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# In the business of dirty oceans: Overview of startups and entrepreneurs managing marine plastic

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ABSTRACT

Plastic pollution, especially in marine environments, is a global problem that is currently inadequately managed. Solutions for marine plastic can occur through policy, behavior change and infrastructure improvements, but also through entrepreneurial ventures and technological innovations. Currently, information about these ventures and innovations is scattered and lacks coherence. This study presents the first comprehensive overview of entrepreneurial and SME led solutions for marine plastic by analyzing a database of 105 SMEs categorized into four functions: prevention, collection, transformation and monitoring. We find that small businesses are successfully commercializing goods and services to reduce the damage of plastics on the marine environment through innovative business models, with a steep growth of startups founded between 2016 and 2019. However, efforts to manage marine plastic are still underdeveloped in many areas, including microplastic management and monitoring. Practitioners, policymakers and researchers can utilize the database to identify solutions, best practices, synergies and avenues for further research, such as quantifying the environmental impacts of this industry.

## 1. Introduction

In the last decade, plastic pollution has become a global concern, especially in terms of the deleterious impacts it has on marine and coastal environments. However, plastic is a ubiquitous material, and production continues to grow in spite of increasing awareness of the problems caused by plastic (Nielsen et al., 2020). Due to uncertain, complicated and interlinked impacts of plastic use and disposal, plastic pollution has been deemed a 'wicked' problem: a problem without clear solutions, and where solutions themselves are uncertain, contain externalities and may trigger rebound effects (Landon-Lane, 2018).

Tackling wicked problems requires a variety of top-down and bottom-up initiatives introduced by a range of stakeholders. For plastic pollution, this can mean corporations increasing recycled content, governments enacting bans or improving waste management, universities researching new materials, civil society groups raising awareness and consumers choosing different products (Napper and Thompson, 2020; Prata et al., 2019; Schnurr et al., 2018). Wicked problems are by definition unable to be completely solved, and therefore managing plastic pollution will not depend on a 'silver bullet' solution but instead on advances on multiple fronts, gradually and experimentally working towards more sustainable plastic management (SPM) (Landon-Lane, 2018).

Sustainable plastic management can be spearheaded by entrepreneurs and startup organizations, which tend to be more flexible and radical than traditional companies, and move faster than governments or civil society organizations (Dijkstra et al., 2020; Hockerts and Wüstenhagen, 2009; Jambeck et al., 2018; Schnurr et al., 2018). Sustainable entrepreneurship literature has shown that startups have the power to improve industries via the introduction of new technologies and business models (Burch et al., 2016). Transition research recognizes startups as niche innovators, who can build momentum towards more sustainable socio-technical systems and force incumbents to adapt (Hörisch, 2015; Kemp et al., 1998). In recent years, numerous accelerators, incubators, grants and innovation awards have been dedicated to the issue of marine plastic pollution. This corresponds with a surge in enterprises focused on marine plastic management (MPM), some of which have gone viral and attracted widespread media attention.

Though the industry is growing, there has been little academic research focused on MPM from the innovation or sustainable entrepreneurship perspective. Literature thus far has focused on mapping the problem of marine plastic pollution or analyzing policy responses (see

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Karasik et al., 2020 for a comprehensive overview), but largely ignored entrepreneurial solutions or discussed them only generically (Mendenhall, 2018; Napper and Thompson, 2020). A recent proposal of 100 critical ocean research questions to support sustainable development goals included the question 'how best can we identify and implement solutions to reduce plastics in the ocean?' (Wisz et al., 2020). This paper begins to answer that question by providing an industry overview of startups and small businesses providing solutions to marine plastic. We consider a company part of the MPM industry if their main product or service minimizes the damage of plastic to the marine environment. This study will answer the following questions.

- What is the current state of startups and SMEs active in marine plastic management?
- Are there typical groups of marine plastic management startups and SMEs?
- What innovations do these companies bring to the market?

This paper is structured as follows. Section 2 reviews the main concepts and theories that informed the design and implementation of the study. Section 3 introduces the methodology, including data collection and analysis. The results are presented in Section 4, including a quantitative and qualitative description of typologies and trends identified from the sample. Finally, we summarize the conclusions of this study, identify limitations and provide suggestion for further research in Section 5.

## 2. Concepts and theories

This section provides an overview of research on the concepts of business models, innovation and sustainable entrepreneurship, and relates these concepts to the theory of sustainable transitions.

### *2.1. Business models and innovation*

Business models are frameworks that can be used to understand and communicate how a firm operates and creates value by breaking down a business into key functions and elements. The business model concept was developed to describe new business structures that emerged with the rise of e-business (Amit and Zott, 2001), but has since been widely applied to companies involved in sustainable development (Lüdeke-Freund and Dembek, 2017). Sustainable-oriented companies produce different types of values – economic, environmental and social – for stakeholders beyond the customer or end-user (Brehmer et al., 2018).

One important study of sustainable business models led to the development of archetypes by Bocken et al. in 2014. These eight archetypes, which already form a widely applied categorization tool, have been validated and extended in subsequent studies, for example the development of archetypes for the banking sector, renewable energy industry and product-as-a-service businesses (Bocken et al., 2014; Bryant et al., 2018; Yang and Evans, 2019; Yip and Bocken, 2018). These archetype studies find that groups of similar business models deploy similar strategies for creating and capturing value, and typologies can therefore serve as a reference frame for academics and practitioners (Lüdeke-Freund et al., 2018; Yang and Evans, 2019). In a similar vein, scholars have called for the development of sustainable business model pattern languages. A shared language can be used to communicate, experiment and support the identification of potential business solutions for sustainability challenges by providing a 'tool box' of opportunities (Lüdeke-Freund et al., 2019; Zufall et al., 2019). Our research adopts these perspectives and is the first study that introduces a typology of business model tools available to manage marine plastic.

Innovation is a topic frequently studied alongside sustainable business models (Geissdoerfer et al., 2018). Innovations implemented by businesses can be viewed as a way to increase competitive advantage, but also a means to improve environmental or social sustainability. Innovations have supported the transition towards renewable energy technologies, the uptake of circular economy principles and improvements to the well-being of stakeholders involved in the value chain (Diaz Lopez et al., 2019; Durán-Sánchez et al., 2018; Sarasini and Linder, 2018). Deploying a business model innovation may require new technologies, activities and can change relationships with customers, partners and other stakeholders. In this study, we consider innovations brought by businesses as social or as technological. Social innovation, on the one hand, is defined by Witkamp and colleagues as 'a new way of doing business, or a new way of pursuing social goals' (Witkamp et al., 2011, p. 669). Considering plastic, an example is a business developing returnable cup systems to replace single use plastic to-go cups (Cottafava et al., 2019). Technological innovation, on the other hand, can be the introduction of new technology, improvements to existing technologies, or creatively applying existing technologies to novel contexts. In the plastics industry, development of bioplastic polymers, which can be made from renewable materials and have biodegradable properties, are technological advances (Oroski et al., 2018).

### *2.2. Sustainable entrepreneurship and transitions*

Since the concept of 'green' or sustainable entrepreneurship emerged in the 1990s, studies have grown steadily (Muñoz and Cohen, 2018). Sustainable entrepreneurship is defined as the pursuit of creating a successful, new business, while also providing environmental and social benefits to a range of stakeholders (Lüdeke-Freund, 2020; Spieth et al., 2019). Examples of research in this field include the enabling conditions for sustainable entrepreneurs (Gast et al., 2017), typologies of entrepreneurs (Spieth et al., 2019), ecopreneurial business models (Jolink and Niesten, 2015), and motivations of entrepreneurs (Dickel, 2018; Vuorio et al., 2018).

A complementary stream of literature has developed around the sustainability of small and medium sized enterprises (SMEs), with the recognition that SMEs are different in some ways from startups and entrepreneurs, but also share similarities. SMEs may be more established and experience more lock-in to existing business practices and behaviors than startups. However, SMEs are by definition smaller and more flexible than corporations and have a variety of motivations beyond financial gains (Burch et al., 2016). Klewitz and Hansen identify a continuum of sustainability oriented innovation of SMEs, and find that sustainability-rooted or innovation-based SMEs are more likely to engage in innovative practices, whereas anticipatory, reactive or resistant SMEs only do so in response to external pressures such as regulations or competition (Klewitz and Hansen, 2014). Startups and small businesses can be more flexible, innovative or radical than large corporations, while on the flipside they struggle with accessing capital, having limited capacity and achieving financial viability (e.g. surpassing the 'valley of death') (Burch et al., 2016; Cantele et al., 2020; Gast et al., 2017; Schaltegger et al., 2016; Yadav et al., 2018).

Startups and small businesses are important actors to study, as they can play key roles in sustainability transitions (Burch et al., 2016; Hörisch, 2015). Sarasani and Linder summarize that the two main forces supporting or blocking transitions are first of all sources of inertia, contributing to lock-in and stability, and secondly sources of change, which can be disruptive and catalyzing (Sarasini and Linder, 2018). Startups and SMEs can be sources of change if they introduce new technologies or business model innovations that disrupt the current stability of the regime. Conversely, conventional startups and SMEs can be considered sources of inertia if they maintain unsustainable business practices and outcompete more radical sustainable companies for customers and investments.

Given recent international and national efforts to manage plastic pollution, mitigate marine plastic and move towards a circular economy, startups and SMEs are an interesting sample to analyze, as they are flexible, produce disruptive innovations and prioritize sustainability goals (Henry et al., 2020). However, in order for widespread system change to occur, innovations and technologies need to be commercially available and widely applied. To date, little is known on the spread and availability of solutions for marine plastic globally. Therefore, we analyze the types of innovations introduced by startups and SMEs, the level of commercial development, and where the companies are located and active. Further, we characterize the marine plastic managed by the businesses. This includes codes for macroplastic, microplastic or both, as well as categories of polymers. In doing so, we can determine if there are strategies available for all types of marine plastic and where there are gaps. We will then be able to comment on the applicability of startups and SMEs as solution providers for MPM.

## 3. Methodology

Our research seeks to analyze the status of the emerging MPM industry, describe innovations deployed and consider qualitative trends. Therefore, we analyze multiple case studies, which is a frequently applied methodology in business model and entrepreneurial research. On the one hand, the multiple case studies method allows for an understanding of individual cases, as businesses are often unique and varied in their histories and motivations. On the other hand, multiple case studies facilitate cross-case comparisons to search for commonalities and differences (Köhler et al., 2019; Yin, 2003). To assess trends and comment on the state of this emerging industry, we include the multiple cases in a coded database and describe and categorize each business using a number of descriptive variables.

### 3.1. Sample

We followed a purposeful sampling method to identify startups engaged in marine plastic management. Cases were gathered over the years 2018–2020, coded and included into a database. Cases were identified using various sources, including academic papers, grey literature as well as in popular media (Schmaltz et al., 2020; SCP/RAC, 2017; ten Brink et al., 2016). In addition, periodic scans of innovation challenges, awards, accelerators and grant websites generated cases. Additional searches on LinkedIn, Google, and Ubuntoo were conducted from March to August 2020 and networks of experts were consulted, such as Climate-KIC and the marine debris community facilitated by Marine-Debris.Info.

Companies were entered into the database if the main product or service offering involved reducing the impact of plastic pollution on the marine environment. Furthermore, there are multiple definitions of what constitutes a startup or SME. As demarcations are based on year of establishment and number of employees, we defined our sample boundary by age and size. Companies were only included in our analysis if they were founded after 2000 and have fewer than 200 employees, thereby excluding large multi-national companies and corporates. Our database is comprised of 105 startups and SMEs working on MPM.

### 3.2. Data collection

Data collection involved gathering documents and information on the identified business cases. Our goal was to describe, in as great of detail as possible, the company characteristics, business model components, activities and innovations of each startup. Publicly available documents were used to source information on age, size, location, and business model structure. We define four business model components for each company in our sample. The four components are (1) value proposition, (2) key activities and partners, (3) customers and relationships and (4) financial model (Diaz Lopez et al., 2019; Dijkstra et al., 2020). We use number of employees listed on LinkedIn as a proxy of company size. Sources include company websites, news articles, blog posts and company profiles, such as on LinkedIn, Crunchbase and Facebook. For each company, a minimum of three sources were used.

### 3.3. Data analysis

To answer our research questions, we utilize the constructed database, descriptive statistics and observations on the sample. We describe the sample based on functional typologies and sub-typologies. We group businesses together that have the same function in managing marine plastics. We then describe trends in the sample such as the size of each (sub-) typology, where the companies are headquartered and where they are active. We classify each business as providing a technological or non-technological (social) innovation and assess the stage of business development. The variables described in the analysis are shown in Table 1. Although data was sought for each variable for each company, information was not always available.

**Table 1**
Overview of variables included in the database for each company.

| | Variable | Description | Units or scale | Source |
|---|---|---|---|---|
| Company description | Location of company | Company headquarters | Country name | LinkedIn or company website |
| | Company size | Proxy variable using number of employees | - Solo: 1<br>- Micro: 2–10<br>- Small: 11–50<br>- Medium: 51–200<br>Employees | LinkedIn |
| | Business model components | Value proposition, key activities and processes, customers and channels, revenue model | Text description based on available information | All documents |
| | Customer | Customers targeted | - Consumers (B2C)<br>- Businesses (B2B)<br>- Government (B2G) | All documents |
| Maturity and innovation | Organizational stage | Stage of business development | - R&D/ideation<br>- Pilot/prototype<br>- Commercial | All documents |
| | Innovation | Type of innovation | - Technological<br>- Social | All documents |
| | Investment funding | Amount of investment | US$ value | Crunchbase |
| Plastic characterization | Location of activities | Location where the company is active in MPM | City, region, country etc. | All documents |
| | Plastic targeted | Type of polymers or plastics targeted with MPM | - Fishing nets and gear, specific polymers (HDPE, PET), microplastic fibers, all floating plastics etc. | All documents |
| | Plastic size | Size of plastic targeted | - Macroplastics<br>- Microplastics<br>- Both | All documents |

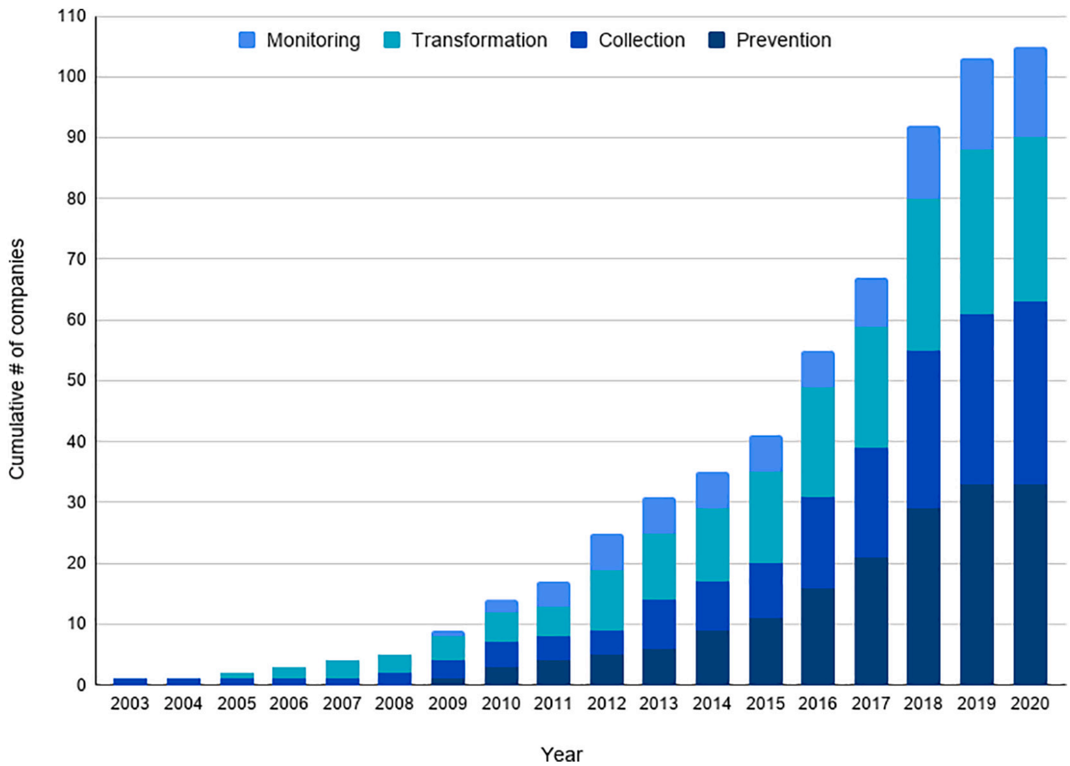


**Fig. 1.** Cumulative graph showing the number of startups founded in the years 2003–2020.

## 4. Results

### 4.1. Database description

Our database includes 105 startups and small businesses targeting marine plastic. The first company was founded in 2003 and the sample grows significantly in the last five years, as shown in Fig. 1. The largest increase of companies was in 2018, when 25 startups were founded. All companies in the database had active websites as of August 2020, suggesting they were still operating. For a complete overview of companies, see the Supplementary materials.

We categorized each company by the function it provides in managing marine plastic based on the waste hierarchy (European Parliament and Council, 2008). The waste hierarchy is a management framework that ranks the preferred options for managing waste, from most to least environmentally viable and can be applied to plastic specifically (see, for example Dijkstra et al., 2020; UN Environment, 2017). The general order is prevention, reuse, recycling, energy recovery and the final option is landfilling. Considering the nature of marine plastic, the hierarchy must be expanded to include actions targeting waste that has been improperly disposed of and has ended up in marine environments. This waste must be collected, and then it can be reinserted into the higher levels of the waste hierarchy.

We therefore define four main activities that can contribute to marine plastic management: prevention, transformation, collection and monitoring. Prevention refers to actions on land and in rivers that reduce the likelihood of plastic waste becoming marine plastic. Collection involves removing plastic from marine environments and can be done using specialized boats, filtration systems or by waste pickers or volunteers. Transformation is the processing of collected plastic, for example by recycling, energy recovery or proper disposal. The final category involves monitoring and developing knowledge on marine

**Table 2**
Categories and sub-categories identified in the analysis.

| Category | Sub category | Sample size |
|---|---|---|
| 1. Prevention at key leakage points (n = 33) | 1. Marine degradable products | 16 |
| | 2. Prevention in rivers | 8 |
| | 3. Prevention in waste water | 7 |
| | 4. Prevention of primary microplastic sources | 2 |
| 2. Collection from marine, beach and nearshore environments (n = 30) | 5. Marine litter removal | 15 |
| | 6. Funding cleanups and waste management | 7 |
| | 7. Plastic offsets | 6 |
| | 8. Fishing nets and gear collection | 2 |
| 3. Transformation of collected plastics into new products (n = 27) | 9. Fishing nets and gear recycling | 11 |
| | 10. Specific polymer recycling | 9 |
| | 11. Energy recovery | 4 |
| | 12. Mixed marine plastic recycling | 2 |
| | 13. Chemical recycling | 1 |
| 4. Monitoring and knowledge development (n = 15) | 14. Monitoring services | 6 |
| | 15. Phone applications | 5 |
| | 16. Awareness, outreach and knowledge | 4 |
| | Total | 105 |

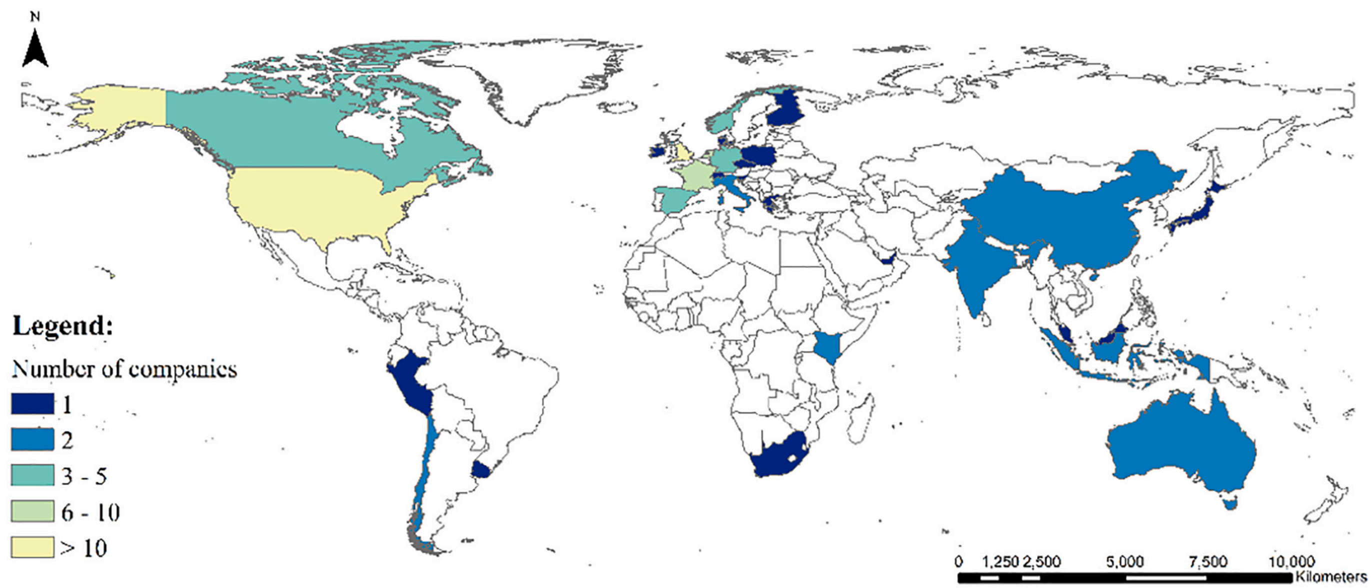


**Fig. 2.** Map of companies based on location of headquarters.

plastic. We analyzed each functional group to identify subgroups, of which we settled on 16, shown in Table 2. These subgroups are defined by similar business activities related to MPM.

Many of the companies are based in Northern America and Europe, see Fig. 2. 90% of the companies are located in World Bank classified high-income countries, while 10% are from upper and lower middle-income countries. No companies were headquartered in low-income countries. For a complete overview of the locations of business cases see the Supplementary materials. We recognize a high proportion of the sample is North American and European businesses, which could be due to the search language (English) and network of the authors. Despite efforts made to contact networks and experts in other markets, a skewed sample remains. This limitation implies that we may have missed a number of business models for marine plastic outside of Europe and North America.

### 4.2. Exploring the emerging industry

The next section will explore the database and is structured around the four main functions of businesses engaged in MPM. We will describe each group of companies based on variables such as location of the business headquarters, where they are active in deploying MPM, the business model structure, revenue model, investments and innovations. The sub-groups are also defined in greater detail.

#### 4.2.1. Prevention

The largest group of MPM startups is engaged in prevention from key leakage points. These leakage points include rivers, wastewater, other primary microplastics sources (such as microbeads and paint chips) and marine degradable products. These 31 startups have identified leakage spots where plastic previously could enter the ocean and harm marine life, and produced preventative measures. The sub-categories within Prevention are described in detail in the following paragraphs and summarized in Table 3.

Companies focused on marine degradable products have produced materials that will benignly degrade if they end up in marine environments. These materials have been made from a variety of feedstock including marine products, such as seaweed, algae and seafood waste, or other organic materials, such as milk proteins and brewery waste. The materials have been designed to replace packaging and a variety of single-use plastic (SUP) products, such as straws, garment bags, sauce packets and six-pack rings. Many of the 16 companies were founded in recent years, suggesting a growing market and demand for sustainable alternatives. A few of these companies are commercially active, while others are still in ideation and prototyping phases. Investment in this industry is significant, half of businesses reported raising investment on Crunchbase, and four companies recorded over $5 million in investment (Loliware, Notpla, Lactips and Cove). This is a higher amount than investments found in most other sub-categories.

River prevention businesses sell barriers made from floating booms, water wheels or bubble screens which trap and aggregate floating litter and plastics before they can reach marine environments. The 8 companies produce variations of barriers and collection devices, and these systems are often designed to allow fish or other animals to pass through unharmed. The systems are flexible, and can be used to not only collect plastic waste but also organic matter, such as water hyacinth, and other floating pollutants. The technologies are relatively well developed and commercialized, though some newer innovations are still in development and pilot stages. Many of the companies are headquartered in Europe or North America, but the systems are often deployed in South East Asia. Research has suggested preventing ocean plastic by halting emissions at rivers is more effective than ocean cleanup devices to mitigate marine plastic pollution (Hohn et al., 2020).

Wastewater prevention measures are all tackling the problem of microfibers shedding from clothing. These fibers are shed during washing and end up in wastewater treatment plants that are not yet able to fully capture the fibers, which are eventually released into the environment. There are five startups offering consumer filtration options, one option for industrial washing facilities, one technology designed to be integrated in washing machines during production, and a final company is working on a solution to be used at wastewater treatment facilities. Solutions are in early stages and are not yet widely available on global markets. An analysis of consumer options for microplastic filtration from washing machines found XFiltra by Xeros was most effective at capturing microplastics with a 78% efficiency rate (Napper et al., 2020). These solutions currently rely on environmentally motivated consumers and companies as customers, since no regulation exists mandating microplastic management from wastewater.

Beyond wastewater filtration and capture, two other companies were found that focused on preventing microplastics from entering marine

**Table 3**
Prevention sub-categories described and defined. (B2C = business to consumer, B2B = business to business, B2G = business to government, EU = European Union, USA = United States of America.)

| Sub category | Description | Example | Defining features |
|---|---|---|---|
| 1. Marine degradable products (n = 16) | Plastic alternatives specifically designed to degrade in marine environments | Loliware makes biobased (marine) biodegradable straws | - B2C products targeting sustainable consumers<br>- B2B materials and processes for manufacturing<br>- Mainly USA/EU – 1 company in Indonesia<br>- Some products are commercial but many are still in R&D and pilot stages<br>- Significant investments |
| 2. Prevention in rivers (n = 8) | Companies focused on systems for trapping floating plastic in rivers, canals, streams etc. | AlphaMERS designed floating barriers for plastic and debris collection | - Primarily B2G and B2B technological solutions<br>- Systems can capture floating plastic and other debris or pollutants<br>- Emphasis on flexible systems<br>- Companies are headquartered in Europe but active in South East Asia |
| 3. Prevention in waste water (n = 7) | Removing (micro) plastic in household or industrial wastewater. | PlanetCare makes consumer and industrial washing machine filters that capture microfibers | - Focus on microfibers from washing clothes<br>- B2G for wastewater treatment<br>- B2C products targeting sustainable consumers<br>- Innovations are relatively new and not widely adopted<br>- All companies in USA/EU |
| 4. Prevention of other microplastic sources (n = 2) | Alternatives to cosmetic beads or technologies to capture paint flakes | Pinovo develops machinery for maritime maintenance, including a vacuum tool to collect paint flakes | - Few technologies available, under developed market for prevention of other microplastic sources<br>- EU companies |

Total = 33.

environments. One is Natuurbeads which creates a bio-based natural alternative to microbeads, and the other is Pinovo which has created a tool to capture paint flakes while replacing paint on ships and other marine infrastructure. Solutions for preventing microplastic pollution are relatively underdeveloped.

#### 4.2.2. *Collection*

29 startups and SMEs were found that focused on collecting plastic from marine and nearshore environments. These companies develop technologies to remove plastics from beaches and waters, manage 'ocean-bound' plastic, finance cleanups or collect fishing gear. There are five sub-categories within the Collection category, defined further in Table 4.

**Table 4**
Collection sub-categories described and defined. (B2C = business to consumer, B2B = business to business, B2G = business to government, EU = European Union, USA = United States of America.)

| Sub category | Description | Example | Defining features |
|---|---|---|---|
| 5. Marine litter removal (n = 15) | Tools, technologies and systems for removing plastics from beaches, nearshore and marine environments. | ONA Safe and Clean sells technologies for boats and drones for nearshore and marine cleanup | - Solutions are sold to governments (B2G) or coastal industries (B2B)<br>- Companies are mainly headquartered in the EU (11), but also North America (2), Asia (1) and the Middle East (1)<br>- Almost all (93%) are small, under 10 employees<br>- Various stages of development – from ideation to commercial<br>- Options for microplastic removal are limited |
| 6. Funding cleanups (n = 7) | Using sales of products, advertising or other financing tools to financially support cleanup activities | Ekoru is a search platform that uses advertising revenue to fund beach cleanups | - B2C of green consumers interested in funding plastic cleanups<br>- B2B with relevant industries<br>- Emphasize the amount of plastic collected and managed<br>- One founded in 2009, the rest founded after 2017<br>- Cleanup activities are spread globally |
| 7. Plastic offsets (n = 6) | Mechanism for individuals or businesses to compensate for plastic usage by financing plastic management activities | rePurpose Global sells offsets for consumers and businesses to become 'PlasticNeutral' by supporting waste management improvements in India | - B2C and B2B targeting green consumers and businesses in the North America and EU<br>- Revenues are subscription or one-time fees<br>- Global spread of companies (Canada, India, Australia, Norway, Singapore and France)<br>- Small to medium sized businesses |
| 8. Fishing nets and gear collection (n = 2) | Providing waste collection services for fishing nets and gear | Net Your Problem LLC gathers used and discarded fishing gear and offers recycling opportunities | - Underdeveloped market for fishing gear collection services<br>- Companies located in the USA and Norway |

Total = 30.

Fifteen companies were identified that have developed technologies and systems to remove litter directly from marine environments. Six companies designed litter collecting aquadrones that roam ports and harbors skimming floating debris. These drones can be either remote controlled, programmed or autonomous and are suited for nearshore waters. Four companies have boat systems that can manage larger amounts of debris and are not restricted to nearshore areas. Another group of technologies include four options for static filtration systems that can be installed in harbors and ports. Two solutions are introduced to manage plastic on beaches: a vacuum system for microplastic and a beach cleaning drone. One company engages in fishing for litter trips in canals and ports and is the only example that engages with citizens to participate in marine cleaning. The technologies are primarily marketed to governments, municipalities or associations responsible for management of coastal areas and infrastructures, for example tourist industries, port authorities or harbor managers. The systems are mainly targeting floating macroplastics, though a few solutions can collect microplastics including the port and harbor filtration devices and a beach cleaning vacuum tool that is still in pilot phase. These companies are overwhelmingly small (under 10 employees), but vary in the development stage with some options highly commercialized and others still in ideation phase.

The next sub-category of seven companies focuses on financing plastic collection and ocean bound waste management. Ocean-bound plastic is a popular industry term to describe plastic at risk of entering marine environments and becoming ocean pollution. Companies and organizations define the term differently, but generally it refers to plastic within 20–100 km of a coastline or ocean tributary. Some organizations only consider mismanaged waste to be 'ocean-bound', while others include plastic managed in recycling and waste management facilities that are near coasts. Three companies sell products (water bottles, bracelets) and two companies sell online advertising space with the explicit intention of using profits to fund beach cleanups. One uses an incentive mechanism to encourage beachgoers to collect plastics and get coupons and benefits, and a final company relies on funding from hotels and tourism industry to pay for beach cleanups and waste valorization activities. In all cases, the companies have innovative mechanisms to acquire funds which are then used for cleanup events, for example by paying waste pickers, purchasing equipment and establishing supply chains for collected plastics. Five out of the seven companies publicly state how much plastic they have collected, though they each have their own methodologies and units of measurement, suggesting that standardization and transparency is lacking. One company (EcoWorld Watamu) is older, being founded in Kenya in 2009, while the rest are young and founded after 2017. They are mostly small and micro, though 4Ocean is categorized as a medium-size enterprise.

The third category includes six plastic offset startups who have modeled their businesses on carbon offsetting schemes. Like carbon offsets, these schemes provide credits for environmental impacts incurred in one location to be mitigated in another. In this case, plastic waste credits are purchased by individuals or companies and the revenues are then used to fund beach cleanups, waste banks and other waste management initiatives. The target customers are primarily from developed countries and charged via one-time fees or subscriptions, and the offsetting activities occur in developing countries. The Plastic Bank was the first offsetting company founded in 2013 in Canada, and since then others have been founded in Singapore, India, Norway, Australia and France. The companies are active in South East Asia, Australia, North America, Africa and on Caribbean and Pacific Islands. Some of these companies ask customers to participate in waste audits to determine the offset amount, while others have a predetermined set fee. Each company develops their own compensation, measuring and tracking structures. These companies advertise on their website the running totals of plastic collected or managed, though transparent accounting on how they calculate these numbers is lacking. All companies emphasize in their communications the importance of partnering with local initiatives and communities in the areas they work.

The final sub-category includes two companies involved in the collection, aggregation and processing of used or discarded fishing gear and nets. These companies serve as a link in the value chain of fishing gear between fishermen and the fishing industry and recycling facilities. The companies help prevent pollution from fishing nets, which can be one of the most environmentally damaging forms of marine plastic pollutions (NOAA, 2016). The two companies in the sample are located in the USA and Norway.

#### 4.2.3. Transformation

The 27 startups and SMEs involved in transformation can be categorized into five subgroups, shown in Table 5. These companies are all engaged in the transformation of recovered marine plastics into new materials, products or into energy. We chose to include companies who were involved in the processing, manufacturing or recycling process of plastics. There are many companies and brands who use recycled ocean plastic in product lines by purchasing pellets, flakes and yarns from those directly involved in recycling. These brands are not included in the database but are discussed in more detail in Box 1.

The first and largest subset of transformation businesses recycle collected fishing nets and gear. Two companies are involved in recycling the gear and selling the processed raw materials as flakes, pellets and yarn. The other nine companies sell consumer products such as sunglasses, watches, skateboards and 3D printing filament. Most of these 11 companies are small, with under 10 employees, and all are under 10 years old. The companies are located in China, Chile, the EU and North America. One critical aspect of recycling fishing nets is accessing a stable supply, and for this reason all companies report a number of partnerships on their websites. The partnerships include fishermen and industry groups, port authorities and NGOs and community groups who assist with collecting old or damaged fishing gear for recycling. Fishing nets are often monofilament high quality plastics, which make them a preferred choice for recyclers – however nets do have to be cleaned and processed before they can be recycled. Nets are often green or black, which further limits the color options of recycled fishing gear. Value chains for recycled nets are relatively developed and there are multinational corporations involved in the recycling of fishing nets. Large companies are not included in our sample of startup and SMEs, but a notable example is Aquafil, an Italian corporation that produces Econyl yarn from fishing gear.

The next sub-category of transformation comprises of the nine companies involved in recycling specific polymers and categories of marine plastics. The majority (5) focus specifically on polyethylene terephthalate (PET), a polymer used to make soda and water bottles, which can be recycled into yarn and used for backpacks, clothing and tennis shoes. The benefits of PET are that it can be relatively easily recycled and maintain a clear color. Two companies, #tide and OceanWorks, sell a range of recycled polymer pellets and flakes, including PET, high density poly ethylene (HDPE) and polypropylene (PP) from a variety of sources. One company sells sunglasses made of recycled HDPE and a final SME creates art products and statues from recovered flip flops. Raw material suppliers sell pellets and yarns to retailers and manufacturers, while the companies creating products market themselves to green consumers using e-commerce and retail (see Box 1). Many of these companies have engaged in successful crowdfunding campaigns. The supply of ocean-bound, beach and marine plastics generally comes from developing countries, whereas sales of new products and materials target developed country markets.

The third category of businesses develop options for mixed or contaminated plastics, which collected marine plastics often are, in the form of energy recovery. Four startups were found to be working on pyrolysis, a process of heating plastics at a very high temperature to produce fuel. The process produces fuels and waste ash, and has been developed by the four companies at different scales. One Italian company, Iris SRL has built a small-scale system which can be used on boats or in ports, Resynergi from the USA and Biofabrik from Germany have modular systems that can be customized to fit different use cases, and IGES Amsterdam is building a larger energy facility. These companies are in prototype or early commercial phases.

Only two companies were found that offer mechanical recycling solutions for mixed marine plastics. One company, ByFusion, offers a

**Box 1**
Brands using recycled ocean plastic.

Our sample includes companies involved in the collection and/or remanufacturing of marine plastics, but there are more companies that create products from recycled ocean plastic. These companies and brands buy recycled pellets or yarns and integrate the recycled materials into their existing manufacturing processes. Some brands create exclusive or unique product lines that contain ocean plastics, while others use recycled ocean or ocean-bound plastics for all products. Brands and retailers who use marine plastics are an important driver of the demand for marine plastic and a link in the value chain between mass markets and niche innovations for collecting and transforming plastics. A few examples of products, brands and sources of recycled ocean product lines are shown below.

| Product | Brand | Company supplying recycled plastics |
|---|---|---|
| Ocean Kayak | Odessey Innovation | Plastix |
| Sports shoe | Avrio Footwear | Oceanworks |
| Watch | Triwa | #tide |
| Backpack | Incase | Bionic Yarn |
| Etc... | Etc... | Etc... |

technology that compresses mixed plastics into a building block which can then be used in construction. Newtecpoly has a process for using mixed waste and marine plastics to make planks for fencing and construction. Both of these technologies offer solutions for plastics that are traditionally difficult to recycle, such as plastic films and bags, and marine plastics which can be contaminated. The technological processes offered by both companies are still in pilot phases, and the market for recycling mixed or contaminated plastics is underdeveloped.

The final option for transforming collected marine plastics is chemical recycling. This is a process for breaking plastic down into its chemical building blocks or monomers, which can then be reassembled into plastic polymers. This process is currently being developed by a Dutch company Ioniqa which carried out a pilot project using PET bottles collected from the ocean to make new bottles. Chemical recycling is not yet a widely available option for the transformation of plastics.

#### 4.2.4. *Monitoring and knowledge development*

The next category of startups is companies involved in monitoring and knowledge development, further described in Table 6. This category has 15 startups in three subgroups, with some companies offering services to monitor marine litter, others creating phone applications for plastic monitoring and the final subgroup implements awareness, outreach and knowledge creation activities. These businesses use a variety of methods to map, analyze and disseminate information about marine plastic pollution.

The first sub-category is a group of companies who sell monitoring services. This includes two consulting agencies who provide drone based mapping and aerial imagery, which can be used by NGOs or governments. There is one tourism company that includes microplastic monitoring as a facet of their Caribbean yacht tours. Two companies are focused on developing new hardware and software tools for monitoring microplastics in the ocean that can be useful for researchers and governments. The final company has developed a certification system to verify if products are made from ocean plastics. This certification is an attempt to improve traceability for companies active in collection and transformation of marine plastic. This sub-category includes a wide variety of business models, plastics managed and customers targeted. Monitoring services are still in their infancy, and only a few companies have successfully commercialized monitoring of marine litter.

The second category is comprised of companies who have developed phone applications for monitoring. This software encourages users to upload and tag litter in their environments, generating a litter database. Mobile phone apps have been developed by five different startups, who rely on citizen and user participation to generate data for litter maps and monitoring. The business models of these software companies differ, and some sell the litter maps to corporations and governments, while others seek sponsorship or valorization through advertising or other services provided. The companies may also provide other services such as consulting based on their methodologies and findings. Three of these companies were founded between 2011 and 2012 with a second wave founded in 2019. The older companies have established commercial phone applications with large user bases, whereas the newer companies are still prototyping or working on building a user base.

The final category of startups are companies involved in educational activities, building platforms to connect solutions to decision makers and financers, and awareness raising through media and campaigning. This sub group is relatively small. It is relevant to note that many startups and SMEs in other categories engage in knowledge creation and dissemination activities through their partnerships, customer relations and communications channels. Fewer have awareness and knowledge creation as their main value proposition. Two companies in this category target specific locations (Indonesia and Peru) and the other two have a global scope, identifying solutions and engaging in awareness raising around the world.

## 5. Conclusions and discussion

Our database indicates a growth of startups and entrepreneurial activity around the problem of marine plastic. The industry analysis reiterates that this is a dynamic sector that is continuing to develop. This study presents an overview of the growing MPM industry, identifying four overarching MPM categories and 16 sub-categories of functions reducing the impact of plastic on the marine environment. The companies deploy a range of technological and social innovations, and business models often include aspects of both. The following section will summarize the findings per MPM startup category in relation to other scientific literature, and further discuss the relevance for industry and policy.

### 5.1. *Prevention*

Technologies and innovations to support prevention of marine plastic are dispersed and, in the case of microplastics, underdeveloped. Prevention is often cited as the most effective tool to reduce marine debris, but business solutions have not yet managed to stem the flow of

**Table 5**
Transformation sub-categories described and defined. (B2C = business to consumer, B2B = business to business, B2G = business to government, EU = European Union, USA = United States of America.)

| Sub category | Description | Example | Defining features |
|---|---|---|---|
| 10. Fishing nets and gear recycling (n = 11) | Recycling of recovered or abandoned fishing nets and gear into pellets, filaments or products | Bureo makes skateboards and other products from recycled fishing nets collected in South America | - B2C e-commerce and retail targeting green consumers<br>- B2B selling pellets, flake or yarn<br>- Reliance on fishing industry and fishermen for gear and nets<br>- Companies located in Chile (2), China (1), EU (7) and USA (1) |
| 11. Specific polymer recycling (n = 9) | Recycling of specific polymers (e.g. PET, HDPE) into pellets, filaments or products | #tide Ocean Material yarn and pellets are made from recycled PET, PP and PE | - B2C e-commerce and retail targeting green consumers<br>- Significant crowdfunding investment<br>- B2B selling pellets, flake or yarn<br>- All companies in commercial stage<br>- Companies range in age, some founded in 2005–2007 and some newer |
| 12. Energy recovery (n = 4) | Techniques to harness energy from marine plastic, e.g. pyrolysis | Iris SRL is piloting a small scale pyrolizer to turn collected marine plastic into clean energy on boats or in ports | - B2B or B2G as a waste management service and energy source<br>- All companies offer a pyrolysis process, with different specifications<br>- Scale of solution can range from micro system to fit on a boat, to a large plant<br>- Companies based in USA (1) and EU (3)<br>- Micro and small companies |
| 13. Mixed marine plastic recycling (n = 2) | Recycling mixed marine plastics into products | ByFusion combines marine plastic with other materials to make durable recyclable construction blocks | - B2B and B2G technological options<br>- Companies founded in 2014 and 2015 with both under 10 employees<br>- Few options available for recycling mixed marine plastics |
| 14. Chemical recycling (n = 1) | Recycling marine plastic into products of the same material quality | Ioniqa has a process to chemically recycle PET that has been piloted with ocean plastic | - One company based in Netherlands and founded in 2009<br>- Underdeveloped market |
| Total = 27 | | | |

plastics into the ocean. River prevention, which was cited in a recent study to be much more impactful in reducing marine pollution than ocean-based cleanup, is a relatively accessible technology (Hohn et al., 2020). There are many river prevention technologies available, however they have not yet been deployed at a meaningful scale, but rather individually or in clusters of streams and tributaries. A wide scale, global application would be necessary to stem the flow of plastics into the ocean (Lebreton et al., 2017).

Additionally, we see that efforts to prevent microplastics are still immature. A handful of solutions exist to capture microfibers, but industrial solutions are needed to manage the large flows from wastewater

**Table 6**
Monitoring and knowledge sub-categories described and defined. (B2C = business to consumer, B2B = business to business, B2G = business to government, EU = European Union, USA = United States of America, UK = United Kingdom.)

| Sub category | Description | Example | Defining features |
|---|---|---|---|
| 14. Monitoring services (n = 6) | Consulting services, technologies or tourism opportunities for marine litter monitoring, mapping | Scoutbots LTD creates Open Hardware technologies to monitor and study marine plastics | - Variety of business models and customers B2B, B2G and B2C<br>- Small companies based in USA, Canada, UK and Hong Kong<br>- Few commercialized options for litter monitoring |
| 15. Phone applications (n = 5) | Software application for smartphones that allows for tagging and monitoring of (marine) litter | Pirika is citizen science app and database to collect and share litter data points | - B2G and B2B sales of litter maps and data<br>- Reliance on user and citizen participation<br>- Phone application software<br>- 3 companies in EU, 1 in USA and 1 in Japan |
| 16. Awareness, outreach and knowledge (n = 4) | Generation of knowledge and awareness raising, including outreach and solution platforms | Ubuntoo is a solutions platform matching sustainability innovations and potential partners and funders | - B2B via corporate sponsoring, subscription revenues or sales of consulting services<br>- Global spread with companies based in Indonesia, Peru, France and USA |

Total = 15.

(Eriksen et al., 2018). Commercial washing machine devices that have been lab-tested ranged in effectiveness in capturing microfibers from 21 to 78% (Napper et al., 2020). The researchers from this study advocate for coupling technological development with scientific monitoring in order to encourage efficiency and accountability.

Products and materials designed to degrade in marine environments are developing rapidly, and these should be paired with scientific monitoring to study not-yet-known environmental or economic impacts. Concerns raised by scientists on bioplastics apply to these material innovations. For example, questions remain about how harmless these materials are, their capacity to protect food from spoiling, and the potential to contaminate traditional plastic recycling streams (Álvarez-Chávez et al., 2012; Soroudi and Jakubowicz, 2013; UNEP, 2015). In summary, there should be efforts to pair technological and material innovations for plastic prevention with scientific monitoring in order to continuously asses effectiveness, environmental impacts and reduce unintended consequences (Zehner, 2011).

### 5.2. Collection

We find that many collection strategies are primarily innovations in financing and securing funding to support waste management. These businesses then rely on people power, such as volunteers, waste pickers, fishermen, NGOs and community organizations to participate in waste management activities. The relationships between those within and outside the business were not always clearly defined, and this leads to questions of fairness and accountability. Best practices for inclusive waste management and improving waste picker livelihoods, have been described in previous research, see for example (Kaza et al., 2018; Vital Ocean et al., 2020). As these companies develop and engage with more stakeholders, there is potential to scale up the environmental and social benefits, but also to cause harm or leave marginalized groups out. For these reasons, it is critical to develop socially inclusive marine plastic collection solutions (Gutberlet et al., 2017).

Regarding technological devices, these may have negative environmental impacts that must be considered alongside the collection potential. For example, boats and drones require energy inputs and may disrupt other maritime industries such as shipping, fishing and tourism. Furthermore, collection should be optimized in locations where there is a known accumulation zone of plastic, and there is evidently a need to integrate monitoring protocols with cleaning strategies. For example, Sherman and van Sebille (2016) modeled microplastic cleaning efforts and determined it was more effective and less harmful to phytoplankton when strategies were deployed nearshore than offshore in gyres.

Regardless of the collection strategy deployed, each business must then consider their options for transformation and disposal of the materials. This is a critical bottleneck; there are not yet many options for marine plastic transformation that are cost effective, environmentally friendly and/or widely available. For example, voluntary fishing-for-litter schemes that encourage fishermen to land and properly dispose of waste collected during fishing activities has been promoted as a marine waste solution. These schemes are positively rated by stakeholders involved, but there remains challenges with disposing of the collected materials (Wyles et al., 2019). Developing clear disposal protocols should be part of a collection business model, however in our sample, few businesses adequately disclosed their disposal strategies and accompanying environmental impacts.

### 5.3. Transformation

Transformation of collected marine debris is mainly focused on high-quality polymers and further innovation is needed to manage plastic recycling challenges. Debris is generally collected as a mix of contaminated and weathered materials that require separation, cleaning and processing and may not be suitable for all recycling processes (Ronkay et al., 2021). For these reasons, collected plastics are often landfilled (Schneider et al., 2018). The companies in our sample provide alternative strategies to landfilling, including recycling and energy recovery. These options have their own sets of tradeoffs, such as transport emissions from shipping collected materials, or energy and water requirements used in processing.

A recent LCA study found that building a boat with ocean plastic caused more environmental impacts than traditional boat building processes, showing the importance of considering holistic impacts when deciding on transformation options (Fang et al., 2020). Recycling is frequently criticized for focusing on the lower levels of the waste hierarchy and falsely giving consumers and stakeholders the idea that sustainable end-of-life solutions exist for plastic (Van Ewijk and Stegemann, 2016). The reality is material quality is inevitably lost in transformation processes, and circular economy advocates encourage a focus on preventing plastic production, refusing plastic products, and reusing materials (Ellen MacArthur Foundation, 2017; Hahladakis et al., 2018; ten Brink et al., 2016).

As value chains for recycled ocean plastic develop, more effort should be given to traceability and accountability. Lack of data is a barrier to assessing the true effects of transformation options, and there is a need for industry standards for marine and ocean-bound plastics led by credible institutions. The industry lacks institutional oversight that is accepted and trusted by businesses and consumers, for example through certification and labeling initiatives (Vince and Hardesty, 2018). Furthermore, a study with Dutch consumers found higher willingness to pay for products made of ocean plastic, especially when these products are branded as such (Magnier et al., 2019). This suggests that purchasing decision for ocean plastic products is related to status, not just environmental motivations. If ocean plastic becomes a luxury good or status symbol, other companies may enter the market to exploit the price premium. To defend against greenwashing and understand holistic environmental impacts, we reiterate the need for oversight and traceability in recycled plastic supply chains.

### 5.4. Monitoring

Environmental monitoring is traditionally an activity done by scientists and researchers, and the increase in citizen science phone-apps has the potential to scale monitoring processes. Utilizing citizen science has the double benefit of increasing awareness while providing information to researchers, especially since litter mapping is a time-consuming, intensive process (Falk-Andersson et al., 2019). A 2019 review of scientific studies on beach debris monitoring concluded that many studies lacked critical information, such as GPS coordinates, and found monitoring strategies to be highly heterogenous (Serra-Gonçalves et al., 2019). The phone applications being developed by startups in our sample could tackle these problems by giving users clear instructions, and automating tasks such as geolocation and calculating litter densities. However, considering that 5 startups are introducing their own applications and accompanying processes, there is potential to run into the same challenge of litter data heterogeneity. Regardless, the increase in knowledge and tools for litter monitoring is a first step towards litter management, as the saying goes, 'what gets measured, gets managed'. Currently, there is untapped potential to integrate monitoring strategies with prevention, collection and transformation processes to better understand the problem, but also to measure and track the effectiveness of solutions.

### 5.5. Future research, limitations and implications

The present study faces limitations that should be considered. We recognize the potential for our sample to be geographically skewed, mainly due to the networks of the authors and the reliance on English language content. The authors welcome suggestions for companies to be included in the sample, which will be a living database. We intend to additionally survey solutions for MPM brought forward by large corporations and by stakeholders beyond the private sector. We hope this paper will be a springboard to inspire future research that adopts a solution-oriented perspective.

Our first suggestion for future action is the development of traceability and accountability in managing marine plastics. There are limited certification options, and the existing labels and terms are not uniformly accepted or widely applied. We ran into numerous definitions of what constitutes 'ocean plastic' and 'ocean-bound plastic', as well as various terms used to describe biodegradability and marine degradability. Utilizing consistent and well-defined terms can support in creating consensus and awareness for users, however without governance or oversight this continues to be led by individual companies. For more insight on what a potential certification body could look like, see Landon-Lane (2018) who proposes a Plastic Stewardship Council modeled after the Marine Stewardship Council.

Second, there is still uncertainty regarding the actual contribution of SMEs and startups to reduce the problem of marine plastic. Further research could quantify the impacts of these enterprises on managing the problem, however at present most companies do not publicly provide data on litter management, let alone information on accounting practices. Integrating sustainability reporting into business practices can be time consuming and require specialized knowledge, however, it will improve credibility in the MPM industry and allow for external oversight. With this information, researchers and practitioners can begin to answer the question of how these companies are contributing to reducing marine plastic. This data can also be used to scrutinize the sustainability of these companies, i.e. how they are contributing to social, environmental and financial goals. Inherent to any management decision are tradeoffs, and these are especially relevant for companies in our sample. MPM contains tradeoffs between financial and environmental benefits, but also tradeoffs between, for example, energy usage or carbon emissions and pollution management. These tradeoffs warrant more quantitative and in-depth analysis, and require data to be shared by companies.

Third, we suggest future research to examine innovations and solutions that will ultimately reduce marine plastic, but have not been covered in our sample. We chose to focus on companies that are specifically targeting marine plastics, however, other upstream solutions are also effective. This would include using alternative materials for packaging, or novel ways of delivering goods, such as with reusable or returnable packages. Product-as-a-service (PSS) business models, in which services are sold but the company maintains ownership of materials, can lengthen the lifetime of products and improve the recovery of materials (Tukker, 2004). Reducing plastic production and banning products like certain single-use plastics have also been shown to be effective. Additionally, there are many companies and innovations focused on improving waste management that will down the line reduce marine pollution. Relevant examples include Kabidiwalla Connect in India and Waste4Change in Indonesia, both startups are creating technology applications and infrastructure to formalize waste management. These companies reduce the amount of waste that would otherwise be mismanaged, and could eventually make its way to the oceans. Recent modeling studies have found that deploying combinations of solutions, including plastic reduction, waste management improvements and cleanup strategies is most environmentally and cost effective in reducing plastic emissions into the oceans (Borrelle et al., 2020; Cordier and Uehara, 2019).

Finally, we hope this baseline overview can provide inspiration not only to academics but also to practitioners, policymakers and stakeholders involved in marine conservation and management. This analysis demonstrates the wide variety of options available in the toolkit to manage marine plastic, and shows that startups and small businesses have already successfully applied and commercialized a number of options along the marine plastic value chain. We hope that financiers, such as venture capitalists, governments and banks can use this database to identify promising ventures to fund, and recognize the investment potential in this growing industry. Though a diverse set of companies are already working in this field, there are plenty of areas where technologies and solutions are not well developed, and marine regions that still have no available options, for example plastics that have sunk to the seafloor or deep sea and microplastics in the open ocean. More innovation, funding and political support will be needed to invent and commercialize solutions for these problems.

## CRediT authorship contribution statement

**Hanna Dijkstra:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Pieter van Beukering:** Supervision, Writing - review & editing. **Roy Brouwer:** Supervision, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.


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## Appendix A. Supplementary data

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