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Circular economy and reduction of micro(nano)plastics contamination

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ABSTRACT

Circular economy is viewed as the most promising path to a more sustainable use of plastic. It aims at reducing the consumption of resources by keeping materials within the value chain for longer periods compared to traditional linear material flow. Apart from reducing the consumption of plastics, plastic pollution (including microplastic contamination) is considered a major environmental risk. However, explicit considerations of microplastic contamination are seldom considered in studies on the transition to a circular plastic economy. In this perspective we provide reflections on why this is important, give examples of areas where recycling can lead to increased microplastic contamination and provide recommendations on how reduction of microplastic contamination and transition to circular economy can interconnected in future research.

Introduction

With the continuous and accelerating increase in plastic pollution, it is paramount to find solutions to this environmental problem. Despite numerous policy initiatives around the globe during the past years (Syberg et al., 2021), the amount of plastic lost to the environment is continuously rising. It has been predicted that emissions of plastic to the aquatic environment will be rise from 9 to 14 million tons per year in 2016 to 23–37 million tons per year by the year 2040 unless more action is taken (Geyer et al., 2017; UNEP, 2021). The transition to a more circular plastic economy is viewed as a central task for reducing this trend (EC, 2018). Circular economy is based on the fundamental principle, that material flows through the value chain should include loops back in the value chain, rather than being a continuous linear flow from production over use to end-of-life (World Economic Forum; Ellen Mcarthur foundation; McKinsey & Company, 2016). Focus is to prolong lifetime of products and ultimately resources, increase recycling and minimizing waste based on the principles laid out in the waste hierarchy (Leal Filho et al., 2019).

Environmental impact of plastic pollution is closely related to the physical characteristics of the plastic pieces. A fishing net and a drinking bottle can both be characterized as macro plastic pollution, but their impact can vary significantly. Whereas a lost fishing net (sometimes referred to as ghost nets (Besseling et al., 2019)) can entangle marine life, a plastic bottle might be ingested by certain organisms depending on size of the bottle and the organism, and contribute to starvation due to its physical presence in the digestive system. A nomenclature for plastics based on size range is not fully agreed upon, but typical references are the GESAMP reports made by an array of plastic pollution experts (GESAMP, 2016). Here plastic pollution is divided into categories based on size, and the term micro- and nanoplastics are used for the smallest particles. Microplastics (MPs) are classified as plastic particles (including shapes such as fibers) in the size range below 5 mm (GESAMP, 2016). MPs are ubiquitous in the environment, are found in all ecological compartments and are considered a priority substances in regulations such as the European Marine Strategy Framework Directive (EC, 2008). A clear distinction between micro- and nanoplastics (NPs) has not been agreed upon (Hartmann et al., 2019), but typically plastic particles below 1000 nm are distinguished from MPs as NPs (GESAMP, 2016). (Other definitions such as 100 nm (definition for engineered nanomaterials) and 20 nm (particles size which can enter the bottom of the food web) have also been suggested. Some data indicate that NPs might pose a specific environmental risk due to the ability to interact with biological systems (Besseling et al., 2019; Thomas et al., 2021).

The link between Circular economy and micro(nano)plastic contamination is seldom made explicitly, even though the vast majority of MPs (and NPs) found in the environment are secondary breakdown products, meaning particles that are products of fragmentation of larger plastic pieces e.g. household products (Syberg et al., 2015). This implies, that reducing plastic pollution in general will also reduce micro(nano)plastics contamination. Further insight into the direct link between increased circularity of plastic products and reduction of micro(nano)plastics pollution might thus improve the scientific foundation

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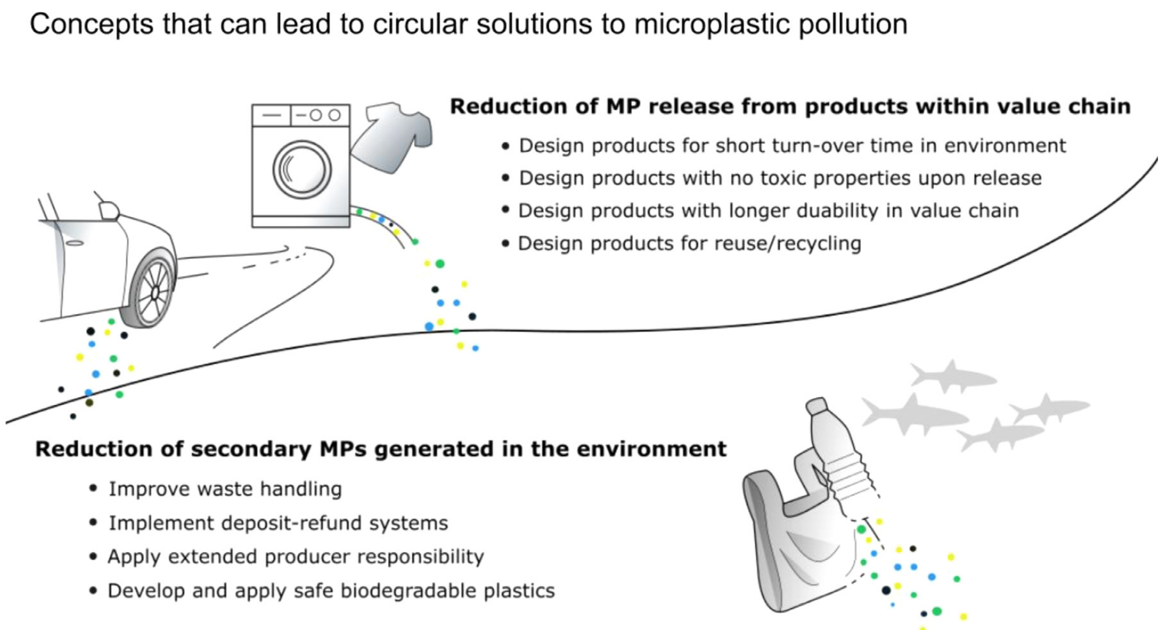

Fig. 1. Solutions to microplastic pollution based on circular concepts. Solutions belong to either the use phase where the plastic products are still in the value chain or to plastic products lost from the value chain to the environment. MP: Microplastic.

for informing societal actions to reduce plastic pollution, including a better understanding of the correlation between recycling of plastic and generation of micro(nano)plastics. In this perspective, we address this link and discuss where circular economy can be linked to reduction of micro(nano)plastic contamination.

Circular economy as the solution

As mentioned, circular economy addresses all steps of the life-cycle of plastic products from design to production over use and into the end-of-life stage (Syberg et al., 2021). Release of micro(nano)plastics typically stems from wear and fragmentation of these products during their life cycle, and measures to reduce micro(nano)plastics can therefore be focused on minimizing these processes. As illustrated in Fig. 1, wear can happen while the product is still within the value chain, e.g., during use. It can further happen to products lost from the value chain when it becomes environmental contamination.

Microplastics release from products within the value chain

Release of micro(nano)plastics can occur at any stage of the value chain, even during production. Especially, release during the use phase has been documented. For instance, tire abrasion is considered a significant source of tire wear particles to the environment (Sommer et al., 2018). Tire wear particles have been found in all environmental compartments and negative impacts have been demonstrated (Halle et al., 2021). Another major source of micro(nano)plastics stems from fibers shed from textiles (Napper and Thompson, 2016). Release of fibers during washing is believed to contribute with a significant part of this contamination and studies indicates that the design and production of textiles are key drivers with respect to amounts of micro(nano)plastic fibers released (Hernandez et al., 2017). A final source of micro(nano)plastics worth mentioning are single-use products, that are typically made in poor quality, which can result in substantial abrasion during use. One example is provided by Lambert and Wagner (2016). They demonstrated that NPs particles are released from single use polystyrene cups. Another example is found in Winkler et al. (2019), which shown that release of MPs from single-use bottles differed between different brands, indicating that the design and production of the bottle are important factors that influence the release of MPs particles.

One important question relates to how transition to a more circular plastic economy can help mitigate the release of micro(nano)plastics like the examples just described. We propose two areas in which future innovation and development can foster such mitigations. These are both related to the design of products and relates to use of new materials, making them more durable alternatives to existing single use products (Fig. 1). In a recent publication, we proposed that historical evidence regarding early warning signs of environmental harm should be accounted for in the development of new materials, such as future generations of plastics (Paulsen et al., 2021). One of the lessons is that materials with long environmental persistency has the potential to pose greater environmental risk. Especially if the environmental harm that they cause is found to be potentially irreversible, such as causing changes in the food-web structure and/or long-lasting toxicity. On the one hand, this calls for innovation of new materials that are easily degraded once they end up in the environment and at the same time do not have toxic properties. On the other hand, a key component of the transition to circular economy relates to ensuring that products are made more durable and can be reused multiple times, e.g., like a strong plastic plate made for multiple use. The solution seems to be that the next generation of polymers should have much shorter environmental half-life (i.e. lover persistency) than existing polymers, but that the end-products are more durable, made by recycled materials and are designed for reuse and subsequently recycling in mind. The strategy should thus be two-fold; on one hand a focus on more durable products and on the other hand development of next generation polymers with less environmental impact.

Increasing recycling rates is seen as a central component of the transition to a more circular plastic economy (European Commission, 2018). Efforts to increase recycling rates are meant to ensure that materials stay longer within the value chain and thus both reduce resource consumption and pollution. This is an ideal scenario, whereas actual recycling often results in down-cycling and loss of materials from the value chain due to ineffective sorting systems etc. Furthermore, some type of recycling can result in increased release of micro(nano)plastics and can thus accelerate pollution with these smaller plastic fractions. For instance, artificial sports fields have been made with recycled rubber, often from worn out car tires. This down-cycling of tiers is one of the few recycling pathways of worn-out car tires and about twenty one percent of European car tires have thus be recycled in this way (Verschoor et al., 2021). It is estimated that approximately 10% of such in-fill materials are lost from the fields per year, leading to concerns regarding negative environmental impact. A recent risk assessment by the European Chemicals Agency have confirmed this concern and the European Chemicals Agency consequently proposed to the European Commission that restrictions on this type of recycling be implemented across Europe (European Chemicals Agency, 2019). Another example are microfibers released from textiles (Liu et al., 2019). There is established correlation between the quality of the textiles and the release of microfibers. The better the quality of the textiles, the fewer microfibers are released (Ramasamy and Subramanian, 2021). Polyethylene Terephthalate (PET) are recycled to make fleece, which reduce the consumption of virgin resources. However, fleece has a relatively high tendency to shed fibers. In this example the conservation of resources, which is a very important focal point in the transition to the circular economy, could thus increase the contamination with micro(nano)plastics. This dilemma should be a priority area for research into the connection between circular economy and release of micro(nano)plastics in the future.

Secondary microplastics generated in the environment

The second source of environmental pollution with micro(nano)plastics that we focus on in this perspective is the unintended release of micro(nano)plastics from products lost to the environment (Fig. 1). The vast majority of microplastic found in the environment can be characterized as secondary microplastic - i.e. breakdown products from larger pieces of plastic (Syberg et al., 2015). This implies that the most obvious way that transition to a circular plastic economy can prevent micro(nano)plastics contamination, is by reducing loss of products from the value chain and into the environment. Losses of products from the end-of-life phase of the value chain is responsible for a significant part of the environmental plastic pollution. Ryberg et al. (2019) thus found that more than 50% of global loss of plastic were lost from this phase in the value chain. A significant part due to poor waste handling, but initiatives at other stages of the life cycle can also prevent these losses. If products still have value, or is assigned value, once they are in the end-of-life phase, there is a chance that they can be kept within the value chain. An example of this is plastic bottles, which are found to a lesser extent in Danish nature compared to the rest of the Europe. This is likely due to the effective deposit-refund system that has been in place for many years in Denmark (Syberg et al., 2020).

Another way to reduce those losses of products to the environment from the end-of-life phase is by broadening the scope of the so-called extended producer responsibility. For instance, the extended producer responsibility is a central measure for European legislators in regard to reducing single-use plastics (European Council, 2019) and is viewed as a vital to ensure that especially cheap and poor-quality plastics, such as packaging, are kept within the value chain (Ellen MacArthur Foundation, 2021). The extended producer responsibility makes producers of packaging responsible for the end-of-life fate of their products, and possibly facilitate innovation of products, which are not meant for single-uses and/or plastics with lower environmental impact in case they are lost to the environment Experiences with the extended producer responsibility has documented, that it can be an important measure for transition towards a more circular economy, since it provides producers with strong incentives to lower the environmental impact of their product, typically by improved take-back systems, improved reuse and better recycling (Leal Filho et al., 2019). Min et al. (2020) assessed environmental degradation of plastics based on physical properties and composition and were able to categorize different plastics potential to degrade. Such knowledge should be accounted for when assessing materials for new products should be produced of within a circular economy framework. Biodegradable plastics could be part of the solution, but it is important not to reproduce the mistakes of the oxo-degradable plastics, where the effort to make plastics easily degradable turned out to produce higher environmental concern (Schiavo et al., 2020).

How circular economy can prevent micro(nano)plastic contamination

Transition to a circular plastic economy is viewed as the cornerstone in ensuring a more sustainable future for plastic consumption (European Commission, 2018). Focus is on keeping the materials within the value chain for as long as possible and reducing the pressure on the environment from resource consumption. To a large extent this focus will reduce the pressure on the environment from micro(nano)plastics, but there are some considerations that are important, to avoid antagony between the aim of facilitating the circular transition and the efforts to reduce micro(nano)plastic contamination. *First*, future innovation and development in the design of products and the use of new polymers should focus on making them more durable compared to existing single use products and are designed with reuse and potential recycling in mind. The potential loss of micro(nano)plastics to the environment has to be accounted for throughout the life-cycle of a given product and the next generation of polymers should have much shorter environmental turn-over times compared to existing polymers. *Second*, it has be ensured that efforts to recycle products that consist of macroplastics do not result in an increase in the release of micro(nano)plastics into the environment. Such recycling activities should be subject to the extended producer responsibility. *Third* and finally, the environmental fate and behavior of different plastics must be taken into consideration in the design of new materials and products to ensure that these are on the one hand durable and have a value through-out their life cycle, not at least in the end-of-life phase and are made for reuse and subsequently recycling, and on the other hand does not pose long lasting pollution if they are lost to the environment.

Declaration of Competing Interest

None.

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