Chapter 17
Application of Material Flow Analysis: Mapping Plastics Within the Fishing Sector in Norway

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Abstract Plastic in our marine environment is now ubiquitous. Abandoned lost or otherwise discarded fishing gear (ALDFG) is of particular concern due to its ability to continue to function as a trap for marine organisms. In order for decision makers to act on this grave issue, we require data on the flow of ALDFG into the marine environment. One key tool for revealing the flow of material within a specific system is Material Flow Analysis (MFA). MFA takes a life cycle approach (cradle to grave) to assess energy or material flows in a system within space and time boundaries. It can be applied at multiple levels from the industrial process level to the national level. This chapter presents a case study of an MFA conducted on fishing gear in Norway. The MFA methodology was used in this case study to assess the flow of plastic fishing gear from production through to recycling, final disposal or loss to the marine environment. Data was collected for the MFA through stakeholder interviews, literature reviews and analysis of government data sets. The MFA revealed that around 4000 tons of plastic fishing gear enters the system in Norway and around 400 tons enter the marine environment each year. An analysis of the implications of the MFA for the key actors within the life cycle chain of fishing gear is presented and a short description of the links between MFA and the circular economy and sustainable development is provided. Furthermore, the relevance and implications of using MFA tool for policy making at national and regional level is discussed and elaborated while associated challenges are presented here.

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17.1 Introduction

Marine plastic pollution is now seen as a threat to the safe operating space for humanity, due to its persistence within the marine environment and its ubiquity (Villarrubia-Gómez et al. 2018), being found in all environments from coastal soil substrates (Cyvin et al. 2021) to the digestive systems of marine species (Gall and Thompson 2015). 8300 million metric tonnes of plastic have been produced since the 1950s, with only 9% being recycled and the majority either lost to the natural environment or landfilled (Geyer et al. 2017). The first recording of plastic in the marine environment was made in 1957 with recordings growing substantially since the 1990s. (Ostle et al. 2019). Jambeck et al. (2015) have estimated that between 4.8 and 12.7 million tonnes of plastic entered the marine environment in 2010 and predict that between 10.4 and 27.7 million tonnes of plastic will enter the marine environment in 2025, if no strategies are implemented to reduce the mismanagement of plastic waste streams on land. A more recent study by Borrelle et al. (2020) predicts that annual emissions of plastic waste to aquatic systems (freshwater and marine) could reach 53 million tonnes by 2030, even when considering current government commitments made to improve the waste management system.

One significant omission from the studies by Jambeck et al. (2015) and Borrelle et al. (2020) was plastic entering the marine environment directly from marine industries, such as *abandoned, lost, or otherwise discarded fishing gear* (ALDFG). ALDFG is a major concern for the marine environment due to its design properties. Fishing gear (FG) is designed to capture or kill and to persist in the natural environment and it continues to meet these design requirements when lost in our seas and oceans (Deshpande and Aspen 2018). Therefore, calculating the volume of ALDFGs entering the marine environment is critical to help policy and decision makers design practical solutions to solve the issue.

In resource management terminology, *information* refers to the fundamental knowledge about stocks, flows, and processes within the resource system as well as about the human-environment interactions affecting the system (Ostrom 2009). Highly aggregated information may ignore or average out local data essential to identifying future problems and developing sustainable solutions. FGs are resources in the fishing sector, and literature suggests the overall unavailability of data and monitoring methods to provide sound scientific information on the amount of plastics in ALDFG that enter the ocean and is available after end-of-life (EOL) collections (Deshpande 2020).

At present, plastics generally follow a linear economy model, where products have a single lifecycle: virgin material is used to produce products that are then sent for disposal in landfills or directly into the natural environment for most of these products. The circular economy (CE) approach presents an alternative model where materials are given several lifecycles, through the 9Rs framework, for example: reuse, reparation, recycling and more. The CE model is hailed by the EU and other international bodies as a solution to the issue of plastic pollution (EC 2018). One of the key tools for generating evidence for the CE strategies is Material Flow Analysis

(MFA). (Brunner and Rechberger 2016) define MFA as "a systematic assessment of the flows and stocks of materials within a system defined in space and time". MFA can be used to reveal the stocks and flows of valuable resources within a system to help industry and businesses, such as plastic recyclers, understand the potential for developing an economically valuable solution.

To build robust resource management strategies and realize sustainable CE opportunities that are capable of utilizing untapped resources across regions, it is essential to know the amount of plastic available for recycling from the fishing sector (Deshpande and Aspen 2018). The following case study presents the application of MFA tool to estimate the flows of plastic polymers from fishing process or activity as presented in Level 1 of the CAPSEM Model.

17.2 Mapping Plastics from Processes Within Fishing Sector

The basic principle of MFA is the conservation of matter and energy in isolated systems, delimited by boundaries of time and space and following the mass-balance principle (Brunner and Rechberger 2016). As explained in the CapSEM Model, MFA is a valuable tool for assessing material and energy flows from the processes and/or industrial sector. Typically, MFA of a selected substance includes the main life cycle stages namely, mine, production, manufacturing, use, maintenance and disposal. The in-depth methodology of MFA is presented in Part II Chap. 5. This case study presents, and elaborates upon, the successful application of MFA method in mapping life cycle processes from the fishing sector and thereby measure the loads of plastic from fishing practices in Norway.

In applying MFA, (Deshpande et al. 2020) studied six major commercial FG types, namely trawls, purse seines, Danish seines, gillnets, longlines, traps/pots and their associated ropes, deployed by the Norwegian commercial fishing fleet. The data was further collected from gear producers, suppliers, fishers (Deshpande et al. 2019), collectors, authorities, and waste management facilities within the region to model the flows of plastics polymers, polypropylene, polyethylene, and Nylon, which are used as the building blocks of advanced gears (Brown and Macfadyen 2007). Data was primarily collected using published literature, government statistics, and interviews of stakeholders. Table 17.1 presents the stakeholder involved and the type of information obtained from each stakeholder category during the period of 2018–2019.

The study focuses solely on the system of the Norwegian commercial fishing fleet, through both use and post-use processes. The recreational fishing and foreign fishing vessels operating in Norway are neglected. FGs are defined using an expansive definition proposed by FAO. According to FAO, FG are 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). Throughout the text, the term *plastics* includes polyethylene (PE), polypropylene (PP) and Nylon (PA). Although the FG unit contains other materials such as metals, lead, polyvinyl chloride (PVC) and wires, plastics constitute around 60–90% of any gear type. Therefore, plastic polymers from FG are treated as resources in developing management strategies throughout this study. A static MFA model was built to present the 2016 stocks and

Table 17.1 Summary of relevant information obtained from MFA on each stakeholder across the life cycle of fishing gear and its potential application

Stakeholder category	Data obtained *for* MFA model from stakeholders	Information provided to stakeholders from MFA study	Application
Gear producers	Annual quantities of FGs sold and material components of each FG type	Amount of FG sold of each type, The market/demand for each type of FGs, The typical tendencies of repair and reuse Need for material improvement for ease in recycling	Development of new FG design suitable for recycling Assessing need for building repair facilities for fishers
Fishers (resource users)	Typical life span of FGs, repair and disposal patterns, purchase patterns and typical rate of FG loss in the ocean upon deployment	The typical life span of FG types The FGs types more vulnerable to get lost in the ocean upon deployment The typical repair patterns of various FG types	Developing best practice guide for handling and management of FG types
Beach clean-up programme	Typical amount of FGs plastic collected through beach clean-up surveys	Efficiency of clean-up operations Need for effective and efficient data management plan	Best practice guide for effective classification and reporting of collected waste items
Regulatory actors	Typical amount of FGs plastic collected through ocean clean-up surveys	Efficiency of clean-up operations Data on potential hotspots for leakage of plastics in the environment Information for effective policy making	Suitable regulatory response for management of plastics from fishing sector
Waste management companies	Typical volume of waste FGs handled annual by WMCs, typical fate of waste FGs (sent to recycle, incineration or landfilling)	The typical handling patterns of waste FGs The amounts of waste FGs generated every year	Best practice guide for waste managers for effective segregation of waste FGs to improve recycling

(continued)

Table 17.1 (continued)

Stakeholder category	Data obtained *for* MFA model from stakeholders	Information provided to stakeholders from MFA study	Application
Recyclers	Typical challenges in FG recycling	The amounts of waste FGs generated every year The typical rate of recycling of FGs Challenges in FG recycling The amounts of recycled polymers produced every year	Considering business case of recycling Improvement in infrastructure for recycling within the region

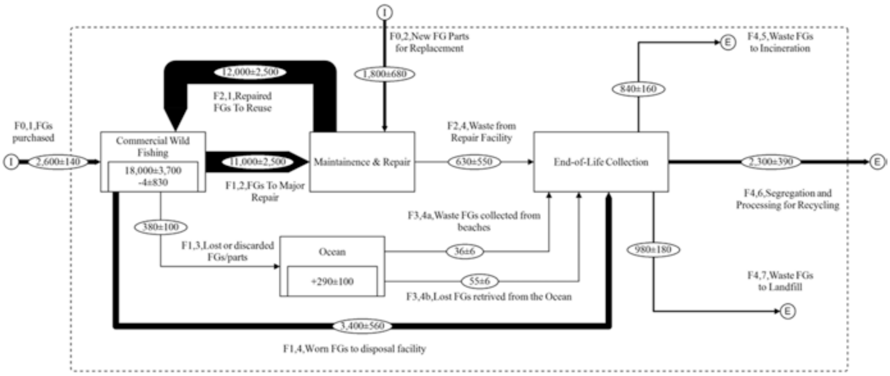

Fig. 17.1 MFA of plastic (PP, PE, and Nylon) from six fishing gears used by the commercial fishing fleet of Norway in 2016 (tons/year). (Adapted from Deshpande et al. 2020)

flows of plastics from FGs because of the maximum data availability obtained through data collection rounds. Primary modelling and flow calculations were performed in Microsoft Excel, while STAN v2.6.8 was used for further data reconciliation (Vienna University of Technology, Vienna, Austria).

Figure 17.1 presents the typical MFA model depicting the annual flow of plastics from the fishing sector of Norway (Deshpande et al. 2020). The results summarize that around 4000 tons of plastics enter the system as new FGs or FG parts every year in Norway. The fishing activity results in leakage of 400 tons of FGs as ALDFG upon deployment during the use phase. The beach and ocean clean-up operations cumulatively remove around 100 tons of ALDFG, resulting in the stockpiling of 300 tons of ALDFG every year from the commercial fishing practices alone. Additionally, MFA reveals that about 4200 tons of waste FGs are collected at the waste management facilities in Norway, out of which only about 50% are segregated and sent for further recycling, whereas 25% are sent to landfilling and for incineration purposes within Norway.

17.3 Application of MFA in the Context of the Circular Economy and Sustainable Development

MFA is routinely applied at multiple levels of governance. At the national level, economy-wide Material Flow Accounts are reported annually by the EU-27 to Eurostat. These accounts are in turn used as indicators of progress towards the EU's Circular Economy Action Plan, such as circularity rate (CGRi 2021), recycling rate, etc. MFA is also used as a methodology to calculate progress towards multiple indicators to meet the SDG targets. For example, MFA is used to calculate progress towards a decoupling of the economy from the material footprint in SDG 8, target 8.4 through material consumption and production rates. At the city level, MFA is a standard methodology for calculating the flows of material and energy through different sectors within a city. MFA can highlight opportunities for cross-sector collaboration, whereby the material output from one sector can be utilised by another (Kick-starting circular cities and regions in Scotland: Glasgow (Del Sordo 2019).

Furthermore, the ISO 14000 series on Environmental Management now includes two standards for Material Flow Cost Accounting (a version of MFA which includes calculation of economic costs of energy and material flows), ISO 14051 and ISO 14052. The ISO standards have now set up a technical committee for the development of circular economy ISO standards which may also include reference to the MFA methodology. Several studies, including regional and industrial sectoral analyses, highlight MFA-based studies' application to define pathways toward circularity (Franco 2017; Huysman et al. 2017).

The case of fishing gear presented here is a good example of an industry/sector level MFA and further illustrates how findings from MFA can aid informed decision-making at the regional level. Table 17.1 illustrates how MFA is calculated and utilized by different stakeholders across the life cycle of fishing gear and provides possible applications resulting from the MFA data. This type of MFA is beneficial for a range of actors in the fishing gear value chain (Table 17.1). Private sector actors, such as Gear Producers, benefit from information on the market demand for fishing gear. Regulatory bodies are provided with information on the hotspots for fishing gear losses to the environment. Environmental non-governmental organizations (NGOs), such as beach cleaning groups, benefit from data on the effectiveness of clean-up programmes.

Stakeholder Dependency for Data Collection

MFA requires intensive data collection from key stakeholders. As MFA maps the system life cycle of a selected product/process and tracks the material of interest from production to its end of life, it demands quantitative and qualitative information from various actors involved directly or indirectly with the system under consideration (Deshpande and Haskins 2021). Therefore, practitioners must invent or adapt methods to extract information from resource users, regulatory actors, published or unpublished literature, datasets, waste management companies, and other relevant information providers. Table 17.1 illustrates how the information was gathered in the case of FG resource management in Norway and which stakeholders were involved.

Systematic monitoring and availability of data on material and energy streams by government and private actors would help to make MFA more accessible to companies. Academia and the private sector can work to develop more accessible software for companies. Industry-relevant research, such as the research in this case study, is a valuable source of information for businesses across the value chain. However, it is essential that research is made accessible to the private sector through open-source publishing.

17.3.1 Practical Possibilities and Obstacles for Companies for Using MFA

Any company can use MFA for mapping energy and material footprint. The information that MFA provides companies with, can help them map where they are losing energy and material from in their value chain. This in turn, can be used to develop a circular economy and sustainable development targets. Data availability is a barrier for applying MFA at the company level resulting in higher costs initially.

Conducting MFA, therefore, may prove time and resource-consuming, but in hindsight, it provides a holistic understanding of the various processes and systems that further aid in developing policies for sustainable resource management. Table 17.1 summarizes information obtained from MFA results for each stakeholder group and how these groups can apply the findings from MFA to improve the system of FGs in accordance with the CE strategies.

17.4 Concluding Remarks

As discussed in Part II, the MFA tool provides in-depth understanding of the various processes and causative factors across the system life cycle of the selected resource/substance. The need for quantitative information demands integration of all the necessary tools and scientific methods (qualitative and quantitative) to obtain data essential to model the processes within the given system. The relevant information, if absent, in official documentation or databases, must be obtained through field visits and subsequent contacts with the stakeholder groups which further improves the understanding of the resource system. The data collection procedures, implemented to gather essential information from fishers and associated challenges and benefits are summarized in Deshpande et al. (2019).

References

Borrelle SB, Ringma J, Law KL, Monnahan CC, Lebreton L, McGivern A, Murphy E, Jambeck J, Leonard GH, Hilleary MA, Eriksen M et al (2020) Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369(6510):1515–1518. https://doi.org/10.1126/science.aba3656

Brown J, Macfadyen G (2007) Ghost fishing in European waters: impacts and management responses. Mar Policy 31(4):488–504. https://doi.org/10.1016/j.marpol.2006.10.007

Brunner PH, Rechberger H (2016) Handbook of material flow analysis: for environmental, resource, and waste engineers. CRC Press, Boca Raton. https://doi.org/10.1201/9781315313450

CGRi (2021). Circularity gap report 2021. Available via https://www.circularity-gap.world/2021. Accessed 14 Sept 2022

Cyvin JB, Ervik H, Kveberg AA, Hellevik C (2021) Macroplastic in soil and peat. A case study from the remote islands of Mausund and Froan landscape conservation area, Norway; implications for coastal cleanups and biodiversity. Sci Total Environ 787:147547. https://doi.org/10.1016/j.scitotenv.2021.147547

Del Sordo E (2019) Circular cities: learning from Glasgow. The Urban Media Lab, Rome. Available via https://labgov.city/theurbanmedialab/circular-cities-learning-from-glasgow/. Accessed 14 Sept 2022

Deshpande PC (2020) Systems engineering for sustainability in the life cycle management of commercial fishing gears. Dissertation, NTNU, Trondheim, Norway

Deshpande PC, Aspen DM (2018) A framework to conceptualize sustainable development goals for fishing gear resource management. In: Leal Filho W (ed) Handbook of sustainability science and research. Springer, Cham, pp 727–744. https://doi.org/10.1007/978-3-319-63007-6_45

Deshpande PC, Haskins C (2021) Application of systems engineering and sustainable development goals towards sustainable management of fishing gear resources in Norway. Sustainability 13(9):4914. https://doi.org/10.3390/su13094914

Deshpande PC, Brattebø H, Fet AM (2019) A method to extract fishers' knowledge (FK) to generate evidence for sustainable management of fishing gears. MethodsX 6:1044–1053. https://doi.org/10.1016/j.mex.2019.05.008

Deshpande PC, Gaspard P, Brattebø H, Fet AM (2020) Using material flow analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. Resour Conserv Recycl 5:100024. https://doi.org/10.1016/j.rcrx.2019.100024

EC (2018) A European strategy for plastics in a circular economy. Available via https://ec.europa.eu/environment/pdf/circular-economy/plastics-strategy-brochure.pdf. Accessed 14 Sept 2022

FAO (2016) Report of the expert consultation on the marking of fishing gear. FAO fisheries and aquaculture report no. 1157. Rome, Italy. Available via https://www.fao.org/3/i5729e/i5729e.pdf. Accessed 14 Sept 2022

Franco MA (2017) Circular economy at the micro level: a dynamic view of incumbents' struggles and challenges in the textile industry. J Clean Prod 168:833–845. https://doi.org/10.1016/j.jclepro.2017.09.056

Gall SC, Thompson RC (2015) The impact of debris on marine life. Mar Pollut Bull 92(1–2):170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

Geyer R, Jambeck JR, Law KL (2017) Production, use, and fate of all plastics ever made. Sci Adv 3(7):e1700782. https://doi.org/10.1126/sciadv.1700782

Huysman S, De Schaepmeester J, Ragaert K, Dewulf J, De Meester S (2017) Performance indicators for a circular economy: a case study on post-industrial plastic waste. Resour Conserv Recycl 120:46–54. https://doi.org/10.1016/j.resconrec.2017.01.013

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015) Plastic waste inputs from land into the ocean. Science 347(6223):768–771. https://doi.org/10.1126/science.1260352

Ostle C, Thompson RC, Broughton D, Gregory L, Wootton M, Johns DG (2019) The rise in ocean plastics evidenced from a 60-year time series. Nat Commun 10:1622. https://doi.org/10.1038/s41467-019-09506-1

Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325(5939):419–422. https://www.science.org/doi/10.1126/science.1172133

Villarrubia-Gómez P, Cornell SE, Fabres J (2018) Marine plastic pollution as a planetary boundary threat–the drifting piece in the sustainability puzzle. Mar Policy 96:213–220. https://doi.org/10.1016/j.marpol.2017.11.035