The Ecodesign Directive as a driver for less microplastic from household laundry

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Preface

The presence of microplastic in the marine environment has gained increased attention in recent years. Washing of textiles is one of the sources of microplastic fibres that has raised increased concern. A study on the EU level has estimated the amount of microplastic released by washing of clothing to 16 000-41 000 tonnes per year (Hann et al., 2018).

The primary source of microplastics from the textile sector in Sweden is the washing and wear of synthetic fibres. Ideally, regulations should be targeted close to the source of an environmental problem to be effective, in this case towards the production of synthetic fibres. However, textile production takes place almost entirely outside Sweden and the EU, and regulations targeted at textile production would therefore require international commitment. As international commitments are harder to enforce, we chose to focus on options at the EU-level.

In 2017 the Swedish Environmental Protection Agency (SEPA) presented a report with results from the first survey of sources and distribution of microplastics in Sweden, as well as an assessment of the key sources of microplastics. One proposal in the report was to further investigate the possibility to introduce requirements for microplastic filters in the Ecodesign regulation for washing machines. The Swedish Energy Agency also welcomes such an assessment.

SEPA has in dialogue with the Swedish Energy Agency assigned Anthesis AB to conduct a socio-economic analysis of the introduction of Ecodesign criteria to reduce microplastics from washing of textiles. The purpose of the study was to examine the problem with microplastics emissions from laundry from a socio-economic perspective. More specifically, the study aims to provide a structure for analysing the performance of policy instruments concerning microplastics, and to demonstrate the potential socio-economic impacts of implementing a filter requirement.

Henrik Nordzell, Åsa Soutukorva Swanberg and Linus Hasselström from Anthesis AB carried out the study.

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Summary

The presence of microplastic in the marine environment has gained increased attention in recent years. There are many different sources of microplastic particles, of which one is synthetic fibres from textiles. This report focuses on microplastic emissions from household laundry.

The problem with microplastic is international and textile production takes place almost entirely outside Sweden and the EU. Regulations targeting at textile production would thus require international commitment. Regulations targeted instead at the laundry phase would be possible to implement at the EU-level, hence a more feasible option. The potential for using the EU Ecodesign Directive as a policy tool for reducing the emissions of microplastic from laundry should therefore be explored further. The purpose of this study is to start framing the problem with microplastics emissions from household laundry from a socio-economic perspective. More specifically the study aims to 1) provide a structure for analysing the performance of policy instruments in the area of microplastics and 2) to demonstrate the potential socio-economic impacts of implementing filter requirements in the Ecodesign Directive. The analysis does not replace other types of assessments carried out in relation to the Ecodesign Directive.

The most important findings in terms of 1) above are:

- A filter criterion has potential to achieve the target of reduced emissions of microplastics from new washing machines (the present stock of machines are not included) but the effect will depend on how the ecodesign requirements are specified, the performance of filters and on how consumers handle the filters. According to stock and sales statistics, a significant part of households in Sweden with a washing machine should have a new machine with a filter in just over 10 years (15 years in EU) after first year of implementation.
- Two types of formulations of requirements are possible; either a criterion for specific filtering techniques, or an emission limit. An emission limit would have the advantage of flexibility, since a target is set but the producers are free to decide on how to reach it. However, the potential of this policy instrument to achieve the target of reduced microplastic emissions is uncertain and depends on at which level the emission limit is set and also on the possibility to regularly measure and control the impacts. By providing more flexibility in how to reach emission limits, this approach would in theory be a more cost-effective solution than to set requirements that filters should be used.

The most important findings in terms of 2) above are:

- The cost of implementing a filter criterion would be borne primarily by the producers of washing machines. In the longer run, parts of these costs would spill over to consumers in terms of higher prices of washing

machines. The expected types of costs include for example investments in filters, installation of the equipment, education of staff, information to consumers, etc. If users of washing machines would have to spend time and effort to take care of the filter, that would also be a cost to them. Further, all users would have to pay for more expensive washing machines regardless of their impact on microplastic emissions, i.e. they will bear the cost even if they take other measures to reduce emission, like buying less synthetic textiles. This is a contrast to other ecodesign requirements where the consumer saves in on energy use in the long run, even if the purchasing price is higher for more energy efficient products. Producers of filters would gain from the new policy by increased revenues. The long-term environmental and health impacts of less microplastics emissions will be beneficial for the general public because of e.g. reduced health risks, and increased recreational values and existence values. The fisheries and aquaculture and tourism sectors would gain from avoided commercial losses due to microplastics.

The following recommendations are given:

- More quantitative evidence on the performance of filters to remove microplastics is needed. One major question is how filters perform in reality, i.e. outside controlled test environment.
- Given the risk that the functioning of filters in laboratory environments is satisfying but that the effect in practice is highly dependent on the behaviour of users in reality, it is crucial that a filter criterion in the Ecodesign Directive is accompanied by careful writings on how to reduce this risk.
- The effect of filters depends on how they are handled. It is thus important that users are fully informed about how to dispose of the microplastics to prevent that the filter is rinsed off in the sink, which would result in lower effectiveness of the policy instrument and a lower likelihood of achieving the target. The risk may be reduced for example by integrating the filter with the machine to make sure it cannot be removed or by-passed by the user.
- If a filter criterion is included in the Ecodesign Directive it is important to avoid potential conflicts (negative synergy effects) associated with primarily energy efficiency by careful writings about this risk in the Directive. The amount of added energy use due to a filter solution is not yet known, but would have to be studied closely before implementing a filter criterion. The cost and potential negative impact on EU climate goals must be considered as part of a deeper analysis of energy use.
- Regardless of whether a filter criterion or an emission limit is set, expanded systems and routines for reporting and control are needed, which are associated with different kinds of transaction costs. For example, a standardized method for measuring emissions of microplastics will be required in order to be able to determine an emission limit. The magnitude and distribution of transaction costs needs to be studied further.

- The impact assessment and distributional analysis indicate that the incentives to act are skewed, i.e. producers would initially have to carry most of the cost burden and other actors (producers of filters, the tourism and fisheries sectors and the general public) would enjoy the benefits. This may negatively affect the producers' willingness to take action and needs to be taken into account when policy is designed. It is important to give the producers sufficient time to adapt.
- An alternative policy instrument is to carry out information campaigns to raise public awareness of microplastics. This may stimulate consumers to use less synthetic fibres and/or change their laundry behaviour (e.g. reducing frequency of laundry, using lower temperatures, switching to eco-labelled detergents, etc.). Some consumers may also decide to invest in filters themselves. Although information alone is not likely to solve the microplastic problem, it may contribute to lower emissions.
- Even if consumers do everything right they will still be tied to expensive technological solutions. The underlying problem is that few options exist to regulate the textile market. One potential alternative could be that producers who place textiles on the EU market were obliged to offer flexible filter solutions for the consumers.
- The chain of events *implementation of filter technology → reduced emissions of microplastics → environmental and health impacts → valuation of impacts* needs to be studied further and deeper. With increased knowledge about these linkages it will be possible to carry out more precise socio-economic impact assessments.
- Additional research is needed to better understand how microplastics influence ecosystems and human health and how people perceive the problem with microplastics.

Sammanfattning

Förekomsten av mikroplast i havsmiljön har fått alltmer uppmärksamhet de senaste åren. Det finns ett flertal olika källor till mikroplastpartiklar, t.ex. syntetfibrer från textiler. Denna rapport fokuserar på utsläpp av mikroplast i samband med hushållstvätt av textiler.

Problemet med mikroplast är internationellt och textilproduktion sker nästan uteslutande utanför Sveriges och EU:s gränser. Regleringar riktade mot textilproduktion skulle därmed kräva internationella åtaganden. Regleringar som istället fokuserar på tvättfasen i värdekedjan för textiler vore möjliga att genomföra på EU-nivå och innebär därmed en större rådighet. Potentialen för att använda EU:s Ekodesigndirektiv som styrmedel för minskade utsläpp av mikroplast i samband med tvätt bör därför utredas närmare. Syftet med denna studie är att rama in problemet med mikroplastutsläpp från hushållstvätt utifrån ett samhällsekonomiskt perspektiv. Mer specifikt syftar studien till att 1) bidra med en struktur för analys av hur styrmedlet fungerar med avseende på mikroplast, 2) att demonstrera de potentiella samhällsekonomiska konsekvenserna av att införa ett filterkriterium i Ekodesigndirektivet. Analysen ersätter inte andra samhällsekonomiska analyser som eventuellt genomförs av direktivet.

De viktigaste resultaten avseende 1) ovan är:

- Ett filterkriterium har potential att uppnå målet med minskade mikroplastutsläpp från nya tvättmaskiner (begagnatmarknaden inkluderas inte) men effekten beror på hur kraven formuleras, hur effektiva filtren är och hur användarna tar hand om filtren. Enligt säljstatistik bör en signifikant del av de svenska hushållen som har en tvättmaskin, ha en ny med ett filter drygt 10 år (15 år för hela EU) efter implementering.
- Det finns två sätt att formulera kraven; antingen som ett kriterium för filterteknik mer specifikt eller som ett utsläppstak. Ett utsläppstak har fördelen att det är flexibelt eftersom maskintillverkarna är fria att själva bestämma hur målet ska nås. Styrmedlets potential att bidra till måluppfyllelse avseende minskade mikroplastutsläpp är dock osäker och beror på vilken nivå för utsläppen som väljs och även på möjligheten att regelbundet mäta och kontrollera effekterna. Genom den större flexibiliteten gällande hur utsläppskraven bör nås skulle ett utsläppstak vara en mer kostnadseffektiv lösning än att bestämma att filter ska användas.

De viktigaste resultaten avseende 2) ovan är:

- Kostnaden för att genomföra ett filterkriterium skulle bäras framför allt av tvättmaskinstillverkarna. På längre sikt skulle delar av denna kostnad skjutas över på konsumenterna genom högre pris på tvättmaskiner. De kostnader som kan förväntas är till exempel investeringskostnader,

installation av utrustning, utbildning av personal, information till användare, osv. Om användarna behöver ägna mycket tid och ansträngning åt att ta hand om filtren utgör detta en kostnad för dem. Dessutom skulle dyrare tvättmaskiner innebära minskade möjligheter för användarna att undvika kostnader genom att göra rätt, dvs. minska sina inköp av syntetfibrer. Producenter av filter skulle vinna på den nya policyn genom ökade intäkter från försäljning. De långsiktiga positiva effekterna på hälsa och miljö skulle vara till nytta för allmänheten på grund av minskade hälsorisker, ökade rekreationsvärden samt existensvärden. Fiske- och turismsektorerna skulle vinna på att policyn genomförs, genom att de kan undvika kommersiella förluster till följd mikroplastorsakade skador.

Följande rekommendationer kan ges:

- Ytterligare välunderbyggd och kvantitativ information om hur olika filter kan minska mikroplastutsläpp från tvätt behövs. En viktig fråga är hur filtren fungerar i verkligheten, dvs. utanför kontrollerad testmiljö.
- Filtren fungerar väl i laboratorium, men i verkligheten beror effekten i hög grad på användarnas beteende. Av denna anledning är det avgörande att ett filterkriterium i Ekodesigndirektivet åtföljs av noggranna skrivningar gällande hur denna risk kan minimeras.
- Filtrens effekt beror på hur de hanteras. Det är därför mycket viktigt att användare är informerade om hur de ska ta hand om filtren på rätt sätt för att förebygga att de sköljs av i diskhon och resulterar i lägre effektivitet och lägre sannolikhet för måluppfyllelse. Risken kan minskas till exempel genom att integrera filtret med maskinen för att säkerställa att det inte kan tas bort eller kringgås av användaren.
- Om ett filterkriterium införs i Ekodesigndirektivet är det av stor vikt att försöka undvika konflikter (negativa synergieffekter) mellan filterfunktion och energieffektivitet, genom noggranna skrivningar i direktivet om denna risk. Det extra energibehovet med anledning av en filterlösning behöver studeras ingående inför ett genomförande av ett filterkriterium. Kostnaden och den potentiella negativa effekten på EU:s klimatmål måste belysas som en del av fördjupad analys av energianvändningen.
- Oavsett om ett filterkriterium eller utsläppstak tillämpas kommer utökade system och rutiner för rapportering och kontroll krävas, vilka förknippas med olika typer av transaktionskostnader. Till exempel kommer det att behövas en standardiserad metod för att mäta utsläpp av mikroplaster för att kunna bestämma nivån för ett utsläppstak. Omfattningen och fördelningen av transaktionskostnader behöver studeras närmare.
- Den samhällsekonomiska konsekvensanalysen och fördelningsanalysen indikerar att incitamenten att agera är snedvridna, dvs. tvättmaskinstillverkarna skulle inledningsvis få betala merparten av kostnaderna för ett införande av ett filterkriterium och andra aktörer (producenter av filter, fiske- och turismsektorn samt allmänheten) skulle få ta del av

nyttorna. Detta skulle kunna påverka tvättmaskinstillverkarnas vilja att agera och behöver tas hänsyn till vid utformningen av styrmedlet. Det är viktigt att producenterna ges tillräcklig tid för omställningen.

- Ett alternativt styrmedel är informationskampanjer för att öka den allmänna medvetenheten och kunskapen om mikroplaster. Detta kan tänkas stimulera konsumenter att använda mindre mängd syntetiska textilier och/eller påverka deras tvättbeteende (t.ex. att tvätta mer sällan, använda lägre temperatur, byta till miljömärkta tvättmedel, osv). Somliga konsumenter kan även komma att själva investera i filter. Även om information ensamt inte kommer att lösa problemet med mikroplast kan det åtminstone bidra till att minska utsläppen.
- Även om konsumenter gör allting rätt kommer de att vara bundna till dyra tekniska lösningar. Det underliggande problemet är att det finns få alternativ för att reglera textilmarknaden. Ett potentiellt alternativ vore om producenter som tillhandahåller textiler för den europeiska marknaden åläggs att erbjuda flexibla filterlösningar för konsumenterna.
- Kedjan *genomförande av filterteknologi → minskade mikroplastutsläpp → miljö- och hälsoeffekter → värdering av effekter* behöver studeras närmare. Med ökad kunskap om dessa samband kommer det att vara möjligt att genomföra mer precisa samhällsekonomiska konsekvensanalyser.
- Ytterligare forskning behövs för att bättre förstå hur mikroplast påverkar människors hälsa och miljö samt hur människor uppfattar problemet med mikroplast.

1 Introduction

In August 2015, the Swedish Environmental Protection Agency (SEPA) was commissioned by the government to identify the key sources of the release of microplastics into the ocean. In 2017 they presented a report with results from the first complete survey of sources and distribution of microplastics in Sweden, as well as an assessment of the key sources of microplastics.

The occurrence of microplastics in the marine environment has attracted more and more attention in recent years. Plastic debris has been found in all major ocean basins, with an estimated 4 to 12 million metric tons (Mt) of plastic waste generated on land entering the marine environment in 2010 alone (Geyer et al., 2017). Where the plastic concentrations are the highest, main factors are assumed to be ocean currents and littering from highly populated coasts, but also broken fishing gear left at sea. Due to UV radiation, saltwater and chemical reactions, the plastic breaks into particles and form what is called microplastic – a generic term for tiny plastic fragments up to 5 mm. Furthermore, deliberately manufactured microplastics are added to products with different desirable properties, for example as a polishing effect in toothpaste and other hygienic articles. They can also be released from different activities on land where plastic products turn into debris that is gradually fragmented into smaller parts and released in nature. This latter category was the focus of the study performed by SEPA.

According to estimates based on the survey results, these following sources represent the principal sources of microplastics emissions to the nature in Sweden (SEPA, 2017):

- roads (500 tonnes/year) and tyres (7 674 tonnes/year),
- artificial turf pitches (1 640–2 460 tonnes/year),
- industrial production and management of primary plastic (310–533 tonnes/year),
- washing of synthetic textiles (8–950 tonnes/year),
- boat hull paint (160–740 tonnes/year), and
- littering (unknown amount).

Possible pathways to the marine environment are via the air, via stormwater and snow dumping, and via wastewater treatment plants and slurry spreading. However, given the limited scientific knowledge and available data for most of the identified sources, it was not possible to calculate the percentage of microplastics being transported to oceans, lakes and waterways. With reference to the precautionary principle, SEPA encourages affected stakeholders to carry out measures that can be implemented at reasonable cost and with reasonable results (SEPA, 2017).

This report focuses on microplastics from household laundry. A number of national and international reviews have identified textile fibres as one of the main sources of microplastics to the oceans. The emissions arise mainly from wear and tear and washing of synthetic textiles, from which small fragments end up in waste water treatment plants (WWTPs).

An estimated 8–950 tonnes of microplastics from household laundry reach Swedish WWTPs each year (Magnusson et al., 2016). Most of the microplastic is removed from the water in WWTPs, where it is retained in the sewage sludge. The sewage sludge containing the retained microplastics is spread on agricultural land (25 %), used in soil production (29 %) or used in landfill cover materials (24 %). But an estimated 0.2–19 tonnes per year remain in the water effluents and is released directly to freshwater and marine water bodies (Magnusson et al., 2016). A study on EU level has estimated the amount of microplastics released to surface waters from washing of clothing to about 13 000 (4 000–23 000) tonnes per year (Hann et al., 2018).

Current research is focusing on potential alternatives to synthetic fibres and also on how the construction and production of synthetic fibres may be changed to minimize the risk for microplastic emissions. The production of natural fibres is very chemical- and water-intense, which leads to major negative impacts on the environment and on human health. There is no practical possibility of meeting the great demand for textiles by supply of natural fibres only. One advantage of synthetic fibres such as polyester is that the recyclability is higher than for cotton. Additionally, synthetic fibres have characteristics that are sometimes hard to replace with natural fibres (personal communication with Yvonne Augustsson, SEPA, 2018-12-07). For these reasons, a ban on production and use of synthetic textiles is neither feasible nor desirable from a political, economic, environmental or practical point of view.

Policies and technologies aimed at reducing the release of textile microfibres are urgently needed but also information campaigns aimed at achieving a shift from overconsumption to sustainable fashion. Further, consumers need to be informed about "microplastic friendly" ways to take care of their clothes. There are currently no policy measures directly aimed at reducing the emission of microplastics from laundry. But a number of optional approaches exists to mitigate the release of microplastics from laundry water to marine ecosystems; i) improved textile production methods, ii) less consumption of synthetic textiles, iii) improved or water-free washing methods and iv) better separation methods at the WWTPs (SEPA, 2017). Clearly, measures may be carried out in every step of the supply chain of clothes. In this report we focus on policies and measures to limit the emission of microplastics from washing of synthetic textiles, i.e. on one specific policy option from a set of potential options aimed at the textile industry.

Since the problem with microplastic is international and since textile production almost entirely takes place outside Sweden and the EU, international policies are needed. Regulations targeted at textile production would thus require international commitment. Regulations targeting the laundry phase would be possible to implement at the EU-level, and is thus judged as being a more feasible option. The potential for using the EU Ecodesign Directive as a policy tool for reducing the pollution of microplastics from laundry should therefore be explored further. The performance of washing machines in terms of energy efficiency, washing result and water usage is already regulated by the Directive. The Directive is however open for including additional parameters which provides an opportunity to also include microplastic.

1.1 Method and structure

The purpose of the socio-economic analysis carried out in this study is to start framing the problem with microplastic emissions from laundry from a socio-economic perspective. More specifically the study aims to 1) provide a structure for analysing the performance of policy instruments in the area of microplastic and 2) to demonstrate the potential socio-economic impacts of implementing filter requirements. The analysis will not replace other types of assessments carried out in relation to the Ecodesign Directive (for example as part of the Methodology for Ecodesign-related Products – MEErP).

Two methods are used for carrying out the socio-economic analysis:

1. Evaluation of policy criteria. A number of key criteria are studied in order to be able to determine whether using the Ecodesign Directive as policy instrument is likely to be socio-economically effective and successful or not. The analysed criteria are: effects on target, cost-effectiveness, distributional impacts, dynamic efficiency, synergy effects and transaction costs.
2. Socio-economic impact assessment. The positive and negative impacts (benefits and costs) of implementing a filter criterion in the Ecodesign Directive are identified and exemplified based on previous environmental, economic and social assessments in the area of microplastics. Indications are given on which groups in society will be affected and how.

The report is structured in the following way: Chapter 2 gives a background to the problem with microplastics from household laundry based on a discussion of the underlying market failures. The chapter briefly demonstrates the current policy landscape. Chapter 3 introduces the Ecodesign Directive as a policy instrument for microplastics. It outlines and evaluates two major options for policy design; either to make use of a specific filtering technique or to apply an emission limit for microplastics from washing machines. Chapter 4 presents an evaluation of the ecodesign directive as policy instrument for reducing microplastic emissions. Chapter 5 contains a socio-economic impact assessment of the implementation of a filter criterion. Chapter 6 aims to broaden the perspective by discussing alternative policy options. Finally, Chapter 7 provides recommendations.

2 Background

This chapter gives a background to the environmental problem by explaining the extent of and reasons for microplastics emission from household laundry (section 2.1) and by framing this it in terms of market failures which currently lack a set of sufficient policy instruments (section 2.2). Additionally, the textile value chain is discussed to provide a perspective on the international context (section 2.3).

2.1 Microplastics from household laundry

Synthetic textiles, normally polyester-, nylon- or acrylic fibres, are mostly derived from crude oil. The main part of produced synthetics comes from developing countries; about 80 % of textiles consumed in Sweden are produced outside of EU. Consumption of synthetic textiles has increased since they were introduced on the market in the 1930s, and with increasing population and a shortage of substitutes the demand is likely to increase additionally in the future. While most synthetics are still consumed in developed countries today, the demand is increasing at a higher rate in countries with a growing middle class (Östlund et al. 2015). Globally an estimated 60 million tonnes of synthetic fibres were produced in 2015, which means that over 50 percent of all textiles used in the world contain synthetics to some extent (Magnusson et al. 2016). Swedish consumers purchase an equivalent of 140 000 tonnes[1] of textiles each year, of which about 30–40 percent are made of synthetic fibres (Schmidt et al., 2016).

Washing of textiles leads to abrasion and wear, which in turn leads to shedding of fibres that end up in the household sewage water (Browne et al. 2011). In one study it was shown that a single textile garment was shedding >1 900 fibres per wash. Another study showed that laundering 6 kg of synthetic materials could release around 138 000–729 000 fibres per wash (Magnusson et al. 2016). The amount of fibres being released from a kilogram of textile per wash depends on a number of factors including material composition, construction and washing parameters. For example, about 140.000 fibres may shed from a polyester-cotton blend, 500 000 fibres from a polyester blend or 700.000 fibres from acrylic textiles.[2] Fleece fabric shed more than knitted fabrics and loose and worn fabrics shed more than other fabrics. Higher temperatures, longer washing programmes and intense centrifugation are also factors that increase microfiber release. Compared to liquid detergents, powder detergents were found to have an adverse impact on shedding from textiles in some, but not all studies (Brodin et al., 2018).

[1] http://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Textil/

[2] https://planetcare.org/en/

Figure 1 illustrates the stages and factors which affect the rate of shedding and emissions of microfibres from washing.

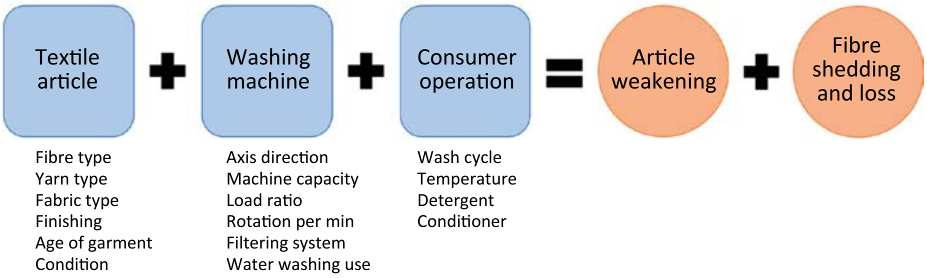

Figure 1. Stages and factors affecting the rate of shedding and emissions of microfibres from washing of textiles. Source: Henry et al (2018).

2.2 Market failures

The term market failure is an economic concept describing a situation in which the market fails to provide an efficient outcome. According to economic theory, competitive markets have the potential to generate welfare to society by providing a transaction mechanism for goods and services. However, under some conditions an unregulated market is unable to deliver an optimal outcome. A typical case for market failures is when the production or consumption of a good or service imposes a cost to a third part. This type of market failure is called an externality and would suggest the need for policy instruments. Other market failures are associated with time-inconsistent preferences, information asymmetries, lack of information, non-competitive markets, or principal-agent problems.

Market failures are the typical motivation for implementing policy instruments. By outlining the situation with respect to market failures, this section aims to provide some additional food for thought on relevant policy response. The most important questions for the section are: Why do microplastic emissions from household laundry occur when we know it damages the environment? Where in the supply chain is the problem being created; among producers or consumers of textiles? Who is responsible for what?

SEPA (2017) describes how designers of textiles, producers, buyers and consumers have so far not been fully aware of the problem with microplastics. This lack of knowledge and awareness is reflected in a number of behaviours, for example:

- Composition of materials – design and production of textiles containing synthetic fibres.
- Construction – manufacturing of textiles which implies fibre shedding when washed.
- Consumer choice – consumption of textiles made of synthetic fibres
- Washing method – washing of textiles which causes fibre shedding, e.g. too often, high temperatures, powder detergents.

One fundamental problem causing the above mentioned behaviours is that the environmental damage costs caused by microplastics pollution are not included in the final price of textiles. This implies that producers do not pay for adverse impacts on the environment and human health which are (or may be) caused by the products they produce and deliver for the market. In other words, the externalities of textile production and consumption are not internalised in the market price. Externalities can be defined as costs or benefits which affect a person/actor who did not choose to incur the cost or benefit. The fact that the environmental damage costs (impacts from microplastic pollution) are not covered by the market price of textiles implies that the supply and demand of synthetic textiles is too high. Low prices lead to high consumption and low incentives for changed behaviour. Another aspect of the problem is that consumers base their purchase decisions on incomplete information and thus buy more than what would be socio-economically optimal. The low price on synthetic and other types of textiles is however not only caused by non-internalized environmental damage costs, but also on the very low cost of labour in countries where textiles are produced. A high consumption of textiles can be expected as long as most of the textile production takes place in countries with very low salaries.

In summary, the underlying market failures which cause microplastic pollution are:

- **Lack of information** – designers, producers, buyers and consumers of textiles do not have full knowledge of the problem with microplastics, which is evident in a number of behaviours among these actors.
- **Externalities** – the true cost of textile production and consumption is not reflected by the market price of textiles. This leads to low prices, overconsumption and low incentives for changed behaviour.

2.3 Value chain of textiles

The level of knowledge and understanding about the problem with microplastics and potential measures to help prevent it is increasing in different parts of society. This section gives an overview of the value chain, i.e. the chain of events from production of textiles to consumption (private and public procurement) and laundry (household and commercial). The report focuses on the laundry phase of the value chain, and the topic for this section is to explore what can be done at the international/EU and national (Swedish) level to mitigate the problem with microplastics emissions when textiles are being washed. Figure 2 illustrates the value chain of textiles.

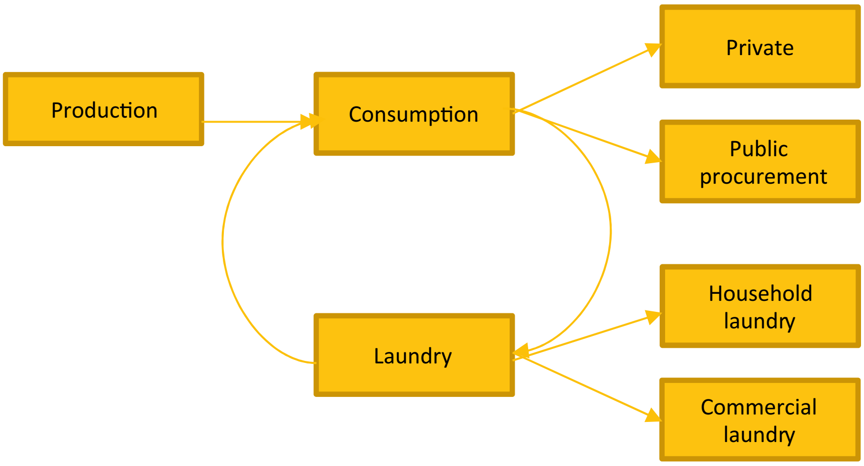

Figure 2. Illustration of value chain of textiles.

In SEPA (2017) current international, EU and national policies and initiatives are described and discussed. No policy instruments exist which are *directly* targeted at microplastics pollution from washing of textiles. However, SEPA (2017) conclude that the types of behaviours that cause microplastics pollution are often the same ones that cause other emissions from the assessed sources. One example is that washing of textiles may also cause emission of chemicals. Additionally, many of the measures taken today to prevent and reduce discharge of various substances into the water and air can be expected to also have an impact on the release of microplastics, e.g. information campaigns to educate people that chemicals of different kinds do not belong in the sewage system. It is therefore recommended that these synergies between measures for reducing the release of microplastics and current or planned actions in other areas are utilized (SEPA, 2017). A number of already existing national and international (EU) policies and initiatives of direct or indirect relevance for microplastics pollution from textile laundry are summarized below.

International/EU

In order to reduce microplastics from synthetic fibre shedding during laundry, policy instruments should be targeted at the composition/content as well as construction of textiles. However, today no such direct regulation of the production of textiles exists from a microplastics perspective. The room to act is restricted by the fact that the production of textiles containing synthetic fibres nearly exclusively takes place outside Sweden and the EU. Regulations targeted at textile production would thus require international commitment. Another important obstacle is that well-recognized methods for measuring and analysing microplastics emissions are lacking.

Regulations focusing on the laundry phase would be possible at the EU-level because EU legislation regulates which products are placed on the market. Regulation targeted at the laundry phase is thus a more feasible option compared to regulating international textile production. EU legislation is also necessary given that the possibility to act is very limited for one country alone. One example of an EU initiative is the EU Life project MERMAIDS with the objective to assess the amounts of synthetic fibres shed during washing. Among other things the project has looked into different methods to reduce emissions, e.g. choice of detergents, temperature, filter solutions etc. The results from the MERMAIDS project include consumer information, estimates from filter tests and policy recommendations. A number of international industry initiatives have been taken to develop filter solutions and microplastic "catching devices". Initiatives have also been taken by the fashion industry and environmental organisations aimed at increasing the knowledge about how clothes should be washed in order to reduce fibre shedding (Brodin et al., 2018).

National

Consumption of textiles. By reducing the consumer demand for synthetic fibres a positive impact on microplastics emissions would be expected. A number of national information campaigns have been carried out focusing on the message that chemicals from clothes (and other sources) do not belong in the sewage system but there is so far no clear link to emission of microplastics. The general level of knowledge about microplastics is still very limited among Swedish households.

Procuring authorities. Green procurement of goods and services in the public sector has been identified as a potentially important policy instrument. By taking advantage of their purchasing power, authorities have an important role to push the development in a more sustainable direction as textiles and associated services (for example laundry) are procured. Microplastics are currently not part of the criteria for sustainable procurement as specified by the National Agency for Public Procurement.

Household and commercial laundry. There are currently no national policy instruments aimed at changing the behaviour of households to avoid or lower the release of microplastics during laundry. There is also no direct steering mechanism targeted at pollution of microplastics from commercial laundries. The discharge of water from larger washing facilities is tested on a regular basis and analysed, normally focusing on BOD, COD, oil, phosphorus, nitrogen and metals. Policy instruments focusing on chemical use is probably more urgent than regulating the release of microplastics.

Based on the above it is clear that Sweden alone cannot solve the problem with microplastics by steering what takes place in the laundry phase. This is also not possible from an international perspective. It seems more promising to regulate on the EU-level. The potential to use the EU Ecodesign Directive as a policy instrument to reduce the emission of microplastics from laundry should thus be explored further. The performance of washing machines in terms of energy efficiency, washing result and water usage is already regulated by the Directive. The Directive is however open for further parameters which means an opportunity to also include microplastics. Requirements included in the Directive must be possible to follow-up, and thus need to be measurable. The requirements for washing machines are currently being revised but microplastics have so far not been a topic for discussion in the EU consultation forum. Nevertheless, it is evident that the current revision will imply that other requirements (than energy efficiency) will also be included for washing machines. The Ecodesign Directive is discussed further in the next section.

3 The Ecodesign Directive

The Ecodesign Directive 2009/125/EC establishes a framework for the setting of ecodesign requirements for energy-related products at EU level. It is a key instrument of the union policy for improving the energy efficiency and other environmental aspects of products placed on the market or put into service in the European Economic Area (EEA). Its scope currently covers more than 40 product groups (such as boilers, lightbulbs, TVs and fridges), which account for a large proportion of the consumption of natural resources and energy in the Community. The implementation of such requirements would contribute to the EU's target of reducing greenhouse gases by at least 20 % by 2020 and by 40 % by 2030. Ecodesign measures can be reinforced also through the Directive 2010/30/EU *on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products*. The EU Commission estimates that the so far implemented ecodesign and labelling requirements will save 537 TWh electricity annually by 2020.

The ultimate aim of the Ecodesign Directive is that manufacturers of energy-using products will, at the design stage, be obliged to reduce energy consumption and other negative environmental impacts of products. While the Directive's primary aim is to reduce energy use, it is also aimed at enforcing other environmental considerations including materials use, water use, polluting emissions, waste issues and recyclability.

The Ecodesign Directive is a framework directive, meaning that it does not directly set minimum ecological requirements. These are adopted through implementing measures for each group of products in the scope of the Directive. Each implementing regulation comes with a set of generic and specific ecodesign requirements. Below follows a presentation of the requirements specified for household washing machines in the Ecodesign Directive (section 3.1). In section 3.2, the ecodesign requirements for another type of product – solid fuel boilers – are also described with the purpose to illustrate the functioning of a different kind of policy instrument, i.e. an emission limit. The key question addressed with this section is which lessons to learn regarding how to design a policy instrument for microplastics based on an emission target rather than filter requirements.

3.1 Household washing machines

Commission Regulation (EU) No 1015/2010 of 10 November 2010 is implementing the Ecodesign Directive 2009/125/EC with regard to requirements for household washing machines. The specific Ecodesign requirements for household washing machines are differentiated by the rated capacity of the appliance, i.e. the maximum mass of dry textiles of a particular type, which the manufacturer declares can be treated in the washing machine on the programme selected, expressed in kilograms. For instance, with stricter requirements regarding the Energy Efficiency Index (EEI) for household washing machines with a rated capacity equal to or higher than 4 kg. The following EU generic and specific Ecodesign requirements apply for washing machines sold on the EU market according to Commission Regulation No 1015/2010;

Generic requirements

1. For the calculation of the energy consumption and the other parameters for household washing machines, the cycles which clean normally soiled cotton laundry (hereafter standard cotton programmes) at 40 °C and 60 °C shall be used.
2. The booklet of instructions shall further provide
   a) The standard cotton programmes shall specify that they are suitable to clean normally soiled cotton laundry and that they are the most efficient programmes in terms of combined energy and water consumptions for washing that type of cotton laundry; in addition, an indication that the actual water temperature may differ from the declared cycle temperature;
   b) power consumption of the off-mode and of the left-on mode;
   c) indicative information on the programme time, remaining moisture content, energy and water consumption for the main washing programmes at full or partial load, or both; and
   d) recommendation on the type of detergents to use.
3. Household washing machines shall offer to end-users a cycle at 20 °C. This programme shall be clearly identifiable on the programme selection device.

Specific requirements

1. Energy Efficiency Index (EEI): Since 2011, for all household washing machines, the EEI shall be less than 68 (i.e. Energy Label class A or better); further, since 1 December 2013, for all washing machines over 4 kg the EEI has to be less than 59 (Energy Label class A+ or better).
2. Water consumption (Wt): has to be $\leq 5 \times c_{1/2} + 35$, where $c_{1/2}$ is the washing machine's rated capacity for the standard 60 °C cotton programme at partial load or for the standard 40 °C cotton programme at partial load, whichever is the lower.
3. Washing Efficiency Index (Iw): for household washing machines with a rated capacity > 3 kg the efficiency must be greater than 1.03, which corresponds to the class A.

The requirements thus cover energy use, water consumption and washing ability. The regulation is however currently being revised and an early draft recommends that also combined washer-dryers are included and that additional requirements on repair and end-of-life aspects to ensure material resource efficiency are added, in addition to more stringent requirements for energy and water use. There are no requirements regarding polluting emissions (of any kind) for household washing machines, although a suggestion is on the table that the next revision (according to article 9) should include studies of adding filters to remove microplastics from the water outlet (personal communication, Lovisa Blomqvist, Swedish Energy Agency, 2018-10-08). These studies should be carried out within five years after implementation of the upcoming revised regulation.

3.2 Example case – solid fuel boilers

As mentioned above, the Directive's primary aim is to reduce energy use, but it is also aimed at enforcing other environmental considerations like polluting emissions. The implementing regulation for central heating solid fuel boilers is one example where this issue has received some attention. By looking at how ecodesign requirements for solid fuel boilers were formulated and what effects they have on emission levels, clues may be given of how to design requirements also for emissions of microplastics. Hence, this case is given some attention below.

With more than 436 000 units purchased in the EU-27 in 2010, solid fuel burners had a market volume clearly exceeding 200 000 sold units, which is the threshold for the Ecodesign Directive. As requested by Article 15 of the Directive, a preparatory study identified the relevant environmental aspects of the products. At the time of the pre-study the solid fuel boilers stock of the EU-27 were significant energy users and contributors to greenhouse gas emissions. They were also major emitters of particulate matter (PM), organic gaseous carbon (OGC) and carbon monoxide (CO), and NOx (oxides of nitrogen) which are harmful for human health and the environment.

Before determining appropriate emission requirements for solid fuel burners, a pre-study analysed emission levels of a base case burner (a representative average product on the market) and a burner using best available technology (BAT) for a range of appliances. The study found that the best available technologies on the market can significantly reduce most of the specific emissions, hence great improvement is possible. The BAT emission level of PM ranges from 25–40 mg/m^3 for central heating appliances between 20–50 percent lower than base case burners (Bio Intelligence Service, 2009).

After reviewing a set of alternative policy options, the specific ecodesign requirements for central heating solid fuel boilers were decided. For particulate matter the requirements were set at approximately the same (or slightly above) level as the emission levels with BAT, i.e. not higher than 40 mg/m^3 for automatically stoked boilers and not higher than 60 mg/m^3 for manually stoked boilers (COMMISSION REGULATION (EU) 2015/1189).

The time of implementation was set to 2020 since early implementation of such stringent requirements at EU level may be a challenge for manufacturers who do not currently have BAT products in their portfolio. This would give them time to develop products which comply with the new regulation (European Commission, 2015). The allocation between old, base case and BAT appliances with ecodesign requirements are showed in Figure 3. In BAU the green field with BAT products is instead red, i.e. BAT products would still be base case products.

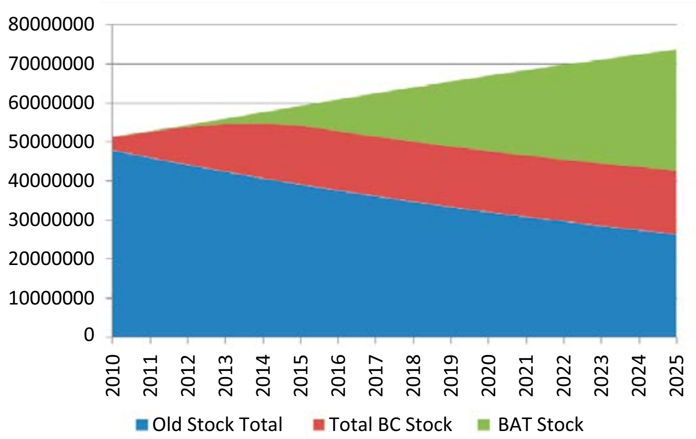

Figure 3. Allocation between old, base case and BAT appliances with ecodesign requirements. Source: Bio Intelligence Service (2009).

Given the long lifetime of solid fuel SCIs new products are going to be slow to penetrate the market and a large portion of the total stock will consist of old appliances for many years. Far more significant energy savings could be realised if the old stock was replaced with new available technology. In the pre-study it was strongly recommended that the renewal of the appliance stock is considered during the implementation phase of any policy measures as the potential reductions of emissions in Europe would be realised much more quickly and to a greater extent (Bio Intelligence Service, 2009).

Furthermore, solid fuel boilers also release emissions of NOx (oxides of nitrogen). According to the current state of knowledge and to stakeholder comments, the emissions of NOx are mostly fuel-derived, and thus could only be reduced with secondary measures. For recently produced boilers, such emissions are usually under 200 mg/Nm^3 (at 10 % O_2) and are thus at present not a significant problem. However, due to new boiler designs with higher combustion temperatures being promoted further as a result of energy efficiency and organic emission requirements, additional NOx emissions (on top of the fuel-derived NOx emissions) may be generated. Therefore, NOx emissions of solid fuel boilers may be increasing as a result of ecodesign requirements (European Commission, 2015).

The case of solid fuel boilers thus shows some interesting facts in the design of ecodesign requirements on PM emissions that could be considered also for policy options regarding emissions from washing machines;

1. The requirements are applied as an emission limit.
2. The required level was set according to what existing BAT burners are emitting in general, and not according to what can be achieved with a certain abatement technique.
3. Policy formulations were based on only one tier with the most stringent requirements from the first date of implementation. However, they start to apply long enough in the future (a four-year complete redesign cycle) for producers in even the least developed markets in EU to be able adapt.
4. The negative synergy effect on NOx emissions generated by more efficient burning was considered by including a requirement on NOx equal to current emissions levels. This would ensure that technological development of solid fuel boilers to achieve the ecodesign requirements does not result in increased NOx emissions and adversely affect health and environment.
5. Given the long lifetime of products already being used it will take many years before most boilers on the market meet the ecodesign requirements. For an effect on emissions in the short run additional policies might therefore be needed.

4 Evaluation of the Ecodesign Directive as policy instrument

By using the Ecodesign Directive as framework, this section outlines two major options for policy design; 1) to make use of a specific filtering technique or 2) to apply an emission limit for microplastics from washing machines. The analysis thereby takes into consideration already existing EU generic and specific Ecodesign requirements for washing machines. The two policy options are evaluated separately based on the criteria described in Box 1.

Box 1. Criteria for evaluation of policies.

Effects on target – To what extent can the instrument be relied upon to achieve the target? Long-run effects – Does the influence of the instrument strengthen, weaken or remain constant over time?

Cost-effectiveness – Does the instrument attain the target at least cost?

Distributional impact/Equity – What implications does the use of an instrument have for the distribution of income or wealth?

Dynamic efficiency – Does the instrument create continual incentives to improve products or production processes in pollution-reducing ways? Flexibility – Is the instrument capable of being adapted quickly and cheaply as new information arises, as conditions change, or as targets are altered?

Synergy effects/leakage/pollutant swapping – What positive and negative synergy effects does the policy bring? Any risk of pollution leakage?

Transactions costs – What are the costs of implementing and maintaining the policy for the control authority and other relevant actors?

4.1 Filtering technique

A mechanical filtering technique is one potential option to consider in order to reduce fibre shedding and emissions of microplastics. The effectiveness of filters is uncertain, although recent laboratory tests of a number of filters available on the market have shown some promising results (Brodin et al., 2018). The filters included in the test do all perform relatively well and do contribute to decrease the emissions of microplastics from washing machines. The functioning of filters will however depend on how they are handled to make sure the microplastics are properly disposed of, and not rinsed off in the sink. Also, a washing machine filter will not prevent airborne and other types of leakage of microplastics.

4.1.1 Effects on target

The potential of a filter criterion to achieve the target of reduced microplastics pollution from washing machines depends on three key factors; 1) how the ecodesign requirements are specified in the Ecodesign Directive, 2) the performance of the filter, 3) how consumers handle the filter.

Introducing a filter criterion in the Ecodesign Directive would provide great opportunities for reduced emissions of microplastics from household laundry because all new washing machines produced within the EU would be covered by the requirements. Given that 350 000 new washing machines are sold in Sweden each year and that the total stock of machines is 3.8 million (see section 5.2.1), a filter criterion would imply that most machines in the Swedish stock of machines would have a filter in approximately 10 years. The policy instrument's potential to achieve the target is therefore high in the long run. There are however uncertainties regarding how a criterion should be formulated to force appropriate measures in place. On the one hand, if the formulations are too vague the effects of a filter criterion would probably be limited. On the other hand, if the ecodesign requirements are too difficult to achieve, the cost-effectiveness of the instrument is negatively affected. The challenge is thus to find requirements that can be relied upon to achieve the target and are cost-effective, at the same time.

A theoretically possible formulation of the ecodesign requirement is that all new washing machines manufactured in the EU by 20XX must have best available technology (BAT) filters installed to reduce microplastics emissions from washing machines by 50 %. One important question is if such filters even exist. Brodin et al. (2018) demonstrate that there are filters on the market which are capable of such a reduction. If – hypothetically – the target is instead a 100 % reduction of microplastics emissions from washing machines (i.e. 13 000 tonnes per year in the EU; Hann et al., 2018), laboratory tests show that all filters would fail to meet such a target. Thus, the tested filters do indeed reduce the amounts of microplastics, but to varying extent. None of them is capable of removing all the microplastics particles. Given the major knowledge gaps associated with impacts of microplastic emissions on the environment and human health, it is very difficult to set a socially optimal target. It seems however that a 100 % reduction target is suboptimal. Such a target would be technically difficult (or impossible) and expensive to achieve and is hard to motivate unless there are clearer evidence available on the impacts of microplastics on human health and the ecosystem.

A target for microplastics also needs to consider what would be an acceptable size of particles. In order to decrease microplastic emissions to the marine environment it may be argued that the ecodesign requirements should target the smallest plastic fibres (<0.3 mm) since only these pass the WWTPs. Measures that only catch bigger fibres would decrease the amount reaching terrestrial ecosystems with WWTP sludge but would not mitigate the impact on water recipients (Magnusson et al., 2016). The problem is that although there exist filters which are capable of catching the very smallest plastic fibres[3] they do require more energy and therefore constitute a potential conflict with other requirements of the Directive (see discussion on synergy effects).

Based on the discussion in Brodin et al. (2018) however it seems that also coarsely meshed filters would be helpful. They argue that all plastic fibres contribute to negative ecosystem and health impacts because larger plastic fibres will degrade into secondary microplastics. Consequently, removing larger microplastic fibres by the use of a filter would mitigate microplastic emissions even if not all fibres are of microplastic size. In other words, if a filter is unable to catch the very smallest plastic fibres it may still help achieving the target of reduced microplastic emissions from washing machines.

Furthermore, the effect of the filters is highly dependent on how the filters are handled by the consumers. Brodin et al. (2018) describe how filters need to be cleaned or replaced regularly, which may be a discomfort to some consumers. Also, it is important that consumers are fully informed about how to dispose of the microplastics to prevent that the filter is rinsed off in the sink. There is a risk that some users will not take proper care of the filter, which would result in lower effectiveness of the policy instrument and a lower likelihood of achieving the target. One way of reducing this risk is to integrate the filter with the machine to make sure it cannot be removed or by-passed by the user. Another option is if the user will receive a new filter if he or she sends the old one back to the producer. The downside of this however is an increased production of filters, i.e. material use and waste.

The above implies that ambitious filter requirements should be formulated but they must still be possible to achieve in a cost-effective way. Even if all new washing machines produced in the EU are equipped with the best filters available on the market there are likely to be inefficiencies, such as the possibility for the user to by-pass the equipment, which would necessitate complementary information campaigns on how to handle the filters correctly. Given the risk that the functioning of filters in laboratory environments is satisfying but that the effect in practice is highly dependent on the behaviour of users in reality, it is crucial that a filter criterion in the Ecodesign Directive is accompanied by careful writings on how to reduce this risk.

4.1.2 Cost-effectiveness

Cost-effectiveness can be seen in relation to different targets. If the target is reduced emissions of microplastics to the sea, the cost of measures related to washing machines should be seen in comparison to e.g. measures in sewage treatment plants. This needs to be studied further. One important note

[3] Available filtering solutions for household washing machines can reduce microplastic emissions of fibres down to 5 micrometres (0.005 mm) with 60–80 percent (PlanetCare add-on filter). Other techniques such as external filters connected to the drain pipe can catch more or less all fibres over 1.6 mm (Lint LUV-R). Both techniques can be used also with old washing machines (Brodin et al., 2018).

however is that even if the cost of measures in sewage treatment plants should be lower compared to taking measures at the source, not catching microplastics at the source constitutes a risk. Microplastics may break into nano-sized particles on their way to the sewage treatment plant, i.e. particles which are more harmful and difficult to handle. In general, it is preferred to deal with different types of emissions directly at the source.

Here, we assume a hypothetical target of reducing the emissions from washing machines. The cost-effectiveness of the policy instrument depends on how the ecodesign requirements are formulated. If, for example, formulated very specifically towards particular filter techniques, other more effective solutions may be excluded. Even the requirement of a filter as means to lowering the emissions may be excluding some solutions concerning e.g. design of washing programs, temperature, physical characteristics of the machine, etc. Hence, a filter requirement is likely less cost-effective than a target for emissions, since it may limit the universe of possible solutions to be taken by the manufacturers.

Importantly, a measure can be expensive but still cost-effective, i.e. costs for the measure is lower than for alternative measures. However, the cost to producers and consumers should be considered. Too high costs for new laundry machines to incorporate the requirements could e.g. risk that old laundry machines are used longer, which would delay the implementation in practice (although other environmental benefits may be associated with lower turnover of the machine fleet).

Future technological development of the filters would potentially lower the producers' cost of meeting the requirements. As more data become available on the performance of filters and costs of producers, it will be necessary to carry out further studies on the balance between effect on microplastics emissions and cost of producers.

4.1.3 Distributional impact

The cost of implementing the policy instrument would be borne primarily by the producers of washing machines. It is therefore important to give the producers sufficient time to adapt. In the longer run, parts of these costs would spill over to consumers by higher prices of washing machines. The expected types of costs include for example investments in filters, installation of the equipment, education of staff, information to consumers, etc. If users of washing machines would have to spend time and effort to take care of the filter, that would also imply a cost for them. Producers of filters would gain from the new policy by increased revenues. The long-term environmental and health impacts of less microplastics emissions will be beneficial for the general public as a whole. All these aspects are discussed further in the socio-economic impact assessment section.

4.1.4 Dynamic efficiency and flexibility

The policy instrument is likely to create continual incentives for technological development leading to more efficient filters and lower costs for the producers of washing machines. An increased demand for filters means that companies who manufacture and supply filters will continue doing so, and also that new actors are likely to enter the market when they see the opportunities. A key to maintaining technological innovation over time is however to raise the requirements continually.

4.1.5 Synergy effects/leakage/pollutant swapping

The current ecodesign requirements for washing machines include energy use, water consumption and washing ability. Increased energy use is a possible negative synergy effect of the policy instrument and needs to be analysed very carefully in order to avoid conflicts with other EU targets in the areas of energy and climate. It has not been possible to estimate the increased energy use in this study. When water is pumped through the filter there will be a pressure drop which requires more energy to pump the water through. Typically, the finer and the more clogged with microfiber the filter is, the more energy will be needed (Brodin et al., 2018). With current technology there is thus a trade-off between having a finer filter which catches more microplastic and having a rougher filter which uses less energy. Given a scenario with higher energy use, the CO_2 emissions would also increase, i.e. an example of pollutant swapping.

A filter solution to reduce emissions of microplastics is not expected to have any impact on water consumption or washing ability, no synergy effects are thus identified.

An example of a positive synergy effect is if the general public – as a result of producers' information about microplastics – also decide to invest in filter solutions in their old washing machines.

In summary, if a filter criterion is included in the Ecodesign Directive it is important to avoid conflicts associated with energy efficiency. No conflicts have been identified in relation to water consumption and washing ability.

4.1.6 Transactions costs

Adding a filter criterion to the Ecodesign Directive will require expanded systems and routines for reporting and control, which are associated with different kinds of transaction costs. The extent of these needs to be studied further.

4.2 Emission limit

An alternative policy option is to determine an emission limit for microplastics. In order to do this a standardized method for measuring microplastics emissions will be necessary. The most important advantage of this is flexibility – a target is set but the producers are free to decide how to reach it. A filter solution may of course still be an option for the producers of washing machines, but the policy instrument opens up also for other measures and combinations of measures. Other advantages of an emission limit are that the policy instrument may facilitate an improved dialogue on how to reach the target and stimulate technological innovation when producers are free to choose measures as long as they reach the target. A disadvantage of using this type of policy instrument is associated with the challenge of correctly measuring if and when the target is met.

Lessons from ecodesign requirements for solid fuel boilers may be considered in the design of an emission limit policy for washing machines. It is for example important to give the producers long enough time to adapt. For further details see section 3.2.

4.2.1 Effects on target

The potential of an emission limit to achieve the target of reduced microplastics pollution from washing machines is uncertain and depends on how (at what level) the emission limit is set and also whether it would be possible to regularly measure and control the impacts. If the emission limit is low it will evidently be easier to achieve, and vice versa. The challenge is to find a balanced level for the target, which takes the trade-off between costs and benefits (avoided damage costs) into account.

4.2.2 Cost-effectiveness

As argued in Section 4.1.2, the cost-effectiveness can be seen in relation to several targets. Here, we assume a target of lowering the emissions from washing machines. Another specification could be related to total emissions to a particular recipient, but to assess cost-effectiveness one would have to study costs of measures e.g. in sewage treatment, which is beyond the scope of this study. Compared to setting requirements of specific filter techniques, an emission target is more free and may allow other solutions to replace or be combined with filter solutions. Today, there is a lot of uncertainty concerning such alternative solutions (e.g. design of washing programs, physical characteristics of the washing machine, temperature, etc.), but one could argue that these should not be abandoned from the start, before we know more. By providing more flexibility in how to reach emission limits, this approach would in theory be a more cost-effective solution than to set requirements stipulating that filter solutions is what should be used. However, given that filters already exist, producers are likely to choose filters as their preferred option to achieve the emission limit in the short run. Another option would be for producers to distribute flexible filters together with the washing machines. The advantage of this is greater flexibility compared to an integrated filter solution. The disadvantage is an increased risk of not reaching the target if the users decide not to use the flexible filters at all.

4.2.3 Distributional impacts

The cost of implementing the policy instrument would be borne primarily by the producers. Producers will have costs for investigating how to reach the target, for example by implementing a filter solution or by developing less emitting washing programs, or a combination of both. The producers would have to pay also for implementing the chosen measure. Given that a filter solution is chosen the same kind of distributional impacts are expected as discussed in section 4.1.3. It should be mentioned here that if producers will choose very different solutions to reach the target, consumers will possibly find it difficult to know how to make their choice and how to care for the products appropriately.

Potentially, the setting of an emission limit may lead to higher controlling costs than a filter requirement, both for the producers who have to prove that their technology meets requirements, and for the controlling and administrating system.

4.2.4 Dynamic efficiency and flexibility

The policy instrument is likely to create continual incentives for technological development. In practice, it is likely that a filter solution will often be chosen as the producers' preferred measure for reaching the target, and the same type of dynamic efficiency as explained in section 4.1.4 also applies here.

4.2.5 Synergy effects/leakage/pollutant swapping

An example of a potential positive synergy effect is technological innovation if the washing machine producers, who are willing to lead the way and start investing in new filter technology, feel rewarded for taking the risk. Another positive synergy effect is if the general public – as a result of producers' information about microplastics – also decide to invest in filter solutions in their old washing machines (see 4.2.4). Given a scenario which implies that higher energy use cannot be avoided due to energy demanding filter techniques, the CO_2 emissions would increase, i.e. an example of pollutant swapping.

4.2.6 Transactions costs

An emission limit will require that the performance of the policy instrument is possible to measure, i.e. to see if and when the target is met. Also, expanded systems and routines for reporting and control will be required, which are associated with different kinds of transaction costs. Just like for a filter criterion the magnitude of these needs to be studied further.

4.3 Summary policy analysis

A filter criterion has potential to achieve the target of reduced emissions of microplastics from *new* washing machines (the second hand market of washing machines is not included) but will depend on how the ecodesign requirements are specified, on the performance of filters, and on how consumers handle the filters. A filter requirement is probably less cost-effective than a target for emissions since it may limit the flora of possible solutions to be taken by the manufacturers. The policy instrument is expected to lead to technological development as the demand for filters will increase. If a filter criterion is included in the Ecodesign Directive it is important to avoid potential conflicts (negative synergy effects) associated with primarily energy efficiency. Careful writings of this risk will be necessary, as well as studies to understand the size of the risk. The additional energy use due to a filter solution is not yet known, but would have to be studied closely before implementing a filter criterion. The cost and potential negative impact on EU climate goals must be considered as part of a deeper analysis of energy use.

The most important advantage of applying an emission limit is flexibility, i.e. a target is set but the producers are free to decide how to reach it. The potential of this policy instrument to achieve the target of reduced microplastic emissions is uncertain and depends on at what level the target is set and also if it would be possible to regularly measure and control the impacts. By providing more flexibility in how to reach emission limits, this approach would in theory be a more cost-effective solution than to set requirements that filters should be used. The policy instrument is expected to lead to technological development. One example of a potential positive synergy effect is improved dialogue between actors on how to reach the target. Both policy instruments will require expanded systems and routines for reporting and control, which are associated with different kinds of transaction costs. The extent of these needs to be studied further.

5 Socio-economic impact assessment

5.1 Introduction to SEIA

A socio-economic impact assessment (SEIA) is a step-wise procedure with the objective to answer the question "what is the net social benefit?" of a given project, policy, measure etc. If the size of the total positive impacts "benefits (B)" exceeds the size of the total negative impacts "costs (C)", a project is socially profitable. It is however unusual that all positive and negative impacts of a project are possible to express in monetary terms. This makes comprehensive, qualitative descriptions of identified impacts important.

A socio-economic assessment is carried out for one of the policy alternatives analysed in this study; implementation of a filter criteria. The corresponding impacts of setting an emission limit have not been assessed primarily due to uncertainties regarding producers' choice and cost of measures. However, a filter is a possible solution also with an emission limit which means that it can function as an estimate of impacts for both alternatives. Furthermore, the types of environmental and health benefits are expected to be the same regardless of whether a filter criterion or emission limit is chosen. The analysis broadly follows the step-wise procedure illustrated in Box 2 below and focuses on step 5 "identify the impacts of the project". Important information for a full cost-benefit analysis is thus provided, if such an analysis will be carried out subsequently when more quantitative information is available.

Benefits of reduced microplastics emissions will occur if damage costs due to negative environmental and health impacts are avoided. The economic valuation literature separates between two main types of benefits or values; use values and non-use values. Use-values refer to values generated from direct use of goods and services, for example to consume fish and shellfish from the sea, or to use a beach for recreation. Non-use values refer to values that occur because people may be willing to make economic sacrifices for improved ecosystems even if they do not plan to use it now or tomorrow. What counts is instead that other people living today or future generations will have the opportunity to experience healthy ecosystems. There are a number of specially designed valuation methods that can be used for measuring non-use values. The total economic value (TEV) is the sum of use- and non-use values. For a step-by-step procedure on how to value ecosystem services see SEPA (2018).

Box 2. Procedure for carrying out SEIA, and what each step may entail for the implementation of a filter criterion. Source: Based on SEPA (2014).

Step 1. Formulation of problem
Microplastic emissions are harmful for the environment and potentially also for human health.

Step 2. Formulation of purpose
To reduce the emissions of microplastics from household laundry.

Step 3. Describe reference alternative
The situation today with no policies in place to reduce the emissions from household laundry. This is the BAU alternative by which the consequences of a policy change are compared and assessed. A BAU alternative may also include the development of optional solutions, i.e. which can be expected regardless of whether a filter criterion is implemented or not.

Step 4. Identify and describe "the project"
A filter criterion for washing machines becomes part of the Ecodesign Directive.

Step 5. Identify the impacts of the project
Impacts on the environment
Direct and indirect environmental impacts related to microplastics emissions.

Impacts on human health
Direct and indirect health impacts related to microplastics emissions.

Other types of impacts
Other types of direct and indirect impacts on society, e.g. investment and operation costs, technological development, new innovations and business opportunities, social impacts.

Step 6. Summary of the impacts of the project
Summary of positive and negative impacts primarily in qualitative terms.

CONTROL STATION: IS THE PROJECT WELL DEFINED?

Step 7. If "yes", estimate the benefits and costs of the project, if "no" try to redefine the project.

Step 8. Distribution analysis
Which groups in society are affected by the implementation of a filter criterion, e.g. producers of washing machines and filters, users of washing machines, the general public?

Step 9. Sensitivity analysis
If a monetized cost-benefit analysis is subsequently carried out, a sensitivity analysis could be done for example by changing interest rate levels and making alternative assumptions regarding the size of costs.

CONCLUSION: IS THE PROJECT SOCIALLY PROFITABLE?

A full-scale monetized cost-benefit analysis would answer whether or not the project is socially profitable. Here, qualitative indications are given on the positive and negative impacts. Monetary examples of costs and benefits are provided when possible.

Step 10. If "no", evaluate if a revised project may become profitable. If so, try to redefine the project.

5.2 Costs

A number of different cost types are expected if a filter criterion is implemented. Producers of washing machines will bear the major share of the cost burden by having to invest in and install filters in their appliances, educate staff and inform consumers. The consumers will have costs for the time and effort required to take care of the filter and, in the longer run, also for more expensive washing machines. There will also be costs for increased energy use and need for adequate recycling systems for used filters.

5.2.1 Investment in filters

According to the Swedish trade organization for household appliances[4] about 350 000 washing machines are sold in Sweden each year and the current stock is estimated at 3.8 million units (personal communication, Matts Spångberg, EHL, 2018-11-13). The EU stock is estimated to around 200 million machines and about 13.5 million are sold each year on the European market (VHK, 2014). This means that the turnover time for the whole fleet in theory can be expected to be approximately 10 years in Sweden and 15 years in the EU. Some households will though have an old machine for a longer time than that, since the lifetime of a washing machine can be expected to exceed 10 years in some cases and old machines are sold on the used market.

Box 3 provides a monetized example for the cost of investment in filters, assuming that the producers would carry the entire cost burden. If the 350 000 washing machines sold in Sweden each year are equipped with BAT filters (see Brodin et al., 2018), the annual cost is estimated to 19.3–35.8 million EURO (MSEK 198–369[5]) depending on the filter technology used (the BAT filters are presented in Appendix 1). The corresponding amount for the 13.5 million machines sold in EU is MEURO 743–1 380 (MSEK 7 650–14 200). The estimation is based on current market prices for filters. It is likely that producers, who buy large volumes, would pay a lower unit price than what is offered to consumers. Therefore, the cost presented should be interpreted as an upper-bound estimate for producers.

In the longer run, parts of the producers' costs for filters would spill over to consumers by higher prices of washing machines. The total cost for consumers in Sweden due to more expensive washing machines can be estimated to 19.3–35.8 million EURO (MSEK 198–369) per year given that the producer would let consumers pay the entire investment cost of filters. For consumers in EU the total cost would be MEURO 743–1 380 (MSEK 7 650–14 200).

[4] Elektriska Hushållsapparat Leverantörer, EHL AB.

[5] Exchange rate 1 EURO = 10.3 SEK.

Box 3. Implementation of a filtering technique.
A monetized example of the total annual investment cost for machines sold in Sweden.

The unit cost of BAT filters (can be found on company websites and/or Amazon).

- Lint LUV-R: 155 Canadian $ per filter = 102 € per filter
- PlanetCare: 30–35 € per filter and an additional cost of 1.50–2 € for exchange filter membranes. The filter is guaranteed to function for 20 washing cycles, then the membrane cartridge has to be replaced with a new one. A household of four washes about 200 times each year.

Annual cost for filters in new machines in Sweden

- 350 000 washing machines × 102 € for Lint LUV-R = M€ 35.8 = MSEK 369
- 350 000 washing machines × (35+2×200/20) € for PlanetCare = M€ 19.3 = MSEK 198

Annual cost for filters in new machines in Europe

- 13.5 M washing machines × 102 € for Lint LUV-R = M€ 1380 = MSEK 14 200
- 13.5 M washing machines × (35+2×200/20) € for PlanetCare = M€ 743 = MSEK 7 648

The Ecodesign Directive targets new machines only. However, if the existing stock of machines (200 million units in the EU/3.8 million units in Sweden) would also – at the consumers expense and free will – be equipped with BAT filters at current prices, the total cost can be estimated to MEURO 11 000–20 500 for EU (Billion SEK 113–211), depending on the filter technology used. For Sweden it amounts to MEURO 168–491 (MSEK 1 730–5 060). It is of course unlikely that all washing machines owners in EU or Sweden would equip their washing machines with a filter, i.e. the figure is an estimate of the maximum cost.

5.2.2 Installation of filters

Assuming that it will take about 15 minutes for an experienced technician (with average salary of SEK 30 000/month) to install the filter, the total annual cost of installation is MSEK 16.5 (0.25 × 188 (SEK/hour) × 350 000 sold machines in Sweden each year) for the producers, equal to 1.60 million EURO.

If the same assumptions can be made for the whole EU the total cost would be MEURO 61.6, or MSEK 635.

5.2.3 Education of staff

Producers of washing machines need to educate their staff about the functioning and installation of filters. According to Europe Economics (2015) more than 3 600 firms across EU-28 manufactured “domestic appliances” in 2012, but the sector is dominated by seven major players. Leading manufacturers operate numerous production locations in different European countries, mainly in Italy, Poland, Germany, Spain, Hungary and Turkey (not an EU-country). Each production location is specialized in one product group and supplies the whole of Europe. Sweden has no large-scale manufacturing of washing machines. Most household washing machines sold on the European market are manufactured in Germany and Turkey (European Commission, 2017).

The number of direct employees in the domestic appliances sector, i.e. not only washing machines, in the EU28 was 211 000 in 2012. For example, in Germany alone nearly 50 000 people are employed in manufacturing of domestic appliances (Europe Economics, 2015). The data does not however specify how many of the employees that work with household washing machines specifically. Given an assumption that each staff in Germany working with domestic appliances (with average salary of EURO 3 000/month) needs an hour of education the total cost is estimated to MEURO 0.94 (50 000 × 3 000/160), equal to MSEK 9.7. This estimate should by lengths cover to the number of employees in manufacturing of household washing machines in the EU. The cost is expected to be the highest the first year and then gradually decrease when only new employees need to be educated.

5.2.4 Information to users of washing machines

Additional information will have to be provided to the consumers on how to handle the filters unless a technique is developed which is completely effortless for the user.

5.2.5 Time and effort to learn about and take care of the filter

The users of washing machines would have a cost in terms of having to spend time and effort to learn and regularly take care of the filter unless a solution is developed which integrates the filter with the washing machine and results in effortless use for the consumer.

The time spent can be valued with the opportunity cost of leisure time, i.e. how much the consumer would be willing to pay to do something else than taking care of the filter. The value of SEK 50–100 per hour was found in a study performed by Tekie et al. (2013), in which they measured the opportunity cost for time spent on waste management in households. The mean value, SEK 75 per hour, gives a good approximation also in this case.

The two filters described in Appendix 1 have different functions which means different amount of time required for cleaning and replacing the filters. One option can be used for 10 years without being replaced but needs to be cleared of lint about every 3 weeks in a household of four, or 17 times per year. It is assumed that each clearing takes up to 5 minutes. In total each household then spends about 85 minutes on taking care of the filter per year. The cost per household, with one washing machine, sums up to SEK 106 (85/60 hours × 75 SEK/hour) per year.

With the other option no cleaning is necessary, instead the membrane of the filter is exchanged for a new one after every 20 washes. A family of four washes about 200 times per year (Magnusson et al., 2016), which implies 10 exchanges each year. Further it is assumed that each exchange takes about 10 minutes and in total per year it takes 100 minutes. Per household with a washing machine the cost per year in this case sums up to SEK 125.

Depending on the technique the opportunity cost every year in Sweden then equals MSEK 403–475 (3 800 000 units × 106 SEK/unit or 3 800 000 × 125 SEK/unit) when the whole stock has a filter, equal to MEURO 39.2–46.1. The first year it equals MSEK 37.2–43.8. For the whole EU the total opportunity cost would be MEURO 2 060–2 430, or MSEK 21 300–25 000, with a stock of 200 000 million units.

5.2.6 More material use, need for recycling systems

Brodin et al. (2018) argue that replaced filter parts should be made of as little material as possible. For some of the filter solutions it is suggested that the user returns the replaced item to the producer for recycling. There are however doubts about this method because of the unlikely scenario that all users will return their used filters without incentives. If the filter needs to be replaced on a regular basis its end-of-life faith needs to be considered when the total environmental performance of the filter is assessed. A similar exchange system as for cartridges to soda streamers, where a reduced price on a new cartridge is given the consumer if the used one is handed in at the same time, could be a way of ensuring that the scrapped filters are taken care of. Compared to incineration, recycling of the material into new items would be a preferred option.

5.2.7 Increased energy use

The finer the filters are, the more energy the washing machine will require. Exactly what the trade-off looks like between finer filters and more use of energy has not been in focus for this study but needs to be looked into more closely. If the trade-off between effective reduction of microplastics and increased energy use cannot be avoided, customers would have to pay by higher electricity bills. Depending on the energy production method, increased energy use can also mean more emissions of other harmful pollutions, e.g. CO_2, NO_X and PM, which implies a cost to society. The amount of added energy use a filter would imply is not yet known, and can not be valued at the moment. The cost and negative impact on climate goals should be considered in the future.

5.2.8 Summary monetized costs

Table 1 below summarizes costs that have been possible to express in monetary terms.

Table 1. Monetized costs of ecodesign requirements to reduce microplastic emission. Values are in million EURO/SEK per year.

Cost item	Sweden		EU	
	EURO	SEK	EURO	SEK
Investment in filters	19.3–35.8	198–369	1 380	14 200
Installation of filters	1.60	16.5	61.6	635
Education of staff			0.94	9.7
Opportunity cost of time (long run)	39.2–46.1	403–475	2 060–2 430	21 300–25 000

5.3 Benefits

Benefits are generated when damage costs due to negative environmental and health effects of microplastics are avoided. The revenues that producers of filters would gain from the new policy is another type of benefit. This section discusses how these benefits can be quantified and valued.

There are very few studies focusing directly on the economic benefits of reduced microplastic emissions. This is not surprising given that the scientific knowledge about how microplastics influence ecosystems and humans is still insufficient. Household laundry constitutes only one of a number of different sources of microplastics and the total damage cost of microplastics is much higher than what is caused by laundry. A filter criterion in the Ecodesign Directive will therefore not alone solve the problem with microplastics, i.e. will not lead to a *complete* avoidance of damage cost. The benefits discussed in this section depend on measures being taken to reduce emissions from washing machines together with policies targeted also at other sources of microplastics.

5.3.1 Impacts on ecosystems and human health

The ecosystem impacts of microplastics are not fully understood but are related to abundance, size, shape and encounter rates. There is evidence for physical, chemical and biological effects from the presence of microplastics and how organisms are affected by them, Lee (2015).

Physical impacts

Tests have demonstrated that zooplankton, filter feeders and vertebrates ingest microplastics and are affected in a number of harmful ways. The physical impacts are displacement of food intake and filling the digestive tract, which may lead to starvation.

Chemical and biological impacts of microplastics

Chemical impacts may occur because microplastics provide a vector for toxic compounds either through release from the plastic itself or through persistent organic pollutants (PoPs) and other harmful chemicals to the hydrophobic surface of microplastics. Biological effects may occur where microplastics host pathogenic microorganisms (bacteria and viruses) which may expose organisms to infection risks and potentially be harmful to fisheries, aquaculture and human health.

Impacts on human health

Compared to the ecosystem impacts the knowledge about human health impacts is even more scarce. The potential for toxins and microorganisms to work their way through the food chain is a main concern for ecosystem health and possibly also human health. Research on human health impacts due to the consumption of fish, seafood, drinking water contaminated by microplastics and intake of airborne particles and fibres is still very immature. From the available evidence UNEP (2016) concludes that microplastics in seafood do not constitute a human health risk. What seems more critical from a human health perspective, but also even more uncertain, are the very smallest nano-sized plastic particles which are capable of crossing the cell wall. Due to the scientific knowledge gaps UNEP (2016) recommends a precautionary approach. This calls for early action at the source, i.e. to catch as much of the microplastics as possible because of the risk that they will break into smaller nano-sized particles which are much more difficult to catch and more harmful to humans.

5.3.2 Avoided damage costs in the fisheries and tourism sectors

UNEP (2016) and Lee (2015) have studied microplastics damage costs. The most important findings are associated to losses in two commercial sectors; tourism and fisheries. The main cause of economic losses in these sectors is if consumers – regardless of what experts say about the actual risk – start to believe that fish, shellfish and bathing water that contains microplastics constitute a risk. If this happens, the behaviour of people may change and their demand for tourism, fish and seafood decrease, which would eventually lead to commercial losses for these sectors. The scale of these commercial losses may be interpreted as a benefit if the losses are avoided.

Fisheries and aquaculture

Based on a UK bivalves industry case, Lee (2015) has developed a valuation model (ECoMip) for estimating the economic cost of microplastics which incorporates uncertainty of biological responses due to data unavailability and complexity in the food chain and food web effects. The model focuses on losses in the tourism- as well as fisheries- and aquaculture sectors.

The UK is a leading aquaculture producer in the European Union with an estimated value of more than 30 million pounds for shellfish production and are thus vulnerable to potential losses due to harmful impacts caused by microplastics, e.g. ingestion related mortality and growth rate. The potential annual loss to the production of shellfish in the UK has been estimated to about 0.13–0.8 million pounds, projected up to year 2100 and at discount rate 3.5 %. An underlying assumption for the estimation is that plastics and microplastics will remain in the marine environment for a very long time although these long-term effects are very difficult to predict and translate into quantitative information on damages and losses.

Tourism

Microplastics may host pathogenic microorganisms (bacteria and virus) and may thus lead to contaminated bathing water. Lee (2015) describes marine litter and microplastics as mini sponges for all kinds of toxic products and habitat for marine bacteria. They argue that the adverse impact such as health (bathing water quality) and losing the Blue Flag Award status (commercial reputation) of marine litter and microplastics would be significant. The Blue Flag Award certification includes criteria for 'bathing water quality' and 'health and safety', but the socio-economic impacts of having the certification have not been assessed by Lee (2015).

5.3.3 Existence values

The benefit items discussed so far are all examples of use-values – commercial value of fish, shellfish and retained bathing water quality. Reduced emissions of microplastics is however also likely to be associated with existence values (example of non-use values). In the case of microplastics, existence values are values that may be generated because people are willing to make economic trade-offs for less microplastics even if they do not personally consume fish and seafood or are planning to do so in the future. The reason why some people are still willing to make economic sacrifices for less microplastics is that they value the mere existence of an ocean free of microplastics. Few studies seem to have been carried out directly focusing on how the general public would value a scenario of less microplastics. One recent example is Choi & Lee (2018) who have estimated the willingness to pay for removing microplastics in the ocean in the Seoul area of South Korea. The estimated annual willingness to pay is USD 2.59 (EURO 2.3), and aggregated for all households in Seoul metropolitan area USD 9.80 million (MEURO 8.6) per year.

5.4 Distributional analysis

The cost of implementing the policy instrument would be borne primarily by the producers of washing machines. In the longer run, parts of these costs would spill over to consumers by higher prices of washing machines. The expected types of costs include for example investments in filters, installation of the equipment, education of staff, information to consumers, etc. If users of washing machines would have to spend time and effort to take care of the filter, that would also be a cost to them. Producers of filters would gain from the new policy by increased revenues. The long-term environmental and health impacts of less microplastics emissions will be beneficial for the general public because of e.g. reduced health risks, recreational values and existence values. The fisheries and aquaculture and tourism sectors would gain from avoided commercial losses due to microplastics.

5.5 Summary

Table 2 summarises the costs and benefits in qualitative terms.

Table 2. Costs and benefits of the policy option.

Costs	**Benefits**
Producers	Industry
Investment in filters	Revenues for filter producers
Installation of filters	Avoided losses in fisheries and aquaculture
Education of staff	Avoided losses in tourism
Information to users	
Consumers	General public
More expensive washing machines	Reduced health risks
Increased energy use	Recreational values
Time and effort to take care for the machine	Existence values
Other costs to society	
More material use	

6 Discussion

The proposed policies in this report means challenges in relation to the polluter pays principle (PPP). Producers of washing machines are not the polluters of microplastics (instead, the users and producers of textiles are), but would – at least initially – have to bear the major cost burden. It is however likely that parts of the costs will subsequently be pushed onwards from producers to consumers, which would be more in line with PPP.

Consumers will most likely find it difficult to act correctly to avoid increased costs. For example, even if a consumer decides to not use (and wash) synthetic textiles at all he or she would still have to pay the price of more expensive washing machines with filters to remove microplastics. The market that, arguably, is responsible in the first place is the textile market, including its consumers and producers. Given a PPP perspective, one could thus argue that the cost of measures should be borne by this market, by more correct pricing of synthetic textiles. It is clearly not an ideal option to tie consumers to expensive technological solutions, but few options exist, at least in the short run, to regulate the textile market. One potential alternative is if producers who place textiles on the EU market were obliged to offer flexible filter solutions for the consumers. If so, the cost burden would be borne by producers of textiles rather than producers of washing machines.

Concerning PPP, one could discuss its motivations. Two types of main motivations are possible – justice and the generation of incentives to decrease environmental pressures. Regarding the justice aspect, it is hard to argue that the targeting of microplastics through the Ecodesign Directive is "fair". However, this solution may be more feasible than many other policy instruments to achieve sufficient incentives for actually reducing emissions, given the complexities involved with regulating a global textile industry. It is important to monitor the performance of the policy instrument closely to see if and when better and less expensive solutions for the industry occur.

Policies focusing on textile production and use could for example be in the form of taxes or fees on synthetic material, or on the fossil contents of these materials. However, such taxes are difficult to set internationally and individual countries may have low incentives to tax their own industry, if other countries do not. Additionally, such taxes may interfere with EU and/or WTO regulations on free trade. Nevertheless, solutions towards incentivizing lower use of synthetic materials on EU-level or national level may be possible and could be further addressed. Given the current EU focus on fossil plastics, synthetic (fossil) fibre material could perhaps be an addition in this discussion.

Alternative, or perhaps complementing, policy options may be associated with changing laundry behaviour and conducting information efforts to raise the knowledge about microplastics in society. For example, washing more seldomly, using lower temperature, using lower rotation speed in centrifugation, using shorter programmes, or changing detergents are all measures that may decrease microplastics emissions. Additionally, information to consumers about the negative impacts of microplastics could lead to decreasing demand for synthetic fibres and/or textiles in general. Such information efforts may be efficient, but the effect is uncertain and while some households will be early to adapt to new information, other households will be slow in changing behaviour.

Concerning laundry behaviour, also the price of water and electricity may be a factor to consider. If these prices go up, one could for example expect incentives to wash more seldomly. Regulating water or electricity prices is however a challenging political task and there are many concerns to balance beyond microplastics emissions.

Finally, as previously discussed, investments in wastewater treatment technology could be an alternative or solution. As pointed out however, filtering at a late stage in the wastewater flow is associated with the risk that the particles are being degraded in too fine particles for being possible to catch. More study is needed on the flows and degradation of microplastics through the sewage system to be able to provide a verdict on the efficiency of home-based vs. WWTP-based filtering. Another option to consider could be filtering at building- or community level. This would most likely require the separation of grey and brown water and is hence currently only possible for new buildings.

7 Recommendations

Evaluated policy options:
A filter criterion has potential to achieve the target of reduced emissions of microplastics from *new* washing machines (the second hand market is not included) but the effect will depend on how the ecodesign requirements are specified, on the performance of filters and on how consumers handle the filters. The following recommendations are given regarding a filter criterion:

- More quantitative evidence on the performance of filters to remove microplastics is needed. One major question is how filters perform in reality, i.e. outside controlled test environment.
- Given the risk that the functioning of filters in laboratory environments is satisfying but that the effect in practice is highly dependent on the behaviour of users in reality, it is crucial that a filter criterion in the Ecodesign Directive is accompanied by careful writings on how to reduce this risk.
- The effect of filters depends on how they are handled. It is thus important that users are fully informed about how to dispose of the microplastics to prevent that the filter is rinsed off in the sink, which would result in lower effectiveness of the policy instrument and a lower likelihood of achieving the target. The risk may be reduced for example by integrating the filter with the machine to make sure it cannot be removed or by-passed by the user.
- If a filter criterion is included in the Ecodesign Directive it is important to avoid potential conflicts (negative synergy effects) associated with primarily energy efficiency by careful writings about this risk in the Directive. The additional energy use due to a filter solution is not yet known, but would have to be studied closely before implementing a filter criterion. The cost and potential negative impact on EU climate goals must be considered as part of a deeper analysis of energy use.

The most important advantage of using an emission limit is flexibility, i.e. a target is set but the producers are free to decide how to reach it. The potential of this policy instrument to achieve the target of reduced microplastic emissions is uncertain and depends on at what level the target is set and also if it would be possible to regularly measure and control the impacts. The following recommendation is given regarding an emission limit:

- Regardless of whether a filter criterion or an emission limit is set, expanded systems and routines for reporting and control are needed, which are associated with different kinds of transaction costs. For example, a standardized method for measuring emissions of microplastics will be required in order to be able to determine an emission limit. The magnitude and distribution of transaction costs needs to be studied further.

Socio-economic impacts:

- The impact assessment and distributional analysis shows that the cost of implementing the policy instrument would be borne primarily by the producers of washing machines, and in the longer run also consumers due to higher prices of washing machines and time and effort to take care of the filter. Producers of filters would gain by increased revenues, the fisheries and tourism sectors would gain from avoided losses due to microplastics and the general public would experience benefits associated with reduced health risks, recreational values and existence values. The incentives to act are evidently skewed, i.e. producers would have to carry most of the cost burden and other actors would enjoy the benefits. This may negatively affect the producers' willingness to take action and needs to be taken into account. It will for example be important to give the producers enough time to adapt. Research funding of efforts taken by the producers is another potential option to support these actors.
- Given that the producers and users of washing machines would have to pay the price for an environmental problem that they have not created, an analysis is needed of how producers and importers of textiles for the European market may be held responsible and bear the cost of washing machine filters.

Other policy instruments:

- Information campaigns to raise public awareness of microplastics is necessary because a filter criterion will not solve the problem with microplastic emission from washing machines alone, especially in the short run. Until the household washing machine market have had time to adapt – and have effect – the problem will have increased unless complementary policies are enforced.
- By raising the common knowledge about microplastics some consumers may decide to use natural materials instead of synthetic fibres. This could in theory reduce the need for filters in washing machines, but a dramatic change in material choice would be needed to significantly reduce microplastics emissions.
- If consumers learn more about microplastics some may, by free will and at their own expense, decide to invest in filters for machines they already have at home. It needs to be studied further if there are ways to make the producers of synthetic textiles pay for such solutions.
- Information campaigns targeted at educating people on a more microplastics friendly washing behaviour, e.g. to not wash too often, use low temperatures, eco-label detergents, etc. could to some extent contribute to reducing emissions. However, such campaigns need to be combined with other policy instruments in order to secure a significant effect.

- Even if consumers do everything right they will still be tied to expensive technological solutions. The underlying problem is that few options exist to regulate the textile market. One potential alternative is if producers who place textiles on the EU market were obliged to offer flexible filter solutions for the consumers.

General:

- Additional research is needed to better understand how microplastics influence ecosystems and human health and how people perceive the problem with microplastics.
- The chain of events *implementation of filter technology → reduced emissions of microplastics → environmental and health impacts → valuation of impacts* needs to be studied further and deeper. With increased knowledge about these linkages it will be possible to carry out more precise socio-economic impact assessments.

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Appendix

This appendix provides more details on functioning and costs of best available technology (BAT) filters.

Lint LUV-R[6]

The cost of the filter is $140, with wall mount installation $155. No replacement cost and 5-year guarantee. 10-year LCC same as purchasing cost.

Lint LUV-R prevents septic system failure by removing lint and untreatable synthetic solids from washing machine discharge. The filter easily mounts under a cabinet or shelf, or to a wall, next to the washing machine. The washing machine discharge hose adapts to the inlet port of the Lint LUV-R. Discharge passes through the filter to the outlet port, leaving behind lint on the outside of the screen. A hose directs the filtered discharge from the outlet port into the washing machine drainpipe and on to the septic system. The clear filter bowl and drain hose allow you to see the filter in operation.

Once the filter bowl is visually obstructed by lint, it's time for cleaning. With a household of four, cleaning is necessary about once every 3 weeks. The filter bowl is easily lowered with a 1/8th counter clockwise turn. The stainless-steel screen can then be lowered from the housing and removed from the filter bowl. Lint is removed from the outside of the screen and discarded. Once everything has been wiped clean, the screen can be placed back into the filter bowl, raised to the housing and pushed back into place. Rotate the bowl 1/8th turn clockwise and it will lock into place – a lock indicator mark shows that you've got it properly in place. The filter is designed to handle any increase in pressure and will never let lint into your septic system, even if you forget to clean it.

PlanetCare add-on filter[7]

The estimated price for a PlanetCare filter is between 30–35 €, depending on the model of the washing machine and the size of original drain pump filter. The only extra cost will be additional filter membrane (to exchange the full one) which will cost between 1.50 €–2.00 € (depending on ordered quantity).

The Planet Care filter is specifically designed to capture microfibres. The cartridge body has a 50-micrometre mesh integrated in the cartridge wall. Furthermore, a patented layered filter structure is designed to distribute fibre capture through the entire depth of the filter preventing clogging and prolonging the lifetime of the filter. The layers ensure that fibres through the entire size range are removed. Optimal performance is possible with the combination of smooth-walled pores and pores with nanostructured walls that enhance the retention of small fibres which are most difficult to catch.

[6] http://www.environmentalenhancements.com/Lint-LUV-R-specifications.html

[7] https://planetcare.org/en/products/add-on-filter/

Independent tests have confirmed this showing a marked reduction in the release of even the smallest particles down to 5 micrometres. The efficiency of the filter has been tested in several environments and the results show that between 60 to 80 % of all microfibres are caught.

The filter is guaranteed to function for 20 washing cycles in a household of four, then the membrane cartridge has to be exchanged with a new one. The cartridge is essentially the filtering medium whereas all the other parts are reused. This way a minimum amount of material is thrown into the trash.

The Ecodesign Directive as a driver for less microplastic from household laundry

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Anthesis AB has been assigned by the Swedish Environmental Protection Agency to conduct a socio-economic analysis of the introduction of ecodesign criteria to reduce microplastics from washing of textiles.

The purpose of the socio-economic analysis carried out in this study is to start framing the problem with microplastics emissions from laundry from a socio-economic perspective.

More specifically the study aims to provide a structure for analysing the performance of policy instruments concerning microplastics and to demonstrate the potential socio-economic impacts of implementing filter requirements.

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