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Co-production of future scenarios of policy action plans in a science-policy-industry interface – The case of microfibre pollution from waste water treatment plants in Norway

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ABSTRACT

One of the ambitions of the UN Decade of Ocean Science is stakeholder interaction to co-produce new ideas and solutions for policy action plans to ensure that environmental challenges are mitigated in a timely manner. Regulations around the release of microfibres are largely lacking, and we are at an excellent point of departure to test integrative methods of such co-production. We co-designed conceptual maps and Bayesian Belief Networks with probabilistic future scenarios within both inter- and intra-sectoral workshops with industry and scientific stakeholders to gain comparable results of policy action scenarios for curbing the challenge of microfibre pollution within this context. We found that when scientists worked on this alone, their focus was different than when working together with industry directly. Scientists focused on methods for avoiding release into the environment from a technical vantage point, whereas industry emphasized regulatory requirements needed to avoid ambiguity within the sector.

1. Introduction

UN Secretary-General Kofi Annan referred in a speech to "…'problems without passports' – challenges so large that they ignore frontiers and … beyond the power of any single Government to tackle on their own…" (Annan, 2013). Arguably, the release of marine plastics into the marine environment, such as microfibres from clothing through washing cycles being released through wastewater treatment plants, is one such wicked problem. Marine plastic pollution in general has increased in concert with the production of plastics (Gourmelon, 2015), from lager pieces visible to the naked eye, like plastic tyres, bottles and fishing nets, to primary microplastics particles in the size range of <5 mm. These pieces either derive directly from consumer products, such as scrub creams or toothpaste (Andrady, 2011), or are secondary results from plastic pieces breaking down or being used (Law and Thompson, 2014; Kubowicz and Booth, 2017). All categories of size and abundance of plastics in the marine environment globally exposes marine biodiversity to potential dangers, and may also pose risks to humans through the ingestion of food from marine sources, though uncertainty of the latter is high (Wright et al., 2013; Anderson et al., 2016; Rochman et al., 2016; Barboza et al., 2017; Law, 2017; Wright and Kelly, 2017). What is clear, though, is that global targeted governance of the release of plastics into the environment is lacking (Haward, 2018; Mendenhall, 2018; Tiller and Nyman, 2018), and that this should be prioritized in the UN decade of Ocean Science.

Planning policy action plans for such prioritizations, however, requires among others stronger focus on and expansion of our understanding of the science policy interface to ensure compliance with and legitimacy in resultant implementation effort (Claudet et al., 2020). This expanded network could include funding agencies, bureaucrats, industry actors, media and traditional knowledge sources – ensuring that there is a grounded transfer of knowledge from science to learning by policy makers, via those who the regulations are for as well (Ellis, 2005; Andonova, 2010; Lidskog and Sundqvist, 2015; Sun, 2017). If scientific knowledge can shape agenda setting and policy making processes, practical and traditional knowledge from epistemic communities, industry and nonstate actors arguably could as well.

After decades of compliance challenges with global environmental

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challenges, one may argue that without bottom-up approaches and deeper inclusion of stakeholders in the governance process and co-production of knowledge, we lose legitimacy, transparency and the all-important compliance factor that is necessary for a successful management of a given environmental challenge (Grafton, 2005; Symes, 2006; Esguerra et al., 2017) – and the UN Decade of Ocean Science may lose its focus and chance of success. After all, we know that environmental governance is not about governing the environment itself – but governing how humans relate to and exploit it. Esguerra et al. (2017) introduce three rationales for this necessary deep stakeholder inclusion. Though originally applied to the framework of global governance processes based on their analysis of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), it is similarly appliable to national governance processes. The first rationale is that there is a need for diverse forms of knowledge that requires different voices and more openness to ensure implementation and management strategies are based on complete knowledge - including specific local and regional circumstances. Secondly, prioritizing deep inclusion of stakeholders ensures a buy-in of the final knowledge product, and reduces scepticism to results, which in turn can ensure that the results have an actual impact. Finally, it is the only way to ensure that solutions tailored to specific groups of stakeholders could be implemented and better governance achieved through ensuring useful products are developed.

It is within this context that we assess the efficacy of developing policy guidelines based on future scenario perception workshops with industry and scientist stakeholders around the issue area of releases of microfibres from clothing into the marine environment. We choose to focus on microfibers because these have caught the attention for reasons of uncertainty surrounding its potential human health impacts since they are small enough to be ingested by humans in either drink or food products (Cole et al., 2011; Hollman et al., 2013). Alarmingly, it is estimated that there are 15–51 trillion microplastic particles currently in the ocean (Eriksen et al., 2014; Bergmann et al., 2015; Jambeck et al., 2015; Jang et al., 2016; Baztan et al., 2017). The following paper first introduces microplastic fibres, followed by the methodology used to involve stakeholders in the co-production of knowledge around the eradication of these. We then present the results of the two stakeholder workshops, and a discussion around the science-policy interface and how results from co-production seminars may supply policy makers with both highly effective solutions and an indication of their perception of how implementable such solutions are in their opinion.

2. The environmental challenge of microfibers

The occurrence of microplastic fibres in the natural environment has been known since the 1970s, where synthetic fibre densities up to 10^5 m^{-3} were reported in North Sea water samples (Buchanan, 1971). Today, we know that microplastic fibres can account for >90% of the total microplastic pollution in the marine environment, and predominantly originate from synthetic textiles (clothes, carpets, upholstery), although synthetic fishing nets and ropes are also contributors (Koelmans et al., 2019; Murphy et al., 2016). Today, ~60% of textiles produced globally are synthetic, where the main polymers are polyester (PET), acrylic (polyacrylonitrile; PAN) and nylon (polyamide; PA) (Barrows et al., 2018). The predominance of microplastic fibres has been reported in different environmental compartments (e.g. waters and sediments), while microplastic fibre contamination is also geographically widespread, from the tropics to the poles (up to 95%) (Lusher et al., 2015).

Domestic and industrial textile washing has been identified as a major source of microplastic fibre emissions to the environment (Browne et al., 2011), a process that is influenced by factors including polymer type, fabric type (e.g. fibre properties, yarn, weave and finishing), type of washing machine, washing program and type of detergent (Hartline et al., 2016; Napper and Thompson, 2016; Salvador Cesa et al., 2017; De Falco et al., 2018). It has been estimated up to 6 million microplastic fibres are released from a single 5 kg load of PET-based textiles (De Falco et al., 2018; Napper and Thompson, 2016). A number of studies have indicated that PET textiles shed more fibres than the other common types of synthetic textiles (Carney Almroth et al., 2018), although this may reflect the frequent selection of PET fleeces as test materials. However, it is important to note that direct comparison of fibre release studies is difficult due to a lack of standard methods for testing fibre release and for reporting data (Carney Almroth et al., 2018; De Falco et al., 2018; Frias and Nash, 2019; Cesa et al., 2020; Freeman et al., 2020).

Although wastewater treatment plants (WWTPs) appear to effectively remove microplastics (including fibres) from influent waters (up to 99%) and retain them in activated sludge, an estimated 1×10^5–1×10^7 MP particles are still discharged daily to aquatic environments in some regions (Freeman et al., 2020; Koelmans et al., 2019; Mason et al., 2016; Mintenig et al., 2017; Murphy et al., 2016, Ben-David et al., 2021). These emission levels have been estimated to correspond to 6.7×10^{12} microplastic particles being released annually from a single WWTP (Leslie et al., 2017). In areas without connection to WWTPs, emissions to the environment will be much higher. It is also important to highlight that microplastic fibres will also be released during the use of textiles, though this has not been studied in much detail to date. Interestingly, microplastic fibres were recently found to be less effectively retained in WWTPs compared to other forms of microplastic and are enriched in WWTP effluents (Ben-David et al., 2021). Furthermore, microplastic fibres retained in sludge are often placed directly into the environment when the sludge is used as agricultural fertiliser (Corradini et al., 2019; Nizzetto et al., 2016).

While we know that microplastic fibres are widespread across all environmental compartments, much less is known about the possible impacts this may have on organisms and ecosystems. In the marine environment, microplastic fibre ingestion has been observed in zooplankton, polychaete worms and sea cucumbers (Graham and Thompson, 2009; Mathalon and Hill, 2014; Desforges et al., 2015), as well as being detected in commercially important species such as mussels, brown shrimp, Norway lobster and fish (Murray and Cowie, 2011; Lusher et al., 2013; De Witte et al., 2014; Mathalon and Hill, 2014; Devriese et al., 2015). Furthermore, the negative effects of fibres on organisms have been less extensively studied than for spherical and irregular shaped microplastics (Cole et al., 2013; Jemec et al., 2016; Cole et al., 2018).

Although the effects of microplastic fibre ingestion by humans are yet to be elucidated, their presence in commercial food species suggests ingestion is an uptake route for humans. Inhalation represents another important exposure route for humans. Inhaled microplastic fibres have already been shown to be taken up by human lung tissues and have been associated with development of tumours (Pauly et al., 1998). In vitro tests have found microplastic fibres to be extremely durable in physiological fluid suggesting biopersistence in the lung (Law et al., 1990), with longer fibres more likely to avoid clearance (Warheit et al., 2001). Beyond a certain exposure level/dose, all fibres seem to produce inflammation following chronic inhalation, which in turn can lead to fibrosis, and in some cases cancer (Greim et al., 2001).

While there is potential evidence for effects derived from the physical properties of microplastic fibres, organic and inorganic additive and production chemicals associated with the fibres can leach into water (Zimmermann et al., 2019; Sait et al., 2021). Softeners and dyes are commonly added to textile fibres, but antioxidants, antimicrobials and even flame retardants may be added in certain cases (Hermabessiere et al., 2017; Sait et al., 2021). Plastic leachates have been shown to induce effects such as oxidative stress, cytotoxicity, estrogenicity, and antiandrogenicity (Hermabessiere et al., 2017; Rummel et al., 2019; Zimmermann et al., 2019; Capolupo et al., 2020).

The potential for negative environmental and human health consequences from microplastic fibres may be dependent on their degree of degradation and transformation in the environment, which is influenced by both intrinsic properties (polymer type, density, size, additive chemicals) and extrinsic environmental parameters (UV irradiation, microbial biofouling). Most polymer products break down very slowly through a combination of photodegradation, oxidation and mechanical abrasion, with the major degradation step being UV-initiated oxidation (Andrady, 2015; Booth et al., 2018). Biodegradation of synthetic fibres is expected to be very slow (Zambrano et al., 2019). Recent studies have shown that polymer type significantly influences the rate at which UV degradation of microplastic fibres proceeds, with PET and PA breaking down and fragmenting more readily than PAN (Sait et al., 2021).

3. Materials and methods

To look at policy action possibilities to curb this release of microfibres into the environment, we chose to focus on Norway, which has taken a lead role in marine fighting plastic pollution through their role as co-chair of the High Level Panel for a Sustainable Ocean Economy, supported by the UN Secretary-General's Special Envoy for the Ocean (Teleki, 2019). We wanted to work closely with the interface of science-industry to co-produce effective policy scenarios, and recruited the stakeholders for the workshops using both the snowball method (Biernacki and Waldorf, 1981) through project contacts, and by tapping into the partners in the project that had agreed to participate before the start of the project.

The snowball approach was selected because the quality of the results sampled from this group outweighs potential low numbers of informants the method often results in. A smaller sample supports the depth of an analysis that is case-oriented, and it is fundamental to this mode of inquiry. The samples were purposive in that they were selected by virtue of the respondent's capacity to provide richly-textured information, relevant to the phenomenon under investigation. As such, this purposive sampling selected 'information-rich' respondents, requiring fewer respondents (Sandelowski, 1995; Marshall, 1996). For the purposes of this workshop, the primary researcher considered from experience that fifteen participants would be the maximum of what could provide a holistic narrative where all participants were provided ample opportunities to share their perceptions on solutions to curbing microfiber pollution from different sources.

The aim of the two workshops held during 2020, and the consecutive steps, was to analyze and understand perspectives from different sources of stakeholders in terms of concrete policy action potentials and future scenarios in terms of curbing microfibre pollution. From these results, we wanted to explore and explain what this entails in terms of policy action limitations and adaptation options and how these affects management and adaptive capacities at different governance levels of analysis. The concrete methods used were based on a wish to quantify narrative-rich knowledgebase and data from experts for the purpose of making management decisions.

The number of participants in the workshops in total were 6 in the first scientist-only workshop (April 2020) and 11 in the scientist-industry workshop (5 and 6 representatives respectively) (September 2020). Given the limitation on social gatherings during the early stages of the global pandemic in the spring of 2020, we chose to hold our first workshop completely online, and used the online whiteboard solution Limnu to achieve similar results as if we were meeting in person (www.limnu.com). During the second workshop five months later, we chose to have a camera directly at the live version of this whiteboard session, which the online participants were equally encouraged to comment on and have input to. This was livestreamed via TEAMS. During the session with the stakeholders the researchers started the group model building experience by presenting relevant background information about the project and the project aims, though in this case, most were familiar with the project and had followed the project closely over a number of years already (Impson, 2011). Since the workshops were undertaken in accordance with personal data regulations through permits from NSD, Data Protection Services, Norway, the participants were given information about the workshops' purpose before attending and were informed that they could leave the study at any time without any questions from the facilitator. They all gave their recorded oral consent to participate in the study based on this oral information as well as an informational letter sent to them. The consent is stored securely and will be deleted at the end of the project period.

3.1. Bayesian belief networks

Quantifying narrative-rich and inherently qualitative knowledge such as that obtained in workshops for the purpose of making management decisions (e.g. adaptive management scenario testing) is difficult at best. On these grounds, we used Bayesian Belief Networks (BBN) and group model building (Hovmand, 2014) for the purposes of this study. This method has been successfully used to elicit stakeholder perceptions and scenario development in other studies (Tiller et al., 2013, Tiller et al., 2014, Tiller and Richards, 2015, Tiller and Richards, 2018). This allowed us to gain critical insight into future scenarios of policy options for curbing the flow of microfibers into the natural environment, regardless of original source, whether it was from the production or wear of the product in question. The software used for the BBN modeling was Netica (www.norsys.com).

BBN modeling utilizes Bayes theorem, which facilitates diagnostic (bottom up) and causal (top down) inference of an acyclic graph. In addition, it facilitates participatory modeling and is well–suited to representing causal relationships between variables in the context of variability, uncertainty and subjectivity (Fenton and Neil, 2018). Furthermore, BBN modeling is a method that is extremely well suited for coalescing knowledge from stakeholders, even if this knowledge comes from a variety of sources (e.g. both scientists and industry) and is of a variety of completeness, into a single modeling framework (Tiller and Richards, 2015). It is particularly effective in eliciting stakeholder opinion through participatory engagement. Firstly, the visual aspect of developing the causal maps that characterize Bayesian network models is easy for participants to understand and accomplish – and gives a good visualization of their perceptions, which the stakeholders often enjoy. The impact of this should not be understated, as this fosters trust during the stakeholder engagement process. Secondly, the mathematical framework of Bayes theory that underpins these models provides a robust mathematical basis for incorporating the subjective beliefs of the stakeholders into the model, something that traditional statistical approaches (e.g. null hypothesis testing) does not allow (Richards et al., 2013).

The methodological process of developing BBNs through stakeholder engagement is outlined in detail elsewhere (Richards et al., 2013; Tiller et al., 2013; Tiller and Richards, 2018). It is important to emphasize though that the underlying probabilistic framework (i.e. Bayes theory) provides a mechanism of directly integrating social, economic and environmental variables within a single model (Kjaerulff and Madsen, 2008). During the workshops used in this study and elsewhere (Richards et al., 2013, Tiller et al., 2013, Tiller and Richards, 2018), development of the structure of the BBNs were done is using a group-level exercise. That is, it represents the group-level belief about which variables are included and how the arcs connect them. Therefore, this process typically requires negotiation within the stakeholder group, and we saw ample discussions in the narratives between the participants, with some discussions and disagreements also being apparent.

Later, each stakeholder populated the Conditional Probability Tables (CPTs) with their own probabilities providing individual-level parameterization. This was done after the workshop, using Surveymonkey, where the probabilities were laid out as several scenarios and the respondents were asked to rank these in terms of probability of each becoming a reality. The individually parameterized BBNs were then combined into a single model as they share the same structure but have different values within the CPTs. This is achieved here by using an auxiliary variable (Kjaerulff and Madsen, 2008), which weights each of the individual stakeholder CPTs so that the beliefs of one stakeholder can be given more or less weighting in the model than others. Note that for this study the stakeholders were weighted evenly, though the removal of divergent stakeholder perceptions can change the results. Finally, the BBN-development process facilitates the capture of further information through the discussions that accompanied the development of these networks with this narrative providing important context to the importance of different variables during the workshops.

3.2. Sensitivity analyses

Sensitivity analyses were carried out on each of the BBNs (one for each workshop) to help identify the nodes that had the greatest influence on a 'target node' – in this study, the target node is the priority node identified by the stakeholders. Through the sensitivity analysis, Netica produces a table showing the current probability for observing a target node 'state' produced by entering findings into each of the finding's node (see Table 2). All nodes within the BBN are in-turn treated as a finding node, including the target node (which is why it has 100% influence). Netica then calculates the Entropy Reduction (also known as Mutual Information) (Pearl, 2014) and the Variance of Beliefs; both of these are measures of the relevance between nodes (Zhang et al., 2018). Entropy Reduction and Variance of Beliefs are influenced by the CPT of the target node and by the prior probability distribution of the finding's node. When the probability distribution of the finding's node is skewed for example, the expected reduction in entropy of the target node is less as compared to when the probability distribution of the finding's node is not skewed. For discrete nodes, the best measure of sensitivity is Entropy Reduction, which is expressed as a proportion (0–1). The greater the entropy reduction of the target node due to findings at a finding's node, the more sensitive the target node is to a change in the finding's node. For continuous nodes, or nodes with real number state values, the best measure of sensitivity is Variance of Beliefs.

4. Results

4.1. Whiteboard sessions

4.1.1. Scientists

The following figure is a presentation of the results from the online whiteboard session with the scientists. The workshop and online whiteboard session worked well, and we had the ability to zoom in closer at all times. The priority issue for the participants in this first workshop was that there would be *no microfiber pollution in the aquatic environment from clothing*. The emphasis on aquatic was put there to emphasize that these fibres do not only end up in the ocean – but also in fresh water, where they also accumulate and can have a negative environmental impact. The session consisted of 6 scientists and lasted more than two hours, with intense discussions throughout on the main issues and what directly influences these variables.

4.1.2. Industry and scientists

We chose not to use the online whiteboard for the second workshop but chose to show the stakeholders the primary issue that we developed with the scientists (Fig. 1, top note), and asked ""*We've already done this once, and we can agree to do the same future again, which is a 'Microfiber-free aquatic environment'. Is that something you think we are striving for, or what is the main aim in terms of microfibers?*" The stakeholders this time around did not agree that we should focus on the aquatic environment only though and asked that the priority issue rather focus on a *microfiber-free environment in general* as a best-case scenario and the worst case scenario being continuous increase, accumulation and no degradation of microfibers in the environment. This session lasted more than two hours as well, and was both light and serious, with actor partners participating with their industry perspective, in combination with scientists that had their input on the topics.

4.2. Scenario development

The development and visualization of the backcasting process (Dreborg, 1996) we did during these two workshops is a method that is

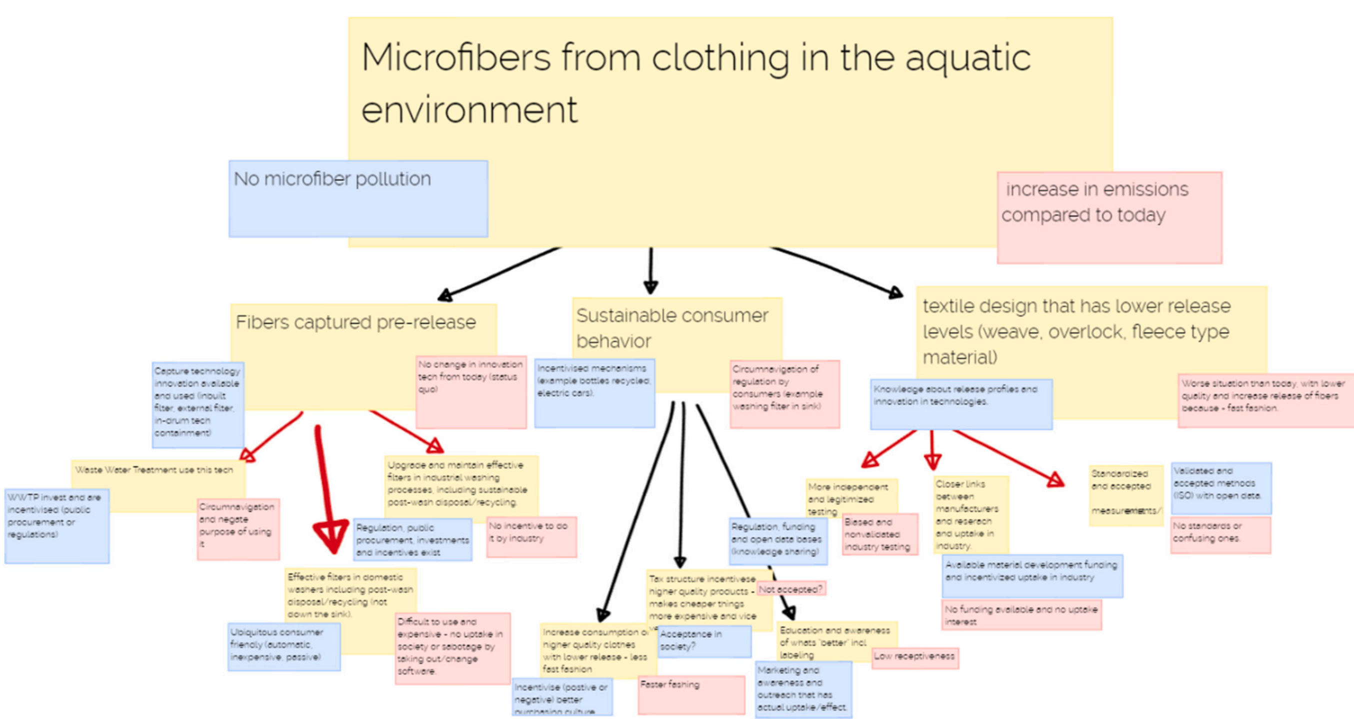


Fig. 1. Graphic representation of the whiteboard of the BBN in Limnu for illustration purposes only.

used to graphically present scenarios that are developed by the stakeholders themselves. In this case, though the premises were the same, the two workshops decided on different priority issues. The industry actors had wanted to focus more on microfiber release into the *environment* in general and the scientists had a stated focus specifically on *water issues* related to the release of microfibers.

Table 1 shows the main differences between the first level variables and the priority issues. We do not compare the secondary variables since they are dependent on the primary one and these diverge greatly. The secondary variables, however, often are the most direct and applicable solutions and we will therefore conclude with these in the discussion section below. The scientists focused on placing the responsibility on three different sectors, namely 1) textile production industry (primary variable I), society (primary variable II) and textile design industry (primary variable III) and the regulation of each of these groups of actors/groups separately. In the industry/scientist workshop, however, the decision was made to focus on the life cycle of the product, namely the 1) production of textiles, 2) wash/use of textiles and the 3) end of life of textiles. This group wanted to focus on what could be done at each of these cycles in the life of the product. As such, with these different foci, the resultant scenarios for policy advice were very different – but complementary to each other.

4.3. BBN - scientists

Fig. 2.

4.4. Sensitivity analysis - scientists

The first workshop consisted of six scientists. After adding individual probabilities to the back-casting process, the combined probabilities the stakeholders considered their priority issue had of coming true was at 43.9%. This indicates that even if they set up the entire back casting process themselves, and developed the correct and most likely paths, that in their opinion would ensure that the priority issue was realized, they still did not believe in the process as being able to solve the issue of ensuring that microfibers would not be a source of pollution in the marine/aquatic environment. In fact, even when we placed the probabilities of each of the three primary variables at a forced 100% probability, the group still did not consider it likely that microfibers would stop being a solution of marine pollution. They still considered it 16.1% probable that microfibers would be an increased source of emissions that even if 1) capture technology and innovations were in use that could capture all fibres pre-release, 2) There were incentivized mechanisms in play that would ensure that society had sustainable consumer behavior, and 3) the knowledge release profiles of textiles led to the design of textiles ensuring lower release levels. One of the reasons for this could be the uncertainty build into their back-casting variables. For example, textile designs leading to "lower release levels" – not "no release". Also, even if incentivized mechanisms for ensuring sustainable consumer behavior exists, it does not mean that consumers are rational actors and follow the projections assumed by these mechanisms.

A sensitivity analysis of the scientists' BBNs was then conducted to find out what scenarios had the highest probabilities according to their perceptions. This is a formal test of the variability of the priority variable to changes in the settings of all other variables within the BBN (three primary variables, nine secondary variables and one auxiliary variable), gave indication of which variables were influential on this priority issue. This sensitivity testing highlighted that at the first hierarchical level of the model, the primary node level, which are those nodes that directly

Table 1
Comparing priority issues, primary and secondary variables between the two workshops. The comparisons are with the preferred outcome in focus.

	Scientists	Industry + scientists
Priority issue	Microfibers from clothing are not a source of pollution in the ***aquatic*** environment	Microfibers from textiles are stopped from being continuously released into the environment
Main focus	Actors in the life of the product	Life cycle stages of product
Primary variable I	Fibres are captured pre-release because capture technology innovation is available and used.	A microfiber-release-free textile production is possible because all release of microfibers has been stopped.
	Textile production industry	Textile production
Primary variable II	Society has sustainable consumer behavior because incentivized mechanisms exist.	The wash and use of textiles do not produce release of any kind.
	Society	Wash and use of textiles
Primary variable III	Textile designs lead to lower release levels because there is knowledge about release profiles and innovation technologies exist.	The end of life of textiles result in shed-free recycling.
	Textile design industry	End of life of textiles

Table 2
Sensitivity analysis for scientist workshop to a finding of another node. 1 = Primary level; 2 = Secondary level.

Node	Mutual info	Percent	Variance of beliefs
Microfibers in the marine environment	0.98715	100	0.2455591
1a - Fibres are captured pre-release	0.19499	19.8	0.0619940
Stakeholders	0.13554	13.7	0.0442699
1b - Textile designs lead to lower release levels	0.03194	3.24	0.0108109
2a - New technology innovations in WWTP	0.03016	3.05	0.0101885
1b - Society has sustainable consumer behavior	0.02682	2.72	0.0091114
2a - Effective filters in domestic washers	0.00984	0.997	0.0033425
2a - Upgraded effective filter in industrial washers	0.00825	0.835	0.0028015
2b - We have non-biased industry testing	0.00173	0.176	0.0005903
2b - Standardization and measurements/labels	0.00142	0.144	0.0004828
2c - Marketing and awareness	0.00119	0.121	0.0004055
2c - Tax structure incentives	0.00074	0.0749	0.0002518
2b - Closer links between manufacturers and scientists	0.00033	0.0339	0.0001138
2c - Increased consumption of higher quality products	0.00020	0.0199	0.0000667

Table 3
Sensitivty analysis for scientist workshop to a finding of another node. 1 = Primary level; 2 = Secondary level.

Node	Mutual info	Percent	Variance of beliefs
Microfibers from textiles	0.92126	100	0.2232117
Stakeholders	0.07601	8.25	0.0226653
1a - Textile production	0.04864	5.28	0.0152725
1b - Wash and use phase	0.03857	4.19	0.0121818
1c - End of life of textiles	0.01687	1.83	0.0053106
2a - Regulation on shedding quality of textiles	0.00618	0.671	0.0019091
2b - Design of textiles and garments	0.00448	0.487	0.0013848
2a - Research and data sharing	0.00431	0.467	0.0013304
2a - Fibre shedding standard	0.00258	0.28	0.0007973
2b - Impact of washing routine communication	0.00148	0.161	0.0004579
2c - Recycling standards and regulation	0.00122	0.133	0.0003782
2b - Inter-stakeholder communication	0.00111	0.121	0.0003442
2c - Technology for recycling of textiles	0.00064	0.0696	0.0001985
2c - Proper take back system	0.00057	0.0615	0.0001753

Table 4
Strategies and Scenarios for mixed workshop of scientists alone. The first column is the event itself – and the scenario is the preferred scenario as defined by the stakeholders during the workshop. The probability is the group probability of how likely this group considered it to be that this would be realized. The last column refers to how high of an impact it would have on the priority issue if this scenario came true.

	Event	Scenario	Ease of impl.	Impact if realized
1	New technology and innovation in WWTP	Uptake is incentivized investment, public procurement and regulations.	45	60
2	Effective filters in domestic washers	Uptake possible because it is ubiquitous consumer friendly	56	67
3	Upgraded effective filters in industrial washing processes exist	Uptake possible because of existence of regulation, public procurement, incentives and investments.	66	72
4	Increased consumption of higher quality products with lower release	Incentives for better purchasing culture exists.	45	48
5	Tax structure incentives on higher quality products.	Acceptance in society	31	39
6	Marketing and awareness raising and outreach on "better" products.	High receptiveness with consumers	58	28
7	We have independent, validated and non-biased industry testing	Available industry incentives through regulation, funding and open data bases	50	52
8	There are closer links between manufacturer and researchers for better uptake of solutions in the material development industry.	Available funding for collaborations	60	47
9	Standardization and measurements/labels exist.	Validated and accepted methods for developing these exist.	63	47
10	Microfibers from clothing	Not a source of pollution in the aquatic environment	37	78

link to the priority node, '*Fibers are captured pre-release*' is the most influential. The second most influential at the primary level (discounting the 'Stakeholders' node for the moment) is '*Textile designs lead to lower release levels'*. A distant third is '*Society has sustainable consumer behavior*'. **The key highlight** is that '*Fibers are captured pre-release*' is clearly the dominant primary level node, meaning this is the variable that this group of scientists, as a group, perceived had the biggest effect on whether microfibers would no longer be a source of marine pollution in the future.

At the secondary level, the most influential pathway is *New technology innovations in WWTP*, which acts through *Fibres are captured pre-release*. Notably, this secondary node that directly links to *Fibres are captured pre-release* has greater influence than the primary node *Society has sustainable consumer behavior*. The second most influential path is *Effective filters in domestic washers*, which also acts through *Fibres are captured pre-release,* as is the third most influential path - *Upgraded effective filter in industrial washers.*

The second most influential variable on the priority node is 'Stakeholders' i.e. the auxiliary node representing the individual scientists that took part in the workshop. This might be unsurprising given that there is a number of stakeholders (n = 6), and so diversity might be expected - not necessarily just diversity of beliefs i.e. what is most important, but in how they represent these beliefs using probabilities. It is harder to do individual assessments i.e. select each stakeholder and look at their individual BBN i.e. based on their probabilities. However, a look at the individual conditional probabilities assigned by the stakeholders indicates that there are many instances where the probabilities (reflecting beliefs) of individuals diverge e.g. for 'Textile designs lead to lower release levels, 'Scientist 4' has 28.3% probability for 'Textile designs lead to lower release levels because there is knowledge about release profiles and innovation technologies exist" and 71.7% probability of the textile design industry having a worse release situation than today; whereas 'Scientist 5' has 63.1% probability for the positive outcome and 36.9% probability of the worst.

The BBN was further tested under *different* scenarios by manipulating the influential variables at the second hierarchical level, which illuminates an important factor of using this method for policy action plans. The variables that were adjusted were the three stem nodes that were identified as most influential on "Microfibers in the marine environment" (at the second hierarchical level) based on the outcome of the sensitivity testing. These manipulations were specifying that 1) There is incentivized uptake of new technologies and innovation in WWTPs, 2) There is consumer friendly uptake of effective filters in domestic washers and 3) Uptake is possible ensuring upgraded effective filters in industrial washers also (all three set to 100%). The results of this manipulation are presented in Fig. 3 and demonstrate that under this scenario, the probability of microfibers not being a source of marine pollution increases to 61.5% from 43.4% originally (Fig. 3).

4.5. BBN – industry and scientists combined

Fig. 4.

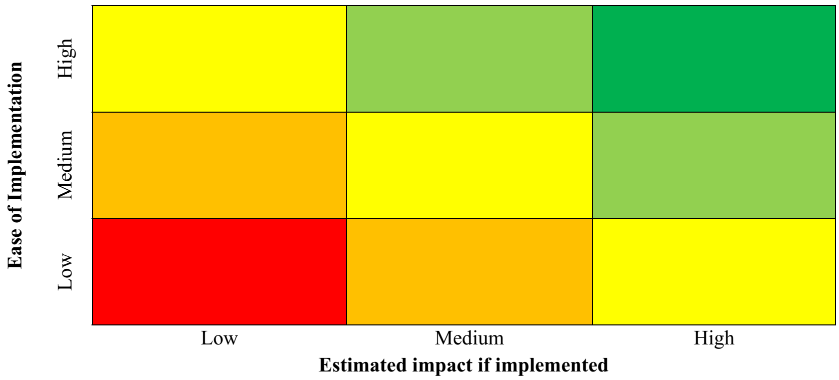
4.6. Sensitivity analysis – industry and scientists

The second workshop was a combination of 11 scientists and industry actors (5 and 6 representatives respectively). After adding individual probabilities to the back-casting process, the combined probabilities the stakeholders considered their priority issue had of

Table 5
Strategies and Scenarios for mixed workshop of scientists and textile industry actors together. The first column is the event itself – and the scenario is the preferred scenario as defined by the stakeholders during the workshop. The probability is the group probability of how likely this group considered it to be that this would be realized. The last column refers to how high of an impact it would have on the priority issue if this scenario came true.

	Strategy	Scenario	Ease of impl.	Impact if realized
SI-L1	Regulation on shedding quality of textile	Complied with and global consensus	37	71
SI-L2	Fibre shedding standard	Implemented and demanded by consumers	63	64
SI-L3	Research & data sharing	Standardized & transparent	73	62
SI-L4	Communication around washing routine impact	Consumer guidance on detergent, bags and centralized washing	65	34
SI-L5	Textile and garment design	Minimal environmental impact	34	87
SI-L6	Communication between stakeholders	Transparent, open & accurate	55	50
SI-L7	Proper take-back system	Panteordning for textiles	49	55
SI-L8	Recycling standards and regulation	Harmonized across municipalities	48	49
SI-L9	Technology for recycling of textiles	Developed, upscaled, established and profitable.	35	71
SI-L10	Microfibers from textiles	stopped from being continuously released into the environment	13	95

Table 6
Estimated impact and estimated probability. High probability-High impact is a preferred option. Low probability- low impact is a non-preferred option, specifically in terms of it not having high impact. High impact but low probability is something that is possible to aim towards, even if it is unrealistic today.



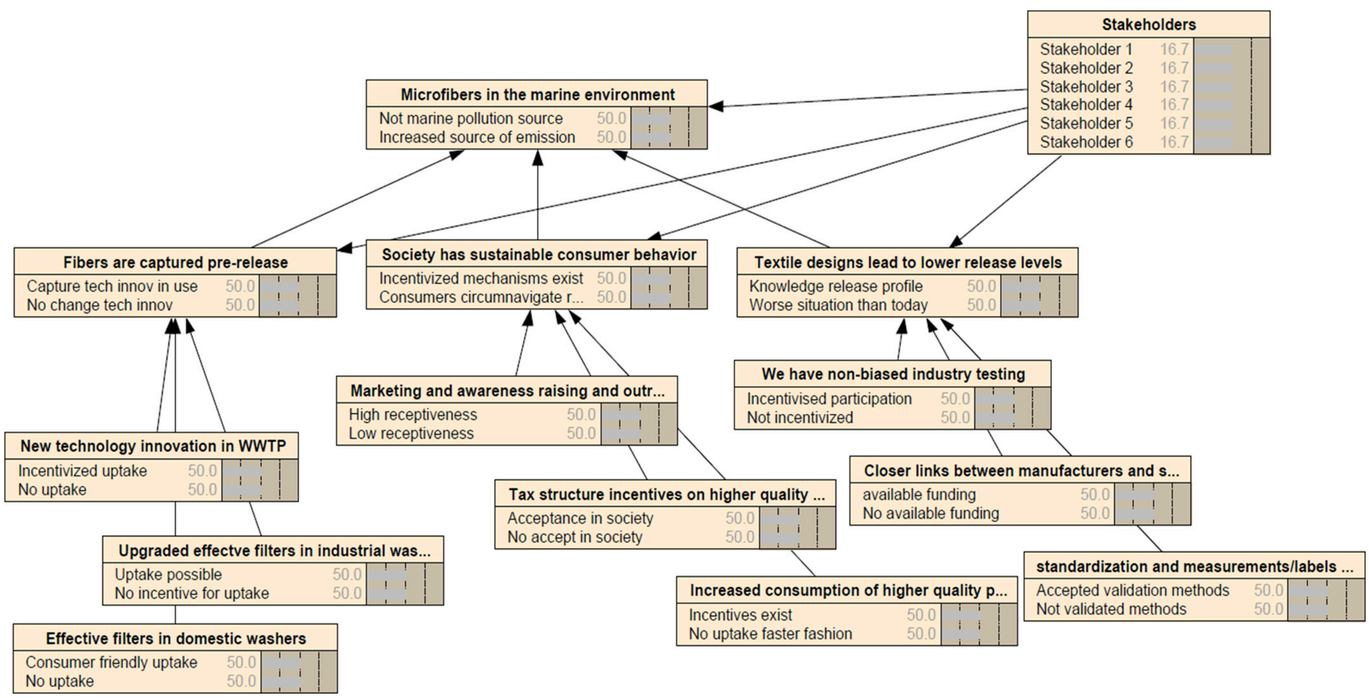


Fig. 2. BBN scientists.

coming true was at only 33.6%. This indicates that even if the stakeholders had set up the entire back casting process themselves in this workshop as well, and developed the correct and most likely paths, that in their opinion would ensure that the priority issue was realized, they still did not believe in the process as being able to solve the issue of ensuring that microfibers from textiles would no longer be released. However, as opposed to the pure scientist workshop, this time, when we placed the probabilities of each of the three primary variables at a forced 100% probability, the group did consider it 91.3% probable that microfibers would stop being released which is in line with what we would have expected.

We did a sensitivity analysis to find out what scenarios had the highest probabilities according to their perceptions as well, as we had in the smaller workshop with only scientists. In this case, the sensitivity testing highlighted that at the first hierarchical level of the model, '***Textile production***' is the most influential (discounting the 'Stakeholders' node for the moment). The second most influential at the primary level is '***Wash and use phase***'. A distant third is '***End of life of textiles***'. The key highlight here is that '*Textile production*' is clearly the dominant primary level node, meaning this is the variable that this mixed group of scientists and textile industry actors, as a group, perceived had the biggest effect on whether microfibers from textiles being released into the environment at any stage of its life cycle.

At the secondary level, the most influential pathway is **Regulation on shedding quality of textiles**, which acts through *Textile Production*. The second most influential path is **Design of textiles and garments**, which acts through *Wash and use phase. T*he third most influential path – **Research and data sharing** also acts through *Textile Production,* like the most influential one. The most influential variable on the priority node however is in this case 'Stakeholders' i.e. the auxiliary node representing the individual scientists and textile industry actors that took part in the workshop. This might be especially unsurprising given that there is a

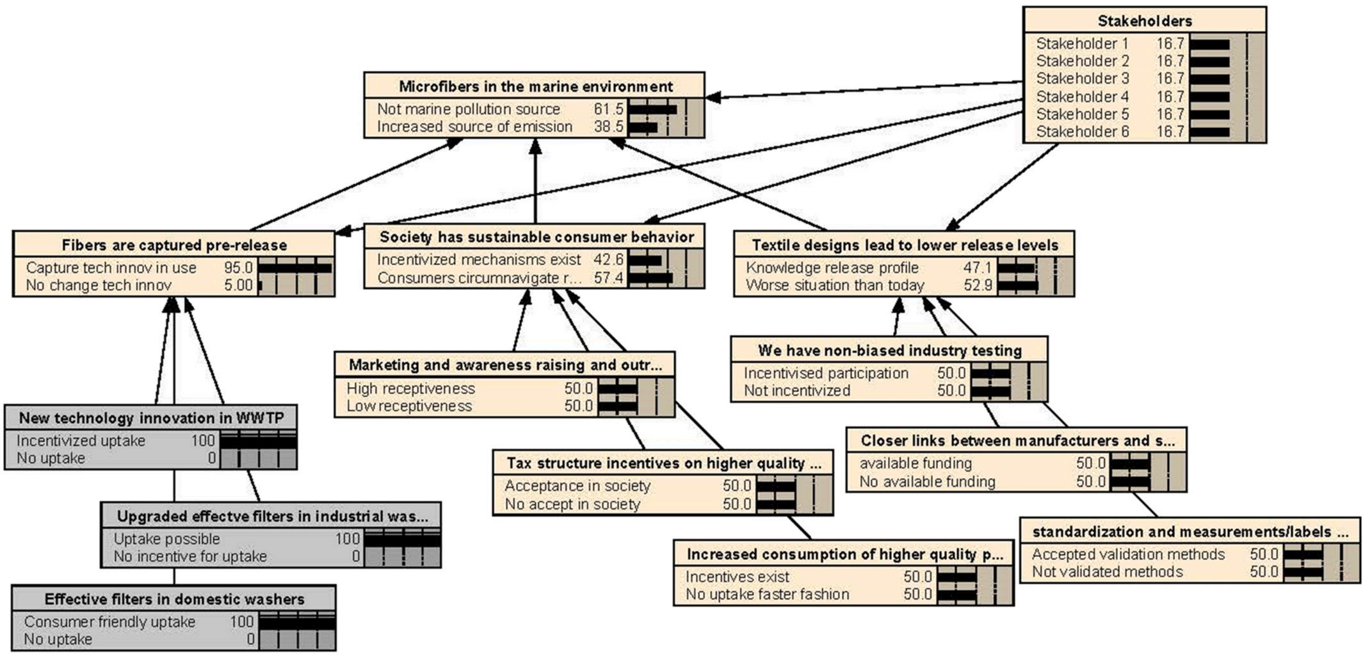


Fig. 3. Manipulated probability outputs with specific stem variables being set to 100%.

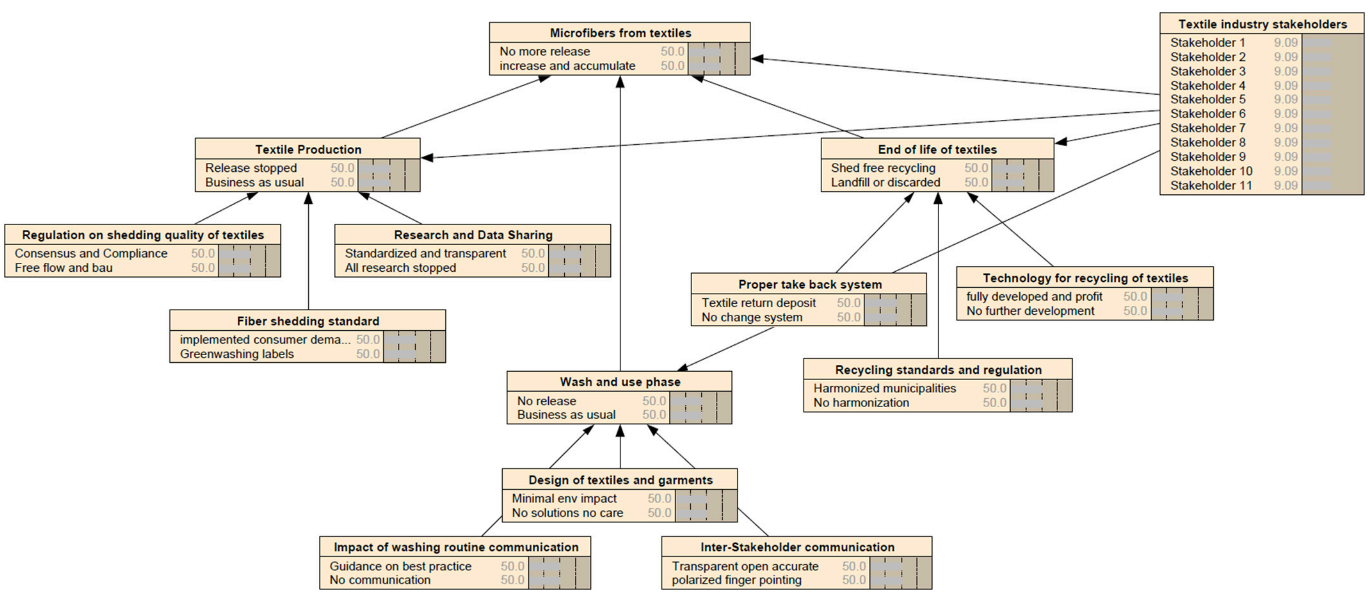


Fig. 4. BBN Industry and Scientists.

fairly number of stakeholders in this case ($n = 11$), and so even more diversity than in the scientist only workshop might be expected. Here too, there were clear divergent perceptions between stakeholders.

'Stakeholder 2' has for example a 55.6% probability for it being probable to achieve shed free recycling at the end of life of textiles, whereas 'Stakeholder 1' has this set to a 12.5% probability (Table 3).

The BBN was also further tested under *different* scenarios by manipulating the influential variables at the second hierarchical level, which illuminates an important factor of using this method for policy action plans. The variables that were adjusted were the three stem nodes that were identified as most influential on " release of microfibers from textiles" (at the second hierarchical level) based on the outcome of the sensitivity testing. These manipulations were specifying that 1) there is consensus and compliance on regulation on shedding quality of textiles, 2) the design of textiles and garments has minimal environmental impact and 3) research and data sharing is transparent and standardized (all three set to 100%). The results of this manipulation are presented in Fig. 5 and demonstrate that under this scenario, the probability of there being no more release of microfibers from textiles increases to 46.5% from 33.6% originally (Fig. 5).

5. Discussion

The main outcome of the workshops is that for the scientists alone, the primary level of fibres being captured pre-release was substantially more important to the stakeholders than the other two primary level nodes. This is seen not only from one of the secondary variables which acts through it – New technology innovations in WWTP – was more influential than one of the other primary level variables, but also that all three secondary level nodes under Fibres captured pre-release were

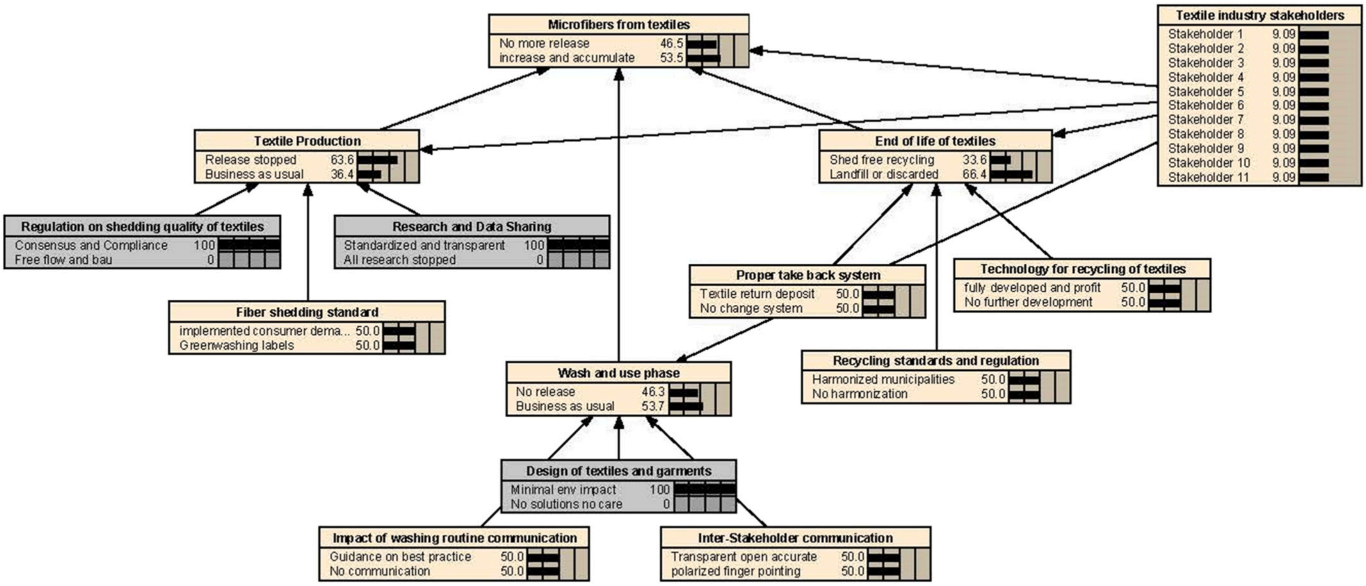


Fig. 5. Manipulated probability outputs with specific stem variables being set to 100%.

more influential than any of the other secondary level ones acting through the other primary variables. The least influential primary node was related to consumer behavior and sustainability, where the scientists appeared to have least faith in its probability in terms of influencing the primary issue of stopping release of microfibers to the aquatic environment. The secondar level variables acting thorough it were also almost exclusively at the bottom of the list, with the exception of the influence the scientists held in terms of probabilities of there being closer links between manufacturers and scientists acting through textile design and release profiles.

For the mixed group of both scientists and textile industry actors, the outcome was at the primary level, *stopping release from textile production* was the most influential variable, with *no release from the wash and use phase* a fairly close second. It was the former's secondary variables that were the most influential as well overall on that level. The least influential primary node was the shed free recycling at the end of life of textiles, where the discussion often centered on the action that would best ensure this would in fact be to burn all the clothing at the end of life.

This allowed the stakeholders to assess what policy actions of these they considered to be the most implementable of the proposed scenarios and reflect on how the impact this would have on stopping microfiber release into the environment, aquatic or not. Tables 4 and 5 list the 10 events and ten scenarios the stakeholders considered (the preferred outcome from the BBN process), and the participants were asked to rate them from 0 to 100 in terms of ease of implementation and impact if realized.

We followed this up by assessing it in terms of a model matrix of depicting likelihood. Table 6 shows the 3 × 3 model of a likelihood matrix that visualizes scenarios in terms of the estimated probability and impact associated to priors assessed by stakeholders. The fields of the model matrix correspond to different levels of likelihood the scenario will come true, from low probability and low impact to high probability and high impact. Items with high impact and low probability may be considered more critical and may therefore be treated with a different policy action approach than scenarios with high probabilities but lower impacts (Figs. 6 and 7).

The following two figures are visualizations based on this matrix. We filled in the probabilities the stakeholders assigned to ease of

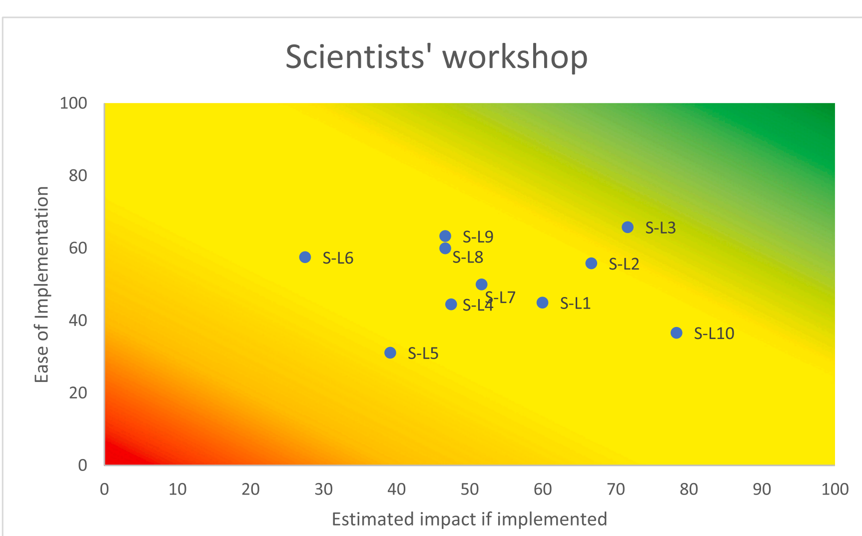


Fig. 6. Scientist scatter plot. The only scenario that was in the green – and as such both not too hard to implement but also was considered to have high impact – was S-L2: Uptake of upgraded and effective filters in industrial washing process is possible because there is regulation, public procurements, incentives and investments available to effectuate it. A close second was S-L3: Uptake of effective filters in domestic washers is possible because they are ubiquitous consumer friendly. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

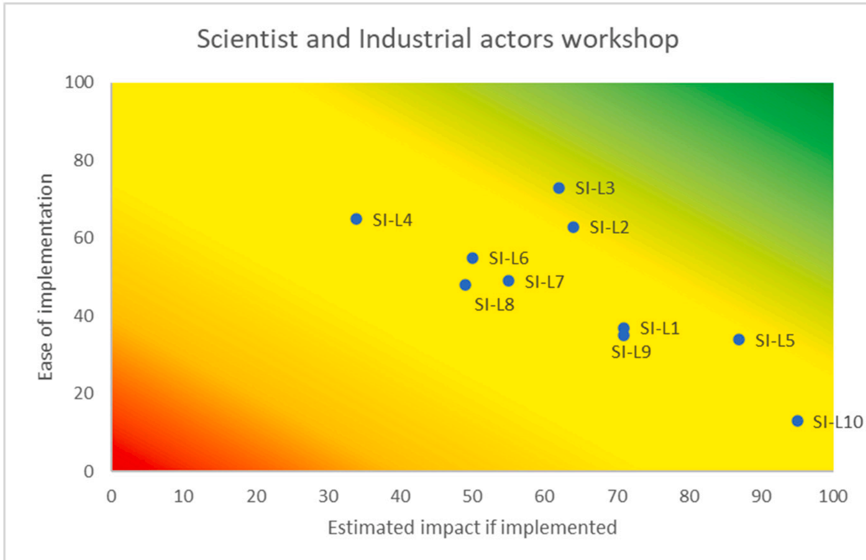


Fig. 7. The joint workshop scatter plot. Two scenarios were in the green: SI-L3: Research and data sharing between the industry and science is standardized and transparent; with a close second being SI-L2: Fibre shedding standards are implemented and demanded by consumers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

implementation and impact if implemented into a scatter diagram, and put gradient colors rather than having boxes in the final figures. The graphs show how the stakeholders in the two different workshops considered the probabilities of a given scenario coming true and what impact it would have if it did, as presented in Tables 4 and 5 above.

6. Conclusions

The elicitation process of this methodology can be intense, but the results outweigh the at times complex and frustrating process that some of the stakeholders that participate in these kinds of workshops express. The details that are derived from it are very satisfying for the stakeholders when presented with the graphs and the scenarios that they partake in developing. We also see from the figures and the results that when stakeholder driven scenarios are used as a method of co-producing avenues for policy action in an integrated framework such as this, managers get presented with several fundamentally different future perspectives to consider when planning for the future (Postma and Liebl, 2005). These perspectives are in this case individual percentage probabilities, driven by stakeholder input, and are most reliable from the contextual setting of precisely that given stakeholder group. This alone is also a single-sector management option, naturally, and should not stand alone any more than biological data or ocean current simulations should, though it is an important first step along the way to ensure stakeholder legitimacy as well.

What we can see from the policy action diagrams however is that when scientists alone consider what the most likely and high-impact scenarios are, they focus on the physical processes during the washing processes themselves – how to de facto stop microfibers from being washed out into the environment from industrial or domestic washers. They also put the emphasis on three different events: 1) fibres captured before they are even released – whether this is at the industry or domestic or at the WWTP levels; 2) on the textile design industry preventing shedding before the textiles even make it to the clothing industry; and 3) even further by society preventing the release by purchasing less or more sustainably at least.

When the industry was involved in discussing this, however, they had a much higher focus on regulatory needs and not the actual process. What they said with this was in a sense that "if you build it, they will come" to reference Field of Dreams. They also coupled this with an expressed need for data to be shared freely and transparently – not just within the research field but also between industry and researchers as well as between the different industries. Their BBNs also reflect this, in that they – rather than focusing on human processes as the scientists alone did – focused on the life time of the product itself – from 1) production, to 2) wash and use and finally to 3) the end of life of the product. Their emphasis was on solving the problem from different stages of the life cycle that together the three would all lead to less release into the environment – and the larger emphasis on regulatory events needing to be in place if there was to be any stop of release – at least from the life stage they considered more important (or at least had the most knowledge and interest in), namely textile production itself.

The lessons learned of this process are that when we co-produce knowledge in collaboration with stakeholders, we can better assess opportunities and challenges to a given issue area. This is especially true with complex wicked issues such as that of marine litter and how plastics from microfibers in clothing contribute to it.

CRediT authorship contribution statement

Rachel Tiller: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Andy Booth:** Conceptualization, Investigation, Writing – original draft. **Stephan Kubowicz:** Methodology, Investigation, Data curation, Writing – original draft. **Susie Jahren:** Conceptualization, Writing – original draft.

Declaration of competing interest

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

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