycling of ghost and end-of-life fishing gear (and plastic beach litter). The starting point was tackling biowaste and wastewater from the local fish processing industries to produce biogas, recycling of fat from restaurants to produce bio-diesel (no longer in operation) and plastic recycling together with Fiskareföreningen Norden (FFN) (also known as Nordic Fishermen Association (NFA)). In parallel, there were ongoing 'fishing for litter' and beach cleaning initiatives. When the activities started, the ideas for recycling ocean plastics locally were at an early stage of conceptualisation and development (Fig. 10.2).

The initial vision also included producing local food and manufacturing products in a self-supporting, financially viable closed loop circular system. What evolved was the vision of a circular economy-based rejuvenation programme involving job creation, upskilling, investment, added-value and more efficient, 'greener' use of local resources.

In 2018, Symbioscentrum brought different projects together under one 'roof'. This included an EC funded Interreg project called 'Ren Kustlinje' ('Clean Coastline') and a nationally funded project to clean beaches from ocean waste aiming to reduce the problem of plastic from the fishing and other industries. With these projects as a base, Sotenäs Marine Recycling Centre (SMRC) was established by Symbioscentrum. Initially, SMRC was designed as a small factory to disassemble fishing gear, sort the different materials, and prepare materials for reuse and recycling.

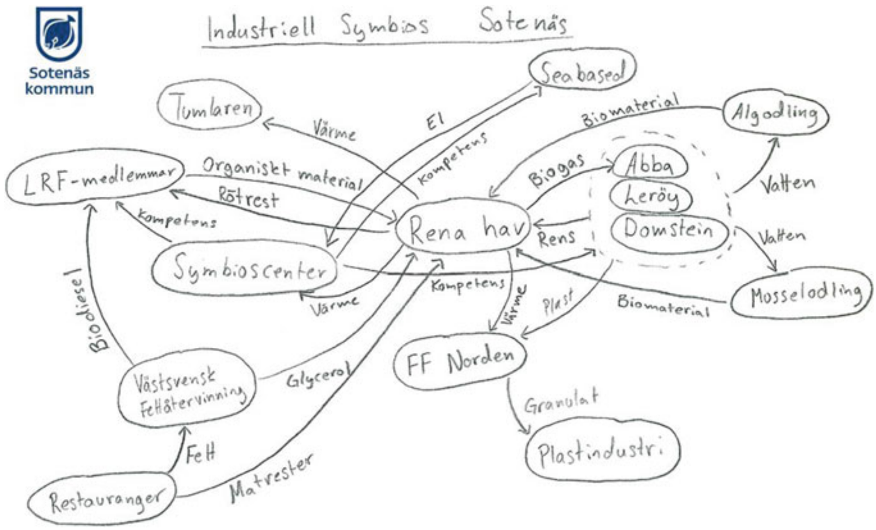

Fig. 10.2 First symbiosis map of Sotenäs
Source: Sotenäs Symbioscentrum, Sotenäs Municipality, Sweden, 2022

Management Structure

Symbioscentrum is coordinated through a manager, who reports (as at November 2021) to Director of Sotenäs Municipality, who has full responsibility for SMRC (Symbioscentrum 2020). Another key role in Symbioscentrum is the municipality's, as well as Symbioscentrum's development strategist.

A steering group was established by Symbioscentrum in 2015 to drive its evolution via project development. As at November 2021, the group comprised the Director of Sotenäs Municipality and representatives from three large companies (Orkla, Leröy, and Marenor) an SME (Rena hav), University West, Innovatum Science Park, a venture capital organisation and local politicians. The steering group was led by two project developers (now based at Chalmers Industriteknik[2] (CIT)), one of whom was subsequently involved in the start-up phase of SMRC, i.e. setting up the structure and arranging the supporting finance. The current CIT project developer was originally employed by the municipality as a project developer at Symbioscentrum, before joining CIT to support the development of SMRC and other projects. SMRC has been, and still is, financed by a mix of internal resources and a number of externally funded projects.

[2] CIT is involved in different projects related to SMRC, design of circular fishing gear and the testbed project.

10.3 Sotenäs Marine Recycling Centre (SMRC)

10.3.1 Background

SMRC was founded in 2018 as part of Symbioscentrum and has been, since its inception, backed by strong political will and engagement from the fishing community. The SMRC vision was to be a flagship for innovation and knowledge related to ocean plastics and waste fishing gear that works with the whole value chain from design to collection and recycling. SMRC is Sweden's first marine recycling centre and also aims to develop new circular products.

Starting-up SMRC included a range of tasks: securing funding, establishing small-scale sorting, building a network, facilitating the development process, and arranging logistics and material analyses. SMRC now focusses on collecting and processing ocean marine plastics including waste fishing gear. The end-of-life fishing gear processed by SMRC includes nets, cages (including lobster pots), and marine plastics found on the beaches. In addition, through its innovation testbed, TOW—working with a series of partners—it aims to identify those polymers that are best suited for use in manufactured products.

Until September 2021, SMRC employed a project developer and a project manager of TOW (Symbioscentrum 2020). Both SMRC project developer and the TOW project manager reported to Director of Sotenäs Municipality. In June 2021 as part of the development of SMRC, the municipality hired a site manager. There is now a growing team working at SMRC and the TOW innovation testbed drawn from different departments within Sotenäs Municipality (Fig. 10.3).

As previously mentioned, SMRC processes discarded and end-of-life fishing gear, e.g. nets, cages, etc. (including lobster pots) and marine plastics from beaches of the coastal area around Sotenäs. It was initially established to help tackle the problem of what to do with the large quantities of stockpiled discarded fishing gear left in harbours that were not being processed due to lack of recycling infrastructure. Fishing gear stockpiled in ports due to a lack of recycling infrastructure is a problem in many parts of the world, and Sotenäs is no exception.

The prime waste management route for end-of-life and retrieved ghost gear in Sotenäs and many other countries has, traditionally, been sending it to landfill. However, beach cleaning and the sorting of marine plastics had been carried out by Sotenäs Municipality and volunteers for decades before SMRC was founded. More recently, NFA became a promoter of cleaner seas and beaches and began to supply the Sotenäs Municipality, and SMRC specifically, with end-of-life and ghost fishing gear.

As highlighted earlier, SMRC's origins were based on a series of funded projects[3] that aimed to address the recycling of plastics from waste fishing gear and marine waste that involved various organisations from Sweden, Denmark, and Norway. One

[3] Project example: 'Ren Kustlinje'.

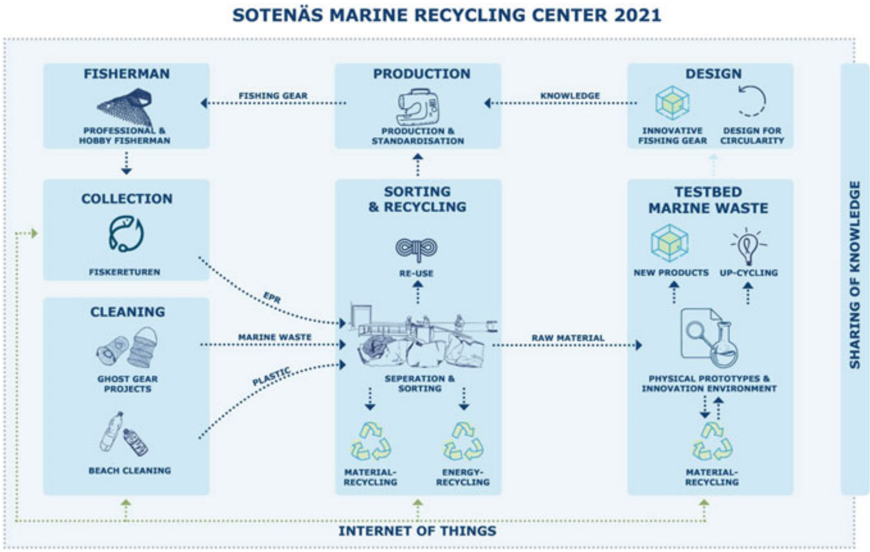

Fig. 10.3 Sotenäs Marine Recycling Centre (SMRC)
Source: Sotenäs Symbioscentrum, Sotenäs Municipality, Sweden, 2022

of those projects was the Interreg funded Clean Coastline[4] project that had different work packages including different areas of R&D. Sotenäs Municipality supported SMRC and R&D projects through funding some of its employees and providing facilities which included buildings, boats, and equipment.

10.3.2 Polymers and Metals

SMRC focusses on the three most commonly occurring polymers used for fishing gear (mainly polyethylene (PE)), monofilament nets (mainly polyamide (PA), e.g. nylon), and ropes (mainly PE and polypropylene (PP)). The types of gear collected include pelagic trawls[5] and other, smaller fishing net types. The polymers collected from ghost and end-of-life gear, and beach cleaning provides SMRC with the opportunity to increase their use in industrial scale recycling via participating manufacturers. Applications for the polymers have been identified as including furniture, building materials, footwear, and clothing.

[4] A 'spin off' of the Clean Coastline programme was the creation of a beach cleaning map of West Sweden.

[5] *Pelagic* trawls are cone-shaped nets that are towed behind one or two vessels and are designed to catch fish in the mid and surface water.

Table 10.1 SMRC: plastics and metals fractions as at November 2021

Plastics
• Combustible black (> 1.5 m: very dirty, mix PA and PET etc.)
• Combustible blue (< 1.5 m: very dirty, mix PA and PET etc.)
• PP mix (very little)
• PP ropes, blue lines
• PE nets, green
• PET (nets, ropes)
• PA nets
• Mixed ropes (PP and PE, not PA)
• PE nets, mixed
Metals
• Iron
• Lead
• Lead, mixed
• Lead ropes
• Stainless steel
• Copper

Source SMRC, 2021

A range of metals and plastics are recycled. The precise mechanism for sorting, or which fractions to be sorted, has not been finally decided at the time of the research, and trials were due to be completed during 2022 (Table 10.1).

'Floats and objects that can be reused are sorted separately', highlighted the SMRC project developer. 'We have around 20-30 different fishing gear components and sub-components that can be recycled after sorting by polymer type. They include buoys, balls, floats, and metal parts, e.g. shackles. Typically, they are 'waste' that can be reused in some capacity'.

Metals from the waste gear are also processed (sorted, broken up, and compressed) by SMRC and include lead (pure), lead (dirty), lead lines, mixed metal (which is the main percentage), and stainless-steel wires.

Fishing gear that is heavily contaminated—by bioaccumulation, sand, seashells, etc.—and that cannot be recycled or upcycled, is transported to an incinerator in Uddevalla located 60 km east of Sotenäs, where the material is used for the generation of heat and electricity for use in the Uddevalla district heating scheme. Metal parts are removed for recycling or upcycling. The contaminated mixed polymer ropes, polyvinyl chloride (PVC), and broken objects are used as 'feedstock' for the incinerator.

In the past, most of the *clean* polymers were exported to Plastix Global in Denmark for shredding and mechanical recycling into pellets for use by manufacturers in Europe and elsewhere. However, the CIT project manager highlighted that a shift in mindset started in 2021, 'we are seeing a shift now, where more and more polymers are being used in Sweden, not going abroad, with different companies using different types of polymer'.

The majority of polymers come from Sweden's 'industrial scale' fishing fleets—rather than from ghost gear (WWF 2020)—because it is easier and cost less to obtain end-of-life gear from them than to scour the seas for ghost gear. However, ghost gear has not been forgotten.

In Sweden, retrieval of ghost gear and ghost lobster pots is carried out by the voluntary actions of divers and fishers as well as retrieval programmes that are funded by various organisations such as the European Maritime and Fisheries Fund (Jordbruksveret n.d) and Sweden Agency for Marine and Water Management (SwAM). SwAM has a larger government project related to the collection and recycling of lost and discarded fishing gear (SwAM 2022). The programmes include a Sotenäs Municipality-led project—funded by a mix of the national government, agencies, and the municipality—which hires fishers and divers to retrieve lost gear (Fishsec 2022). It is a collaborative effort between Sotenäs and the neighbouring municipalities of Tanum and Lysekil with retrieval work completed by the volunteer divers and fishers.

SMRC is now accepting end-of-life gear from other coastal regions of Sweden, as a result of funding from the Swedish Agency for Marine and Water Management's department that aims to establish a nationwide collection initiative called Fiskereturen (or 'Return of Fishing Gear'). The initiative, started in December 2019, is a joint partnership between Sotenäs Municipality, NFA,[6] Båtskroten Boat Scarp Service, and Keep Sweden Tidy Foundation ('Håll Sverige Rent').

> In Sotenäs, we accept various fishing gears because it has nowhere else to go in terms of what can be done with it. We now have people, mainly fishers and divers - a mix of volunteers and paid people - bringing ghost and other fishing gear from all over Sweden to us for disposal and recycling (interview with SMRC project developer).

10.3.3 Lobster Pots

In the waters in the Sotenäs area, several hundred ghost lobster pots are retrieved each year. To put that in context, ghost lobster pots have been gathering on Sweden's seabed for decades, with the result that there are an estimated tens of thousands of them, many still trapping sea life. Those retrieved and in a useable condition are sold directly to fishers and via the Sotenäs municipality's 'Secondhand Store'. Some are cleaned and given minor repairs at the recycling centre before being sold.

'They sell quickly', highlighted the SMRC project developer, adding, 'we are also looking at collaborating with a company that is interested in carrying out more comprehensive repairs and including innovative solutions to reduce entrapment of fish, crabs, and lobsters in case the recycled pots are lost again'.

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[6] Fishers and fishing gear producers locally established in the municipality (NFA, n.d).

10.3.4 Hubs

Hubs are typically located where fishers get their fishing nets repaired by fishing gear producers, although many fishers will repair and patch their own nets. The producers and fishers repair and adjust gear for best performance and to extend product life of the fishing gear whilst adhering to the appropriate technical regulations.

During 2020, it is estimated that SMRC processed more than 170 tonnes of waste and end-of-life fishing gear that was collected locally and from elsewhere through a series of recycling hubs located in the different regions of Sweden. There are around 10 hubs in total, located in fishing villages and ports, from where fishing gear is transported by truck to SMRC.

Fishers who do not plan to repair nets themselves drop their gear off at the hubs. In some cases, gear is collected from the fishers by Fiskereturen (‘Return of Fishing Gear’ project) and taken to a hub, at no cost to the fishers.

10.3.5 SMRC Testbed

SMRC’s innovation testbed—‘Testbed Ocean Waste’ (Sotenäs Symbioscentrum 2021) (TOW)—carries out different tests on the material derived from the processing of waste fishing gear and beach litter that is beyond reuse, repair, or upcycling. The tests use different production methods and consider different applications for the polymers. The goal is to support participating companies with their own innovation, for example, by advising them how to apply the tests and the results to new ‘circular products’.

‘That goal supports an aim of SMRC to ‘Keep it all in Sweden’. A circular economy model keeps, or helps to keep, material/value locally, in Sweden, rather than it going overseas’, highlighted SMRC project developer.

TOW is partly funded by Vinnova, the Swedish government’s Innovation Agency, and is run by Sotenäs Municipality and testbed partners. The partners include CIT, who provide academic expertise and consultancy related to energy, materials, digitalisation, design, and project management, and other support related to circular economy thinking and practical application; Research Institute of Sweden (RISE n.d); NFA and University West.

TOW is a part of a network of testbeds in Sweden that includes the testbed for plastic recycling run by RISE in Gothenburg. RISE has a huge variety of instruments and research equipment including a large-scale 3D printer, fibre spinning, larger injection moulding, and extrusion machines, for the production of pellets, and equipment for analyses and tests managed by RISE. RISE also performs different tests on the materials to determine the properties of the polymers.

The motivation for companies to use TOW comes from a growing interest in transforming waste to value by incorporating marine plastic in products by upcycling or reuse, or by recycling polymers to produce pellets prior to manufacturing final products or product parts. Companies participating in the TOW project co-finance through providing in-kind funding related to staff time and other contributions to the value of 100,000–200,000 SEK per company.

Nine companies are participating in TOW and a further two are in the process of joining. They range from small start-ups to large and global organisations and include producers of furniture, interior design objects, clothing and accessories, and automotive components. The companies are Sculptur—3D printing furniture; Out of Ocean—interior design and building material; XV Atelier—fashion; Scandinavia Form—interior design; add: north—3D filaments; Rewyld—accessories; Store Enso—Biocomposites; Appelviken watches—watches; and IAC Group—automotive components.

TOW uses SMRC owned equipment that includes a large and a small shredder (that creates fibres/flakes, from which pellets are made by RISE and other external partners, via its compounder); an oven; a customised compression press; a small scale/prototype scale injection moulding machine; extrusion machine; and small scale 3D printer along with handheld tools and machinery. The equipment, processes, and analyses are complemented by RISE's polymer recycling laboratory in Gothenburg.

The SMRC project developer highlighted that 'tests carried out at TOW and, where necessary, at RISE, are driven by the requirements of the participating companies and partners. In some instances, companies want information on the specific properties of a plastic, for example, to help them decide if additives need to be added to a plastic to help optimise the final consumer or business to business product. New product prototyping is primarily carried out on the companies' own production lines'.

Tests, analyses, sorting, and the use of equipment at SMRC are provided free of charge for participating companies but they are expected to give feedback to SMRC and TOW for development purposes (as part of the companies' in-kind in the project). Other benefits to companies are consultancy related to circular business development and innovation provided by Symbioscentrum, and the opportunity for companies to join Symbioscentrum's larger network of companies, institutes, and research organisations.

The tests provide a data-led basis for innovation. 'The testbed is customer-led and so responds to requirements and requests from the participating companies. It started from a clean sheet, not knowing what the companies would be interested in, or what methods, fine-tuned to each of them, they required. But we quickly adapted, in close partnership with them' highlighted the CIT project developer.

The SMRC project developer highlighted also that, TOW's participating companies come from throughout Sweden. That is good, but overall, we prefer at least some makers to be more local as we look to job creation in the circular economy in Symbioscentrum.

'Some of the companies have successfully tested and developed products with the help of TOW and are soon to launch new products. The next challenge, which we are working on, is to secure a larger scale production and flow of material to and from SMRC, all within Sweden'.

To summarise, TOW is developing and applying tests, and this process is indicating which tests perform most closely to participating companies' needs. The tests also provide a data-led basis for innovation for the participating companies. In addition, TOW is producing a number of prototype circular products. The work at TOW and lessons learned is helping SMRC to get more involved in developing European standards for the circular design of fishing gear and other areas—see the section on 'Standards' in this chapter.

10.3.6 Social

There is a strong social element to SMRC. The municipality's work training programme includes trainees from: (i) the local unemployed, who gain work experience and (ii) migrants and refugees who benefit from becoming better acquainted with Swedish culture and language, developing social skills, and better understanding the Swedish work environment. All trainees receive an income from the municipality.

The trainees' work covers separating and sorting fishing gear and beach plastic. In addition, they help to clean the beaches and coastal area of the municipality when the weather allows for it—primarily, but not exclusively, in the summer. This way they gain experience of both indoor and outdoor work whilst making a positive contribution to cleaner beaches and improving their prospects for re-entering the workforce locally or elsewhere in Sweden.

10.4 Challenges

10.4.1 Funding

> An early challenge was gaining funding. The resources required to do what we are doing needs funding because SMRC was not a commercially viable entity, although multiple benefits can be leveraged from it, highlighted the CIT project coordinator, further adding, key for an operation like SMRC is public funding with the long-term aim of achieving commercial viability via the supply to businesses of recycled and other post-processed raw materials of high value.

10.4.2 Bringing Fishers on Board

Engaging fishers in the recycling of fishing gear is essential. The SMRC project coordinator added 'a perceived early-stage challenge was getting fishers and producers to work with us. However, the fishers did not really present much of a challenge to engage because they were keen to help and in fact were a key partner—as represented by the NFA—from the beginning. Members even voluntarily gathered fishing gear together, at their own docks, for several years before SMRC was started. The NFA has been supporting the centre and been a driving part of it from day one'. So, the challenge actually became an opportunity due to the leadership displayed by NFA.

10.4.3 Different Stakeholders, Different Responsibilites

Another major challenge faced by SMRC was working with a variety of different stakeholders, each with their own, different, responsibilities but all being unsure over what to do with marine waste. A big problem was identifying who was responsible for marine waste in government, because it fell between different bodies. That means that even waste fishing gear—for example—was the same, whether it is in the ocean, has floated ashore, or was lying in harbours, the question of which agency should do what with the waste was generally not addressed.

'Historically, that created confusion and wasted time, but now SMRC is helping to coordinate things more effectively', highlighted the CIT project developer.

The agencies involved—with their responsibilities are in brackets—include the Swedish Environmental Protection Agency (SEPA) (waste on land/beaches), Swedish Agency for Marine and Water Management (SAMWM) (waste in water), Swedish Transport Agency (waste in docks), and municipalities (waste in the local environment/local beaches). SEPA and SAMWM provide funding to SMRC.

The issue illustrated above is not just a Swedish challenge but is also true in other countries in Europe and worldwide as marine plastics and waste fishing gear are increasing being recognised as a horizontal issue. Developing a cross-cutting policy development and coordination that works across different government ministries would perhaps start to address some of the duplications and complexities. This will be increasing important with the emergence of EPR legislation in Europe and other emerging policy development associated with marine plastics globally.

10.4.4 Persuading Businesses to Start up in Sotenäs

A further challenge has been persuading businesses to start up in Sotenäs, and for early stage and established businesses, to be able to deal with the availability of fluctuating volumes of polymers from waste fishing gear for production. 'We are having successes with established businesses—for example, with an interior design and building materials company, Out of Ocean, that was set up in Sotenäs (Out of Ocean n.d), but our main focus is supporting start-ups in an early development stage and attracting them to be based in Sotenäs as part of Symbioscentrum. For example, Impossible Plastics are in the process of setting up a facility in the municipality', indicated the CIT project developer. The approach aims to support start-ups applying innovation to waste fishing gear to develop circular products that then generate 'green' jobs in the municipality or elsewhere.

10.4.5 Provenance and Traceability—Track and Trace/ The Internet of Things

Traceability is another challenge as with increasingly environmental and climate change anxieties, businesses and consumers are becoming more concerned about the genuine provenance of raw materials and finished products and demanding higher quality proof. Provenance is all about proof of authenticity of origin (Woodham 2021).

Increasing traceability of fishing gear components used in manufactured products will be beneficial to all stakeholders. By developing processes that enable tracking and tracing of fishing gear, this will give more confidence to customers and other stakeholders in what the sector of the provenance of discarded fishing gear at the end of life.

A Vinnova funded project based on Internet of things (IoT) has been set by CIT in association with SMRC to help us develop a best of breed 'track and trace' system through tagging raw materials and auto-tracking them, end-to-end from the start of the supply chain to the point of manufacture.

The CIT project developer explains 'increasing demand by consumers for transparency, and the facts about provenance of materials are driving the need for higher quality traceability. IoT provides the means to track and trace fishing gear throughout the lifecycle. We have had a simple system with name tags on materials in the different stages of the value chain (collecting, sorting, etc.). The data related to the tags are then fed into an IT system. In the future, we might use QR-codes and equipment, such as scales for weighing fishing nets, directly connected to the IT system'.

10.4.6 Extended Producer Responsibility

EC Extended Producer Responsibility (EPR) legislation will place responsibility on fishing gear producers for the financing, collection, and recycling of end-of-life disposal of fishing gear throughout Member States. The system is an all-embracing recycling system including reporting to the agencies, collection, transportation, and recycling, and in parallel, a European standardisation process has started.

SMRC is already preparing for EPR rollout across the EU in early 2025. SMRC project developer highlighted that SMRC's experience will be useful in the future EPR development in Sweden. 'We are involved in a project with SEPA and SAMWM which aims to involve different stakeholders that will be affected by the EPR to implement and test the system before it becomes legislation in 2024'. The main focus of this project is to test and develop the EPR system nationally, with one element also focussing on the standardisation process.

Standards

A new project on *design for circularity of fishing gear* has been set up at SMRC. It is led by CIT, working closely with NFA and SMRC. 'Together, we are looking to create standards for how gear can be designed for circularity. Circularity, as it applies to fishing gear and beyond, is a key element of Symbioscentrum's ethos', says CIT project developer.

In November 2021, the European Standards body (CEN) started a technical committee TC 466 to development a series of standards related to circular design, circular business models, and digitalisation of fishing gear. 'We are at an early stage in our thinking about standards, but we believe that standards will evolve at a European and Swedish national level. To that end, we are collaborating with Swedish Institute for Standards (SIS) and others as the project develops to ensure that we are inputting our knowledge and influencing the process'.

Lessons learned at SMRC and TOW will be helpful for stakeholders in the fishing industry in Sweden, and across Europe and elsewhere, because EPR and circular design will force a rethink by all parties, e.g. fishing gear designers, manufacturers, etc., about their post-sales responsibilities.

'Historically, fishing gear has not been designed to be easy to disassemble and/or recycle. Design for circularity overcomes the problem of the complex work, and therefore, time involved in separating the component parts of ghost and end-of-life gear, and then reusing and/or recycling them'.

The CIT project developer highlighted that

> It is highly desirable to have gear that is designed specifically for easy disassembly and with the parts easier to recycle. Historically, gear has used three different types of plastic where, today, just one type could in theory be used, making life easier for us and therefore product manufacturers (Charter et al. 2020).

The SMRC project developer comments, separately, SIS has set up a Swedish technical committee related to waste fishing gear that includes SMRC and others, which means that SMRC is involved in forthcoming European standardisation work on 'sustainable fisheries, aquaculture, and fishing gear' (CEN TC 466). The technical committee's start-up meeting was in November 2021 which means that SMRC and other Swedish stakeholders will be engaged in the future meetings.

10.5 Key Findings: SMRC and Its Work

There are a number of key findings from the development and operation of SMRC that are listed below. These findings are important for stakeholders that are in the process of establishing the infrastructure for the recycling of fishing gear.

10.5.1 Local Support and Funding

The involvement of the local municipality, specifically its funding, buy-in, and political support was essential to establishing SMRC in Sotenäs. Funding from central government and the engagement from local organisations including NFA has also been key factors in SMRC development.

It is uncommon for a municipality in Sweden to become so involved in a project like SMRC, but its support has been vital to kick-start the project and keep the momentum going.

10.5.2 The Role of External Partners and Companies

Different projects require different partnerships with different expertise. Sotenäs Municipality has built expertise at collaboration, identifying potential projects, and finding funding. Where specific skills are needed, the execution of a project is often carried out by one of the partners. The collaboration provides expertise, flexibility, and 'agility' at lower cost or more cost effectively. The municipality collaborates with external partners because—as is typically the case with a municipality in Sweden—it does not have all expertise in-house; and if it did, it would be at a high cost.

The support of CIT and other academic partners—that provided expertise and manpower—has also been important to the project. CIT continues supports the municipality with expertise in industrial symbiosis, circular economy, innovation management, logistics, resource mapping and analysis, etc. The input and engagement with fishers via NFA were essential to the development of SMRC and TOW, as they have deep knowledge about fishing gear, its components, and why different materials are used.

10.5.3 Vision

It is essential to have a vision and guiding principles to support future direction. The key players—Symbioscentrum and NFA—both developed visions that were aligned to support the overall development of recycling of fishing gear with SMRC have developed a more specific vision.

Symbioscentrum's vision (see 10.2.1). The vision started with the recycling of fishing gear and has evolved to consider the circular design of nets and the creation products from polymers from end-of-life gear.

NFA vision. NFA developed a vision 15 years ago that incorporated sustainability in its working practices, when it recognised that it had to become more sustainable to survive. ‘NFA began to see the benefits of using more selective fishing[7] gear and started to collect end-of-life gear to prevent it from becoming ghost gear—and to recycle rather than dump it in landfill’, highlighted the SMRC project manager.

NFA subsequently invested considerable time and expertise in recycling fishing gear. The founder and Chairman of the Board of NFA highlighted that fishers ‘should have a holistic view and not leave anything behind in the sea’, and further added:

‘SMRC allows us to demonstrate to the fishing industry, in an informed way, the benefits of picking up all the nets and all the rubbish dropped into the sea and the importance of keeping the seas clean and the fish healthy’ (Symbioscentrum 2020).

It was recognised early which is there must be no cost to fishers to engage with fishing gear recycling, e.g. if there is a cost to fishers, they will not be interested in participating.

SMRC vision: SMRC vision is to be a flagship for innovation and knowledge for ocean plastics and fishing gear that works with the whole value chain from design, collection, and recycling to the development of new circular economy products. This is to be achieved through:

- Creating and developing a value chain related to polymers and other materials arising from waste fishing gear
- Creating a world class research centre lab for ocean plastic waste in Sotenäs, e.g. to be a ‘centre of excellence’ for research, development, and networking related to ocean plastics
- Acting as a testbed for sorting and recycling of fishing gear
- Contributing to the development of standards development relevant to EPR and the circular design of fishing gear
- Having a digital twin of the facility, through creating transparent tracking of the entire system via IoT
- Sharing the model with other countries to help: (i) increase the reuse and recycling of ocean plastic, (ii) increase value of the materials, and (iii) help clean the oceans globally by working ‘glocally’—working globally and locally.

10.5.4 Project Development

Since SMRC was founded, several projects of different sizes have been carried out that contributed to its development. Some of these have been funded through EU funded Interreg projects, Swedish government innovation projects and other financial support programmes as well as regional and locally financed projects. The ability to join up the separate, individual projects, and build on the knowledge and learning has helped SMRC move forward despite a lack of strategic core funding.

[7] Selective fishing gear is a process that has been developed and used by NFA to reduce by-catch and the ‘wrong’ catch by using parts in their nets that let unwanted fish out. It also allows fishers to capture only the size of catch they want (SLU 2021).

10.5.5 Best Practice

SMRC is developing examples of best practice related to the recycling of fishing gear that includes collection, sorting, circular design, and testbed development. At present, this has not been documented or published. The goal is to share knowledge and experience in Sweden, Europe and/or the rest of world particularly related to: (i) test methodologies, e.g. the use testing of a different types of polymers for possible use in the manufacture of new products, (ii) technology methodologies, e.g. manufacturing methodologies, and (iii) sharing of the findings of how to set up and manage a fishing gear recycling system with interested parties.

10.6 Key Lessons Learnt and Insights

There have been two key learnings that have been crucial for the development of SMRC: (i) gaining the local political will from Sotenäs Municipality to invest in SMRC and related initiatives and (ii) getting fishers' and volunteer marine waste collection groups' buy-in to the project. Fishers, via NFA, have been highly instrumental in the success to date of SMRC. The success includes the creation—driven by SMRC—of regional hubs throughout Sweden that feed end-of-life fishing gear and ghost gear to the centre.

SMRC:

- Is developing a model, aligned to its vision—that could be duplicated elsewhere in the world—for an end-to-end, closed loop system starting with circular designed fishing gear, locally-based manufacturing and services, and related work experience, training, and job creation
- Will potentially act as a magnet for new businesses that align to the goals of Sotenäs Symbioscentrum, in which SMRC is playing the leading role related to waste fishing gear
- Is sharing best practice, knowledge, and information, in order to help accelerate change in fishing gear recycling and circular economy thinking elsewhere
- Is engaging in standards development related to the recycling and circular design of fishing gear, e.g. design to increase the speed and ease of disassembly and improved recyclability. SMRC is now involved in providing inputs into European standards development in relation to EPR legislation that will impact on the fishing industry in Europe starting in 2025.

10.7 Conclusions

SMRC—under the umbrella of Symbioscentrum—has come a long way since it emerged as an idea from an EU funded Interreg project that aimed to help prevent marine waste involving partners from Sweden, Denmark, and Norway.

SMRC's progress has been built on a close working relationship with NFA (fishers) and with CIT (research and innovation). The collaborative relationship with CIT has fostered critical thinking and work, related to circularity, testing, IoT-based tracking, and initial standards development.

These collaborations demonstrate that partnerships can help make things happen at a regional or local level, and more speedily, because typically, a local municipality will not have all necessary resources in-house to do all the work itself. It is simply too costly. Partnering has also allowed for greater flexibility and greater business agility.

SMRC is showing that its local model for the retrieval and processing of waste fishing gear and ocean waste can be expanded to include an entire country via remote hubs; and can, with its parent, Symbioscentrum, be part of something transformative: strengthening and deepening a local economy through circularity and innovative thinking.

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Chapter 11
The Effect of Fishing Nets Aging on Metal Uptake

Ana Teresa Macas Lima, Ida Maria Gieysztor Bertelsen, Lisbeth Mølgaard Ottosen, and Neil A. James

Abstract Fishing nets are mainly constituted of Polyethylene (PE), Polyamide, Polyethylene terephthalate (PET), Polypropylene (PP), and Nylon. While new, these plastics exhibit pristine mechanical performance but lose it as they age. But what about their metal adsorptive performance? Literature finds that plastics like PET and PVC accumulate Al, Cr, Mg, Fe, Co, Ni, Zn, Cd, and Pb, even when exposed to very low concentrations. This is mainly true for aged PVC (Kedzierski et al. Adsorption/desorption of Micropollutants. Mar Pollut Bull. 127:684–694, 2018). In this study, we look at the effect of age on the properties of fishing nets, including their capacity to adsorb metals. Because fishnets are in great part constituted by PE, we used standardized PE pellets as our reference. In calorimeter signaling, we observed that end-of-life fishing nets display a very different differential scanning calorimetry (DSC) pattern; both new and old fishing nets are very different from standardized PE polymer. Preliminary results show that Cr, Cu, Pb, and Se adsorption onto fishing nets occurs in the first 10 min to 6 h of exposure (24 h for Se). The maximum uptake was registered at 11 mg Cr kg^{-1}, 38 mg Cu kg^{-1}, 27 mg Pb kg^{-1}, and 15 mg Se kg^{-1}. All these concentrations refer to *old* end-of-life PE fishing nets, where *new,* unused PE fishing nets adsorb 2–20 times less (*Old* in this chapter refers to used fishing nets. The term is not attempting to attribute a particular life span/age to the nets). A comparison to different EU directives that regulate metal content in plastics for different end-uses shows that the old end-of-life PE fishing nets, after exposure to heavy metals, do not meet the regulations for hazardous waste. We believe that Greenlandic old waste

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fishing nets can be used to clean the wastewater, or metal-contaminated water, in Greenland and eventually, the rest of the world.

Keywords Fishnets · Polyethylene · Metal adsorption · End-of-life · Wastewater

11.1 Introduction

Fishing nets are mainly comprised of Polyamide, Polyethylene (PE), Polyethylene terephthalate (PET), Polypropylene (PP), or Nylon (reference). Production of plastics is currently around 381 million tons annually (Amirkhanian 2020), with production estimated to increase annually if no ban is officially set by governments (Geyer et al. 2017). Approximately 8 million tons of these plastics end up in the oceans (Jambeck et al. 2015), with an estimated 10–20% of global ocean plastic waste coming from marine sources, such as fishing nets (Hannah and Roser 2018; Moore 2008). Ghost nets are fishing nets found in the seawater, floating or deposited together with sediment after usage (Moore 2008). In Greenland, where 50% of plastic waste on the shores is from marine sources (McGwin 2021), fishing nets pose a great threat to local fisheries. The ministry suggests starting clean-up efforts in three of the most heavily fished areas, covering 420 km^2 (McGwin 2021).

It is known that metals adsorb directly to plastic surfaces or co-precipitate with or adsorption to hydrous iron and manganese oxides (Mitchell et al. 2019). In 1978, Cutter observed a loss of 59% of selenate in Polyethylene bottles within five days. Longer-term adsorption of metals onto plastics has been studied in situ to understand the impact of plastics on the ocean and its role in the cycling, retention, and desorption of elements in the ocean environment (Kedzierski et al. 2018; Rochman et al. 2014). Plastics like PET and PVC have been widely studied for metal adsorption, in particular, and accumulated Al, Cr, Mg, Fe, Co, Ni, Zn, Cd, and Pb (Rochman et al. 2014; Zhang et al. 2020). Ashton et al. (2010) considered that the possible mechanisms for metal adsorption were due to the direct adsorption of cations (or complexes) onto charged sites or neutral regions of the plastic surface. They also concluded that heavy metals have a high affinity for plastics since plastics are composed of organic polymers. The reactivity of plastic pellets toward trace metals is attributed to the short-term adsorption of organic matter and the long-term aging and modification of the plastic pellet surface. Quantitatively, adsorption constants on a mass basis are lower than respective constants defining adsorption to suspended sediments; however, it must be appreciated that the specific surface area of weathered or modified plastics is orders of magnitude lower than that of fine sediment (Holmes et al. 2014). From these studies, Kedzierski et al. (2018) found that aged PVC adsorbs large amounts of heavy metals. This is a curious result since most plastics at sea are used and aged to a certain degree (Holmes et al. 2012).

Plastics, or polymers, can be characterized by different techniques. One of them uses thermal treatments. Thermal gravimetric analysis (TGA), coupled with differential scanning calorimetry (DSC), is a method which has been previously used as a polymer characterization tool, where a unique endothermic/exothermic signal characterizes individual polymers (Kayacan and Doğan 2008; Kannan et al. 2014). These signals create a fingerprint to the material that depends on (i) the molecular weight distribution and branching, (ii) crystallinity, and/or (iii) crystallite morphology of the polymer. The wear and tear of fishnets, i.e., the usage of the polymers, may be detected by thermal treatment.

In the BCE project, we looked at ways to reuse/recycle these fishing nets because of the increasing amount of fishing nets found at shores and drifting in the ocean. In this chapter, we look if EOL fishing nets are hazardous after increased exposure to metals. We test the hypothesis that they can be (re)used one last time as adsorbents for metals in, e.g., wastewater. Conventional methods for heavy metal removal from wastewater include reduction, precipitation, ion exchange, filtration, electrochemical treatment, membrane technology, and evaporation removal, all of which may be either ineffective or prohibitively costly, especially in the case of the metals dissolved in large volumes of solution at relatively low concentrations (Özcan et al. 2005; Feng et al. 2009). With this in mind, we test the hypothesis that *old* end-of-life PE fishing nets can be used to adsorb metals and treat industrial wastewater. This hypothesis stems from previous findings, where studies have observed that metals and hydrophobic organic chemicals adsorb onto plastic (Holmes et al. 2012; Koelmans et al. 2016).

11.2 Methodology

11.2.1 Materials

Four different types of Polyethylene (PE) fishnets were chosen to carry out this study. Figure 11.1 shows the 2 types of PE polymer. New, unused fishnets were collected at the producer—EURONETE, Denmark. The main factory characteristics are listed in Table 11.1. These fishnets were chosen because of their widespread use by Greenlandic fishermen. Discarded fishnets were collected at a dumpsite in Sisimiut in April 2016, at the end of their usage by local fishermen (Fig. 11.2).

We characterized 4 fishing net samples as illustrated in Fig. 11.1: 2 unused (new) fishing nets and 2 used (old) fishing nets of the same type. The next sections describe the methods used.

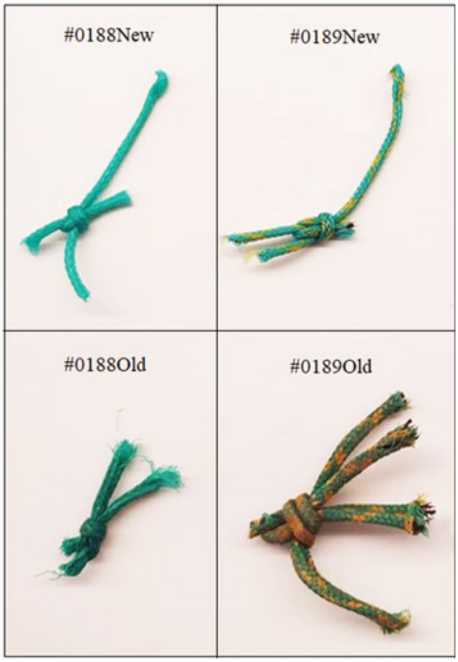

Fig. 11.1 Visual representation of unused and discarded, end-of-life fishnets. Photograph by the authors

11.2.2 TGA and Fishing Nets Visualization

Thermal gravimetric analysis (TGA), coupled with differential scanning calorimetry (DSC), uses between 3 and 1000 mg of sample to determine accurate mass loss from exposure to the rising temperature. These tests are standard for determining PE kinetics, namely dynamic methods (Kayacan and Doğan 2008; Aboulkas et al. 2010; Cai et al. 2008) and isothermal methods (Encinar and González 2008). In these studies, sample weight loss data is obtained by heating the sample under controlled conditions of desired temperature and gaseous environment, adopting non-isothermal (dynamic) or isothermal techniques. In this study, we used dynamic settings in which the sample is submitted to a thermal program that includes a temperature range from 30–600 °C at the heating rate of 10 K min^{-1}. All experiments used a constant flow rate of nitrogen as a purge gas, as described in (Kannan et al. 2014), followed by an N_2 flow rate of 250 cm^2 min^{-1}. The initial mass of each sample was approximately 20 mg.

High-resolution pictures were made with a macro lens, Nikon D 610 (24 Megapixel), Kaiser RB 5000 Daylight Copy Light Set at 5.5 cm between lens and sample.

Table 11.1 Description of the unused fishnets, their composition as described by the seller, physical performance, and applications (described in http://www.euronete.com/products/view_product/1/5/)

Internal ref.	Name	Composition	Diameter (mm)	Breaking strength (kg)	Applications
#0188	Twisted Polyethylene	Polyethylene	2.5	100	Bottom Trawling (Cod-ends, upper and lower panels) Aquaculture' (Bird Netting)
#0189	Euroline	Polyethylene	2.2	100	Bottom Trawling (Cod-ends, upper and lower panels) Aquaculture (Predator Netting, Bird Netting)

Fig. 11.2 Dumpsite containing discarded fishing nets in Sisimiut, Greenland. Photographs by the authors taken in April 2016

11.2.3 Adsorption Experiments (1)

Of the selected fishnets, we exposed #0188 and #0189 fishnets, both new and old, to a known concentration of metals. The metal solution was prepared from a standard concentrated solution of 0.5 mg L^{-1} of Cr, Cu, Pb, and Se aqueous solution, at a neutral pH (≈7). These concentrations are approximately two orders higher than those in contaminated inshore waters (Jonas and Millward, 2010). Still, we chose those values for determining the maximum adsorption of Cr, Cu, Pb, and Se onto PE.

The experimental procedure was adapted from Holmes et al. (2012). 0.25 g of fishnet PE was put in contact with 20 ml of 0.5 mg L^{-1} Cr, Cu, Pb, and Se aqueous solution in glass vials with Teflon caps for 5, 10 and 30 min, 1, 3, 6, 24, 48, 113, and 163 h. The vials were kept at a shaking table, as exemplified in Fig. 11.3. The (kinetic) experiments were undertaken in duplicate and included a metal-free control, with the same 0.25 g of fishing net PE, and added to 20 ml of ultra-pure deionized water. Blank vials were also added with only 20 ml of 0.5 mg L^{-1} Cr, Cu, Pb, and Se aqueous solution (no PE fishing nets added). After the contact time, liquid and solid PE were separated and analyzed. Liquid samples were transferred to polypropylene flasks and acidified to pH < 2 with 50 μl of HNO_3. Then, liquid solutions were analyzed directly in an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). A solid PE fishing net was first microwave digested, and then, the solution was analyzed in ICP-OES. Pellets were transferred to 8 ml glass vials with 2.5 ml of ultra-pure deionized water and ultrasonicated for 3 min to extract adsorbed trace metals and minimize digestion of pre-existent metals. After this, fishnet PE was transferred to Teflon vials (Fig. 11.3b) and then digested in a Multiwave GO microwave digestion system (Fig. 11.3c). Plastics were digested in a mixture of concentrated HNO_3 and HCl (Hildebrandt et al. 2020). Finally, digested fishnet PE was diluted and measured in the ICP-OES.

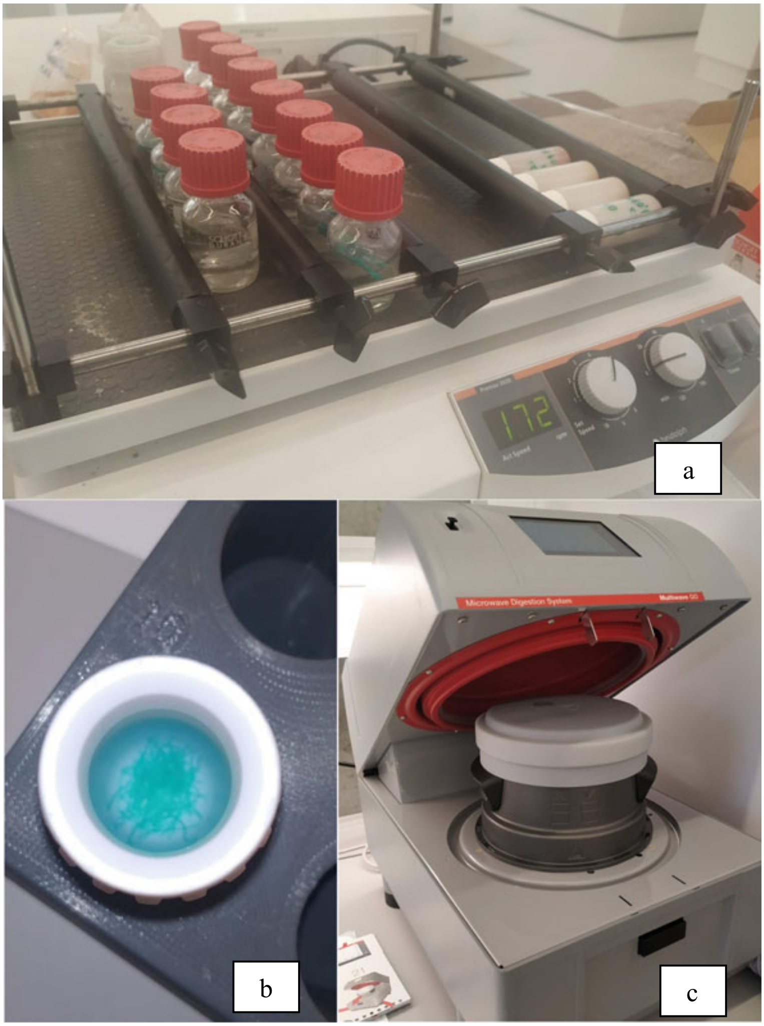

Fig. 11.3 Illustration of the instruments used in obtaining metal adsorption curves. **a**—fishnet PE in contact with metal solution in a shaking table; **b**—PE in a Teflon vial in preparation for microwave digestions; **c**—multiwave GO microwave digestion system. Photograph by the authors

11.3 Results and Discussion

11.3.1 Evidence of PE Fishing Nets Aging

The aging of fishnets is visible in Fig. 11.4. We show the effect of aging at the microscale by comparing unused fishnets provided directly by the supplier (Table 11.1) from the supplier clearly shows the aging of fishing nets at the microscale.

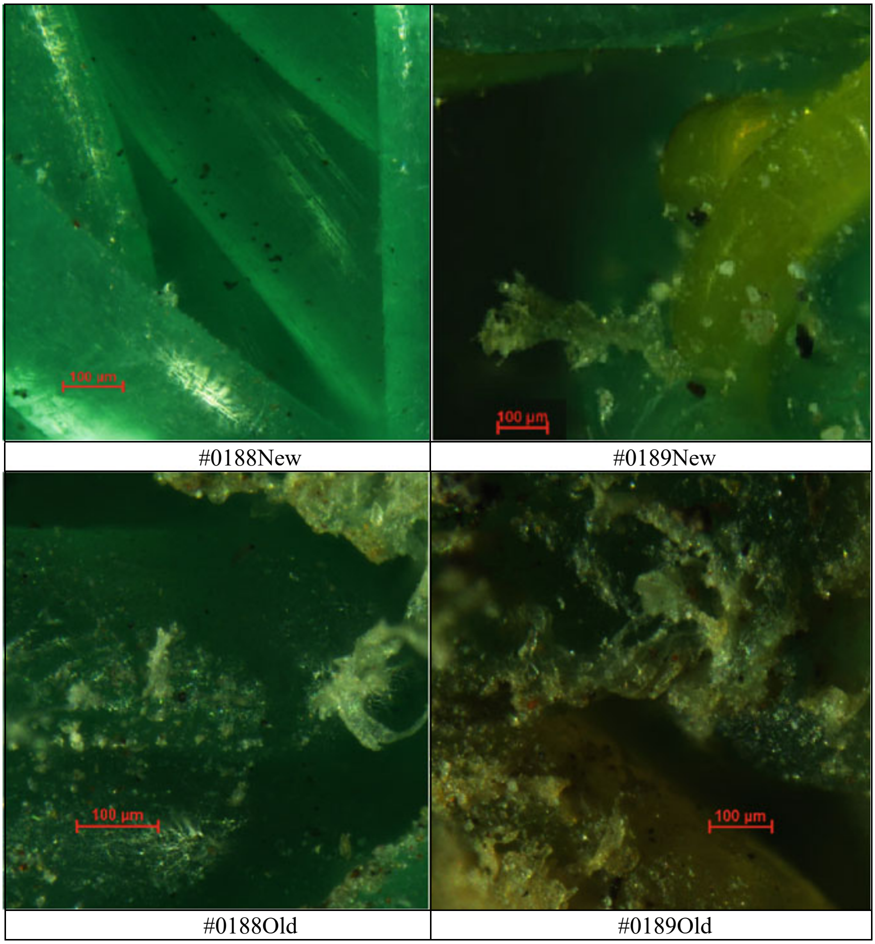

Fig. 11.4 Images of PE fishing nets #0188 and #0189 both in unused and end-of-life conditions. Pictures were made with a macro lens, Nikon D 610 (24 Megapixel), Kaiser RB 5000 daylight copy light set at 5.5 cm between lens and sample. Microscope pictures by the authors

By comparing the old and new #0188 and #0189 fibers, we see that the old PE fishing net shows a higher surface rugosity and increased fiber tear (Fig. 11.4). This effect is a consequence of the wear and tear of plastics, widely reported as one of the pathways to increased microplastics in the marine environment (Kedzierski et al. 2018; Hildebrandt et al. 2020; Brennecke et al. 2016). In addition, we also performed TGA analysis, where DSC signals when endothermic or exothermic changes occur in the sample—while exposure temperature increases. This method has been previously used as a polymer characterization tool, where a unique endothermic/exothermic signal characterizes individual polymers (Kayacan and Doğan 2008; Kannan et al. 2014). Figure 11.5 shows the spectra for a reference PE plastic and #0188 and #0189 old and new PE fishing net samples. There are several striking results from these graphs:

- Standardized PE presents a very different DSC signal from the studied PE fishing nets, but the weight loss curve is identical;
- In terms of gravimeter differences between new and old PE fishing net fibers, the weight loss differences are minimal – only #0189 old PE fiber shows a slightly more attenuated curve, perhaps due to increased adsorption of foreign elements;
- Drastic differences between DSC signals of old and new PE fishing nets fibers. The peaks do not precisely match the same sample's old and new samples (#0188 or #0189). One endothermic peak appears around 250 °C in both #0188 and #0189 old PE fishing nets absent in the new sample. And one exothermic peak in both old samples was around 410 °C.

We can then conclude that the aged PE fishing nets are physically and chemically altered (Figs. 11.4 and 11.5). The melting temperature of a polymer is usually associated with the peak temperature, about 258 °C in this case. In the temperature range between 350 and 500 °C, several overlapping endothermic and exothermic effects are observed in the DSC signal, which are due to the pyrolytic decomposition of the polymer content of the sample (Schindler et al. 2017). Polymers melt in the range of 200–300 °C (Schindler et al. 2017), but our samples do not show an obvious peak in this range (Fig. 11.5). Because the peak at 150 °C matches perfectly between #188 and #189 and standard PE, we conclude that the melting point occurs around 150 °C (Fig. 11.5). Exothermic (positive) peaks are associated with crystallization reactions while endothermic (negative) peaks are associated with glass transition or melting reactions. Crystallization is molten amorphous material changing to crystalline material upon cooling, with two distinct phases: nucleation and crystal growth (Ipina et al. 2018). In summary, the main point of this part of the study is to prove that fishnets change properties at the EOL when compared to the "new" unused material. And here we show that both crystallization and melting moments differ in the old, used fishnets compared to the new, unused ones. This might imply new crystalline phases in the old, used fishnets that could act as nuclei for metal ions. In the next sub-chapters we will explore the use of old, used fishnets as sinks for metals, in comparison to new, unused ones.

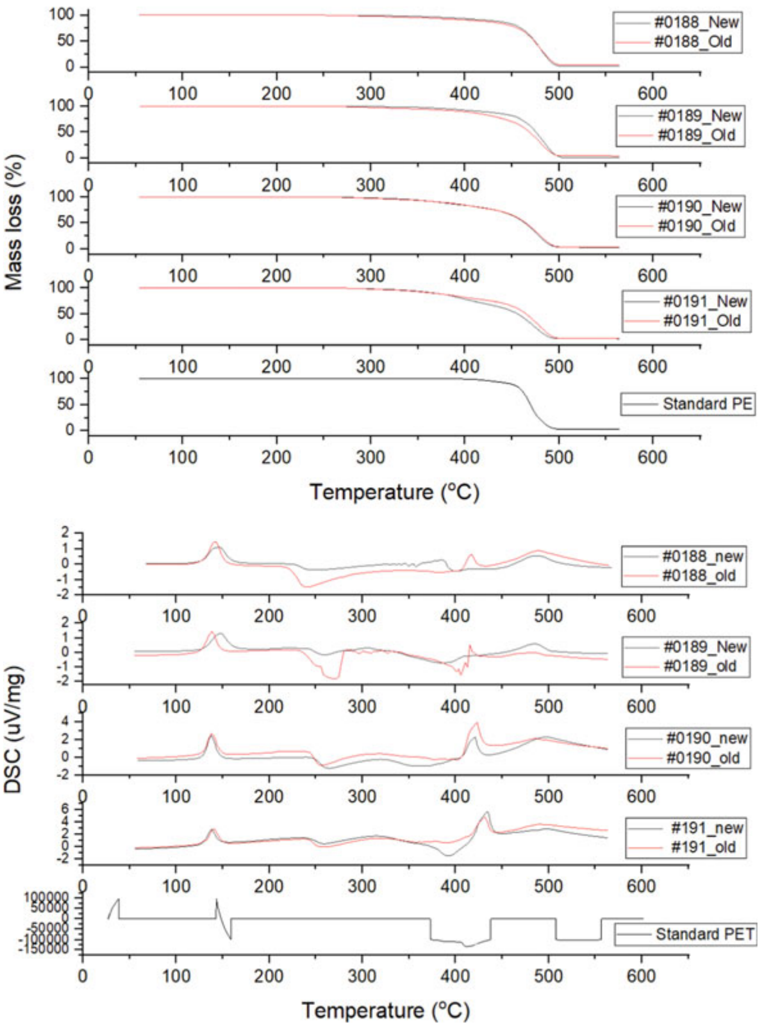

Fig. 11.5 Mass loss and DSC changes in the #0188, #0189, and PE reference samples with temperature performed in TGA, up to 550 °C. Data treatment by the authors

11.3.2 Adsorption Experiments (2)

11.3.2.1 Chromium

Cr can be found in the environment in varied speciation because of its Cr use in various industries such as metallurgical (steel, ferro-, and nonferrous alloys), refractories (chrome and chrome-magnesite), and chemical (pigments, electroplating, tanning, and other) (Kotaś and Stasicka 2000). In the environment, Cr can form and be adsorbed onto different minerals depending on its oxidation state: Cr(III) and Cr(VI) (Nagajyoti et al. 2010; Alloway 1995; Burke et al. 1991). But while Cr(III) is a trace element essential for the proper functioning of living organisms, Cr(VI) exerts toxic effects on biological systems (Kotaś and Stasicka 2000). The soluble Cr(VI) species depend on pH and vary as H_2CrO_4 at pH less than 1, $HCrO_4^-$ at pH between 1 and 6, and CrO_4^{2-} at pH above 6 (Arar and Pfaff 1991). 0.79 μg L^{-1} can be found in seawater (Tao et al. 2021), while up to 1 μg Cr L^{-1} can be found in wastewater (Lesage et al. 2007).

Cr(III) was investigated in this study. When we subject a relatively high concentration of 0.5 mg Cr L^{-1} of soluble Cr(III) to the fishing nets, we are clearly above the threshold of dissolved Cr found in seawater (0,000,104–0,00,026 mg Cr L^{-1}) and wastewater (0.014–0.113 mg Cr L^{-1}) (Lesage et al. 2007). Nevertheless, this gives us an idea of the limiting adsorption capacity PE fishing nets possess in the present study. Figure 11.6 shows both Cr concentrations in the solution and the fishing nets after each contact point. We assume that metals are adsorbed and uptake by the fishing nets (and not the other way around, as some authors suggested). Indeed, Fig. 11.6 shows a decline of Cr in the solution with increasing contact times, while a rise in Cr concentrations can be observed in the PE fishing nets fibers. While the new, unused fishing nets adsorb negligible amounts of dissolved Cr (for both #0188 and #0189 types), the *old* end-of-life PE fishing nets seem to uptake around 0.1 mg Cr L^{-1} from the solution (Fig. 11.6). Analogously, the *new,* unused PE fishing net fibers seem to increase 2 mg of Cr kg^{-1} after being in contact with dissolved Cr, while *old* end-of-life PE fishing nets fibers seem to uptake 4 mg of Cr kg^{-1} extra than their initial Cr content. The uptake happens in the first 5–10 min of contact with the solution.

11.3.2.2 Copper

Copper (Cu) has been extensively researched, especially regarding water quality (Crane et al. 2007; USEPA 2000). Cu is a trace element (micronutrient) for plants and animals, including humans, and has relatively low toxicity (except for invertebrates and microorganisms) when compared to other metals (Artiola 2005). But acute copper poisoning can show effects such as hemolysis, liver and kidney damage, and fewer with influenza syndrome (Feng et al. 2009). Local effects reported include irritation of the upper respiratory tract, gastrointestinal disturbance with vomiting, diarrhea, and a form of contact dermatitis (Rengaraj et al. 2004). Copper at the concentration of 10 μg L^{-1} greatly impacts the growth and reproduction of the sea anemone (Trenfield 2017). At a concentration higher than 1 mg L^{-1}, CuO nanoparticles negatively impact zebrafish hatching and increase malformation prevalence (Vicario-Parés et al. 2014).

Copper is found in natural surface waters at an average concentration of 0.002 mg L^{-1}, ranging from 0.001 to ~0.1 mg L^{-1}. Cu in seawater is at the upper end of the range (Alcacio et al. 2001). In wastewater, however, Cu concentrations can reach 2–32 μg Cu L^{-1} (Lesage et al. 2007). Once released into the water environment, Cu^{2+} ions will hydrolyze and form soluble Cu hydroxides that dominate at

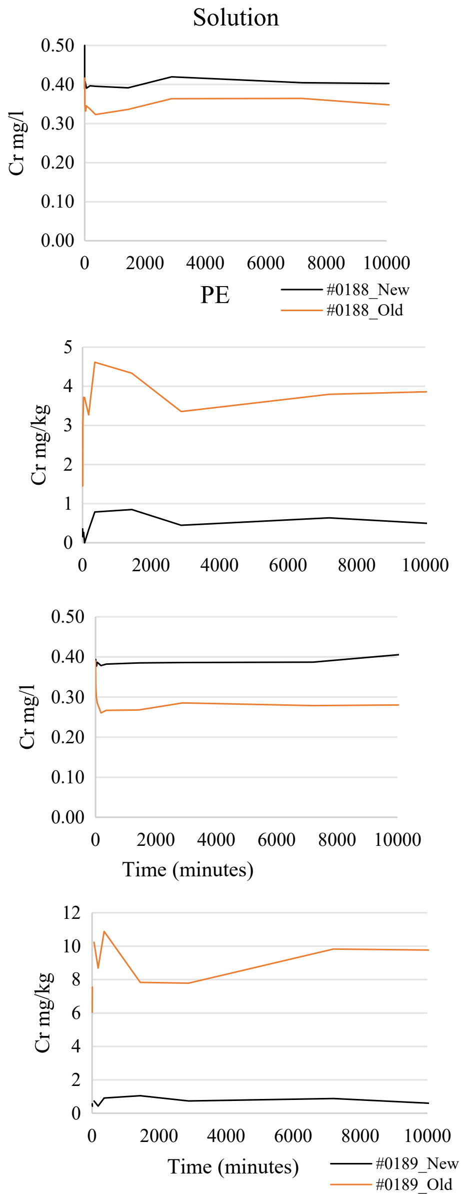

Fig. 11.6 Cr time series uptake by the #0188 and #0189 fishing nets, both unused (New) and end-of-life (old) samples. Visual representation of unused and discarded, end-of-life fishnets. Photograph by the authors

pH > 7 (Artiola 2005) and can be easily assimilated by invertebrates. Therefore, it is necessary to treat wastewater containing copper before being discharged into water streams.

Cu adsorption onto plastics follows the same tendency as Cr (Fig. 11.7). Cu dissolved in solution decreases about 0.1 mg Cu L^{-1} (in both #0188 and #0189 fibers),

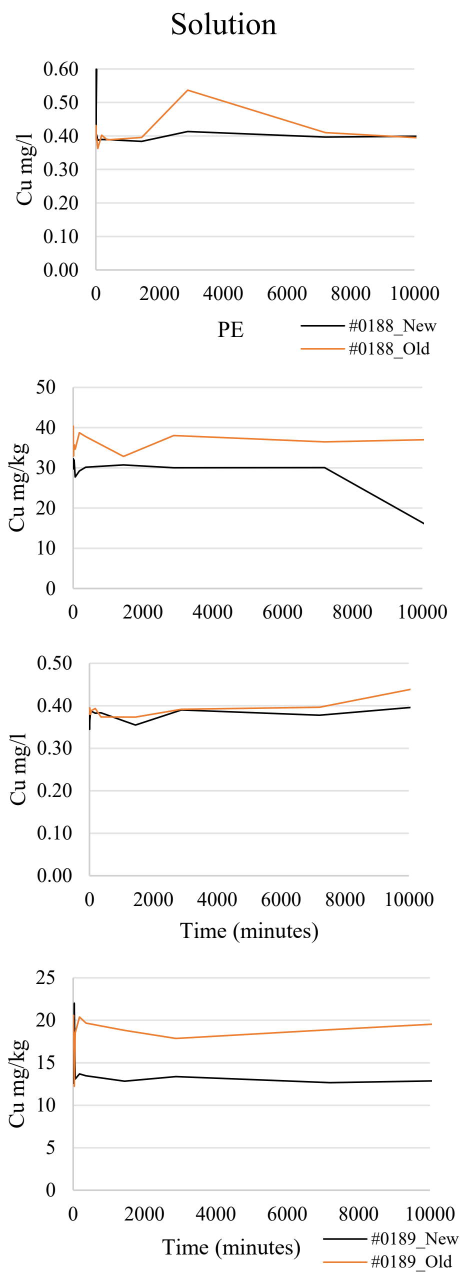

Fig. 11.7 Cu time series uptake by the #0188 and #0189 fishing nets, both unused (New) and end-of-life (old) samples. Visual representation of unused and discarded, end-of-life fishnets. Photograph by the authors

while concentrations in both *new* unused and *old* end-of-life PE fishing nets fibers increases, again in the first 5–10 min of the experiment. The curves are not as clear as in the case of Cr, but again with Cu we observe that the old end-of-life PE fishing nets fibers adsorb higher amounts of Cu than the unused PE fibers counterpart. #0189 *new,* unused fishing nets seem to desorb Cu from the fibers (Fig. 11.7). Nevertheless, the *old* end-of-life PE fishing nets fibers adsorb up to 5 mg kg^{-1} of Cu from the solution.

11.3.2.3 Lead

Lead (Pb) in the environment may derive from either natural or anthropogenic sources (Hoet 2005). Although the use of Pb has been declining since the Roman period, it is still widely used in batteries, cable sheathing, medical equipment, paints and pigments, ceramic glazes, metal rolled and extruded products like pipes, military equipment, ammunition and lead fishing weights, crystal glass, and alloys (Hoet 2005). The usual valence state in inorganic lead compounds is +2, but inorganic Pb rarely exists in its elemental state but is found in the environment in various complexes (Hill 1997). In water, these include simple inorganic species such as $Pb(OH)_2$, $Pb(OH)_3^-$, and polymeric lead ions such as $Pb_2(OH)_3^+$ and $Pb_4(OH)_4^{4+}$ (Artiola 2005). Concentrations in seawater are 0.002–0.2 mg L^{-1} (Lavilla et al. 2015), and in wastewater, it can range from 2 to 5 μg Pb L^{-1} (Lesage et al. 2007).

Lead is also widely used in the plastic industry to extend the temperature range at which it can be processed without degradation (thermal stabilizer) (Hoet 2005). All these lead compounds are pigmenting white powders and thus cannot be used when clear or translucent articles are required (Hoet 2005). In terms of dissolved Pb adsorption onto PE polymers, we observe slight differences from the previously studied Cr and Cu. Pb adsorption seems to decline with time (Fig. 11.8). While Pb in solution shows an approximately constant concentration – with a slight rise at the end (around the 10,000 min), Pb in PE fishing net fibers seem to in fact desorb with time (Fig. 11.8). Nevertheless, if we continue to consider the initial 5–10 min of contact between PE fishing nets and the 0.5 mg Pb L^{-1} solution, we conclude that 1–10 mg Pb kg^{-1} are adsorbed onto the *old* end-of-life PE fishing net fibers.

11.3.2.4 Selenium

Selenium is essential to living organisms (Tan et al. 2016). The interest in selenium has risen in the last decades due to its application in health areas (Tan et al. 2016), mainly due to its narrow beneficial range for living organisms, where toxic vs safe concentrations only have a 3–fivefold (Brozmanová et al. 2010) up to tenfold (40–400 μg in one day) (El-Ramady et al. 2015) difference. Studies highlight excess Se

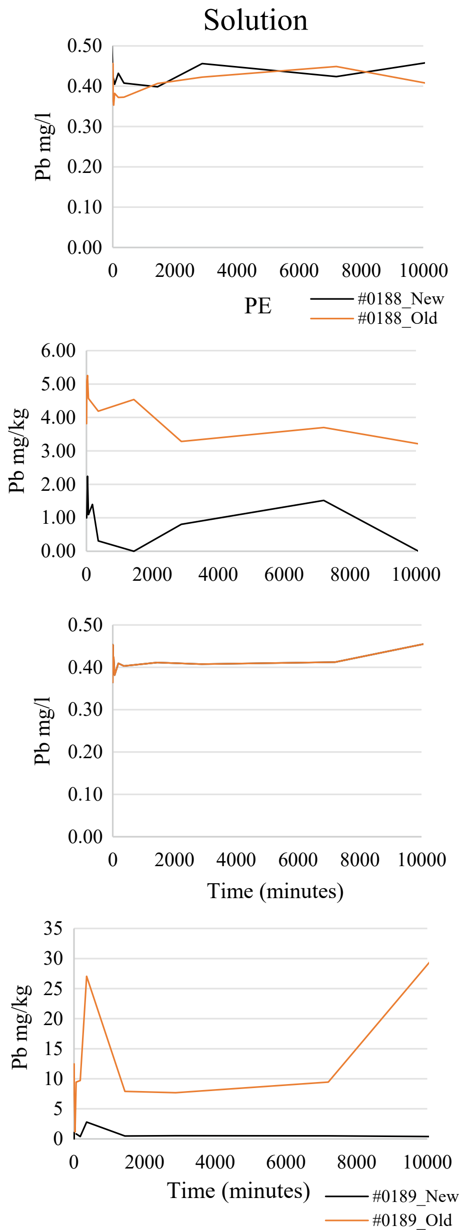

Fig. 11.8 Pb time series uptake by the #0188 and #0189 fishing nets, both unused (New) and end-of-life (old) samples. Visual representation of unused and discarded, end-of-life fishnets. Photograph by the authors

in wastewater as a potential environmental concern (Tan et al. 2016), namely as toxicity for human beings and provoking physical deformities, mutations, reproduction failures, and even death in aquatic fauna (Ellis et al. 2003). USEPA has established 20 μg Se L^{-1} for acute aquatic life toxicity (USEPA 2016). It is then important to clean wastewater of excess Se.

Se adsorbs to untreated plastic and ferrous and manganese oxides (Balistrieri et al 1992; Missana et al. 2009), and by biofilm growing on ocean plastic debris (Mitchell et al. 2019). In this study, we find that both #0188 and #0189 *old* end-of-life PE fishing net fibers show Se adsorption with time, but not the *new* #0188 and #0189 unused PE fishing net fibers (Fig. 11.9). We observed a drop of 0.5–0.2 mg Se L^{-1} in the solution and a peak of Se adsorption in the first 6–24 h of contact, followed by a constant concentration comparable to the initial one (before contact was started). The peaks represent a 3–10 mg Se kg^{-1} increase of the initial Se concentration in the PE plastics. Again, this effect was only observed in the *old* end-of-life PE fishing net fibers.

11.3.3 Are Metal-Enriched Fishing Nets Hazardous Waste?

After exposing the old end-of-life PE fishing net fibers, we can now compare the total metal amounts that are adsorbed into the PE fibers to the different plastic regulations. The *Toy Safety Directive* and its amendments list criteria that toys must meet before being marketed in the EU (Council of the European Union 2017). The *Restriction of Hazardous Substances (RoHS)* Directive includes electronic and electrical plastic housings and insulation (European Parliament and Council 2011), and the *End-of-Life Vehicles* (ELV) Directive, encompasses plastic components of vehicles (Commission Directive 2017), sets total concentration limits for metals (see Table 11.2). The *Packaging and Packaging Waste* (PPW) Directive is also restricted to these metals. Still, it sets a combined total concentration limit of 100 mg kg^{-1} (European Parliament and Council of the EU 1994), while the Directive relating to plastics intended to come into *Contact with Foodstuffs* (CFS) stipulates different but substantially lower total concentration limits for five metals (Commission Directive 2002). To learn more about the regulations, please see Turner and Filella (2021).

The metal solution in contact with the *old* end-of-life and *new,* unused PE fishing nets was 0.5 mg L^{-1}, which was (depending on the metal) 1000 times higher than the amounts found in seawater and wastewater (see Sect. 11.3.2). Old end-of-life fishing nets adsorbed the highest quantities of metals onto the PE fibers (Figs. 11.6, 11.7, 11.8 and 11.9), but that amount is still below the *RoHS* and *PPW* directives (Table 11.2). The concentrations for Cr and Pb are well below these directives—which indicates that the old end-of-life PE fishing nets are not hazardous waste—even after being in direct contact with a high concentration of these metals in a liquid and available form for up to 7 days. These concentrations would be more in the order of the CFS requirements for plastics (contact with foodstuffs). But compared to plastics found in the environment, these numbers are still on the lower end of the spectrum.

Fig. 11.9 Se time series uptake by the #0188 and #0189 fishing nets, both unused (New) and end-of-life (old) samples. Visual representation of unused and discarded, end-of-life fishnets. Photograph by the authors

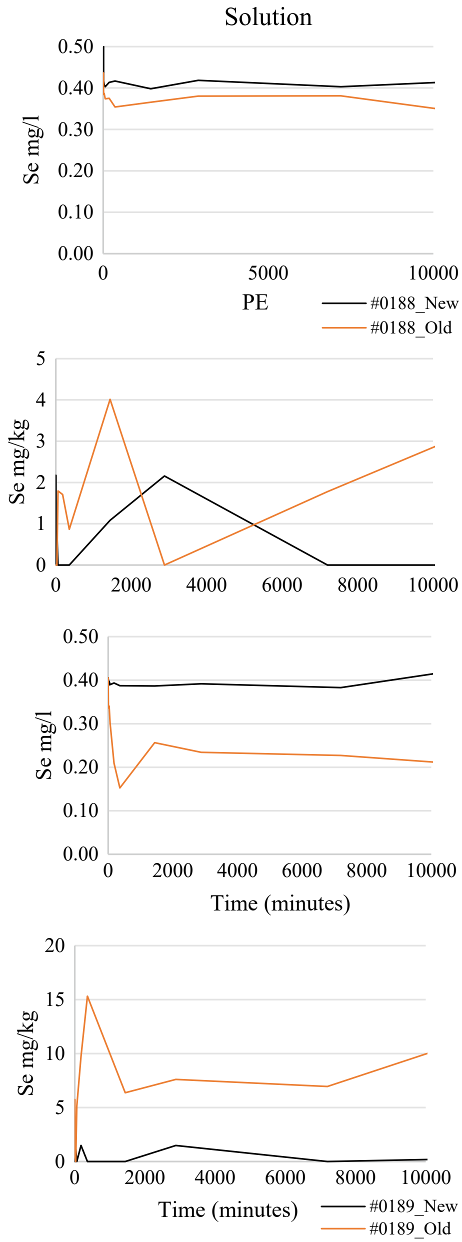

Table 11.2 Metals in plastics are regulated in Europe, and current limit values (in mg kg^{-1}) are according to various directives. Adopted from (Turner and Filella 2021) and comparison to the maximum achieved metal concentrations

	Toy safety directive	Restriction of hazardous substances	End-of-life vehicles	Packaging and packaging waste	Contact with foodstuffs	Hazardous	Maximum achieved in #old fishing nets
Cr (mg kg^{-1})	0.2	1000	1000	100	1	yes	5–12
Cu (mg kg^{-1})	7700				5	No current regulation	20–40
Pb (mg kg^{-1})	23	1000	1000	100	2	yes	5–30
Se (mg kg^{-1})	460					No current regulation	4–15

In PE beads used for water treatment, Pb concentrations were found in the order of 5380 mg Pb kg^{-1} (Turner et al. 2019) or 23 500 mg Pb kg^{-1} in beached plastic litter in Lake Geneva (Filella and Turner 2018). More research is needed for more conclusive remarks.

11.4 Final Considerations

This study is a stepping stone to understanding metal adsorption onto PE fibers. To the author's knowledge, such high concentrations of 0.5 mg L^{-1} of Cr, Cu, Pb, and Se have never been tested before. Overall, the results of this study corroborate previous findings. Holmes et al. (2012) found that virgin PE pellets could adsorb trace metals rapidly but that aged beach pellets had much higher equilibrium partition coefficients. The same authors also considered adsorption to virgin and beached (aged) pellets (PE) in an estuarine environment and found that the adsorption rate for Cd, Co, Ni, and Pb decreased with increasing salinity and decreasing pH (Zhang et al. 2020; Holmes et al. 2012). Cu was not significantly affected by these factors. They also found an increase in Cd, Co, Ni, and Pb adsorption, with increasing pH (Zhang et al. 2020). This study does not corroborate this effect since the solution used possessed a neutral pH (≈7). However, we observe a stagnation (Se) or desorption behavior (Pb) with increasing contact between dissolved metals and PE fishing net fibers.

We therefore recommend using old end-of-life fishing nets to remove excess Cr, Cu, Pb, and Se from polluted waters, such as industrial wastewater and contaminated surface waters, on any solution with high metals levels. Hamadi et al. (2001) suggested using waste tyres and a sawdust pyrolysis product to adsorb aqueous Cr(VI) present in complete wastewater removal at low pHs. We did not observe complete metal removal, but our study had concentrations 100-fold higher than those in Hamadi et al. (2001). We believe that Greenlandic old waste fishing nets can be used to clean the wastewater, or metal-contaminated water, in Greenland. This would be a circular cheap solution for one last use of EoL fishing nets, without the fishnets becoming hazardous waste. As shown in the study, a comparison to different EU directives that regulate metal content in plastics for different end-uses shows that the old end-of-life PE fishing nets, after exposure to heavy metals, do not meet the regulations for hazardous waste. Eventually, this could be used worldwide as a circular option for EoL fishing nets.

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Chapter 12
Possible Applications for Waste Fishing Nets in Construction Material

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Abstract Research on the use of recycled plastics in construction materials has increased over the last decade. The major trends and recycling applications for plastic waste in construction materials are reviewed in this chapter with a special focus on the use of discarded fishing nets as reinforcing material. The experimental part of this project included the characterization of discarded fishing nets of polyethylene with the aim of discovering new recycling alternatives for the use of fishing nets as reinforcement in different types of construction materials. The fishing net material was added either in the form of fibers or as pieces of net. The characterization of the polyethylene fibers showed that the material properties were in the same range as some commercially available fibers used in construction materials. The influence of the addition of fishing nets to construction materials was evaluated based on the mechanical performance and early-age shrinkage properties of cement-based mortars, gypsum, and earth-based adobe bricks. The results showed that the addition of fishing net fibers improved the post-crack performance of all types of tested construction materials, but the most prominent gain in mechanical properties was obtained for the earth-based adobe bricks. The addition of fibers was also found to mitigate shrinkage deformations and cracking of cement-based and earth-based materials.

Keywords Recycling of fishing nets · Construction materials · Fibre reinforcement · Mechanical properties

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12.1 Introduction

Recycling of various forms of plastic waste in construction materials has gained increasing attention in recent decades and several studies have shown that it is possible to improve the mechanical performance and different durability-related properties of construction materials by including waste plastics in the forms of fibers, aggregates, or net shapes to the material (Ahmed et al. 2021; Gu and Ozbakkaloglu 2016; Merli et al. 2020; Pablo Ojeda 2021; Sharma and Bansal 2016). Section 12.2 provides an overview of recent research on the use of waste plastic in construction materials.

The experimental work described in this chapter is described in Sect. 12.3 and was conducted as part of the two international projects funded by the European Union's Northern Periphery and Arctic Programme, Circular Ocean, and Blue Circular Economy. Arctic DTU, DTU Civil Engineering, was the Greenlandic partner in both projects. Thus, the starting point was based on the situation in Greenland, with the focus on the accessible types of waste fishing gear, which were available in large quantities at local landfill sites in towns along the Greenlandic coastline. However, it was quickly realized that the types of fishing net materials used in the entire Northern Periphery and Arctic (NPA) region were relatively homogeneous. Hence, the encountered solutions for the recycling of fishing nets in construction materials could also be implemented in other regions. Figure 12.1a shows an example of the storage of fishing nets and trawls at a landfill site in Greenland (a). The most used types of nets are made of polyethylene. Figure 12.1b shows fibers of recycled polyethylene (R-PE) obtained from discarded fishing nets by mechanical cutting operations at the Danish recycling company, Plastix A/S (b). Fishing nets often consist of bundles of monofilament fibers with a shape corresponding to those used as synthetic fiber reinforcement in construction materials. This observation led to the idea of investigating the use of fibers obtained from discarded fishing nets as fiber reinforcement with the aim of identifying possible recycling options (Bertelsen 2019).

(a) (b)

Fig. 12.1 **a** Discarded fishing nets piled up at the landfill site in Sisimiut, Greenland. **b** Monofilament R-PE fibers from discarded fishing nets processed by a mechanical cutting operation by the Danish recycling company, Plastix A/S (Bertelsen 2019)

12.2 Aim of the Project

The aim of the project was to investigate the use of discarded fishing nets as reinforcement in construction materials by experimental testing. Fishing nets were in most cases included in the form of fibers, but some test series were carried out on the addition of net pieces as a reinforcing layer in the construction materials.

Moreover, a literature review was conducted on the use of plastic waste materials in construction materials with special focus on the use of discarded fishing nets.

12.3 Use of Recycled Plastic in Construction Materials

The potential use of recycled plastic and polymeric waste materials in construction has been widely studied in the literature. The application has gained recognition in the construction industry due to their broad applicability, low price, and sustainability aspects (Gu and Ozbakkaloglu 2016; Sharma and Bansal 2016; Siddique et al. 2008). In the recent decade, there has been an exponential increase in the number of studies as well as review studies on the topic. To confirm this, a literature search was carried out using the Scopus database. The search criteria were “Title, Author, Keywords, Abstract”, and the selected keywords are shown in Table 12.1 for Search #1 and Search #2, respectively. Search #1 is focused only on review studies, while Search #2 is focused on research studies on the topic. No exclusion criteria were adopted about the publication date.

The Scopus search returned 128 results for Search #1 including “review” and 1249 results for Search #2. The results from the literature search are shown in Fig. 12.2 showing the total number of results per year. There has been an exponential increase in the number of published papers, both in terms of review papers and research papers. Note that the figures show the total number of results without exclusion.

The next step was to critically evaluate the results to allow the selection of relevant publications focusing on the use of plastic waste fractions in construction materials. The selected 42 publications were only selected from Search #1 (review papers). These are listed in Table 12.2. Review studies on asphalt materials were excluded.

Table 12.1 Search criteria used for the literature search in Scopus

Keywords	Selected hits (total hits)
Search #1: TITLE-ABS-KEY(Review AND “Plastic waste” OR “Recycled plastic” OR “Waste plastic” OR “Polymeric waste” AND “Concrete” OR “Cement” OR “Construction material”)	42 (128)
Search #2: TITLE-ABS-KEY(“Plastic waste” OR “Recycled plastic” OR “Waste plastic” OR “Polymeric waste” AND “Concrete” OR “Cement” OR “Construction material”)	(1249)

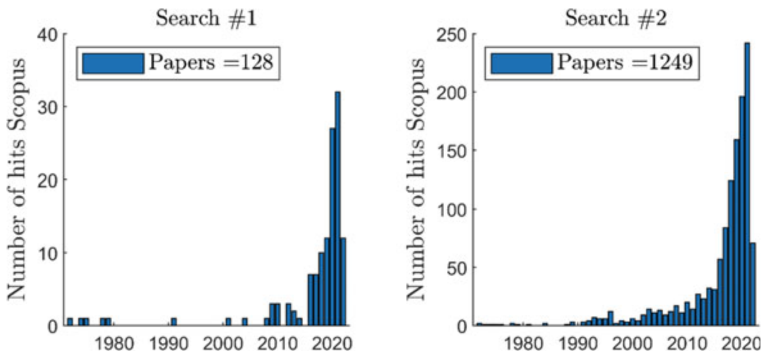


Fig. 12.2 Overview of results in Scopus search

As seen in Table 12.2, the application of plastic waste in construction materials has been studied in the form of aggregates, fibers, or other functions such as using the polymer as the binding material. Most of the review studies covered the use of plastic waste in the form of aggregates replacing material aggregates in cementitious composites. This was also found in the meta-analysis by Pablo Ojeda (2021). The reason for this could be that larger volume fractions of plastic waste can be used in the form of aggregates compared to that of fibers. In the review study by Almeshal et al. (2020), replacement levels of aggregates in cementitious composites with recycled plastic aggregates were up to 100% for mortar and up to 75% for concrete were reported, although lower replacement levels are more widely studied. However, when replacing natural aggregates with increasing additions of plastic aggregates in cementitious composites, not only does the density decrease, but also the mechanical properties such as the elasticity modulus, compressive, flexural, and tensile strength are impaired (Almeshal et al. 2020; Pablo Ojeda 2021). For most types of construction materials, a high elastic modulus and high strength properties are preferred since it creates stiffer and stronger materials resulting in higher load-bearing capacity.

Recycled plastic fibers are commonly added in much lower fractions to cementitious composites and for other reasons than plastic aggregates, which is explained in Sect. 12.3.1. Ahmed et al. (2021) conducted a review on the use of recycled fibers in cementitious composites. The maximum fiber addition reported was up to 5 wt% (weight% of fibers by mass of the other dry materials such as cement, sand, and gravel depending on the type of construction material), but for fiber-reinforced concrete, the beneficial effects of adding the plastic fibers can, depending on the fiber properties, be obtained at much lower fiber additions.

Since the fishing nets investigated in the present project already have the fiber shape with one line consisting of multifilament fibers, they were investigated with the aim of being used as fiber reinforcement.

Table 12.2 Selected review studies from Search #1 on the use of recycled plastic in construction materials

References	Year	Title	Aggregate	Fiber	Other
(Siddique et al. 2008)	2008	Use of recycled plastic in concrete: a review	x	x	
(Pacheco-Torgal et al. 2012)	2012	Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): an overview	x	x	
(Saikia and De Brito 2012)	2012	Use of plastic waste as aggregate in cement mortar and concrete preparation: a review	x		
(Gu and Ozbakkaloglu 2016)	2016	Use of recycled plastics in concrete: a critical review	x	x	
(Tiwari et al. 2016)	2016	Feasibility assessment for partial replacement of fine aggregate to attain cleaner production perspective in concrete: a review	x		
(Sharma and Bansal 2016)	2016	Use of different forms of waste plastic in concrete—a review	x	x	
(Alfahdawi et al. 2016)	2016	Utilizing waste plastic polypropylene and polyethylene terephthalate as alternative aggregates to produce lightweight concrete: a review	x		
(Krishna and Jagadeesh 2017)	2017	Influence of admixtures on plastic wastes in an eco-friendly concrete—a review	x		
(Sodhi and Salhotra 2017)	2017	Utilising wastes as partial replacement in concrete—a review	x		
(Babafemi et al. 2018)	2018	Engineering properties of concrete with waste recycled plastic: a review	x	(x)	
(Meng et al. 2018)	2018	Recycling of wastes for value-added applications in concrete blocks: an overview	x		
(Usman et al. 2018)	2018	Effect of recycled plastic in mortar and concrete and the application of gamma irradiation—a review	x		
(Mercante et al. 2018)	2018	Mortar and concrete composites with recycled plastic: a review	x		
(Kishore and Gupta 2019)	2019	Application of domestic & industrial waste materials in concrete: a review	x		

(continued)

Table 12.2 (continued)

References	Year	Title	Aggregate	Fiber	Other
(Law et al. 2019)	2019	A review on waste materials usage as partial substitution in self-compacting concrete	(x)	(x)	
(Frhaan et al. 2022)	2020	Relation between rheological and mechanical properties on behaviour of self-compacting concrete (SCC) containing recycled plastic fibres: a review		x	
(Sidhardhan and Albert 2020)	2020	Experimental investigation on light weight cellular concrete by using glass and plastic waste—a review	(x)		
(Gupta et al. 2020)	2020	Utilization of recycled aggregate, plastic, glass waste and coconut shells in concrete—a review	x		
(Tang et al. 2020)	2020	Advanced progress in recycling municipal and construction solid wastes for manufacturing sustainable construction materials	x		
(Faraj et al. 2020)	2020	Use of recycled plastic in self-compacting concrete: a comprehensive review on fresh and mechanical properties	x	x	
(Bahij et al. 2020)	2020	Fresh and hardened properties of concrete containing different forms of plastic waste—a review	x	x	
(Almeshal et al. 2020)	2020	Use of recycled plastic as fine aggregate in cementitious composites: a review	x		
(Goli et al. 2020)	2020	Application of municipal plastic waste as a manmade neo-construction material issues & wayforward	x		
(Kumar et al. 2020)	2020	A review on utilization of plastic waste materials in bricks manufacturing process			x
(Dadzie et al. 2016)	2020	Exploration of waste plastic bottles use in construction			x
(Mahmood and Kockal 2020)	2020	Cementitious materials incorporating waste plastics: a review	x	x	
(Park and Kim 2020a)	2020	Mechanical properties of cement-based materials with recycled plastic: a review	x	x	

(continued)

Table 12.2 (continued)

References	Year	Title	Aggregate	Fiber	Other
(Rathore et al. 2021)	2021	Influence of plastic waste on the performance of mortar and concrete: a review	x		
(Lamba et al. 2021)	2021	Recycling/reuse of plastic waste as construction material for sustainable development: a review	x		x
(Uvarajan et al. 2021)	2021	Reusing plastic waste in the production of bricks and paving blocks: a review	x		x
(Raj and Somasundaram 2021)	2021	Sustainable usage of waste materials in aerated and foam concrete: a review	x		
(Mohan et al. 2021)	2021	Recent trends in utilization of plastics waste composites as construction materials	x		x
(Abeysinghe et al. 2021)	2021	Engineering performance of concrete incorporated with recycled high-density polyethylene (HDPE)—a systematic review	x	x	
(Ahmed et al. 2021)	2021	Use of recycled fibers in concrete composites. A systematic comprehensive review		x	
(da Silva et al. 2021)	2021	Application of plastic wastes in construction materials: a review using the concept of life-cycle assessment in the context of recent research for future perspectives	x	x	
(Alqahtani and Zafar 2021)	2021	Plastic-based sustainable synthetic aggregate in Green Lightweight concrete—a review	x		
(Zulkernain et al. 2021)	2021	Utilisation of plastic waste as aggregate in construction materials: a review	x	(x)	
(Kazemi et al. 2021)	2021	State of the art in recycling waste thermoplastics and thermosets and their applications in construction			x
(Alyousef et al. 2021)	2021	Potential use of recycled plastic and rubber aggregate in cementitious materials for sustainable construction: a review	x		
(Kaliyavaradhan et al. 2022)	2022	Effective utilization of e-waste plastics and glasses in construction products—a review and future research directions	x	x	

(continued)

Table 12.2 (continued)

References	Year	Title	Aggregate	Fiber	Other
(Ferdous et al. 2021)	2021	Recycling of landfill wastes (tyres, plastics and glass) in construction—a review on global waste generation, performance, application and future opportunities	x		
(Kazemi and Fini 2022)	2022	State of the art in the application of functionalized waste polymers in the built environment			x

12.3.1 Fiber Reinforcement Used in Construction Materials

The addition of plastic fibers (virgin or recycled) to construction materials is a commonly used technique for improving different material properties such as:

- The enhancement of post-crack performance by increased ductility, impact resistance, and other mechanical properties of quasi-brittle materials such as concrete (Balaguru and Shah 1992; Bentur and Mindess 2006).
- For mitigating early-age shrinkage cracking (plastic shrinkage cracking and drying shrinkage cracking) in construction materials susceptible to shrinkage cracking (Banthia and Gupta 2006; Naaman et al. 2005). Cracks in concrete or other types of construction materials should be avoided since water and other aggressive agents can penetrate the materials through the cracks and thereby lower the durability and lifetime of the construction material.
- For improving fire safety by preventing spalling in concrete structures such as tunnel linings under fire exposure (Banthia et al. 2012; Heo et al. 2010).

Besides the addition of fibers to cement-based materials, similar fiber types have also been used to improve the performance of other types of construction materials such as gypsum plaster, bitumen, and earth-based construction materials (adobe, CEB, rammed earth) (Abtahi et al. 2010; Araya-Letelier et al. 2019; Binici et al. 2005; Eve et al. 2002). Depending on the specific application of the material, fiber characteristics play a significant role: e.g., the geometry and shape of the fiber, chemical/geometrical bonding to the matrix, mechanical strength and stiffness, and thermal properties.

12.3.2 Recycled Plastic Fibers

As shown in Table 12.2, the use of different fractions of plastic waste materials as fiber reinforcement in both cement-based materials and other types of construction materials has been widely investigated in the literature. Various types of plastic waste deriving from different sources have been studied as fiber reinforcing material in construction materials. Researchers suggested fibers from waste fractions such as:

- Carpet (nylon, polyester) (Awal and Mohammadhosseini 2016; Ozger et al. 2013; Ucar and Wang 2011; Wang 1999; Wang et al. 2000).
- Plastic bags (Ghernouti et al. 2015; Jain et al. 2021).
- Plastic bottles (mainly PET) (Borg et al. 2016; Dadzie et al. 2016; Foti 2013; Fraternali et al. 2013; Kim et al. 2008a, b; Pelisser et al. 2010; Rebeiz 1995).
- Fishing nets (Nylon or PE) (Nguyen et al. 2021; Orasutthikul et al. 2017; Park and Kim 2020b; Park et al. 2021; Spadea et al. 2015; Srimahachota et al. 2020; Truong et al. 2020).
- Different types of mixed industrial or post-consumer waste (Auchey 1998; Naik et al. 1996; Pešić et al. 2016; Yin et al. 2015).

Several studies have focused on the performance of plastic waste fibers in construction materials for various applications. The main application of plastic waste in construction materials is described below:

- for mitigating early-age shrinkage cracking in cement-based materials (Al-Tulaian et al. 2016; Auchey 1998; Bertelsen et al. 2019b; Borg et al. 2016; Kim et al. 2008a, b; Pešić et al. 2016; Serdar et al. 2015),
- for improving the mechanical performance in cement-based materials (Foti 2013; Fraternali et al. 2013; Orasutthikul et al. 2017; Pereira De Oliveira and Castro-Gomes 2011; Spadea et al. 2015),
- for improving the mechanical performance in other types of construction materials, e.g., gypsum (Parres et al. 2009; Vasconcelos et al. 2015) and earth-based materials (Bertelsen et al. 2021; Gandia et al. 2019; Prasad et al. 2012; Tavares and Magalhaes 2019).

These studies have shown that several types of plastic waste materials can be profitably employed to create low-cost reinforcement techniques for applications similarly to commercial fibers. The use of local waste fractions as resources can reduce the need for production and transportation of fibers of virgin materials and the reuse or recycling of a waste material could potentially solve disposal problems.

12.3.3 Reuse of Fishing Nets as Reinforcement in Construction Materials

The interest in reusing discarded fishing nets in construction materials is also gaining attention. Recent studies have found that the addition of nylon or PE fibers cut down from discarded fishing nets can improve the mechanical performance (Nguyen et al. 2021; Orasutthikul et al. 2017; Ottosen et al. 2019; Park and Kim 2020b; Park et al. 2021; Spadea et al. 2015; Srimahachota et al. 2020) or early-age shrinkage cracking of cementitious composites (Bertelsen et al. 2019a, c). A few studies have investigated the use of fishing nets as continuous reinforcement of cement-based materials (Mousa 2017, 2018; Bertelsen et al. 2022; Truong et al. 2020), and for soil reinforcement (Kim et al. 2008a, b; Tran 2021). More research is needed on the use of fishing nets in other types of construction materials than cement-based materials. Table 12.3 provides a more detailed overview of research studies investigating the use of discarded fishing nets as reinforcement of construction materials.

12.4 Research Program

The first part of the experimental work was to characterize selected types of fibers or net materials from discarded fishing nets. The second part was to test and evaluate their use as reinforcement in different types of construction materials to explore suitable applications. The results presented in the following sections were made as part of the Ph.D. project, published in Bertelsen (2019), and as part of various student projects carried out at DTU Civil Engineering.

12.4.1 Characterization of R-PE Fibers from Discarded Fishing Nets

Fibers from different types of fishing nets were included in the experimental work, but most of the experimental activities were conducted on fibers of recycled polyethylene (R-PE) received from the Danish recycling company, Plastix A/S. An example of such fibers is shown in Fig. 12.1. The discarded nets were collected by Plastix A/S at national and international harbors. After being collected, the nets were transported to the recycling plant, sorted into the respective material fractions, pre-washed, mechanically cut into shorter fibers, and finally reprocessed to produce new plastic pellets of the recycled material. The R-PE fibers investigated in the present study were only processed into fibers by mechanical cutting operations and pre-washed. Thus, R-PE fibers were collected prior to the final reprocessing at the recycling plant.

Variations in the material properties of the R-PE fibers were expected. The main reasons for these variations were the various types of PE net materials with different inherent properties, but also the ways the nets had been used and stored. The fiber characterization included measurement of the geometrical properties and shape, visual investigation of the morphology by SEM, mechanical properties, and alkali resistance; properties which are of importance when being used as fiber reinforcement in construction materials. These tests were performed on fibers from discarded fishing nets as well as from corresponding new nets to examine the degree of deterioration of the used nets.

Table 12.3 Overview of studies investigating the use of discarded fishing nets in construction materials

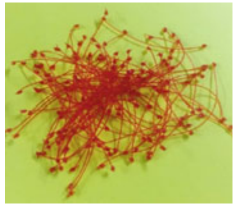
References	Polymer	Processing method	Image
Fibers added to cement-based mortar			
(Spadea et al. 2015)	R-Nylon fibers	Manual cutting of fibers to desired fiber length of 13–38 mm. Fiber diameter of 0.33 mm. Tensile strength of 290–350 MPa. Fiber addition of 0.5–1.5 wt% The addition of fibers increased the first-crack flexural strength and toughness of mortar prisms, while the compressive strength was reduced	
(Orasutthikul et al. 2016, 2017)	R-Nylon fibers	Manual cutting of fibers to desired fiber length of 20–40 mm. Straight fibers and fibers with knots. Commercially available fibers of PVA were included in the test program. Fiber diameter of 0.2–0.7 mm. Tensile strength of 440–975 MPa. Fiber addition of 0.5–2.0 wt% The addition of straight R-Nylon fibers to mortars improved the flexural strength, while the compressive strength decreased with increase in fiber fraction and fiber length	 

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Table 12.3 (continued)

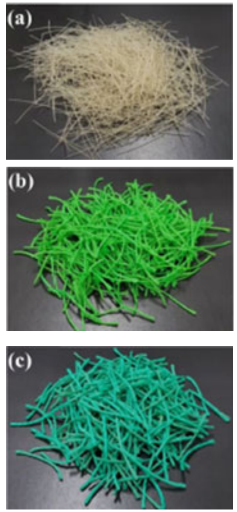
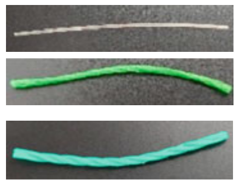
References	Polymer	Processing method	Image
(Park et al. 2021)	N/A fibers	Collection, selection of three types of fishing nets, with different geometrical shapes (monofilament, twisted multifilament, and braided multifilament) Processing: water jetting, drying, and cutting to desired fiber length of 40 mm. Fiber diameter of 0.45–1.5 mm. Fiber addition of 0.5–1.0 wt% The mechanical behavior of waste fishing net fiber-reinforced cementitious composites subjected to direct tension, or compression were tested. As the fiber volume increased, both the compressive and first cracking strengths decreased, while the post-cracking strength increased. The multifilament fibers (twisted or braided) resulted in better post-crack performance than the monofilament fibers. This effect is attributed to the improved mechanical fiber-to-matrix bond for the multifilament fibers	
(Park and Kim 2020b)	N/A fibers	Fibers similar to those in Park et al. (2021) were used. The pull-out resistance of short fibers embedded in cement mortar was investigated by conducting fiber pull-out tests. The bundled structures of the multifilament fibers gave the best results due to the generated mechanical interaction between fiber and matrix during fiber pull-out	

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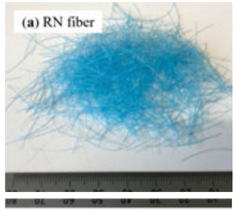
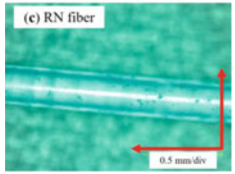
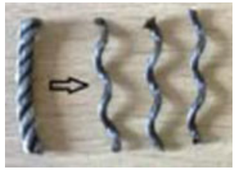
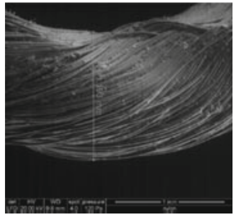
Table 12.3 (continued)

References	Polymer	Processing method	Image
(Nguyen et al. 2021)	R-PE fibers	Processing of fibers as explained in Park and Kim (2020b) and Park et al. (2021). Fiber length of 40 mm. Fiber diameter of 0.23 mm. Fiber addition of 1, 2, and 3 vol% The compressive strength, toughness, splitting tensile strength, and biaxial flexural tests were conducted on fiber-reinforced concrete. Compressive strength decreased but other properties increased as a function of fiber proportions	
(Srimahachota et al. 2020)	R-Nylon fibers	The FN was obtained from local fishermen in Hokkaido. Processing of fibers: washed, dried, and manually cut. Fiber length of 20 mm. Fiber diameter of 0.24 mm. Tensile strength of 440 MPa. Fiber addition of 1 vol% The short fibers were added to improve the mechanical properties of cement mortar used as repair mortar of reinforced concrete (RC) beams. The tested RC beams were subjected to four-point flexural tests to study their load-carrying capacity. It was found that the fibers helped transfer stresses through cracks and distribute stresses by transforming a single wide crack into many small cracks	 
(Bertelsen et al. 2019a, c)	R-PE fibers	Processing of fibers: mechanical cutting of fibers at recycling company; subsequent washing and drying. Fiber properties as described in Table 12.4. Fiber addition of 0.2–2 vol% The addition of fibers resulted in reduced plastic shrinkage cracking of cement-based mortars subjected to drying	

(continued)

Table 12.3 (continued)

References	Polymer	Processing method	Image
(Ottosen et al. 2019)	R-Nylon fibers	Processing of fibers: the nets were washed by soaking in tap water for 30 min repeated four times. Manual cutting of fibers to desired length of 20–40 mm. The nets were made of three twisted bundles (multifilament), which were separated and used in the test. Tensile strength of 260 MPa. Fiber addition of 0.5–2 wt% Fiber-reinforced mortar prisms were cast and subjected to three-point bending test and compression test. The compression and first-crack strength decreased with addition of fibers, but the post-crack performance increased	 
Pieces of net for continuous reinforcement in cement-based mortars			
(Mousa 2017, 2018)	R-Nylon nets	Pieces of fishing nets of multifilament threads were cut to the desired shape Net-reinforced mortar was cast with one layer of fishing net (dog bone specimens). Direct tensile tests were carried out on the dog bone specimens. The mortar with fishing net had higher displacement capacity	 

(continued)

Table 12.3 (continued)

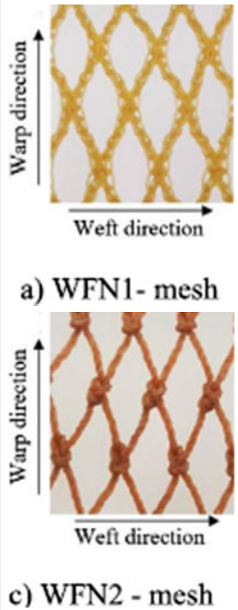
References	Polymer	Processing method	Image
(Truong et al. 2020)	R-PE nets, two types	The WFNs used in this study were collected from the seabed nearby Dalpo Port, Ulsan, Republic of Korea. The nets were cleaned by water jet to eliminate organic and inorganic impurities and saline water. Pieces of fishing nets were cut and washed prior to use Fishing nets (WFNRC) and commercial net reinforcement (TRCC) were used as continuous reinforcements in cement-based matrix. Although the commercial TRCCs produced better mechanical resistance than the WFNRCs, the addition of four layers of W2 to cement-based matrix also produced pseudo-tensile-hardening behavior. WFNRCs containing W2 produced higher tensile and flexural resistance than those containing W1	

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Table 12.3 (continued)

References	Polymer	Processing method	Image
Fishing nets (pieces or fibers) added to earth-based materials			
(Bertelsen et al. 2019d, 2021)	R-PE fibers	Processing of fibers from fishing nets as explained in Bertelsen et al. (2019c). Fiber addition of 1–5 wt% Fiber-reinforced unfired adobe bricks consisting of clay (Greenlandic sediments) and gravel were produced as prismatic specimens The addition of fibers improved all tested properties: compressive and flexural strength, post-crack performance, linear shrinkage, and drying shrinkage cracking	
(Bertelsen et al. 2022)	R-PE nets	Nets were washed and cut into smaller pieces like the size of the mold Adobe bricks consisting of clay (Greenlandic sediments) and sand were produced with 0, 1, or 2 layers of FN While the flexural post-crack performance was improved, the flexural first-crack strength decreased from 0.53 MPa for the reference to 0.36 MPa for the bricks with two layers	

Table 12.4 Properties of R-PE fibers

	Length L (mm)	Diameter d (μm)	Tensile strength σ_t (MPa)	Stiffness E (GPa)
R-PE	15 ± 9 (1–65)	280 ± 30	380–450	1.0–2.0

Density, length, and diameter were measured on R-PE fibers in the R-PE samples, while the tensile strength and stiffness were measured on three types of selected fishing nets in Fig. 12.4 (Braided Polyethylene, Euroline, and Euroline Premium from Euronete) (Bertelsen and Ottosen 2021)

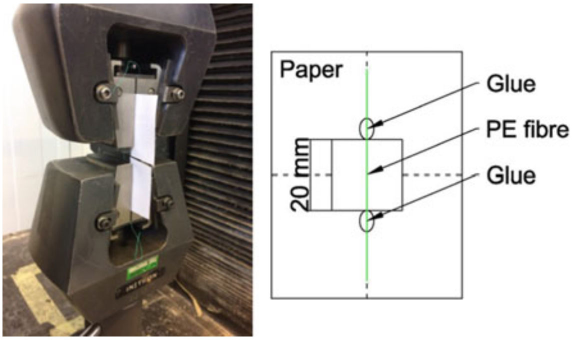


Fig. 12.3 Test setup for tensile test of fishing net fiber (Bertelsen and Ottosen 2021)

The R-PE fibers received from Plastix A/S were not long enough for performing tensile tests of single fibers as shown in Fig. 12.3. To get an indication of the variations in the mechanical properties of the R-PE fibers, fibers obtained from selected types of PE fishing nets were tested with respect to tensile strength and stiffness. Three types of fishing nets commonly used in the NPA region were selected for the mechanical testing (Braided Polyethylene, Euroline, and Euroline Premium from Euronete). These net types were chosen because of their mechanical properties, which were expected to represent the range of fibers present in the R-PE samples. For each type of fishing net, both new and used fibers were tested to get an indication of the level of deterioration. Mechanical tensile tests were performed on fibers extracted from new nets and discarded nets of the corresponding type, see Fig. 12.4.

12.4.2 Results: R-PE Fiber Characterization

The characterization of R-PE fibers is presented in this section. Table 12.4 shows relevant fiber properties for the R-PE fibers obtained by experimental testing.

Although the R-PE fibers were reprocessed from different types of PE fishing nets, the diameter of 280 ± 30 μm was found to be consistent. As a result of the mechanical cutting operation, the fiber length varied significantly. However, this operation could be optimized to cut the fibers into the desired length. From the SEM images (Fig. 12.5), it was observed that all fibers had an approximate circular cross

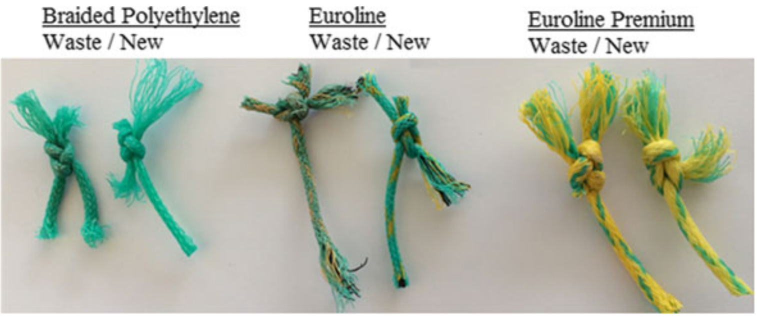
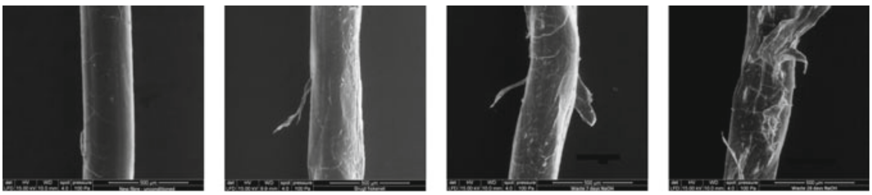


Fig. 12.4 Waste and new PE fishing nets from Euronete, used for characterization of mechanical properties. "Braided Polyethylene" (BP), "Euroline" (EU), and "Euroline Premium" (EP) (Bertelsen and Ottosen 2021)

section, a relatively smooth surface, and a straight shape. However, because it had been used, and later stored, for an unknown period under different environmental conditions, the surface of the recycled fibers was rougher and more damaged than the new fibers. The alkali resistance of the PE fibers was evaluated to simulate the fibers' deterioration in a highly alkaline environment such as cement-based materials and is important for the overall durability of the material. If the fibers deteriorate and leave channels inside the material, the channels may enhance the ingress and transportation of aggressive agents into the concrete.

The effect of the exposure to the highly alkaline environment is shown in Figs. 12.5 and 12.6. The SEM images show that the R-PE fibers were influenced by the alkaline solution by having more loose parts on the fiber surface. However, no reduction in cross section area was observed during the 28 days of exposure.

The mechanical performance of the fibers was evaluated based on tensile tests of single fibers as shown in Fig. 12.3. For all the tested fiber types (Fig. 12.4), it was found that fibers extracted from new (N) fishing nets had a higher tensile strength and stiffness than fibers from corresponding recycled (R) fishing nets. Examples of the stress–strain behavior of N-PE and R-PE fibers are illustrated in Fig. 12.6



(a) New - Unconditioned *(b) Recycled - Unconditioned* *(c) Recycled – 7 days in 1M NaOH* *(d) Recycled – 28 days in 1M NaOH*

Fig. 12.5 SEM images (300×) of unconditioned new **a** and recycled **b** fibers from fishing nets of the type "Braided Polyethylene" immersed in a 1 M NaOH solution at 50 °C for 7 **c** and 28 days **d**, respectively. FOV = 1.27 mm (Bertelsen 2019)

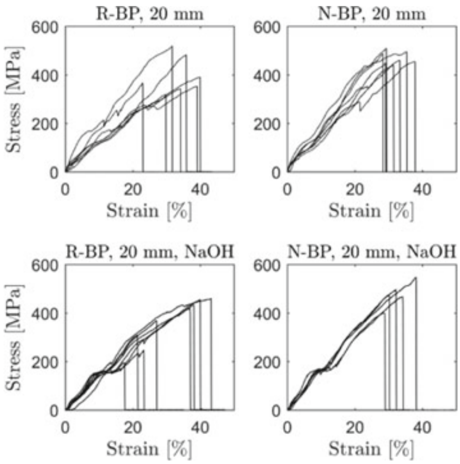


Fig. 12.6 Tensile stress–strain behavior of unconditioned and alkali-cured PE fibers from recycled (R) and new (N) nets of the type "Braided Polyethylene" (BP). Gauge lengths of 20 mm (Bertelsen 2019)

showing the strain versus the tensile stress during the test. An almost linear behavior until failure is observed for all fibers, which also followed approximately the same trend. The exposure of the fibers to a highly alkaline environment did not have any significant influence on the tensile strength.

The mechanical properties are in the same range as other low-modulus fiber types used in construction materials, such as PP fibers with tensile strength and stiffness around 150–800 MPa and 0.5–10 GA, respectively (Banthia et al. 2012; Daniel et al. 2002; Zheng and Feldman 1995). The results on the mechanical performance of the R-PE fibers indicate that they are very similar to that of PP fibers.

12.5 Applications for Discarded Fishing Nets in Construction Materials

12.5.1 Fiber Influence on Mechanical Performance of Construction Materials

The use of R-PE fibers as fiber reinforcement in different types of construction materials was investigated with the aim of obtaining a broad overview of the fiber influence on the mechanical performance and shrinkage properties of the composite materials. The tested construction materials were:

- earth-based adobe bricks (unfired clay bricks)
- gypsum-based plaster
- cement-based mortars.

(a) (b) (c)

Fig. 12.7 Example of the preparation and test procedures of small-scale prisms used for the three-point bending tests shown for gypsum-based specimens. **a** Mixing raw materials and R-PE fibers; **b** casting specimens in steel molds; **c** and three-point bending testing (Bertelsen 2019)

The selected types of construction materials had very different intrinsic mechanical properties, with the cement-based mortar being the strongest and stiffest, followed by gypsum and finally the earth-based adobe bricks. Adobe bricks are unfired clay bricks made of a mixture of clay- and gravel-type soils (Houben and Guillaud 1994) and in this case made from Greenlandic fine-grained sediments. The three evaluated construction materials had different levels of R-PE added (the R-PE fibers added are those shown in Fig. 12.1).

A test program including small-scale prisms measuring 40 × 40 × 160 mm of the three mentioned types of construction materials was carried out in accordance with the standard UNI/EN 196-1 on flexural testing of small-scale prisms (UNI/EN-196-1 2005). For more details on the test program and the results, see (Bertelsen 2019). The basic steps in the casting and testing procedure are shown in Fig. 12.7 for the gypsum-based specimens including mixing (a), casting (b), and during the three-point bending testing (c).

All specimens had similar dimensions and test procedures were kept constant for all three types of materials, whereas the mixture proportions, curing time, and curing method varied depending on the requirement for the respective material. This can be seen in Table 12.5. The three-point bending tests were all performed in the same displacement-controlled testing machine with a displacement rate of 1 mm/min and an example of the test setup is shown in Fig. 12.7d.

12.5.2 Results: Influence of R-PE Fibers on Mechanical Performance of Construction Materials

The results from the mechanical testing of small-scale prisms of different types of construction materials (cement-based mortar, gypsum-based plaster, and earth-based adobe) are briefly described in this section. Selected results for the stress–strain behavior are presented in Fig. 12.8 for the respective reference specimens (no fiber addition) and specimens with the maximum amount of R-PE fiber which could be

Table 12.5 Overview of materials, mixture proportions, curing conditions, and fiber content for small-scale prisms

Material	Proportions	Curing	Fiber content (wt%)	Fiber content (vol%)
Earth-based adobe	["clay" : water : gravel] [1.0 : 0.44 : 1.0]	3 d of dry-curing inside molds + 25 d of air-curing at ~21 °C	1.00, 2.00, 3.00, 4.00, **5.00**	2.05. 4.1, 6.15, 8.2, **10.25**
Gypsum-based plaster	[gypsum : water] [1.0 : 0.44]	1 d of dry-curing inside molds + 2 d of air-curing at ~21 °C	0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, **2.00**	0.44, 0.87, 1.31, 1.74, 2.18, 2.62, 3.05, **3.50**
Cement-based mortar	[cement : water : sand] [1.0 : 0.5 : 3.0]	1 d of sealed dry-curing inside molds + 27 d of wet-curing at ~21 °C	0.17, 0.33, 0.50, 0.67, 0.83, 1.00, 1.17, **1.33**	0.38, 0.77, 1.15, 1.54, 1.92, 2.31, 2.69, **3.07**

The maximum fiber content possible to mix into the respective mix proportions is written in bold

added to the respective material during mixing. For more detailed information on the results, see (Bertelsen 2019; Bertelsen et al. 2021; Bertelsen and Ottosen 2021).

First, the flexural strength of the three materials varies significantly. The mortar specimens had the highest stiffness and a flexural strength of ~8 MPa, followed by the gypsum specimens with a flexural strength of ~3.5 MPa and finally the adobe specimens, which gained the lowest flexural strength of 0.7–1.2 MPa. Secondly, the fibers improved the post-crack performance of all three materials, although the effect was poor for both the cement-based and gypsum-based specimens. A large drop in stress is seen for the mortar and gypsum specimens, whereas no drop occurs for the adobe specimens. Moreover, the flexural strength of the adobe specimen is almost doubled for the specimen with the addition of R-PE fibers, which is not the case for mortar or gypsum. Another interesting finding was that the addition of R-PE fibers to adobe bricks resulted in increased compressive strength from 2.6 to 3.5 MPa (Bertelsen et al. 2021). Again, this was not the case for the two other materials (mortar and gypsum). The findings for the cement-based mortar are quite similar to previous studies on the use of fishing net fibers added to cement-based mortar (Orasutthikul et al. 2017; Ottosen et al. 2019; Spadea et al. 2015).

12.5.3 Results: Influence of R-PE Net Pieces on Mechanical Performance of Earth-Based Adobe Bricks

Based on these results, and the assumption that it would be easier to remove the plastic fibers from the adobe material compared to the cementitious material at the

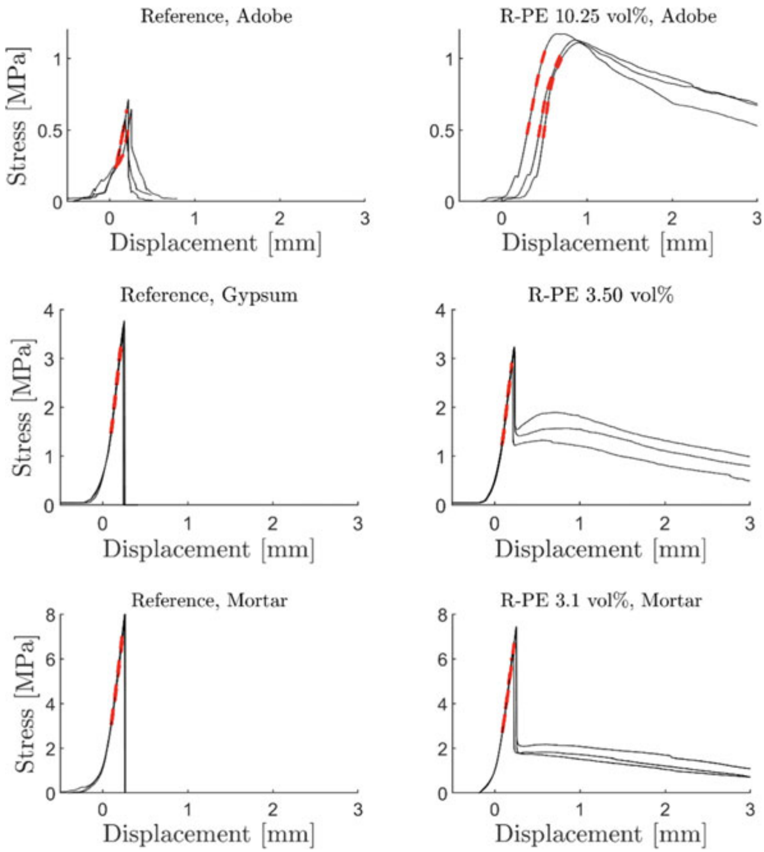


Fig. 12.8 Flexural stress-displacement behavior of prisms with no fibers (reference) or with the maximum addition of R-PE fiber, which could be mixed into the material. Note the different scales on the *y*-axis (Bertelsen 2019; Bertelsen et al. 2021)

end of life, it was decided to continue the research on the adobe material. The fishing nets were added to the adobe material either in the shape of fibers or as pieces of net cut out of the fishing net. This was done for larger-scale adobe bricks of Greenlandic fine-grained sediments as shown in Fig. 12.9. The results of the study is published in Bertelsen et al. (2022). One of the main benefits of this type of construction material in a Greenlandic context, is that it can be produced from locally available resources in Greenland, where both the fine-grained sediments and discarded fishing nets are available in large quantities along the coastal towns. The advantage of using larger pieces of fishing net as reinforcement compared to fibers is the improved recyclability of the material, where larger pieces can more easily be removed than fibers. However, the increased flexural strength was not as good as when the adobe bricks were added the reinforcement in the shape of fibers.

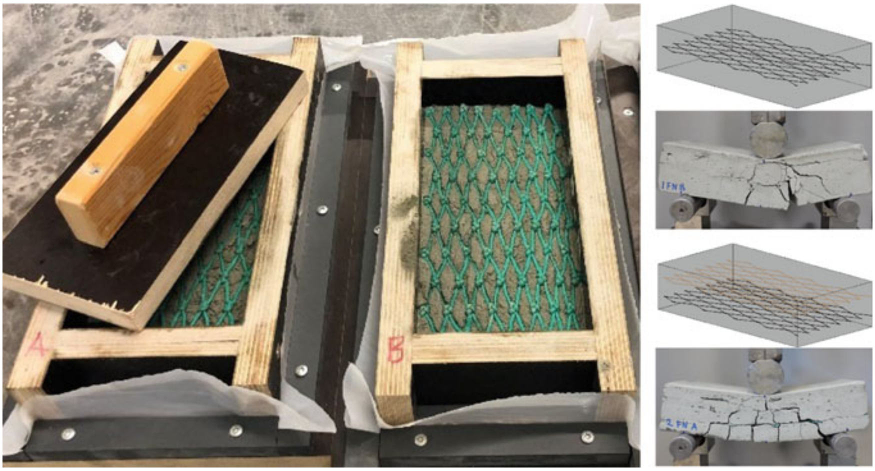


Fig. 12.9 Production of adobe bricks with one or two layers of fishing net reinforcement (Bertelsen et al. 2022)

12.5.4 Mitigation of Shrinkage Cracking in Construction Materials by Adding Fibers

Other uses of the R-PE fibers in construction materials were, for example, to mitigate shrinkage cracking in brittle materials, which tend to shrink during drying. The evaluated types of construction materials included in this part of the study were cement-based mortars and earth-based adobe material susceptible to early-age shrinkage deformations and cracking. Examples of the influence of R-PE fibers on shrinkage cracking of cement-based mortars and earth-based adobe material, are the plan views of material samples shown in Fig. 12.10. There is a clear tendency that the addition of fibers reduces the degree of shrinkage cracking. For more information, see (Bertelsen et al. 2019b, 2021).

12.5.5 Use of Fishing Net-Reinforced Adobe Bricks as Construction Material

Construction material in unfired clayey soil, such as adobe bricks, is a highly sustainable alternative to, for example, concrete or fired clay bricks, since the production procedure is very simple and requires no firing at high temperatures (Salih et al. 2020). The technique has been used for more than 9000 years and is still widely used, especially, in developing countries (Minke 2012). Adobe bricks are commonly used all types of walls in dry climates, but in harsher climates, the material is mainly intended for inner walls due to the relatively poor durability. It is common practice

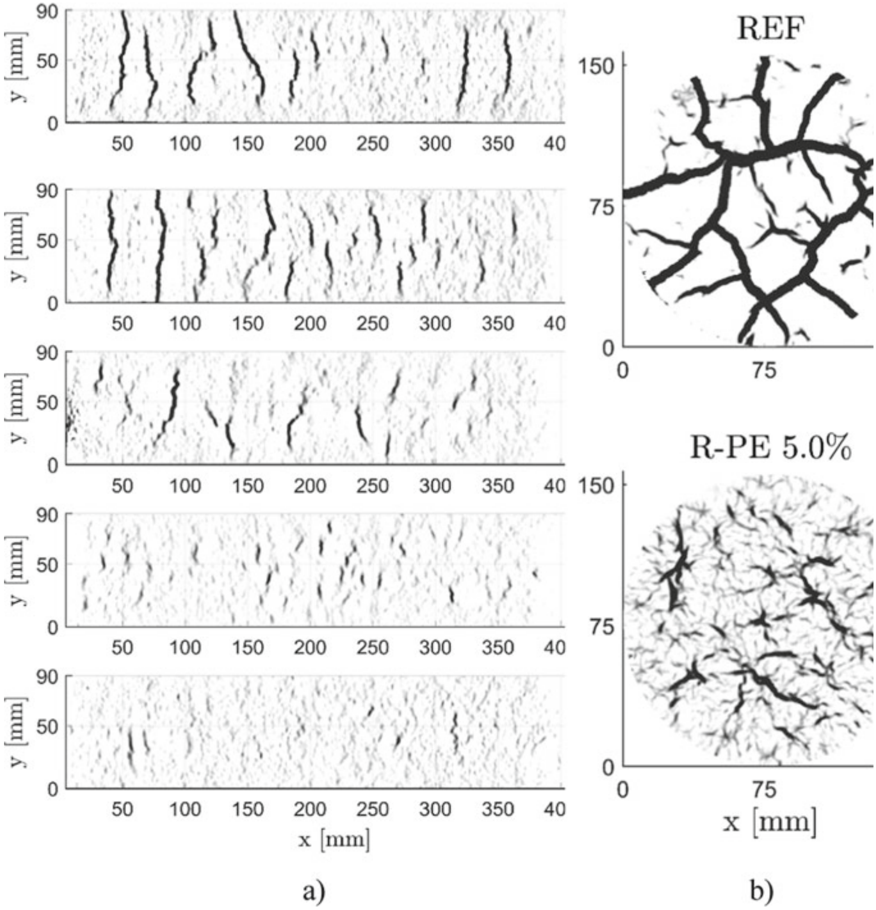


Fig. 12.10 Plan view of material samples with shrinkage cracking: **a** cement-based mortars susceptible to plastic shrinkage cracking and the influence of R-PE fibers (0% (REF) to 2.0 vol%); **b** earth-based adobe material susceptible to early-age shrinkage cracking and the influence of R-PE fibers (0% (REF) or 5.0 wt%) (Bertelsen et al. 2019d, 2021)

to reinforce adobe bricks with fibers of either natural origin or derived from waste materials (Salih et al. 2020).

The best results for the use of fishing net reinforcement from the experimental program described in this chapter were found for adobe bricks. A challenge for the implementation of adobe bricks in Greenland could be that it is a "new" type of construction material, which is not used in Greenland today. However, adobe bricks with fishing net reinforcement would not only be applicable to Greenland, but also globally where the construction technique is already used and thus more easily applicable.

12.6 Overall Conclusions

Discarded fishing nets were investigated as reinforcement in different types of construction materials. The findings showed that fishing nets, especially in the form of fibers, can improve the post-crack performance of construction materials such as cement-based mortars, gypsum, or earth-based adobe bricks. The best results were obtained for high fiber additions (up to 5 wt%) to the earth-based adobe bricks. The adobe material is a low-stiffness construction material, where the addition of fibers resulted in improvement of the mechanical properties (compressive, flexural, post-crack strength) as well as reduction in the early-age shrinkage cracking. The addition of fibers was also found to mitigate plastic shrinkage cracking in cement-based mortars. The findings in the present project were supported by those in recent studies on the use of discarded fishing nets in cement-based mortars. However, very little research is carried out on the use of fishing nets in other types of construction materials, and this needs more research. Overall, there is a great potential in reusing discarded fishing nets as reinforcement in especially low-stiffness construction materials not only in Greenland, but also globally.

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Chapter 13
The Influence of Involvement and Attribute Importance on Purchase Intentions for Green Products

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Abstract Consumer interest is driving growth in the use of greener products, such as those using recycled materials. However, several outstanding questions remain regarding purchase intentions for green products. One current debate regards the role of age, with some findings showing older consumers are more willing to purchase green products, and other studies to the contrary. There are also a number of studies with differing results regarding the role of product involvement. We conduct an experiment and use conjoint analysis to test for the influence of age and involvement on purchase intentions for green products. We find that younger consumers are more likely to purchase green products if they are affordable. We also observe that being green can directly lead to higher purchase intentions for a low involving affordable product, whereas the green attribute is one of several attributes a consumer evaluates for a high involving affordable product.

Keywords Green purchase intentions · Product involvement · Environmental concern · Conjoint analysis · Age

13.1 Introduction

Environmentally friendly products are increasingly important for consumers and societal welfare. This is mirrored by a growing popularity and number of products made from recycled products (Polyportis et al. 2022). For example, IKEA the Swedish furniture giant is actively working toward sourcing and using only renewable and recycled materials by 2030 (Ikea 2022). A subset of available resources for recycling resides in the sea. Plastic in our oceans, or marine plastics, is a growing and major problem, as it kills wildlife and enters the human food chain (Parker 2019).

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Waste fishing gear, such as fishing nets, is one of the major sources of marine plastics. Attempts to recover and recycle fishing gear are underway, but markets must be found to sell products made from this recycled material if the process is to be sustainable (Milios et al. 2018; Polyportis et al. 2022). In its most recent annual report, Interface, an over $1 billion office carpet manufacturer, lists the use of recycled material as central in reducing its environmental impact (Interface 2021). The recycled material used in their carpets is partly made from recycled fishing gear, and the use of this material is driven by customer demand (Interface 2021). Hence, we can see an increased interest in the use of recycled materials in the production of new and more environmentally friendly products. Other illustrations of this include the NextWave consortium which includes several companies collecting and using recycled fishing gear in their products, such as IKEA, Interface, Dell, MillerKnoll, and Trek Bicycle (NextWave 2022). Aquafil, which produces Econyl, a fabric produced from recycled material including fishing nets, lists over 500 apparel and interior brands that use their recycled Econyl nylon in their products, including Speedo, Burberry, Mercedes-Benz, H&M, Tom Dixon, and Tarkett (Econyl 2022). Aquafil, the manufacturer of Econyl, states that for every 10,000 tons of Econyl they create, they save 70,000 barrels of oil and 65,100 tons of CO_2 emissions, with a resulting 90% reduction in greenhouse gases by producing recycled rather than new, virgin nylon (Econyl 2022). Nofir, another collection company, notes that they have helped recover almost 55,000 tons of waste fishing nets which are then recycled (Nofir 2022).

Prior research shows that the use of environmentally friendly or, *green*, products can differentiate and be a competitive advantage among at least some consumer segments (He and Deng 2020). Those who are more concerned about the environment are shown to be more likely to purchase green products (Tanner and Wölfing Kast 2003; Taufique et al. 2017). This is also the case when consumers perceive a product to be more relevant, or involving, for them (Vermeir and Verbeke 2006). However, the interplay of product involvement and purchase intentions for green products can vary, with increased involvement leading to higher purchase intentions for some product categories, but not others (Rahman 2018). There is also an ongoing debate regarding the role of age in purchasing green products, with some studies finding that older consumers are more likely to purchase green products and others observing the opposite (Coderoni and Perito 2020; Zhao et al. 2014).

In this study, we look further into the role of consumer age and involvement for purchase intentions for green products to add to the discussion regarding both. We conduct an experiment and utilize conjoint analysis to uncover preferences and test the influence of age and involvement on purchase intentions for typical products made from recycled materials. In the next section, we review the relevant literature and present the hypotheses. This will be followed by a description of the methods employed, presentation of results, and a general discussion including implications, limitations, further research, and conclusion.

13.2 Literature Review

We will now review product opportunities for products made from recycled fishing gear, followed by a discussion of purchase intentions for such products and develop hypotheses.

13.2.1 Green Product Opportunities from Recycled Fishing Gear

There are a growing number of products made from recycled fishing gear. Econyl is a regenerated nylon product made from recycled fishing nets, carpet, pre-consumer, and other waste and is used by over 500 apparel and interior brands (Econyl 2022). Products made from Econyl are often used in formfitting apparel, sportswear, swimsuits, rope, and carpet (Sewport 2022). Another actor, the NextWave consortium, brings together several large firms to use recycled fishing nets in their products. Their members include CPI Card Group, Dell Technologies, HP Inc, Humanscale, IKEA, Interface, Logitech, MillerKnoll, Prevented Ocean Plastic, Shinola, Solgaard, #tide, Trek Bicycle, and Veritiv, and they develop products from office chairs, laptop components, backpacks, watch bands, payment cards, bicycle parts, shoes, stereo components, printer ink cartridges, packaging, cosmetics, tablecloths, to carpet tiles (NextWave 2022). Other firms, such as PartnerPlast (2022), Vartdal Plast (2022), and Plasto (2022), are using recycled fishing gear in developing marine components, such as electronic buoys, tools, car chargers, construction materials, and insulated packaging. Companies like Bracenet (2022), Planet Love Life (2022), and Kettle Cove Enterprises (2022) are creating small items like bracelets, earrings, baskets, and keychains from recycled fishing nets. Bureo (2022) and Fishpond (2022) produce outdoor, clothing, and sporting goods products from recycled fishing gear. The existence and increasing development of these green products suggest that there is market interest, yet research regarding purchase intentions for green products is not conclusive (Park and Lin 2020; Polyportis et al. 2022; Rahman 2018).

13.2.2 Purchase Intentions for Green Products

Many studies have examined purchase intentions for green products (for reviews, see Groening et al. 2018; Wijekoon and Sabri 2021; and Zhuang et al. 2021). Commonly cited drivers of green purchase intentions include attitudes, such as environmental concern (Newton et al. 2015; Taufique et al. 2017), knowledge of environmental issues (Kanchanapibul et al. 2014; Kang et al. 2013), green product attributes (Park and Lin 2020), and demographics (D'Souza et al. 2007; Diamantopoulos et al. 2003; Zhao et al. 2014), among others (Groening et al. 2018).

Demographics, such as higher income and education, have been shown to have a positive influence on purchase intentions for green products (D'Souza et al. 2007; Diamantopoulos et al. 2003; Zhao et al. 2014). However, the role of age in green purchase decisions is unclear. It has been established in the literature that younger consumers are more likely to be concerned about environmental issues (Buttel 1979; Liere and Dunlap 1980), though there is debate regarding whether this leads to an increased willingness to purchase sustainable products (D'Souza et al. 2007; Zhao et al. 2014). Often, price is more important for a purchase than a product's environmental credentials (Gleim et al. 2013; Mansuy et al. 2020; Wang et al., 2022). However, some recent research has shown a negative relationship between age and willingness to purchase green products (Coderoni and Perito 2020). Furthermore, Diamantopoulos et al. (2003) have argued that although younger consumers may be more concerned about the environmental impact of their purchases, they do not have the income to purchase more green products because they tend to be more expensive. This latter research suggests that the reason for the gap between environmental concern and purchase intentions for younger consumers is due to the price level, where price is a barrier. Hence, if we remove this barrier by presenting consumers with products that are inexpensive, we should observe a negative relationship between age and purchase intentions for green products. Hence, affordable green products, that is, products that are not expensive for younger consumers, should be more likely to be purchased by younger, relative to older, consumers. The above discussion leads us to our first hypothesis:

H_1: Younger consumers will be more likely to purchase affordable green products than older consumers.

Product involvement, defined as "*a person's perceived relevance of the object based on inherent needs, values, and interests*" (Zaichkowsky 1985), has been shown to influence how we make decisions (Cacioppo and Petty 1984; Petty et al. 1983). When products are lower involving, hence less relevant to us, we pay less attention to information we are given about a product and tend to use quick heuristics to make a choice (a non-compensatory process); often based on a single attribute such as price. When a product is more involving, we tend to pay more attention to the information given to us about it and evaluate the product based on a weighting of different attributes (i.e., a compensatory process). Higher involvement has been associated with increased intentions to purchase green products (Vermeir and Verbeke 2006), though this can depend heavily on the product category (Rahman 2018). We expect higher purchase intentions for green products among those who indicate higher involvement for those products. However, we believe there is a difference in how processing a choice for green products is influenced by product involvement.

For less involving products, consumers often resort to simple non-compensatory choice strategies, such as "I'll choose the cheapest option" (Cacioppo and Petty 1984; Petty et al. 1983). In such cases, the most salient attribute may be used in decision-making. Promotion of a green attribute can lead to the use of that attribute in decision-making (Atkinson and Rosenthal 2014). A consumer with some interest in the environment would then choose an alternative with a green attribute, if price does not over-ride. When considering a less involving product, a green-focused consumer may give high importance to a single attribute, e.g., the use of green materials used to make a product. Based on the above arguments, we hypothesize as follows:

H_2: The importance of the materials used attribute for products will be positively associated with purchase intentions for low involvement products when the green attribute is preferred.

For more involving products, consumers often resort to more compensatory processing, whereby they evaluate more attributes related to a product when making a choice (Cacioppo and Petty 1984; Petty et al. 1983). Given their reliance on and evaluation of more attributes, any single attribute should be less important in relation to other attributes for a more involving relative to less involving product. This leads us to our third hypothesis:

H_3: The importance of the materials used attribute for products, will not be associated with purchase intentions for high involvement products even if the green attribute is preferred.

We will now turn our attention to the methods we employed to test the above hypotheses, including the use of conjoint analysis to infer consumers' unconscious preferences. This will be followed by a discussion of the results and implications for theory and management.

13.3 Methods

A pre-test was conducted to identify products that varied on involvement for use as stimuli in a main study. The main study used an online survey design that included a choice-based conjoint analysis task to measure consumers' preferences for both products.

13.3.1 Pretest

To choose focal products for the main study, we conducted a pre-test ($n = 44$) in which we asked respondents to rate several products on product involvement. We wanted product categories that would be typical for recycled material and vary on involvement, but still be relevant and affordable for most consumers. Backpacks and socks were chosen from this pre-test, as they were typical recycled products, varied on involvement, were affordable to most consumers, were relevant (as backpacks and socks are commonly purchased by most consumers at some point), and allowed for the stimulus used in the main study to be applicable for both women and men.

13.4 Main Study

We conducted a conjoint-based online survey among 193 Norwegian respondents. They were aged 18+, and 57% of the respondents were women. First, choice-based conjoint analysis was used to elicit preferences for two product categories that varied on involvement. Some conjoint analysis studies have examined consumers' intentions to purchase sustainable products, with a general finding being that although consumers are interested in sustainable products, price is often more important (Mansuy et al. 2020; Wang et al. 2022). Therefore, we control for price sensitivity, as measured by price importance in the conjoint task. The other attributes used in the conjoint task were design, brand, and the amount of recycled material used in the product (0% vs. 50% vs. 90% recycled). The output of the conjoint task is a measure of the importance of each attribute to a consumer's overall intention to purchase each product. The sum of the importances for each attribute for a respondent totals to 100%. For example, a respondent might place 35% importance on price, 10% on Brand, 30% on material, and 25% on design. Following the conjoint task, respondents were asked to indicate their concern for the environment, level of involvement with the two product categories, and some limited demographic information (e.g., age and gender). These variables were measured as shown below.

13.4.1 Variables

Environmental concern was measured by a 4-item, 7-point Likert scale (Nhu et al. 2019) where respondents were asked to rate how much they agreed with the statements: "I am worried about the worsening quality of the environment", "the environment is my major concern", "I am emotionally involved in environmental protection issues" and "I often think about how the environmental quality can be improved" (Cronbach's = 0.883, $n = 193$).

Product Involvement was measured on a 4-item, 7-point Likert scale (adapted from McQuarrie and Munson 1992). For each product used in the study, respondents were asked to rate the importance, their interest for, how much they mean, and relevance of [*product*] to them (Cronbach's $_{\text{low involvement}} = 0.888$, $n = 193$ and Cronbach's $_{\text{high involvement}} = 0.893$, $n = 193$).

Purchase intentions were measured by a single item, 7-point Likert scale in line with Bergkvist and Rossiter (2007) who endorse the use of a single item when measuring a specific singular and concrete attribute. For each product used in the study, respondents were asked "How likely is it that you would purchase [*product*] made from recycled fishing nets?".

13.5 Results

Before conducting our tests, we checked that our two products varied on involvement. Backpacks were seen as higher involvement ($M_{\text{backpacks}} = 4.9$, $n = 193$) than socks ($M_{\text{socks}} = 3.7$, $n = 193$). Hence, we can consider backpacks as high involvement and sock as low involvement for our tests.

We also needed to check that our products were affordable. For the low involvement product, Design was the most important attribute ($M_{\text{design}} = 36.8\%$), followed by Price ($M_{\text{price}} = 28.5\%$) and Material ($M_{\text{material}} = 28.2\%$), and finally Brand ($M_{\text{brand}} = 6.5\%$). For the high involvement product, Design was the most important attribute ($M_{\text{design}} = 36.0\%$), followed by Price ($M_{\text{price}} = 33.3\%$), Material ($M_{\text{material}} = 21.0\%$), and finally Brand ($M_{\text{brand}} = 9.7\%$). This suggests that both products were affordable, as price was not the most important attribute.

13.5.1 Age

To test H_1, that younger consumers are more likely to purchase green products, we conducted a correlation analysis. For both products, younger consumers showed higher purchase intentions than older consumers ($r_{\text{low involvement product}} = -0.15$, $n = 225$, $p < 0.05$ and $r_{\text{high involvement product}} = -0.18$, $n = 225$, $p < 0.01$), providing support for H_1. Age was not correlated with environmental concern ($r_{\text{age}} = 0.00$, $n = 225$, $p > 0.05$).

13.5.2 Involvement

To test our hypothesis that a general intention to purchase sustainable products would lead to purchase intentions for specific products, but influenced by involvement, we conducted a regression analysis for each product category. In each regression, we also controlled for price sensitivity, as this has been shown to have a stronger influence on purchase intentions than environmental concerns (Mansuy et al. 2020; Wang et al. 2022). We also control for product involvement within each product.

The model explained 21% of variance in purchase intentions for the high involvement product ($PI_{\text{high involvement}}$: F (7, 185) = 8.23, $p < 0.001$). Age, environmental concern, and involvement were found to be predictors of purchase intentions for the high involvement product (see Table 13.1). That is, younger consumers, those more concerned about the environment and those more involved, had a higher intention to purchase the higher involving green product. This provides support for H_3.

The model explained 30% of variance in purchase intentions for the low involvement product ($PI_{\text{low involvement}}$: F (7, 185) = 12.77, $p < 0.001$). Environmental concern,

Table 13.1 Regression predicting purchase intentions

	High involvement		Low involvement	
	Beta	Sig	Beta	Sig
Age	**−0.24**	**< 0.001**	−0.09	0.176
Environmental concern	**0.33**	**< 0.001**	**0.29**	**< 0.001**
Product involvement	**0.14**	**0.040**	**0.15**	**0.017**
Price importance	−0.05	0.457	−0.03	0.639
Material importance	0.13	0.847	**−0.52**	**< 0.001**
Material rank	−0.02	0.866	−0.02	0.837
Material rank *X* importance	−0.05	0.940	**0.40**	**0.006**

Bold indicate that the result is statstically significant at the $p < 0.05$ level

involvement, material importance, and the interaction of material rank and importance were found to be predictors of purchase intentions (see Table 13.1). Hence, we found support for H2 which states that the importance of the materials used attribute for products will be positively associated with purchase intentions for low involvement products when the green attribute is preferred.

The interaction of material rank and importance suggests that as the rank is lower (i.e., prefer non-recycled), the consumer chooses based on non-recycled being the preferred material, whereas those who prefer the 90% recycled material choose based on this preference (see Fig. 13.1) and provides support for H_3. Price importance was not found to be a driver of purchase intentions for either product.

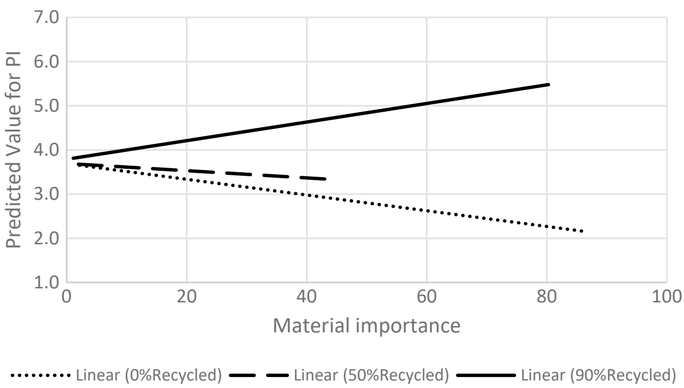

Fig. 13.1 Interaction of material rank *X* importance predicting PI for low involvement product

13.6 Discussion

Our findings make important contributions to the literature and debate regarding purchase intentions for green products and age. Our study provides increased understanding and insight on the role of material importance in the purchase of green products. In addition, our study shed light on the role of age in the consumer decision-making process in relation to the purchase of green products. The result of our study suggests that younger consumers are more likely to purchase affordable green products, as suggested by Diamantopoulos et al. (2003). We also saw an influence of environmental concern and product involvement on purchase intentions that are in accordance with results from prior research (Newton et al. 2015; Vermeir and Verbeke 2006). More environmentally concerned and more involved consumers had higher intentions to purchase green products. We also found an interaction between the importance the consumer place on the materials used in the product and the positive or negative desirability of the green attribute for the low involvement product. This interaction was not seen for the high involvement product. We will now discuss the theoretical and managerial implications, followed by identification of some limitations.

13.6.1 Theoretical Implications

Age was negatively correlated with intentions to purchase affordable green products. This adds support to previous studies showing younger consumers are more interested in purchasing green products than older consumers, when price is not a barrier (Diamantopoulos et al. 2003), suggesting that a disconnect between green attitudes and green purchasing intentions has to do with younger consumers not having the ability to purchase more expensive green products. Our findings support this line of reasoning.

We also find support for arguments that consumers are less influenced by the green attribute for more involving products relative to less involving, as suggested by Atkinson and Rosenthal (2014). It appears that consumers of low involving products seek out simple cues from which to make a choice. A green product attribute can provide such a cue, hence increasing the importance of that attribute in a choice. For more involving products, the green attribute is one of the potentially several core attributes that a product is evaluated on. If the consumer is interested in green products, the product still must be good enough on other attributes weighed in the consumer's evaluation.

13.6.2 Managerial Implications

Focusing on green attributes can be a primary focus for low involvement products among younger consumers, as they may use a simple heuristic choice strategy to choose the green product, when making a decision among competing affordable alternatives. However, for more involving products, the sustainability attribute will be considered among other attributes in a compensatory process. This suggests the overall utility of higher involving products will be considered when a consumer is making a choice and more careful thought should be given to developing the products accordingly.

Younger consumers may be a better target group for green products when the price level is not a barrier for them. Our research showed that there was a general tendency for younger consumers to be more interested in purchasing affordable green products than older. Hence, marketing communication activities may be more effective when targeted at younger consumers when the price is considered reasonable, given their more limited budgets.

13.7 Limitations, Further Research, and Conclusion

We only tested our hypotheses with two products meant to represent a lower and higher involving product. Also, the difference in mean involvement for these two products was greater in the pre-test relative to the main study. This makes it difficult to generalize our findings. Prior research also suggests that involvement is highly dependent on product category (Rahman 2018). We suggest further research using more products and services to see whether these results hold in other categories and to test for boundary conditions. In conclusion, our analysis shows that younger consumers are more likely to purchase green products if they are reasonably priced. Being green can directly lead to higher purchase intentions especially for low involving, affordable, products. Firms have a great deal of potential to differentiate themselves from their competitors, through creating value from waste and offering environmentally friendly, and green products that target the relevant customer segments. Thus, we believe is a win–win business solution to the marine plastics pollution problem.

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Chapter 14
Role of Resource Users' Knowledge for Developing Realistic Strategies for a Circular Economy for Plastics from the Norwegian Fishing Sector

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Abstract The complexity of resource management often demands an integration of transdisciplinary methods to find sustainable solutions. The absence of aggregated scientific information threatens holistic and robust resource management. Contrary to traditional resource management studies, the involvement and engagement of resource users are prioritized here. As resource users and stakeholders are significant, yet unexplored sources of information, this study presents a stepwise approach that includes resource users' local ecological knowledge in gathering the information necessary for resource management. The framework's application is then demonstrated in the case of plastic fishing gear deployed by the commercial fishing fleet of Norway. The insights from stakeholders were used to ascertain potential barriers and opportunities in establishing circular and sustainable management strategies for Fishing gear resource management in Norway.

14.1 Sustainable Resource Management: Global Context

The science of resource management involves generating a systematic understanding of the processes that lead to improvements in, or the deterioration of natural or anthropogenic resources. The management of resources is relatively straightforward, especially when the resources and use of the resources by users can be monitored, and the information can be verified and understood in a non-complex way (Dietz et al. 2003). In the terminology of resource management, information refers to the real knowledge about stocks, flows, and processes within the resource system, as well as about the human–environment interactions affecting the system (Dietz et al. 2003). Highly aggregated information may ignore or average out local data, which is essential for identifying future problems and developing sustainable solutions (Dietz et al. 2003).

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Historically, local and regional governments have been deemed responsible for managing resources through political instruments, and resource users have been assumed incapable of reversing the tragedy of commons (Hardin 1968). Dietz et al. (2003) and Johannes (1984), however, provided strong arguments advocating the necessity of studying not only the resource itself but also the local methods, traditions, and knowledge associated with its use. As all humanly used resources are embedded in complex, social-ecological systems (SES) (Ostrom 2009), one needs to incorporate both ecological and socio-technical knowledge in describing the resource system. Accordingly, Ostrom (2009) proposed a multilevel, transdisciplinary framework for analyzing the sustainability of resource systems. The framework was designed to capture the complex interactions among the system and subsystems.

A system is ‘a combination of interacting elements organized to achieve one or more stated purposes’ (ISO 2008). Here, the SES framework proposed by Ostrom (2009) is adapted, the case system of fishing gear (FG) resources deployed by the commercial fishers in Norway. The system is studied for developing sustainable strategies in the life cycle management of FGs in the region. The interacting elements or *subsystems* are defined by adapting the SES framework proposed by Ostrom (2009), which is modified to represent the SES of FG resources in Norway. Figure 14.1 provides an overview of the framework, showing the relationships between the four core subsystems of an adapted SES that affect each other, as well as linked to social, economic, and political settings and related ecosystems. The central system and associated subsystems for management of the selected anthropogenic resource are:

14.1.1 Main Social Ecological/economic System: Fishing Gear Resources

A. **Resource system**: The Norwegian commercial fishing sector.
B. **Resource units**: Plastics from commercial fishing gears and ropes.
C. **Governance systems**: The regulatory framework and governing institutions.
D. **Resource users**: Fishers and other stakeholders.

The framework highlights the need for interaction and engagement between the four subsystems to gather holistic scientific information about the system. SD and the circular economy provide a global context to define and outline the improvement of FG resource management in the region. This chapter suggests outcomes in the form of strategies and mechanisms for achieving the overall goal of sustainable life cycle management of FG resources in Norway. Although the suggested outcomes are limited to the case of the commercial fishing sector of Norway, the knowledge can be adapted to similar ecosystems elsewhere.

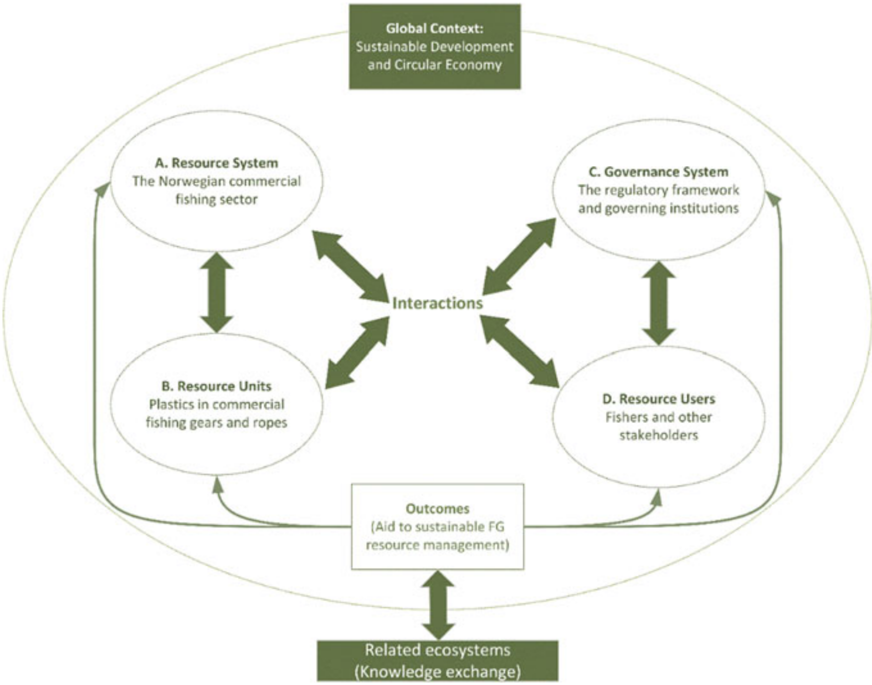

Fig. 14.1 The core subsystems in a framework for analyzing the social-economic system of FG resources. Modified from Ostrom (2009)

14.2 Description of Case Study

Norway is a Northern European country surrounded by water to the south (Skagerrak), the west (the North Sea and the Norwegian Sea), the north, and north-east (the Barents Sea). With a marine resource-rich coastline of more than 25,000 km, Norway is the European leader regarding both commercial fishery and aquaculture (Lawson 2015). The commercial fishery has always played a critical social and economic role, nationally and regionally, and has been the basis for settlement and employment along the entire Norwegian coast (FAO 2013). The commercial capture fishery sector is segmented into the coastal and ocean fishing fleet. The coastal fishing fleet comprises smaller vessels operated by 1–5 fishers and size ranges from 10 to 20 m. On the other hand, the ocean fleet is known for its deep-water and sophisticated fishing practices, where fishing vessels are generally more than 28 m in size, and crew members can vary from 20 persons or more (FAO 2013; Fiskeridirektoratet 2017). The primary capture species include herring, cod, capelin, mackerel, saithe, blue whiting, and haddock. A few additional species are caught in smaller quantities, but have a high commercial value such as prawns, Greenland halibut, and ling.

Six major Fishing Gear (FG) types, namely trawls, purse seines, Danish seines, gillnets, longlines, traps/pots, and their associated ropes, are most commonly deployed by the fishers and hence considered for this study. FG is defined as:

> Any physical device or part thereof or combination of items that may be placed on or in the water or on the seabed with the intended purpose of capturing or controlling for subsequent capture or harvesting, marine or freshwater organisms whether or not it is used in association with a vessel (FAO 2016).

The design and material of FGs vary based on the type and purpose of that gear. Plastic polymers (PP, PE, and Nylon) remain the primary building blocks of any FGs, constituting approximately 60–90% of FG material (Deshpande et al. 2019b). Therefore, plastic polymers from FGs are termed as resources in developing management strategies throughout this chapter. Among the total plastic waste entering the oceans, ALDFG is considered as a particularly troublesome waste fraction that may continue to trap marine animals for decades upon release (Laist 1997; Macfadyen et al. 2009). The amount, distribution, and effects of ALDFG have risen substantially over the past decades, with the rapid expansion of fishing efforts and fishing grounds, and the transition to synthetic, more durable, and more buoyant materials used for FG (Derraik 2002; Gilman 2015). In addition to the threat to marine ecology, the loss of fish stocks due to ghost fishing and the expanded cost of valuable resources on lost or abandoned FGs also possess significant economic setbacks (Deshpande and Aspen 2018).

Although ALDFG is the proven most dangerous fraction of marine litter (Brown and Macfadyen 2007), little or no information is available on the regional flows, sources, and fate of plastics from the fishing sector. Jambeck et al. (2015) identify this knowledge deficiency about plastic flows from fishing activities in the quantification of total plastic in marine debris. Lack of scientific evidence resulted in strong dependence on precautionary principles or conservative methods to manage FG resources in coastal countries. The risk of ALDFG accumulation is ever pertinent to countries characterized by a long and productive coastline. The geographic location and a strong dependence on fishing activity make Norway among the most vulnerable countries in the EU-EEA region from the detrimental effects of ALDFG pollution. Consequently, there is a pressing need to build a holistic and systemic understanding of fate, transport, sources, sinks, and end-of-life (EOL) management alternatives of the regional plastic flow from the fishing sector. Additionally, the lack of scientific data on FG resources necessitates the need to incorporate alternative information sources into assessment models.

Therefore, this study aims to showcase how multi-stakeholder inputs can be used to facilitate problem-driven research and generate valuable evidence for managing a system of FG resources in Norway.

14.3 Theoretical Background

Aligning the SES framework presented in Fig. 14.1, the knowledge from stakeholders is deemed essential in obtaining the information for resource management. In the case of the data-less sector, scientists often need to rely on resource users' knowledge to work with the resources under study.

Two theoretical developments explain the need and mean to obtain the missing information from *resource users*, namely *Local Ecological Knowledge* (LEK) (Mackinson 2001) and *Fishers' Knowledge* (FK) (Johannes et al. 2000) relevant to fisheries-related research. These theoretical frameworks are elaborated upon here.

14.3.1 Local Ecological Knowledge and Fishers Knowledge

Resource users develop a comprehensive knowledge of their resources and their environments, and is rarely collected systematically. Scientific attempts to collect such knowledge in highly structured formats can elicit large amounts of information on the ecosystem and its elements (Neis et al. 1999). This type of knowledge is often referred to as *Local Ecological Knowledge* (LEK), where a group of individuals holds a cumulative body of knowledge, often site-specific, about an ecological system (Zukowski et al. 2011). LEK includes the knowledge local people have of nature: their perceptions, classifications, and understanding of ecological dynamics and functions (ethnoecology), as well as their beliefs (Berkes et al. 2000). It is often based on long-term observations of the local ecosystem considering local variations and behavioral patterns, and focusing on essential resources/species of the concerned ecosystem (Ruddle 2000). Practical applications of LEK range from a variety of systems, including but not limited to, small-scale agriculture, horticulture, forestry, and fisheries (Fischer et al. 2015). In applying LEK on fisheries management, Johannes (1982) and colleagues played a crucial role in establishing and documenting the use of LEK in the sector of fishery management through their work between 1980 and 2000 and coined a new term as *Fishers Knowledge* (FK).

In his first documented study on applying FK, Johannes (1984) emphasized the variety and depth of information local fishers possess on marine ecology and conservation, fish behavior/habitats, fishing practices, FG types, and other ecosystem concepts. Further, Johannes et al. (2000) argued that by ignoring such readily available and inexpensive source of knowledge while studying the local system, humanity runs the danger of 'missing the boat' on fisheries sustainability. The information captured through LEK is proven critical for resource management studies, especially in the data-less or data-poor systems.

Although fishers possess a valuable source of information, integrating and translating that information to the science of resource management demands creativity in applying suitable scientific methods (Fischer et al. 2015; Hind 2015). So far, the application of LEK was demonstrated to manage biodiversity and marine protected areas (Johannes 1984; Silva and Lopes 2015), studying fish species, habitats, and catch patterns (Granek et al. 2008; Martins et al. 2018), fishery resource management (Fischer et al. 2015; Ruddle 2000; Silva et al. 2018) and to understand the impacts of fishing methods and equipment (Ratana et al. 2003; Wallner-Hahn and de la Torre-Castro 2017).

In this case study, fishers are identified as key resource users, possessing valuable *information* on the system life cycle stages of commercial FG resources. Therefore, this study contributes to the science of capturing information from fishers' LEK or FK on fishing practices.

14.4 Methods

To develop sustainable management strategies in the case of fishing gear resources in Norway, a stepwise approach is proposed and executed. Figure 14.2 demonstrates the stepwise approach including the identification of information needs, relevant stakeholders, and further collection and validation of data before finally devising the evidence-based strategies for sustainable management of FG resources. The steps are elaborated below.

Step-1: Identify and map the system life cycle of the selected resource

Here, the typical system life cycle of six commercial FGs deployed in Norway is developed and demonstrated by Deshpande and Aspen (2018). The six FGs, namely Trawls, Purse seines, Danish seines, Gillnets, Longlines, and Traps, most commonly deployed FGs by the commercial fishers are selected, and their life cycle stages were identified. The system life cycle is mapped and presented in Fig. 14.3.

Step-2: Define *Information* needed for resource management

Scientific information is the backbone of any resource management strategy. In the terminology of resource management, *information* refers to the real knowledge about stocks, flows, and processes within the resource system, as well as human–environment interactions affecting the system. Information on three critical factors is considered essential in analyzing the performance of the FG resource system.

1. Composition of the commercial fishing fleet and stakeholders.
2. Sources, sinks, and flows of resources throughout the system lifecycle of commercial FGs.
3. End-of-life handling and management of FGs.

After finalizing the lifecycle processes for FGs, Material Flow Analysis (MFA) was considered an apt method for analyzing the system lifecycle sources, flows, and sinks of substance/materials (Brunner and Rechberger 2016). These information needs were identified and elaborated in Deshpande et al. (2020a).

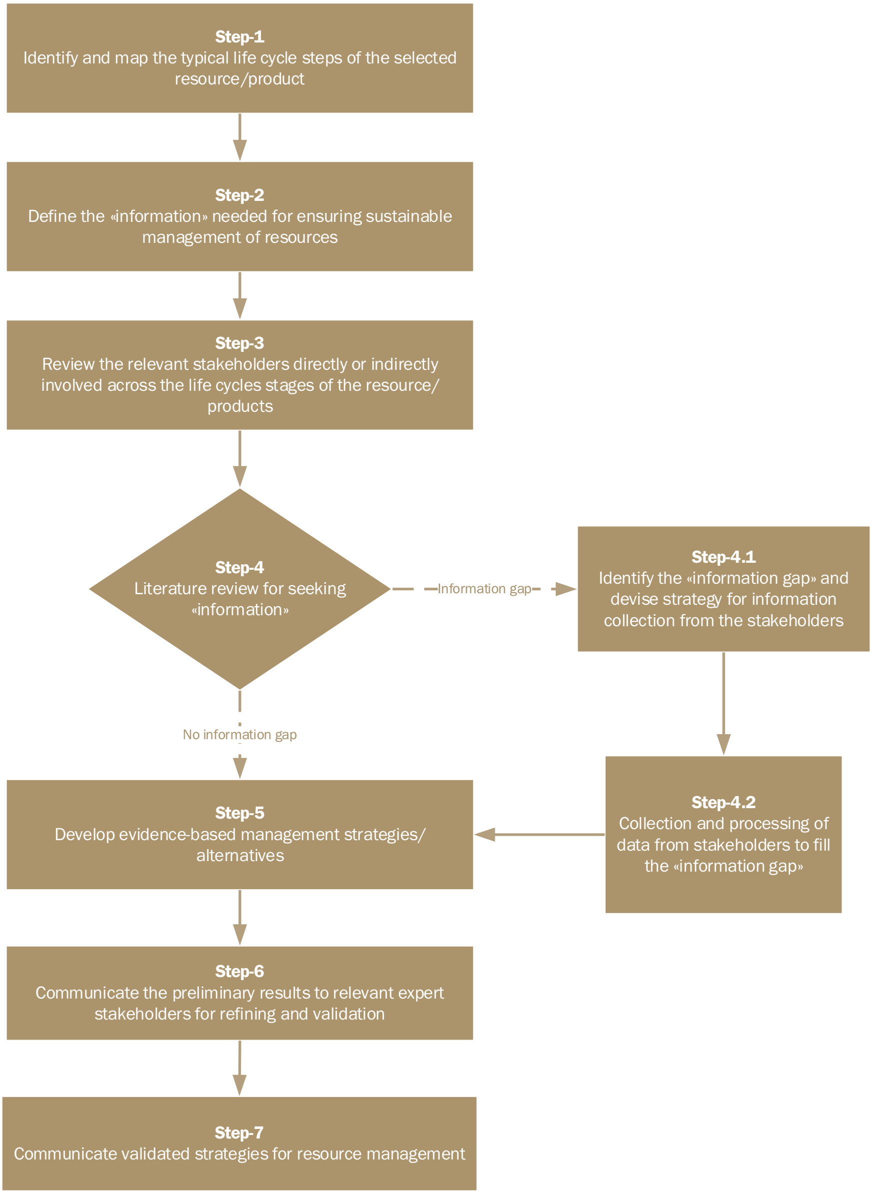

Fig. 14.2 Stepwise framework for evidence-based strategy development using multi-stakeholder perspective

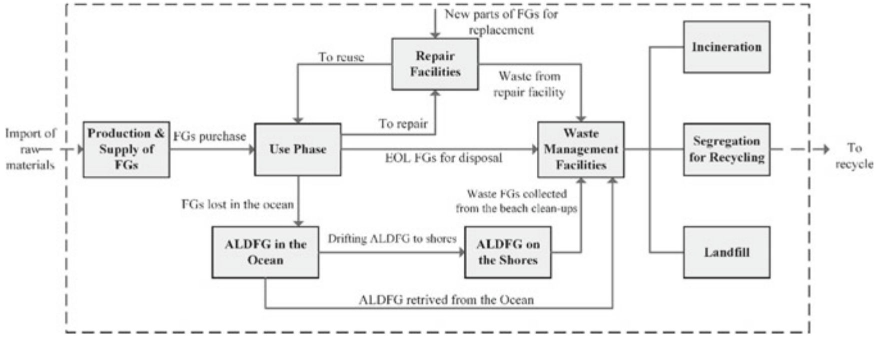

Fig. 14.3 Typical processes involved in the system life cycle of commercial FGs in Norway. (Modified from Deshpande 2020b: 2)

Step-3: Stakeholder mapping

This step involves identifying system stakeholders and mapping their needs. Users and other stakeholders are individuals or groups of individuals who use the resource system in diverse ways for sustenance, recreation, or commercial purposes (Ostrom 2009). The classification and mapping of stakeholders can be carried out in several different ways based on the applicability and relevance to the problem. Here, stakeholders are classified based on their ability to provide information on the processes of the FG system lifecycle as presented in Fig. 14.3. Purchase, use, and EOL are the three main lifecycle phases of FGs. Stakeholders that are directly involved in one or more lifecycle phases are presented in Table 14.1.

Table 14.1 List of stakeholders and their relevance to the life cycle stages of the FG system

Stakeholders'	Pre-use (Purchase)	Use-phase	End-of-life phase	Other
Directorate of fishery			X	
Ports and harbors		X	X	X
Fishers and fishermen associations	X	X	X	X
FG producers/suppliers	X			
Relevant NGO's	X		X	X
Research and consultancy companies and academia			X	X
Waste management companies			X	
Waste collection and recycling companies			X	X

Step-4: Collection of relevant "information"

The information needs defined in Step-2 are met through a comprehensive review of available literature on the fishing sector, fishing patterns, FG waste management, and purchase patterns. However, the overall lack of systematic data on FGs resulted in aggregated or absence of data identified as *essential information*, for developing management strategies for FG resources.

Therefore, in this case, Step-4.1: identification of information gaps and targeting relevant stakeholders and further Step-4.2: devising strategies for data collection were deployed.

Step-4.1: Information gaps and key stakeholders

After the literature review, some of the key information gaps include overall understanding on the handling and management of FGs. Compared to Step-2, the missing information included:

(a) Mass flows of plastics across the life cycle stages of FGs
(b) Norwegian fishers and fishing vessels and organization of commercial fishing activities
(c) Selected FG types owned by a fishing company
(d) Annual purchase patterns for new FGs
(e) Annual repair pattern and frequency of FGs
(f) The typical lifespan of selected FGs
(g) The average annual rate of FG loss in the ocean
(h) Typical end-of-life alternatives for FGs
(i) Typical ocean and beach clean-up operations and mass of fishery-related plastic recovered annually.

As shown in Table 14.1, fishers are identified as key resource users, capable to address the highlighted information gaps, and therefore, methods are used to extract fisher's knowledge (FK).

A systematic survey was designed using the Delphi method to extract fishers' knowledge on the handling and management of six different FGs, commonly deployed by commercial fishers in Norway. Further, the fishers' LEK was then analyzed to quantify the average rates of listed FGs to understand their repair and disposal patterns and to quantify the number of FGs contributing to the ALDFG problem from Norwegian capture fishery. The questionnaire used and collected information is presented in Deshpande et al. (2019a).

For developing circular management strategies, we need information from other stakeholders: FG producers, waste management companies, agencies responsible for beach and ocean clean-up operations in Norway, recyclers, incineration, landfill companies, regulatory agencies, etc. Figure 14.4 demonstrates the list of contacted stakeholders and various methods for collecting relevant information.

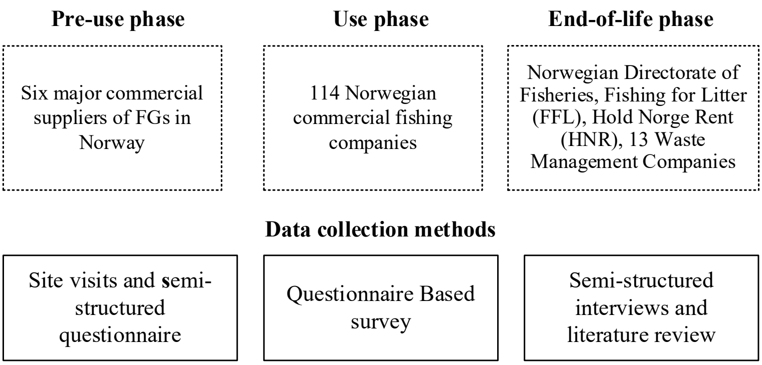

Fig. 14.4 Identification of relevant stakeholders and methods used for collection of relevant information for FG resources management. Modified from Deshpande (2020b)

Step-4.2: Methods for data collection from stakeholders

Survey and Questionnaire

A survey provides a quantitative or numeric description of trends, attitudes, or opinions of a population by studying a sample of that population. From sample results, the researcher generalizes or draws inferences to the population (Creswell and Creswell 2017). Most surveys involve the use of a questionnaire, and Robson (2011) stated three main ways applied for administrating questionnaires:

Self-completion: Respondents fill in the answers themselves.

Face-to-face interviews: An interviewer asks the questions to the respondent or the respondent fills in the questionnaire in the presence of an interviewer.

Telephone interview: The interviewer records the responses from the respondent via telephone conversation.

Here, a questionnaire-based survey was designed and face-to-face and telephone survey methods were used to obtain data from fishers. The details on survey design, administration, and analysis of responses are presented in Deshpande et al. (2019a). Apart from the structured questionnaire, site visits and semi-structured interviews were used to gather additional information from FG producers and waste management companies (Fig. 14.4). The collected data from 114 fishers and other stakeholders were processed using statistical tools and further presented as annual flows of plastic from the Norwegian commercial fishing practices using Material Flow Analysis (MFA) as elaborated in Deshpande (2020b).

Step-5: Develop evidence-based management strategies

In resource management, strategies backed by scientific evidence and stakeholder inclusion are considered robust. Therefore, based on the collected *information*, a set of strategies can be developed. This phase includes mapping of opportunities and barriers of realizing circular management of plastics from the fishing sector of Norway. The preliminary strategy development was conducted and potential strategies are presented in Deshpande and Haskins (2021).

Step-6 and Step-7: Validation and communication

Here, the suggested strategies and findings from the analysis are presented to the relevant expert stakeholders. The *expert judgment* is used to determine the sustainability of suggested management strategies for FG resources in Norway. Finally, the refined and validated strategies are communicated to the relevant stakeholders and regulatory actors for proposed improvement in the system. The suggested strategies, associated challenges, and opportunities are summarized in (Deshpande et al. 2020).

14.5 Lessons Learnt from a Multi-stakeholder Perspective

In designing strategies for circular economy for sustainable FG management, necessary scientific information was either segregated, outdated, or absent. This lack of information on FG system lifecycle processes and flows demanded the use of methods like MFA to help generate key evidence on mass flows of plastics from FGs. However, conducting MFA on FGs was challenging owing to significant variation in all of the six selected FGs. All the quantitative and qualitative information was obtained through several rounds of face-to-face or telephone interactions with stakeholders in the region. The data collection lasted for about 20 months, followed by verification of results through the stakeholders. Verification proved to be a critical step as converting all of the information to a uniform quantitative form resulted in uncertainties. Through verification, the uncertainties were minimized, and robust results were communicated. The results from MFA, where the data were collected from stakeholders ranging from producers, recyclers, fishers, waste managers, waste collectors, beach cleaning agencies, and regulatory actors, are compiled and presented in Deshpande (2020b).

Dealing with multiple stakeholders, and especially fishers, was a distinctive experience. As a primary resource user, fishers possess an abundant source of information, but extracting that information for scientific purposes was challenging. While designing the questionnaire, an emphasis was given on constructing lucid, concise, and apt questions in the local language (Norwegian) with the help of the *Fishers Association in Trondheim* and the *Institute of Marine Research in Bergen* to avoid ambiguity in the questions. The face-to-face survey method was used to minimize confusion in the survey responses. However, uncertainty in survey responses can be attributed to responders speculating while answering specific questions where they lack knowledge. For designing management strategies for FGs, it was important to capture the annual purchase, repair, loss, disposal patterns, and typical life span of FGs. Therefore, survey questions required fishers to summarize the past 10–20 years of fishing practices, which could lead to memory bias and unavoidable subjectivity. Additionally, statistical variations in responses from fishers are due to differences in fishing practices, target species, fishing grounds (coastal or deep-water), fishing quotas, and experience, among other things. The detailed method of data collection and formulas used in estimating the patterns in FG use are discussed in Deshpande et al. (2019a).

Interaction with regional and local waste managers, collectors, and recyclers established that waste FGs could be recycled at the industrial scale using mechanical recycling technology. The mechanical recycling of plastics from EOL FGs results in the production of HDPE and LDPE polymers, the effective use of which has been demonstrated in injection-molding technology by various plastic industries in the Nordic region. Site visits and interviews with industrial stakeholders made clear the possibility of replacing virgin polymers in the production of fish farming brackets and walkways used in the aquaculture sector with recycled polymers from the fishing sector. Currently, plastic producers in the region are exploring these opportunities through pilot projects and physical tests on recycled polymers to establish the industrial symbiotic models, as presented in the study by Deshpande et al. (2020a). The interaction with waste recyclers and collectors also highlighted the barriers in establishing circular strategies for plastics from FGs. Few of the challenges mentioned by the stakeholders are quality of waste FGs, absence of segregation facilities, lack of strong policy drivers allowing landfilling over recycling, and mixed waste resulting in non-uniform quality of recycled plastics. The barriers and opportunities for circular and sustainable waste management of FGs are discussed in the study (Deshpande and Haskins 2021).

14.6 Conclusion

Stakeholders are vital in generating information essential for sound decision-making. This chapter highlights the need for stakeholder and resource user knowledge and its relevance for developing sustainable strategies for resource management using a case of the commercial fishing sector of Norway. The stepwise framework is presented here to identify an overall goal, information gaps, map relevant stakeholders, and propose methods to extract information from them. The developed strategies can then be validated through expert stakeholders to ensure robust decision-making.

The multi-stakeholder perspective was applied using the case of FG resource management in Norway. The successful application of a framework for the case was possible due to the engagement and support of various regional stakeholders. Hence, although subjective and uncertain, the knowledge of resource users (fishers) and other stakeholders was key to generating valuable evidence on the circular management of a resource system previously considered subject to mismanagement due to a lack of scientific knowledge.

In conclusion, involving the resource users, ‘fishers’, through the framework was proven to be an effective strategy for building evidence on FG parameters that are otherwise not measurable. These parameters can be used to estimate regional flows of plastic and other FG materials through material flow analysis (MFA) models. Furthermore, the simplicity of the stepwise method makes it practical and easily reproducible elsewhere to obtain the relevant scientific estimates on studied parameters for respective countries/regions, which is the critical necessity for good science.

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Chapter 15
Concluding Remarks

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It is clear that there is an urgent need for coordinated and considered efforts to mitigate the impact of end-of-life (EOL) and derelict fishing nets and associated gear. Over the last decade, there has been a significant increase in awareness of the impact of discarded fishing nets, which cause negative impacts on marine life, ecosystems, human health, and the economy. Despite the increased awareness there remain multiple and significant knowledge and data gaps. Collectively, we are still missing vital information on the source, distribution and fate of marine plastics, and their impact on species, particularly at a population level. There are numerous reports of individuals becoming entangled or ingesting plastics, causing injury or mortality (e.g. see Chap. 1). However, a comprehensive understanding of the scale of the impact of marine plastics, put into context with other threats and pressures faced by marine species, and how this is changing over time, currently eludes us. There are several approaches which can help inform and fill these gaps. For instance, the use of citizen science (see Chaps. 1 and 8) is proving invaluable in providing data on the distribution and type of plastics in the environment particular, whilst remote sensing (mentioned in Chap. 1) has the potential to significantly increase the ability to identify environmental plastics hotspots. Both citizen science and remote sensing are likely to be increasingly important approaches in the future, with the potential to help locate and target cleanup operations and enable the return of a great deal more plastics to the economy.

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An additional issue with fishing nets is that they are a vector for micropollutants. Fishing nets are primarily made of plastics, which have been shown to absorb micropollutants, including metals (Chap. 11). Measuring the concentration of metals on used fishing nets is important in understanding the pathway into the marine food web, with potential implications for human health. The level of metals accumulated on fishing nets also has consequences for the reuse, recycling, and upcycling of this material and could be a prohibitive barrier in certain circumstances. However, at present the fishing nets in Greenland have metal content at acceptable levels, potentially allowing reuse as a low-cost water treatment and in building materials (Chap. 12).

Identifying existing and emerging hotspots of marine plastic can assist the accumulation of material with a view to material being recycled or otherwise used or processed. This material could be used in addition to end-of-life fishing nets at known locations, for example at port facilities, or in established collection streams. Understanding the amount and type of material that is available for recycling, and the rate at which fishing nets reach end-of-life, is vital to enable and inform the development of sustainable business models. The Drivers, Pressures, States, Impacts, and Responses framework for abandoned, lost, or otherwise derelict fishing gear (DAPSIR-ALDFG) outlined in Chap. 2 provides a model allowing a better understanding of how aquaculture and commercial fishing industries in Norway impact. This model could be used by policy makers to inform and prioritise actions and circular economy tools to reduce negative impacts and enable sustainable business models. The model can also be tailored and implemented in other countries and regions.

In addition to the need to further identify the presence and impact of marine plastics, there is a pressing need to increase sustainability of fishing gear and develop end-of-life and second life solutions. In many instances, sustainability can be achieved through the movement towards a more circular economy and the formation and the implementation of sustainable business models. Chapter 4 provides insights on the level of circularity of SMEs within the marine plastic recycling value chain in the north-western part of Norway. Advancing fishing gear sustainability and implementing circular economy tools is particularly important for regions such as the Northern Periphery and Arctic region (Chap. 3), which has vast coastlines, important fishing industries, few large urban areas, and is predominantly composed of remote regions. Developing sustainable business models and a circular economy for fishing nets for such reasons is particularly challenging, as there are often large distances from the sources of disposed and/or end-of-life material, and recycling facilities and business infrastructure. To enable circularity, the value chains need to become more mature and reliable, and there is a problem as discovered in Chap. 6 that the current regional cluster for fishing nets in Norway is at an early stage and suffers from the deficiency imposed by insufficient reverse-chain relations. There is a need to identify best practice of collecting and handling EOL fishing gear, ghost gear and beach debris, and Sotenäs Marine Recycling Centre (SMRC), in Sweden seems to be just such a case. The marine recycling centre is seen as a pioneer on its field in the Nordic Countries, and the centre has a lot of expertise regarding collection, sorting and recycling of fishing gear since their start-up in 2018. Sotenäs operations are described in Chap. 10.

However, remote and rural regions also represent opportunities, with residents often invested and active in the protection and clean-up of their home region. This is exemplified in Chap. 9 where the findings revealed that value chain collaboration between SMEs and NGOs stimulate innovation in the local environment and within the industry and thus enhances recycling of marine plastics. For entrepreneurs and SMEs to enter the recycled fishing gear industry, there needs to be a viable business opportunity, in other words there must be a large enough target customer group for these products who are willing to pay the price for more sustainable products. Chapter 13 studies the purchase intentions for consumers for greener products. If the appropriate steps can be made concerning the implementation of business models, with supporting policy and initiatives, the NPA-region could become a flagship for a circular economy surrounding fishing gear. In particular, Norway appears to be leading the way in several areas. One of these is in the reporting of lost fishing gear. Another is in the engagement of stakeholders in developing a strategy for fishing gear resource management (Chap. 14). National Circular Economy policy developments are on the increase in Europe, and these are likely to present significant challenges for the sector, but may also highlight new opportunities for the development of new circular business models for fishing gear across its life cycle (Chap. 5). Opportunities continue to present themselves for the further development of products reusing fishing gear and using recycled polymers from waste and end-of-life fishing gear in new applications within or outside of fishing sector. Recycling opens up the possibility to add a positive value to the plastic waste and can thus be a key to avoiding discharge in the environment. It is important, however, to understand the environmental impacts of recycling processes to avoid problem shifting, and with life cycle assessment as tool it was found that production of recycled PP/PE granulate compares favorably with the production of virgin PP and PE (Chap. 7). Another option other than producing granulates for valorizing the discarded nets, can be to use shredded nets as fibre reinforcements in construction materials, e.g. for reinforcement of earth-based adobe bricks (Chap. 12). The encouraging results point at the potential to be explored in the use of fishing nets for reinforcement of, or in, other types of (construction) materials. The work in the chapters originates from the Circular Ocean and Blue Circular Economy projects, and a holistic approach (as in these projects) is necessary to find solutions to the on-going challenge of discarded fishing gear. This book is thus a contribution to the understanding of the current practice for collecting and handling EOL fishing gear in the NPA area, whilst demonstrating a future need for more elaborate practices of such collection and handling. It is therefore both apparent and imperative that relevant stakeholders are prepared and ready when legislative changes (such as extended producer responsibility and EU port reception facilities directives) come into force.