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The ivory tower of academia in the era of climate change: European scientists' engagement in science popularization related to single-use plastics

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A R T I C L E I N F O

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A B S T R A C T

Single-use plastics (SUPs) pose a major threat to the environment and public health due to their persistent popularity, exponential growth, and skeptical predictions regarding disposal methods. However, despite the declared importance of this topic in the scientific community, related science popularization efforts remain superficial. Here, we present a novel approach integrating the circular economy (CE) with the quintuple helix model to reveal interlinkages between academics, CE stakeholders and the public to assess how scientists face their responsibility for knowledge brokerage and popularization. SUP related researchers from four EU countries (Germany, France, Italy, and Poland) participated in a survey, followed by a complementary focus group. Most respondents considered science popularization as very or extremely important, and primarily to be carried out by scientists and journalists. The most popular channels were workshops, press, social media, while target audiences included mainly consumers, policy makers and local authorities. Despite the acknowledgment of the scientific mission (social impact, care for nature), popularization activities are discouraged by lack of time and improper research evaluation. Consumers' decisions are closely linked to environmental awareness which cannot be raised based on often false, easily accessible viral news. Involving the latter in science popularization requires systemic changes that, on the one hand, encourage researchers to leave their ivory towers (e.g., by including popularization achievements into research evaluation) and, on the other hand, provide them with relevant skills. This will hopefully increase trust in science among the public, and ultimately lead to a more rational use of plastics..

1. Introduction

The use of single-use plastic (SUP) products seems to represent consumers' general orientation in the 21st century, as they represent the safe and affordable comfort, rapidity, and temporality to which consumers have grown accustomed, while they are seemingly unaware of either the exponential plastic waste growth or the related impact on the environment and human health (Benson et al., 2021; Chen et al., 2021; Silva et al., 2020). Although legislation around waste governance has theoretically been rather strict, it was enough to launch the National Sword policy in China in 2017 (WTO, 2017), such that the dynamics of the global waste turnover changed dramatically, with China importing up to 45 % of the waste produced globally (Brooks et al., 2018). This policy stipulated the control of transboundary movements of hazardous wastes and their disposal, including plastic waste, as regulated material, according to the Basel Convention (Ragossnig and Agamuthu, 2021). However, the EU member states, the United States, and Australia faced a wide-ranging crisis resulting from insufficient infrastructures to process waste in their own countries (Vedantam et al., 2022). Despite the logistic and economic chaos this decision caused, China's National Sword policy was, however, one of the first and most significant actions towards reducing global waste (Wang et al., 2020).

Subsequently, in 2018, the European Strategy for Plastics in a Circular Economy (CE) was adopted as a key element of Europe's transition towards a carbon neutral and circular economy, meant to contribute to reaching the UN's 2030 Sustainable Development Goals and the objectives of the Paris Climate Agreement (Elliott et al., 2020; European Commission, 2018). Consequently, the Single-Use Plastics Directive (on

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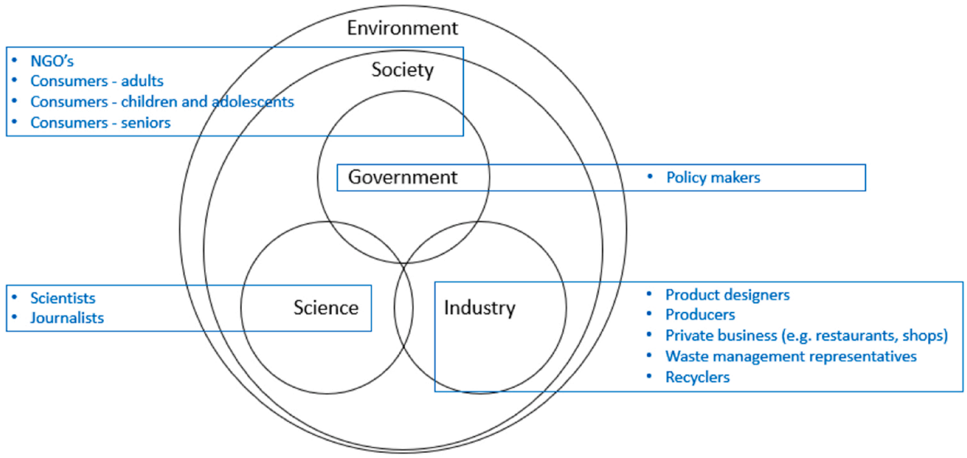

Fig. 1. The quintuple helix innovation model with a re-arrangement of SUP CE stakeholders, developed based on Grodzińska-Jurczak (2022) and Carayannis et al. (2012).

the reduction of the impact of certain plastic products on the environment, EU 2019/904), implemented in 2021, continued the course of the European waste policy. Although seemingly off to a successful start, its implementation coincided with the COVID-19 pandemic, which significantly diverted the attention of the public and authorities away from the waste crisis problem (Cohen, 2020; Grodzińska-Jurczak et al., 2020). Accordingly, the implementation of this directive has been and still is delayed, thus slowing down the decrease in SUP waste production. Moreover, the proposed regulations have triggered many controversies, due to several factors, including the prioritization of pandemic-related health and hygienic aspects over environmental issues and the state of the economy (Elliott et al., 2020).

Current representations of circular economy (CE) models are based on macro-loops associated with product life extension, redistribution and reuse, remanufacturing, and recycling (Schandl et al., 2021; Urbinati et al., 2017). CE-related research primarily focuses on the environmental performance of products or services over their life cycle, including resource consumption, production, utilization, and eventually disposal (De Los Rios and Charnley, 2017; Ghosh and Agamuthu, 2018). In contrast, CE business models are meant to serve as catalysts for collaboration, communication, and coordination within complex networks of interlinked yet independent CE stakeholders (Grodzińska-Jurczak et al., 2020; Urbinati et al., 2017). However, despite the growing interest in CE by decision makers and practitioners, we still do not fully comprehend how the different mechanisms involved in co-creating (brokered) knowledge can be translated into CE performance (Sassanelli et al., 2019). For example, the social aspects of this process have been considered secondary (Geissdoerfer et al., 2017), and therefore the social dimension of CE is still poorly understood (Kyriakopoulos et al., 2019). In response to this knowledge gap, this project aims to unveil the communication-related interlinkages among scientists, CE stakeholders, and the public in order to better understand the factors that shape the behaviors and attitudes that affect the knowledge flows and diffusion across the circular economy.

The transition towards sustainability requires science, business, politics, and society to join forces in novel innovation processes to jointly develop solutions that are only possible through the interaction of their different perspectives, competencies, and resources. Accordingly, the quintuple helix model (Fig. 1), a spiral model of innovation, assumes a novel process in which knowledge and technology transfer between different social sub-systems in the process of gaining importance. Explicitly, it refers to the three social sub-areas of science, industry, and government, which form the inner triple helix (Cai and Etzkowitz, 2020; Etzkowitz and Leydesdorff, 1997), while considering the additional dimensions of society and nature. Consequently, in the quintuple helix model, knowledge and know-how are created, transformed, and circulated as inputs and outputs in a way that affects the natural environment. The new relationship structure of originally bilateral relations between equal, independent areas, yet increasingly overlapping in their fields of activity, in turn, requires an internal redesign and functional expansion of the subsystems involved. Understanding these socio-ecological interactions is useful in defining opportunities for the knowledge society and knowledge economy to address sustainable development, including the effects of climate change (Carayannis et al., 2012). The relationships between the different sub-systems arise worldwide from different starting points and are at different stages. The helix can be formed either bottom-up through the interactions of the relevant actors and organizations or top-down, as supported by political measures. In most cases, both processes can be observed as reinforcing each other (Ranga and Etzkowitz, 2015).

Arguably, under these circumstances, science must motivate and engage with the public while connecting stakeholders in the transition towards a knowledge-based society (Unger, 2019). These efforts, however, will likely fail without the support of complex scientific analyses integrated with practical knowledge and expertize. For the past 50 years, SUP products have been one of the most important commodities in the global market (PlasticsEurope, 2022). Understandably, therefore, conflicts of interest between stakeholder parties have been (and still are) inevitable. What is surprising, though, is that these parties, although representing different interests, mutually agree that the key towards successful consumer transformation around plastics use is trustful science communication and education rooted in academia (Grodzińska-Jurczak et al., 2022).

On the one hand, major global environmental catastrophes (e.g., climate change, species extinction) generate a broad and diverse interest in research and science, while on the other hand, in the era of broad access to information, there is no longer a monopoly on expertize (Vohland et al., 2021). Therefore, knowledge transfer has become a recognized performance dimension of science. However, a broadly shared understanding of science and knowledge transfer is missing. This is a problem especially in those areas where scientific findings are intended to make important contributions to mitigate social problems (Adler et al., 2018; Oliver, Wuelser et al., 2021, 2021). Consequently, transdisciplinary sustainability research finds itself in the field of tension between aiming for context-specific solutions and enabling knowledge transfers to other contexts. Moreover, in order to transfer transdisciplinary knowledge, linear transfer understandings of the generalization, translation, and packaging of knowledge fall short, since the context- and problem-specific approach of transdisciplinary research requires that its results be adapted to the respective target context

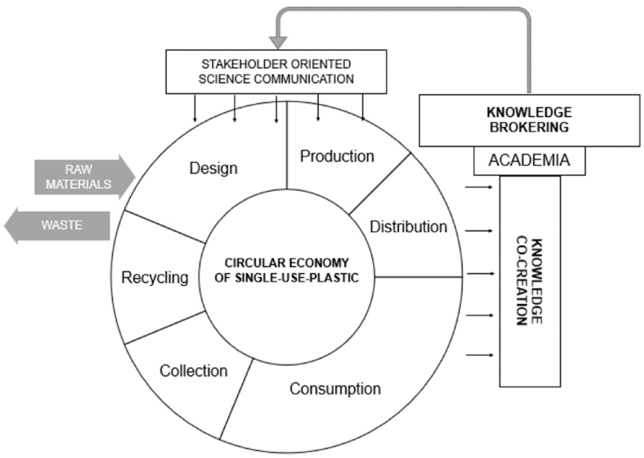

Fig. 2. Science communication as collaborative knowledge co-creation and brokering within a circular economy of single-use plastic. Author's elaboration based on the concepts of the circular economy in Schandl et al. (2021) and science communication and knowledge brokering in Bielak et al. (2008).

(Hoffmann et al., 2019; Lawrence et al., 2022). Contrary to the linear understanding of science communication, knowledge transfer within transdisciplinary research is often understood as a reciprocal and joint learning process that provides different types of knowledge and transfers it to other contexts, where knowledge is, in turn, adapted, enriched, and modified (Ebi et al., 2020).

With the proposed study, we aim to better understand how scientists can act as knowledge brokers to contribute to the individual transformations of different stakeholders engaged in the circular economy of SUP. To achieve this goal, we ask the following research questions: (1) Do scientists related to SUP engage with the broader society? If yes, through which channels and to which CE stakeholder audiences? (2) What is the main encouraging and discouraging factors in popularizing science? (3) What skills or competencies do the scientists perceive as most crucial when popularizing science?

For this purpose, following the trend of bridging the concepts of CE and the quadruple helix model (Durán-Romero et al., 2020; Ishak et al., 2021), we integrate the concept of knowledge brokering for effective science communication (Dobbins et al., 2009; Hering, 2016) into the circular economy framework (Fig. 2). This framework conceptualizes the various stakeholders of the SUP circular economy (starting from the stages of the product design, production, over distribution, consumption, till the collection and eventual recycling) as the co-creators of knowledge, and academics as knowledge brokers meant to diffuse this knowledge via science communication methods to the actors linked to the SUP CE.

In this study, we present the multinational aspect of environmental science communication based on a SUP governance case study in Germany, France, Italy, and Poland, although all these EU member states are at different sustainability transition stages. Our study aims to elaborate on the prevailing gaps to be taken into consideration by policy makers and academics. In doing so, it not only will enrich the rather scarce data on how academics understand the mission of popularization, its eventual obstacles, and/or the gratification among the research fellows but also will indicate a novel approach of transdisciplinary and transsectorial research in the area of environmental science communication.

2. Methods

The following study utilizes a standardized survey with both open-ended and closed-ended questions, followed by a sequential exploratory (consecutive focus group) mixed-methods approach (Creamer, 2017; Johnson et al., 2007; Morse, 2016) integrating both quantitative and qualitative tools for data collection. The results are then further discussed based on literature and current research in the field.

2.1. Sampling

Our sampling covers scientists who published SUP related scientific papers in internationally recognized journals over the period 2017–2021, with academic affiliation to at least one of the four investigated countries: Germany, Poland, Italy, and France. These four EU countries were selected because they are at different levels of sustainable transition and thus constitute a representative model for a European setting. To determine these levels, the Transitions Performance Index (TPI) was used, which monitors countries based on the four pillars of sustainability transition: economic (education, wealth, labor productivity, research and development intensity, industrial base), social (health life, work and inclusion, free or non-remunerated time, equality), environmental (greenhouse gas emissions reduction, biodiversity, resource productivity, energy productivity), and governance (fundamental rights, security, transparency, sound public finances). In this index, Germany shows top results in the overall score as well as in the economic, social, and governance dimensions, followed by France, which is second best in all categories. Italy scores the lowest on the social and governance indicators but best in the environmental dimension. Poland scores the lowest in the overall TPI as well as in the economic and environmental dimensions (European Commission, Directorate-General for Research and Innovation, 2021).

The timeframe of the published manuscripts was chosen based on China's National Sword policy of 2017, which caused an escalation in the prevailing waste crisis in Europe (Brooks et al., 2018), and marks two years before and after the COVID-19 outbreak in 2021. Data about the SUP-oriented scientific publications were retrieved from the Web of Science database following the systematic review method. The Web of Science database was selected from among the others due to its large representation of natural and engineering sciences and the reliability of the sources. It meets the criteria of selectivity, includes impact factors, and contains detailed information on the profiles, statistics, and affiliation of the authors (Pranckutė, 2021). Articles published by authors with academic affiliations to Poland, Germany, France, or Italy were searched and selected based on limiting criteria for abstracts and titles. The search was conducted on March 14, 2022, using the advanced search engine window and searching in all fields. The following query was entered: ((ALL = ("single use plastic *")) OR ALL = (plastic * "single use")) OR ALL = (plastic * "circular economy"), in conjunction with the following filters: publication year: 2017–2021; document types: articles or review articles; languages: English; countries: Germany or Poland or France or Italy.

2.2. Survey

Based on the database of 317 identified articles, a total of 836 authors were identified: 377 with an affiliation to Italy, 266 to Germany, 105 to Poland, and 88 to France. Online surveys were sent to all the selected authors, out of which 65 were excluded because they either had no e-mail, the e-mail was returned, they had passed away, or they were on maternity leave. The anonymous survey measured their experience in science popularization, including chosen audiences and channels; their opinions about encouraging and discouraging factors; and the necessary skills/competencies to popularize science, and it consisted of 11 closed-ended and three open-ended questions, shown in Appendix A. The first question asked if they popularize science, and, if so, how they do this. Likert scales (Joshi et al., 2015) served to rank the researchers' perceptions of the importance of science popularization and to identify perceived responsibilities to popularize science among the various groups of potential communicators. To gather insights regarding their specific science popularization behavior, the respondents were asked to select target audiences and the channels used. The presented selection of

Table 1
Distribution of respondents regarding affiliation country, highest academic degree, age, and gender.

	All Countries in %	All Countries	France	Germany	Italy	Poland
Degree						
Professor	41 %	37	5	11	14	7
Habilitated doctor	11 %	10	2	0	5	3
Doctor	31 %	28	2	6	13	7
Master	15 %	14	0	9	1	4
Bachelor	2 %	2	0	2	0	0
Sum	100 %	91	9	28	33	21
Age						
Less than 25	2,2 %	2	0	2	0	0
25–34	19,8 %	18	0	7	6	5
35–44	19,8 %	18	2	5	7	4
45–54	34,1 %	31	5	6	14	6
55–64	15,4 %	14	1	4	6	3
More than 64	8,8 %	8	1	4	0	3
Sum	100 %	91	9	28	33	21
Gender						
Woman	48 %	44	2	11	21	10
Man	51 %	46	7	17	12	10
Prefer not to say	1 %	1	0	0	0	1
Sum	100 %	91	9	28	33	21

Table 2
Distribution of respondents' research focus related to SUP Per country.

Q14: Which aspects of single-use plastics are you mostly focused on?	Total %	Total	FR	DE	IT	PL
Environmental + Technical	33.3 %	30	3	5	14	8
Environmental	21.1 %	19	3	5	9	2
Technical	15.6 %	14	2	5	5	2
Environmental + Technical + Economic	8.9 %	8	0	2	1	5
Environmental + Technical + Social	5.6.%	5	0	2	2	1
Environmental + Social	5.6 %	5	0	4	1	0
Environmental + Technical + Economic + Social	3.3 %	3	0	0	0	3
Environmental + Economic	1.1 %	1	0	1	0	0
Environmental + Technical + COVID-19	1.1 %	1	0	1	0	0
COVID-19	1.1 %	1	0	0	1	0
Social	1.1 %	1	0	1	0	0
Technical + Economic	1.1 %	1	0	1	0	0
Technical + Economic + Social	1.1 %	1	0	1	0	0
Sum	100 %	90	8	28	33	21

options was derived based on the current research related to SUP and the related circular economy model (Camilleri, 2020; Grodzińska-Jurczak et al., 2022; van Langen et al., 2021) and included producers, private businesses, consumers (adults, children, adolescents, and seniors), waste management representatives, recyclers, product designers, policy makers and local administration, journalists, and NGOs. To understand what motivates or demotivates the respondents to popularize science, open-ended questions were asked, such as "What discourages you from popularizing science?"; "What encourages you to popularize science?"; and "What skills/competencies are crucial when popularizing science?" The question "What encourages you to popularize science?" was asked only to those who answered affirmatively to the question "Have you ever popularized science?".

2.3. Focus group

To gain more insights regarding the obtained survey results, a virtual focus group organized via MS Teams was conducted among the survey respondents in May 2022, led by two scientists from our research team. In total, seven participants from Italy, France, and Poland were present. We would like to emphasize that the results of the focus group serve rather to better understand the obtained survey results than to claim distinctive findings. The focus group lasted two hours, was recorded and transcribed, and was conducted according to a previously prepared study scenario: First, the participants were introduced to the aim of the research. In the next step, we showed the respondents the results of the survey conducted in the previous stage of the study. After analyzing the results of each question, the participants were asked for their comments and conclusions about the statistics we obtained. At each stage, the scientists debated the possible explanations of the results; additionally, they discussed their own experiences related to the issue of science popularization. The meeting ended with a summary of the potential solutions and opinions offered by the group.

2.4. Data analysis

Aiming to ensure the three key quality criteria of research design, reliability, internal validity, and external validity (Creswell and Creswell, 2003), three members of our research team were independently engaged in the data analysis and interpretation in order to reduce possible procedural bias. Following the framework analysis approach (Ritchie and Spencer, 2002), we performed a consistency annotation of the emerging thematic frames across the responses to the open-ended questions. This resulted in 13 thematic frames identified for the question "What encourages you to popularize science?", 13 thematic frames for "What discourages you to popularize science?", and 18 thematic frames for "Which skills/competencies are crucial when popularizing science?" Based on these frameworks, we performed an indexing of the given answers, whereby one answer could be classified under multiple frames. Appropriate citations from the focus group were added to the frameworks and are cited to deepen the understanding of the described survey results.

3. Results

The survey reached 771 authors and delivered 91 responses, which is equivalent to a response rate of 11.8 %. From these respondents, 76 individuals stated to have experience in science popularization which allowed them to answer the experience related questions of the survey. A detailed distribution regarding affiliation country, highest academic degree, age, and gender are shown in Table 1. No major cross-country differences were observed; however, the less experienced group (master, bachelor) were mostly affiliated in Germany (11 out of 16), while France was represented only by researchers with doctoral degrees or higher.

Due to the non-representativeness of the sampling, we are not eligible to use our data for cross-country comparisons, however, it possibly shows trend observations to be used as insights for further research.

3.1. Research area of respondents

Most of the respondents were conducting research related to the environmental (72, 90 %) or technical (63, 78.75 %) aspects of SUP, while the social (15, 16.67 %) and economic (13, 14.44 %) aspects, followed by the impact of COVID-19 (2, 2.22 %), were emphasized to a lesser extent. No major differences were revealed in cross-country comparison; however, the social aspects were taken into consideration mostly by the researchers from Germany (see Table 2).

3.2. Attitudes

3.2.1. Perceived importance of science popularization

The results showed that 87 % of the respondents perceived science

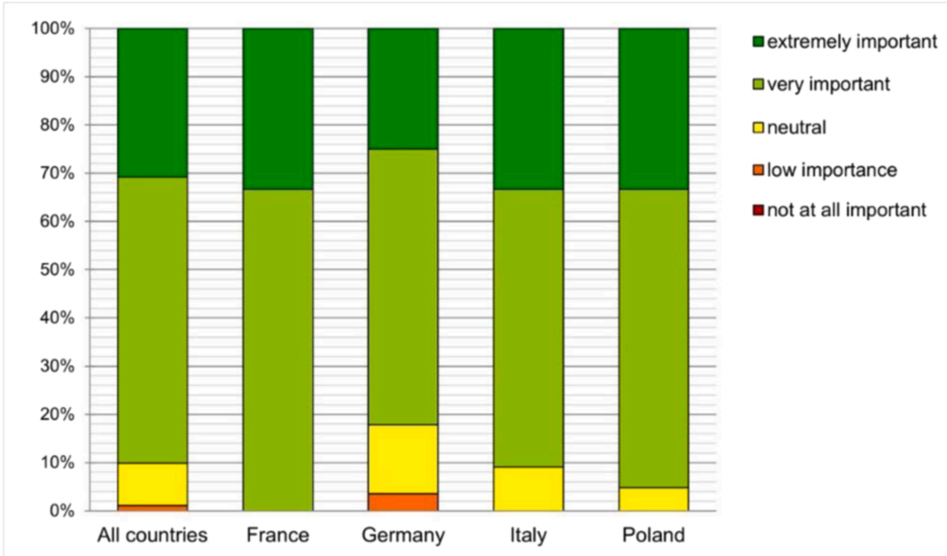

Fig. 3. Perceived Importance of Science Popularization Among SUP-Related Scientists.

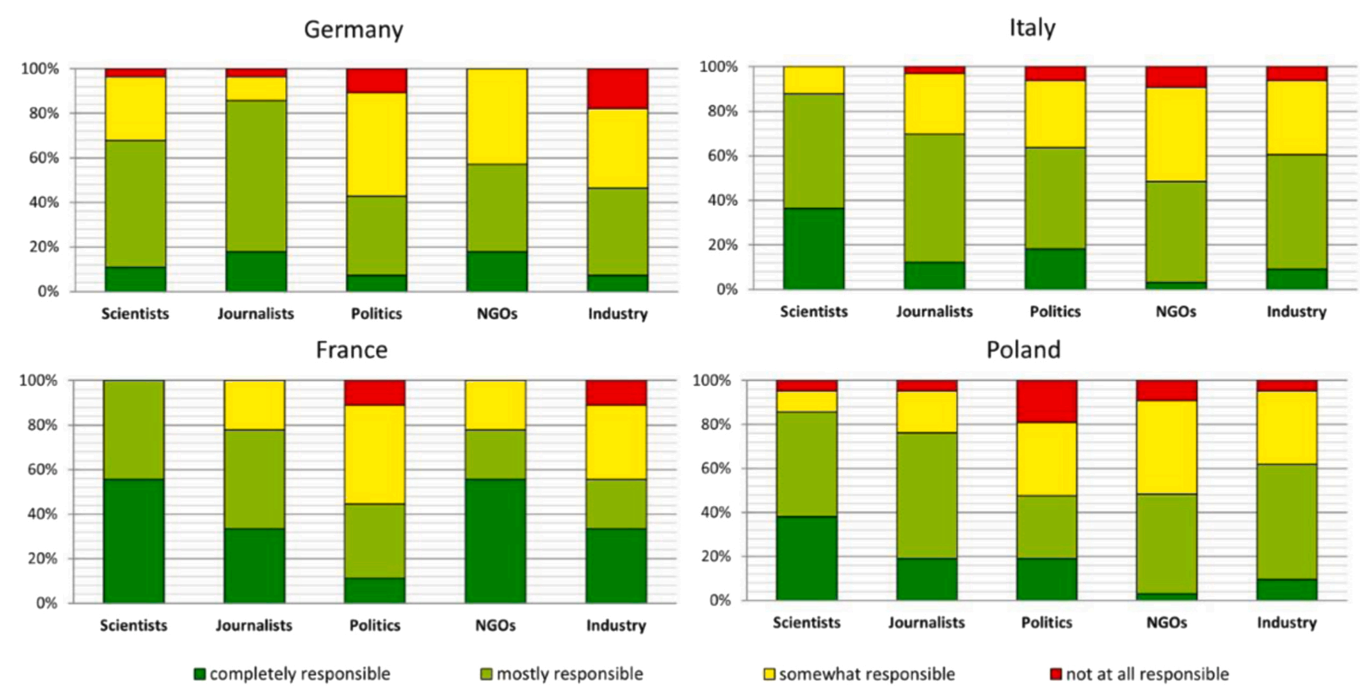

Fig. 4. Perceived Responsibility to Popularize Science Among SUP-Related Scientists, Distribution Per Country.

Table 3
Experience in Science Popularization.

Q3: Have you ever popularized science?	Total	FR	DE	IT	PL
Yes	76	7	25	25	19
No	15	2	3	8	2

popularization as very or extremely important (Fig. 3). No scientists indicated that it was not at all important. In addition, no dependency regarding the affiliation country, gender, age, or highest academic degree was observed.

3.2.2. Perceived responsibility to popularize science

The responsibility for science popularization was perceived similarly among the researchers from the investigated countries. The majority indicated scientists (82.4 %) and journalists (76.9 %) as the completely or mostly responsible groups. Mostly, scientists were perceived as more responsible than journalists; only the researchers from Germany saw journalists as more responsible than scientists. For France, the responsibility of NGOs was perceived as significant, even surpassing that of the journalists (Fig. 4).

3.3. Experience

Over three-fourths of the researchers (76 %) stated they have experience in popularizing science, emphasizing a discrepancy between declared importance (87 %) and actual engagement (Table 3).

This result was further elaborated among the focus group participants indicating that related activities remain poor due to various barriers and limitations:

Table 4
Experience in science popularization regarding channels.

Q4: Please select the channels through which you have popularized science.	Total	FR	DE	IT	PL
Workshops	57	5	16	21	15
Press	44	4	18	12	10
Social media	37	3	14	12	8
TV	32	2	15	7	8
Radio	30	3	11	10	6
Popular science literature	28	1	12	6	9
Blog	8	0	6	2	0
Events	7	2	4	1	0
Schools	6	1	1	3	1
Sum (N = 76)	249	21	97	74	57

Table 5
Experience in Science Popularization Regarding Target Audiences.

Q5: Please select your main target audiences.	Total	FR	DE	IT	PL
Consumers – adults	53	7	15	18	13
Policy makers and local administration	39	2	19	11	7
Waste management representatives	32	2	14	7	9
Consumers – children and adolescents	31	3	9	11	8
Producers	24	1	12	4	7
Recyclers	24	2	9	4	9
Journalists	22	1	13	3	5
NGOs	21	1	10	4	6
Consumers – seniors	17	4	6	5	2
Private business	10	0	2	1	7
Product designers	10	1	5	1	3
Sum (N = 76)	283	24	114	69	76

Table 6
Crafted list of thematic frames for declared encouraging factors.

Q5: What encourages you to popularize science?	#
Increased awareness	19
Scientist's mission	14
Social impact	14
Care for nature	9
Audience interest	8
Self-promotion	8
Future generations	6
Fighting fake news	5
Innovation	5
Empowerment	4
Inform decision-making	4
EU regulations	2
Networking	2

Table 7
Crafted list of thematic frames for declared discouraging factors.

Q7: "What discourages you from popularizing science?"	#
Lack of time	28
Evaluation	15
Audience indifference	14
Lack of skills	7
Distrust	6
False knowledge	5
Journalists	5
Lack of channels	5
Lack of experience	5
Other scientists	5
Costs	4
Need to simplify	4
Limited applicability	2

- "*We are 60 researchers at my institute, we are only two involved in science popularization. Maybe the other ones consider that the topic is important or very important, but they have no time to do it.*";

Table 8
Crafted list of thematic frames for declared crucial skills/competencies.

Q8: Which skills/competencies are crucial when popularizing science?	#
Communication skills: Clarity, Entertaining, Public speaking, Storytelling	66
Simplification & Applicability skills	45
Knowledge	29
Ability to engage people	17
Understanding the target group	16
Open-minded attitude	8
Emotional intelligence	7
Authenticity & Charisma	7
Networking & Reputation	5
Self-discipline & Time management	4
Objectivity	4
Enthusiasm	3
Analytical & Strategic thinking	2
Humility & Positive handling of criticism	2
English proficiency	2
Ethical attitude	1
Designskills	1
Social media skills	1

- *"There is a real difference between considering it important and doing it in real life."*;
- *"You are not evaluated for side activities like public engagement activities. In the curriculum, out of 100 points, there are only 5 points for public engagement activities. Most people say 'yes' but do not do anything."*

3.3.1. Channels. In all countries, the most popular communication channel was workshops; in Italy and Poland, they accounted for about a quarter of all the channels (Table 4). The second most important channel was the press, which together accounted for 17 % of all channels. Only in Germany was the press mentioned more often than workshops as a channel used to popularize science. The remaining communication channels obtained similar results of a dozen or so percentage points. Social media in total accounted for only 14 % and was chosen by scientists of all ages, although most often by the youngest and least often by the oldest. More than half of the professors indicated social media as one of the few channels they use for popularization. Women use social media more often to popularize science than men. LinkedIn ranked first (41.5 %), followed by Facebook (24.6 %), Twitter (18.5 %), and Instagram (15.4 %). The researchers from France indicated only LinkedIn and Twitter, while Twitter was not mentioned by the researchers from Poland.

Further insights were obtained during the focus group:

- *"On the Facebook of our university, they put the information about who was speaking on TV, radio, or in popular magazines related to politics but also to environmental protection. This is one of the sources of information, especially for students who are always on Facebook searching for such information."*

In addition, the participants elaborated on the negative impact of the COVID-19 pandemic. During this time, while some channels could be replaced by others (i.e., conferences changed to online format), especially activities implying direct contact with the audience were mostly put on hold due to introduced restrictions:

- *"For popularization activities, I used to go to schools to meet children. During the pandemic, I couldn't do any of these activities. (…) I must rebuild again the communication with schools. We lost this kind of activity during the pandemic, but I hope it will resume to how it was before the pandemic."*

3.3.2. Audiences. When popularizing science, 69.7 % of the respondents declared consumers (adults) as the main target audience,

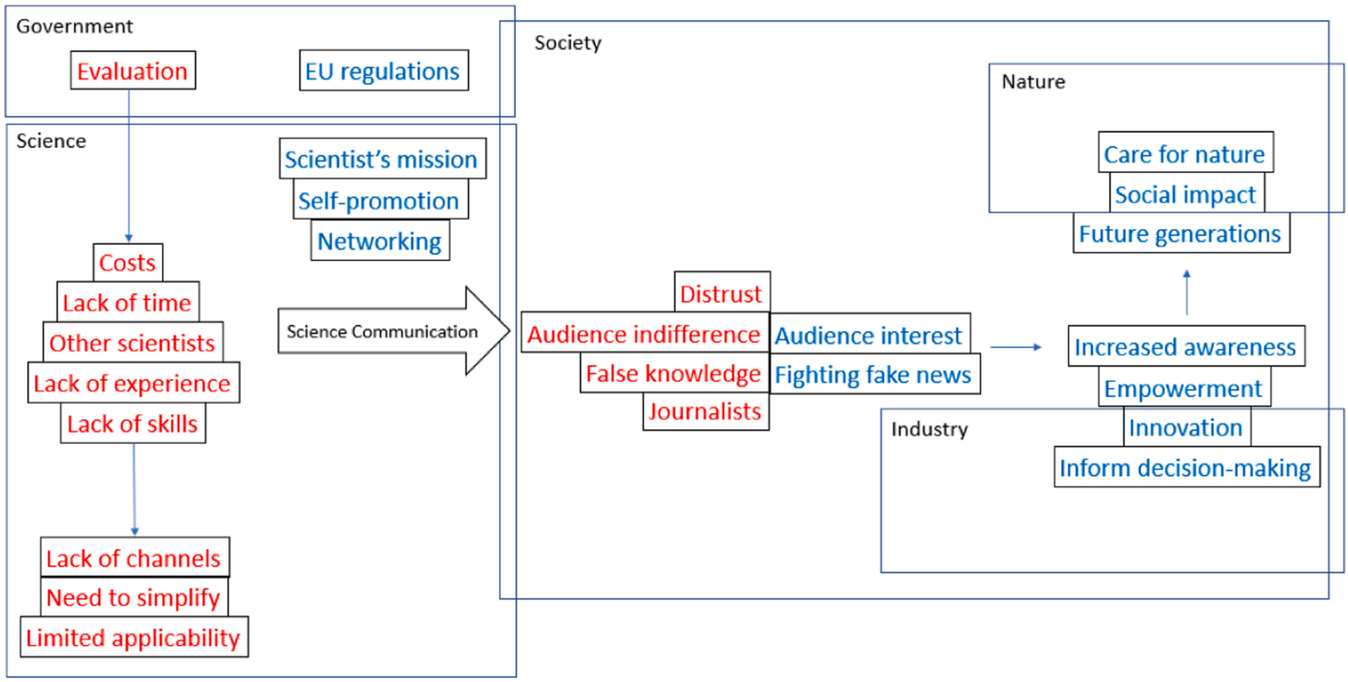

Fig. 5. Causal map of encouraging (blue) and discouraging (red) factors for science popularization among scientists engaged in SUP related research, based on the conducted framework analysis of the answers to "What encourages you to popularize science?" and "What discourages you to popularize science?" Author's own elaboration.

followed by policy makers and local administration (51.3 %) and waste management representatives (42.1 %). The least represented were private businesses (13.2 %) and product designers (13.2 %) (Table 5).

3.4. Motivation

The most encouraging factors for the survey respondents to popularize science included the idea of increasing societal awareness, their mission as scientists, and the potential social impact of the popularization activities. In addition, caring for nature was perceived as encouraging. Further factors included audience interest, self-promotion, the care for future generations and empowerment. Equally important were the factors related to the creation of innovations and the fight against fake news and greenwashing. Several people found the possibility of helping in the decision-making process encouraging. A few people also mentioned the supportive effect of EU regulations (i.e., requirements of R&D EU-founded projects, specifically Horizon 2020) and the positive impact of networking. The category frequencies are outlined in Table 6, while the exact quotes with category annotations are listed in Appendix Table A2.

Most of the discouraging factors the respondents mentioned addressed the time-consuming nature of science popularization and an adequate evaluation of this type of activity in the workplace. The third most frequently mentioned factor was related to audience indifference. Further discouraging factors included audience indifference, a perceived lack of necessary skills and the lack of trust towards scientists. Our respondents also complained about the spread of false knowledge, especially often highlighting the challenges to communicate with journalists. In addition, several other factors were mentioned, such as the lack of communication channels, lack of experience, demotivating behavior of other scientists, costs, the need to simplify complex problems, or limited applicability of research findings. The category frequencies are shown in Table 7, while the exact quotes with category annotations are listed in Appendix B.

Complementary insights were gathered during the focus group:

- *"The lack of time is related to academic evaluation. We do not have time because we do not have the priority."*
- *"Lack of time because it is still a parallel activity but not the heart of our missions. If this changes, we will dedicate time to do it, like we teach or do research. It should be included as one of our missions."*
- *"Together with the lack of time is a lack of incentive in doing this kind of activity together with our regular activities."*

3.5. Skills

Of the skills identified as crucial to successful popularization, the vast majority were communication skills, such as clarity, entertaining, public speaking, or storytelling, and the ability to transfer knowledge in a simple and applicative way. Many scientists also emphasized that the basis for popularization is knowledge, expertize in a given field. Issues related to the ability to engage people and understanding the target group also appeared frequently. In addition, there were skills described as open-minded attitudes, emotional intelligence, and authenticity and charisma. The need for networking and reputation-building was also identified. According to the respondents, issues related to self-discipline and time management are also important. Furthermore, the following skills were mentioned by some respondents: objectivity, enthusiasm, analytical and strategic thinking, humility and positive handling of criticism, English proficiency, and ethical attitude. The only hard skills that appeared in the entire set were design and social media skills. The category frequencies are shown in Table 8, while the exact quotes with category annotations are listed in Appendix B.

Complementary insights were gathered during the focus group:

- *"You cannot speak to people about plastics in a scientific way. It is better to even tell some jokes. From my point of view, it's important."*
- *"Pedagogic skills involve storytelling, imagining a way to explain a topic to the target public. Understanding the target group is the first step."*

3.6. COVID-19 impact

In total, most respondents declared no significant impact by COVID-19 on the amount of scientific paper publication (58 %). On the one side,

Table A2
Responses and categories to the open questions (Q6–8).

#	Q6: What encourages you to popularize science?	Category
1	environmental issues	Care for nature
2	in case of waste management and recycling the whole system depends on acceptance of waste producers, so they must understand how systems and technology work and what are the limitations.	Inform decision-making
3	It is important that people become more aware about how science works.	Self-promotion
4	satisfaction, act for social impact	Social impact
5	Desire to pass on good practices to future generations	Future generations
6	people interest to science	Audience interest
7	We are working on a chemical recycling technology for PET waste materials and want to increase the awareness of the waste material cycle problem. We believe that our technology is capable to solve the problems for the PET waste material circle and therefore want to influence policy makers, NGOs, governments, and the overall mindset of consumers.	Inform decision-making; Social impact
8	The spread of knowledge	Increased awareness
9	It is so important. Scientist must popularize science	Scientist's mission
10	the necessity to transfer knowledge to layman public to let people understand why some decisions are taken and not others	Increased awareness
11	Raising awareness about environmental problems	Care for nature; Increased awareness
12	intervention of scientists in schools (preferably primary and secondary)	Future generations
13	The feedback from people	Audience interest
14	Especially people who are actively asking me or show interest in the science i do.	Audience interest
15	Making people to understand that science means technological innovation and economic growth, and to fight against fake news.	Fighting fake news; Innovation; Scientist's mission
16	social responsibility	Scientist's mission
17	Consumer awareness	Increased awareness
18	Clarify misleading concepts, let people know of possible sustainable solutions	Fighting fake news; Increased awareness
19	The possibility to make people understand and appreciate the latest findings of science	Self-promotion
20	My love for science	Scientist's mission
21	To transfer knowledge and make aware citizens	Increased awareness
22	The development of new products and development of society	Innovation
23	Responsibility to the nature	Care for nature
24	The idea to involve youngs in making decision for the future - climate issues	Empowerment; Future generations
25	Realizing people that they can also help solve environmental problems	Empowerment
26	Exciting achievements	Self-promotion
27	the global challenge ahead	Care for nature; Future generations
28	Obligation towards the citizens, increase of scientific literacy	Scientist's mission
29	Population should have information about what is toxic and what no, what is degradable and what is not etc	Increased awareness
30	Sharing scientific knowledge with people without specialistic backgrounds.	Increased awareness
31	To disseminate real information about plastics and its recycling.	Fighting fake news; Increased awareness
32	impact on sustainability transformation	Social impact
33	More and more people want to learn more about the subject.	Audience interest
34	Mission of our organization	Scientist's mission
35	Share the knowledge and raise awareness to environmental causes	Care for nature; Increased awareness
36	EU project rules and friends	EU regulations
37	To increase people's knowledge and improve the future, especially with respect to the environment.	Care for nature; Future generations; Increased awareness
38	The need of knowledge transfer and the fear about ignorance	Increased awareness
39	its importance and my feeling that I have something to say	Scientist's mission
40	Multiplier function	Scientist's mission
41	I see it as a responsibility of doing science, an essential part of science. Also, people have a right to know the impact and results of tax-funded science.	Scientist's mission; Social impact
42	awareness that it can help make development more sustainable	Social impact
43	To solve problems, to develop society in the direction of sustainability, to correct industries greenwashing and sustainability washing, to get people attracted to science	Fighting fake news; Self-promotion; Social impact;
44	The importance of public acceptance of recycling measures taken.	Empowerment
45	the need to disseminate and train people towards a more responsible use of resources	Care for nature; Increased awareness
46	customer involvement	Empowerment
47	to make technical concepts understandable to people who are not familiar with that sector or that language	Increased awareness
48	It is extremely important	Scientist's mission
49	my knowledge and willingness to raise awareness of the society	Increased awareness; Self-promotion
50	interesting scientific articles, meeting with scientific people	Networking
51	I am a teacher, and a popular science is one of my competitions	Scientist's mission
52	interested environment - if we are working on real needs of people or companies	Audience interest; Social impact
53	Possibility to present my scientific interests to many people which are not related to science.	Self-promotion
54	public and policy interest, interested target groups, vision of achieving real change/implementation of research results	Audience interest; Social impact
55	Willing to spread the knowledge	Increased awareness

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Table A2 (*continued*)

56	It is necessary to create sensible technological solutions for the future and lead new professionals in the field	Future generations; Innovation;
57	willingness to develop new products needed by consumers	Innovation
58	Participation in R&D EU founded project, SUP idea	EU regulations; Innovation
59	give a better knowledge to citizens, fight the fake idea or news driven by "populists" very often	Fighting fake news; Increased awareness
60	Dissemination of own results, dissemination of project results, feedback	Audience interest; Self-promotion
61	To make an impact based on research results and allow for more informed decision making.	Inform decision-making; Social impact
62	Bringing an understanding of scientific results into the community/society	Increased awareness
63	Without the population Science in the end can't go into practice	Social impact
64	The need to explain causalities so that people can make better decisions.	Inform decision-making
65	real world impact	Social impact
66	Making research results accessible and applicable for the general public, policy makers, producers etc.; broadening the impact of research and facilitating a systemic shift towards a more circular economy	Care for nature; Social impact
67	We are science-based researcher and consultants. To spread scientific result is part of our business.	Scientist's mission
68	The will to tell the truth	Scientist's mission
69	- create impact through science (facts and numbers), raise awareness	Increased awareness; Social impact
70	Contact with people out of academia, new experience, self-promotion	Networking; Self-promotion
71	To have an effect	Social impact
72	Explain how science can help to solve plastic pollution	Care for nature; Scientist's mission
73	public attention for the topic	Audience interest

#	**Q7: What discourages you from popularizing science?**	**Category**
1	Lack of time & no active social media account or other communication channel.	Lack of channels; Lack of time
2	The interest of journalists often is to tell the story they decided to produce. My experience is that they reduce scientific information based on journalistic aspects.	Journalists
3	The hate and distrust one receives.	Audience indifference; Distrust
4	lack of time, not properly evaluated in academic career	Evaluation; Lack of time
5	the time it takes on the rest	Evaluation; Lack of time
6	the lack of experience	Lack of experience
7	The scientific processes have to be simplified drastically to be suitable for a popular publication.	Need to simplify
8	Problems/difficulties with social media	Lack of channels; Lack of skills
9	scientists are not believed	Distrust
10	It is time-consuming	Lack of time
11	the involvement of not experts	Journalists
12	Chronical delay in supporting laws and Regulations	Evaluation
13	did not have the chance to	Lack of experience
14	I do not often communicate with the public about science simply because my explanatory skills are not that high. Also it proved to be very time consuming.	Lack of skills; Lack of time
15	Nothing really, maybe time availability	Lack of time
16	Time	Lack of time
17	The wrong data and concepts they got from not scientific information (web) that they consider as "truth"	False knowledge
18	The lack of knowledge of the scientific method, it should be taught at school, together with the mother tongue rules	Lack of trust
19	People not believing in science	Lack of trust
20	The cost of popularization and time needed for these activities	Costs; Lack of time
21	Bad examples of people too much dogmatic	Other scientists
22	Lack of time	Lack of time
23	People are not open to new knowledge	Audience indifference
24	Intellectual property limitations	Regulations
25	low feedback	Audience indifference
26	no access	Lack of channels
27	scientific concepts are often misunderstood or over simplified driving to wrong conclusions or wrong expectations. People tend not to spend time to get properly informed on their own therefore to provide enough information is very time consuming due to	Audience indifference; Distrust; Lack of time; Need to simplify
28	Nobody ever asked me to popularize science	Audience indifference; Lack of experience
29	skepticism in science	Distrust
30	did not have the chance	Lack of experience
31	The lack of time for that kind of activities during scientific work	Evaluation; Lack of time
32	The lack of participation of specific kind of events.	Lack of channels
33	high workload	Evaluation; Lack of time
34	It is necessary to fight with many people who claim to be experts	False knowledge
35	lack of time	Lack of time
36	Lack of channels beyond newspaper articles/talkshows	Lack of channels

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Table A2 (*continued*)

37	I am introvert and not self-confident, so I am more relaxed when writing more than in a speech. Anxiety triggers me	Lack of skills
38	I'm very busy with academia engagement	Evaluation; Lack of time
39	Nothing, just having the time to do it.	Lack of time
40	It is not coordinated at a higher level	Evaluation
41	lack of time and distortions by journalists	Journalists; Lack of time
42	Time constraints, no impact within the scientific community	Evaluation; Lack of time
43	The low pay in research sector	Evaluation
44	Difficulties in presenting in a simple way complex problems	Lack of skills; Need to simplify
45	Time needed, industry behavior	Audience indifference; Lack of time
46	the absence of experts from science in political discussions	Audience indifference
47	such activities are not recognized (in most of case) as "scientific works" by academia	Evaluation
48	have not had an opportunity	Lack of experience
49	lack of time	Lack of time
50	Unclear communicators, expressing opinions instead of explaining, and colleagues reluctant to share their results and experiences	False knowledge; Other scientists
51	needed time and communication skills	Lack of skills; Lack of time
52	boring and uninteresting teachers	Other scientists
53	manipulation of information	False knowledge
54	The popularization of science is usually not possible during working hours and the lack of funds for the purchase of necessary materials necessary for experiments.	Costs; Evaluation; Lack of time
55	lack of coherent information policy regarding waste management matching real situation in the sector	False knowledge
56	brak czasu z powodu ogromu obowiązków zawodowych [lack of time due to the enormity of professional duties]	Evaluation; Lack of time
57	Lack of time due to much work	Evaluation; Lack of time
58	The preconcept that science is inherently complex and not understandable by anybody but specialists of the field	Audience indifference
59	no popularization of presentations among companies at industry conferences	Audience indifference
60	The attitude of politicians, reluctance of scientists from PL universities to cooperate	Other scientists; Audience indifference
61	nothing, as long as I am enthusiastic to deliver "simple" science and knowledge	Need to simplify
62	Misuse and misinterpretation of public statements.	Message distortions
63	when people do not listen	Audience indifference
64	other Scientists who think that this is not important	Other scientists
65	The usual disinterest by the vast majority of people. And that usually the loudest or the one with the most money influence decisions.	Audience indifference
66	effort and resource intensity	Costs; Lack of time
67	waste of time, keeps me from doing research and scientific publications	Evaluation; Lack of time
68	lack of time/resources, low reach	Audience indifference; Costs; Lack of time
69	I have no training to do that and I have made Bad experiences with Journalists the FED times I tried to Communicate scientific facts in Publicity.	Journalists; Lack of skills
70	science often too far from reality, no time	Lack of time
71	The fear to be misunderstood	Lack of skills
72	Sometimes studies etc. are very complex and have a narrow focus which does not always match our target audience (NGO)	Limited applicability
73	Responsibilities at the university, the need to conduct research for publishing. It is difficult to be a scientist and at the same time a promoter of this science in the unscientific world	Evaluation; Lack of time
74	Low level of scientific culture, and cultural attitude of refuse of complexity	Audience indifference
75	complex realities	Limited applicability
#	**Q8: Which skills/competencies are crucial when popularizing science?**	**Category**
1	Communication skills (design of figures; scientific language needs to be translated into a language that is understandable for a wider audience;.)	Communication skills; Design skills; Simplification & Applicability skills
2	to understand how the addressed group is coming in contact with the topic.	Understanding the target group
3	The understanding how to communicate with one another.	Communication skills; Understanding the target group
4	public speaking, storytelling,	Ability to engage people; Communication skills
5	Ta have clear, simple, limpid message with applicable solutions without too many constraints, and above all, visible effects at the individual level	Communication skills; Simplification & Applicability skills
6	empathy and easy talks	Communication skills; Emotional intelligence
7	You need to be able to simplify the scientific findings and processes in order to be understandable for everyone.	Simplification & Applicability skills; Understanding the target group
8	Simple to understand and straightforward language	Communication skills
9	Knowledge, reputation, enthusiasm	Enthusiasm; Knowledge; Networking & Reputation
10	simple language and easy examples	Communication skills; Simplification & Applicability skills

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Table A2 (*continued*)

11	Clarity and empathy	Communication skills; Emotional intelligence; Simplification & Applicability skills
12	capability of involves people, mostly the young learners	Ability to engage people; Communication skills; Understanding the target group
13	Public speaking and circular economy bases	Communication skills; Knowledge
14	strategic view and communication skills	Analytical & Strategic thinking; Communication skills
15	The ability to simplify the topics and explain it in an understandable way	Communication skills; Simplification & Applicability skills
16	Speak the language of the audience	Communication skills; Simplification & Applicability skills; Understanding the target group
17	simplicity	Communication skills; Simplification & Applicability skills
18	Communication abilities	Communication skills
19	A strong real scientific background, easy of communication, simple words and simple concepts	Communication skills; Knowledge; Simplification & Applicability skills
20	The ability to explain difficult topics in an entertaining, clear way.	Ability to engage people; Communication skills; Simplification & Applicability skills
21	scientific expertize and ability to tell stories	Communication skills; Knowledge
22	To communicate not easy concepts in a simple manner	Communication skills; Simplification & Applicability skills
23	Good knowledge of the subject, rhetorical skills	Ability to engage people; Communication skills; Knowledge
24	Making influence. Presentation skills	Ability to engage people; Authenticity & Charisma; Communication skills
25	Teaching skills	Ability to engage people; Communication skills; Simplification & Applicability skills
26	Openness, extrovertism, easy networking	Authenticity & Charisma; Enthusiasm; Networking & Reputation; Open-minded attitude
27	Presentation/communication	Ability to engage people; Communication skills
28	domain competences, communication skills, empathy	Communication skills; Emotional intelligence; Knowledge
29	To explain science in a form which the citizens understand	Communication skills; Simplification & Applicability skills; Understanding the target group
30	provide a complete information keeping simple and brief communication	Communication skills; Simplification & Applicability skills
31	I think that to effectively popularize science, not only scientific competencies, but also communication skills are necessary.	Communication skills; Knowledge
32	simplicity, clarity, authenticity	Authenticity & Charisma; Communication skills; Simplification & Applicability skills
33	communication skills and knowledge go the topics to be divulgated	Communication skills; Knowledge
34	knowledge, charisma, open mind	Authenticity & Charisma; Knowledge; Open-minded attitude
35	Simplifying concepts. Involving people.	Ability to engage people; Simplification & Applicability skills
36	simplify and popularize scientific knowledge, know your audience, make an exciting twist	Ability to engage people; Communication skills; Simplification & Applicability skills; Understanding the target group
37	Mastery of the subject matter that makes maximum simplicity and clarity possible	Knowledge; Simplification & Applicability skills
38	interdisciplinary knowledge	Knowledge
39	Excellent communications skills to simplify issues for the general public	Communication skills; Simplification & Applicability skills; Understanding the target group
40	flexibility, kindness, passion, clarity, be engaging	Ability to engage people; Authenticity & Charisma; Communication skills; Emotional intelligence
41	To avoid the use of technicisms	Simplification & Applicability skills
42	ethical and long-term experience	Ethical attitude; Knowledge
43	Have pedagogy and humility.	Ability to engage people; Communication skills; Humility & Positive handling of criticism
44	communication ability to talk in public without having people sleeping. equilibrium,	Ability to engage people; Authenticity & Charisma; Communication skills; Objectivity; Understanding the target group
45	being able to explain complicated matters as simply as possible without oversimplification	Communication skills; Simplification & Applicability skills
46	Expert knowledge, analytical and structured thinking, understanding of the needs and prerequisites of the respective target group, ability to learn, positive handling of criticism	Analytical & Strategic thinking; Humility & Positive handling of criticism; Knowledge; Understanding the target group
47	Open-minded attitude, ability to communicate complex things in simple manner	Communication skills; Open-minded attitude; Simplification & Applicability skills
48	Knowledge of the science communication at the level of citizen science.	Communication skills; Knowledge; Simplification & Applicability skills

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Table A2 (*continued*)

49	equilibrium between scientific rigor and simplicity of communication	Communication skills; Knowledge; Simplification & Applicability skills
50	to be able to simplify things, to be open minded, to have a message and engagement	Ability to engage people; Communication skills; Open-minded attitude; Simplification & Applicability skills
51	the right communication level and adapted language	Communication skills; Simplification & Applicability skills; Understanding the target group
52	popular and well understandable speech	Communication skills; English proficiency; Simplification & Applicability skills
53	the clarity of the interpretation of the terms	Simplification & Applicability skills
54	Have a good understanding of scientific data and facts, and being able to translate it into a material accessible to a larger public	Communication skills; Knowledge; Simplification & Applicability skills; Understanding the target group
55	extrovert	Ability to engage people; Authenticity & Charisma
56	Clarity, simplicity but not banality, ability to involve and interest the audience, ability to explain objectively without influencing the audience with one's own convictions.	Ability to engage people; Communication skills; Objectivity; Simplification & Applicability skills; Understanding the target group
57	communication skills	Communication skills
58	Being able to communicate with simple and straightforward language; providing numerical evidence of what you are communicating	Communication skills; Knowledge; Simplification & Applicability skills
59	broad scientific knowledge, the ability to communicate it in a simple way	Communication skills; Knowledge; Simplification & Applicability skills
60	knowledge, practice, experience	Communication skills; Knowledge
61	the ability to translate clearly, the ability to interpret phenomena, having knowledge	Communication skills; Knowledge; Simplification & Applicability skills
62	presentation skills and be basic in the showing science results	Communication skills; Simplification & Applicability skills
63	In my opinion, the ability to use simple language and general teaching skills.	Communication skills; Simplification & Applicability skills
64	ease of communication, experience, good contacts	Communication skills; Knowledge; Networking & Reputation
65	rozeznanie w dostępnej wiedzy, łatwość przekazywania informacji, samodyscyplina [discernment in available knowledge, ease of information transfer, self-discipline]	Communication skills; Knowledge; Self-discipline & Time management
66	Great knowledge in a given field	Knowledge
67	Ability to present the topic in an interesting way	Communication skills; Ability to engage people
68	Good communication and synthesis	Communication skills; Simplification & Applicability skills
69	using a language that industry can understand	Communication skills; Simplification & Applicability skills
70	knowledge of English - to actively participate in international projects; curiosity to discover new possibilities; willingness to create and build something new	English proficiency; Networking & Reputation; Open-minded attitude
71	having right and update scientific information able to be simply explained	Communication skills; Knowledge; Simplification & Applicability skills
72	time	Self-discipline & Time management
73	Identify topics of public concern and use laymen language.	Communication skills; Simplification & Applicability skills; Understanding the target group
74	to translate the scientific results into the languages of the target group	Communication skills; Simplification & Applicability skills; Understanding the target group
75	Communication, openminded	Communication skills; Open-minded attitude
76	Understanding what level of detail you can show without scaring the audience away.	Emotional intelligence; Simplification & Applicability skills
77	common understanding and language (i.e., the meaning of words and making science simpler)	Communication skills; Knowledge; Simplification & Applicability skills
78	communication skills, knowledge about the methods of popular media	Communication skills; Knowledge
79	communication, cultural sensitivity	Communication skills; Emotional intelligence; Understanding the target group
80	To understand Mechanisms of how Publicity and Journalism works	Communication skills
81	time, "simple speech" for complex topics	Self-discipline & Time management; Simplification & Applicability skills
82	Communication skills and the skill to be able to look from outside on one own work	Communication skills; Objectivity

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Table A2 (*continued*)

83	Understanding the science (prior knowledge usually necessary) to understand numbers/to know which numbers to rely on in which context	Knowledge; Simplification & Applicability skills
84	openness, ease of expressing thoughts, knowledge of social media, managing your own time and contacts	Communication skills; Networking & Reputation; Open-minded attitude; Self-discipline & Time management; Social media skills
85	To create a perspective of collective action	Ability to engage people; Objectivity
86	information accuracy, openmind and kindness	Emotional intelligence; Knowledge; Open-minded attitude
87	simplifying, storytelling, illustrate examples	Communication skills; Simplification & Applicability skills
88	To have scientist on board	Enthusiasm; Knowledge

65 % stated there were fewer conferences than before the pandemic (44 % significantly less), while on the other side, 29 % stated there were more conferences (23 % significantly more). The impact on popularization activities remained balanced: 35 % less than before the pandemic, 35 % no impact, and 30 % more than before the pandemic.

4. Discussion

In the era of a deepening crisis of trust in science, with widespread access to information, academia plays a key role in building public understanding and support for science. These activities include but are not limited to making the results of scientific research more accessible, presenting in a popular format the problems of science to a wide audience, and supporting the scientific way of thinking (Hopkins et al., 2018; Kislov et al., 2017).

Due to the complexity of the waste crisis, originated from various causes, its' risk to the environment and public health, even exacerbated by the COVID-19 pandemic, (Dey et al., 2021), the scientists in this study discussed many aspects related to SUP and it is difficult to define an unambiguous direction in which the scientific discourse on plastic is currently heading. Surely, all efforts are focused on how to reduce the plastic pollution (UNEP, 2021), but researchers work in different, sometimes complementary directions depending on their discipline and interest. Chemists and technologists are studying the properties of plastics, investigating alternative materials and innovative recycling and processing methods (Hidayah, 2018; Kabir et al., 2020), while broadly defined environmentalists and conservationists are focusing instead on the effects of the plastic pollution on land and in the oceans (Chen et al., 2021; Li et al., 2021). In addition, sociologists and psychologists are investigating human attitudes and perceptions around the prevailing plastic crisis (Walker et al., 2021; Grodzińska-Jurczak et al., 2022), while political scientists and legal specialists are analyzing the actions of leaders towards the circular economy (Xanthos et al., 2017). Given these highly diversified interests, intrascientific communication is challenging. Here in this study, academics and journalists were perceived as the primarily groups of knowledge brokerage, its' translation into popular language and dissemination to the public. Moreover, consistent science outreach activities, in our respondents' opinion, can be achieved only under circumstances of a good cooperation and interdisciplinary action between researchers and journalists. However, the structural link between transdisciplinarity, knowledge transfer, and science popularization has not yet been sufficiently explored (Nagy et al., 2020). In particular, the inclusion of social issues and multicultural perspectives in the research is relevant if the dialog orientation in (transdisciplinary) research and science popularization is to be taken professionally. However, the individual starting points are already known in order to better leverage the impact and transformation potential – especially by focusing on the social relevance of research and expanding the spectrum of research modes beyond the classic separation of basic and application-oriented research (Grodzińska-Jurczak et al., 2022).

Our results indicate that there are stakeholder groups who, although significantly related to the plastic governance, are surprisingly overlooked in communication activities. These groups were private businesses and product designers. In fact, there is hardly a manufacturing industry in which plastic does not play a role today. While policies can create the framework conditions for the transition to a resource-efficient circular economy for plastics, the involvement of the private sector is a key success factor that cannot be neglected. Science communication, as well as participative approaches, face the problem that (apart from small pioneering projects with limited reach) they usually only reach a socioeconomically better-off, academically inclined audience (Guenther and Joubert, 2017). This shows the necessity of efforts to contact hard-to-reach target groups, not only groups with an affinity for science, and it emphasizes the need for scientific institutions to develop a more differentiated understanding of exclusion processes. Only stepping down from their ivory tower and acting in other contexts than just the scientific research environment, let research fellows developing skills and expertize that support the understanding of their potential target groups and the respective channels through which to reach them.

Research on science communication spans a very wide range and includes all aspects of the communication of scientific work and scientific results, both within science and in the communication between science and the public (Iyengar and Massey, 2019; Van der Bles et al., 2019). Scientists' outreach is shaped by social factors of various origins, depending on institutional and national priorities, cultural contexts, age (stage of carrier), gender, discipline, and individual skills (Bauer and Jensen, 2011; Martín-Sempere et al., 2008). Such an output therefore displays regional differences (Guenther and Joubert, 2017). In general, senior and female experts are more open to leaving the golden cage of academia, perceiving translating science to the public as a societal mission and ethical duty, especially in the era of global policy and environmental and economic crises (Ecklund et al., 2012). The rate of engagement depends on their discipline; formal and natural science fellows (especially from science technology, engineering, and mathematics) are significantly less active and eager to communicate with the public than the humanistic and art experts (Poliakoff and Webb, 2007).

Despite the wide range of available communication channels, our respondents showed rather limited related knowledge and skills, which were rather theoretical, being not applied in practice. Most public research activities are completed by a very limited number of the most active fellows. However, the majority of those who see a sense of urgency in such actions, or who are willing to reshape their interest in public outreach, face many obstacles, limitations, and barriers in doing so, especially at the individual level. Reasons given by our respondents were rather universal, not varying significantly between the countries, e.g., no support from their home institution; no system of gratification included into research assessment; and no interest in, understanding of, and respect for such activities among academic colleagues (Suleski and Ibaraki, 2010). Although many academics state that altering the perceptions around scientific outreach and working within the cultural, national, and institutional contexts around this is highly challenging, there are optimistic indications, especially for the future generation of academia, that contacts with the public and media can positively affect their carrier. It has been argued, for example, that scientists who engage with society perform better academically (Burchell et al., 2015; Jensen et al., 2008), and significantly affect the public discourse (Cooper, 2018).

Fig. 5, we present a scheme that shows the declared encouraging and discouraging factors in the form of a causal map. The areas of government, science, industry, society, and nature are inspired by the previously discussed quintuple helix model and show how the motivational factors affect each other. Specifically, Responsible Research Assessment proposed by Royal Society of London and American Association for Advanced Science in the format of a less numeric and extra scoring system for popularization had a direct impact on scientists' actions to popularize science which subsequently impacted the access to channels and the ability to simplify and apply science (https://royalsociety.org/topics-policy/projects/research-culture/tools-for-support/resume-for-researchers/; https://www.aaas.org/resources/communication-toolkit). However, practicalities are different, especially at the local faculty level. What is commonly used in the EU universities nowadays is bibliometric system considering primarily the number of published articles, the citations received (the h-index), and the impact factor (IF) of the journals that publish these articles eventually measuring the impact of a particular researcher (Abramo et al., 2020; Massin et al., 2007; Campbell and Felderer, 1997).

Combined with the sense of the scientist's mission, self-promotion, and networking, successful science communication can be directed to the broader society, thus impacting the factors of trust, interest, false knowledge, and cooperation with journalists. This, in turn, leads to increased awareness, empowerment, innovative thinking, and informed decision making, not only in society but also in industry (private businesses). As a result, this causal chain can potentially lead to a positive social impact, increased care for nature, and the enhanced well-being of future generations.

5. Conclusion

Investment in education is the basis of a knowledge-based society. Although this mantra is frequently espoused by politicians, business representatives, and academics alike (Adhiatma et al., 2020; Lungu, 2019), the actual investment in education and the inclusion of this topic in social discourse are out of proportion to its propagated importance (Aarrevaara et al., 2021).

In fact, science in Europe is hardly connected to society (Davies et al., 2021) and instead is enclosed in the proverbial ivory tower decreasing an importance and reliability of academics among public (Hopkins et al., 2018; Kislov et al., 2017). Scientific discourses are exclusive in the truest sense of the word, as they generally exclude non-academic participants.

Given the ongoing sustainable transitions among European countries, an active scientific engagement with the rest of society around sustainability issues is all the more important to explain the scientific positions and make them widely accessible.

Last but not least, there is a certain moral and ethical responsibility to strive for the legitimacy of science. The social perception of an academic ivory tower to some extent results from a defensive attitude on the part of scientists that is not appropriate to science and that urgently needs to be overcome. In the fight against populist claims, the communication task of scientists is to make the fundamental function of research and science clearer for society as a whole.

6. Limitations and future research

Our findings cannot be generalized due to rather low response rate for callings to join the focus group. Although social researchers face such a problem often among various groups of respondents, in case of investigated European academics became frustratingly minimal. Potential speakers excused themselves by a high workload, time limitations, and lack of interest.

Results of the following study may serve as a primary trial assessment of academics (dis-)engagement in science popularization whereas, a broader qualitative research approach is needed to explain a deeper motives of factual situation. Moreover, we hope we added extra value to the discussion about a strategy on how to effectively engage academia into science communication practices, which in the era of climate threat is obviously required.

We believe that the quality and effectiveness of science communication, has a systemic character depending mainly on stereotypes of how science should be practiced. In the era of open and citizen science availability, role of research fellows has evolved. We need to identify ourselves with the public, engaging them into decision making processes (Charles et al., 2020; Irwin, 2018) other words serve them also outside the ivory towers. Changing attitudes takes time which in the era of climate threat is crucial. We propose, as the most effective strategy, alter the system of current research assessment. Why not to continue proposals of The Leiden Manifesto on Responsible Research Assessment and consortia which already declared a need to revise it (e.g., DORA The San Francisco Declaration on Research Assessment, European University Association (EUA) Roadmap on Research Assessment in the Transition to Open Science, and many others) for not just numeric but also covering other than citation procedure? Communication with non-scientists raises academics satisfaction and empowerment (Bauer and Jensen, 2011), whereas achieving communication competences raises their skills (Díaz et al., 2020; Suleski and Ibaraki, 2010). To support this process, research about the *status quo* of the evaluation practices is indispensable.

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Data availability

The data that has been used is confidential.

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Appendix

A1. Survey

1. How important is Science Popularization to you?

o not important at all
o low importance
o neutral
o very important
o extremely important

2. Who should be responsible for Science Popularization?

	not at all responsible	somewhat responsible	mostly responsible	completely responsible
Scientists	○	○	○	○
Journalists	○	○	○	○
Politics	○	○	○	○
Industry	○	○	○	○
NGOs	○	○	○	○

3. Have you ever popularized science? (outside of academia)

o Yes
o No

4. Please select the channels where you popularized science. (few possible)

o TV
o Radio
o Press
o Popular science literature
o Social media – Instagram
o Social media – Facebook
o Social media – Twitter
o Social media – LinkedIn
o Blog
o Workshops
o Others:

5. Please select your main target audiences. (few possible)

o journalists
o policy makers
o consumers - adults
o consumers - children and adolescents
o consumers - seniors
o product designers
o producers
o private business (e.g. restaurants, shops)
o waste management representatives
o recyclers
o NGO's
o Others:

6. What encourages you to popularize science?
7. What discourages you from popularizing science?
8. Which skills/competencies are crucial when popularizing science?
9. How did the COVID-19 pandemic impact your activities?

	significantly less than before the pandemic	little less than before the pandemic	no impact	little more than before the pandemic	significantly more than before the pandemic
Scientific paper publication	○	○	○	○	○
Conferences	○	○	○	○	○
Popularization activities	○	○	○	○	○

10. Gender

o Woman
o Man
o Prefer not to say

11. Age

o Less than 25
o 25–34
o 35–44
o 45–54
o 55–64
o More than 64

12. What is your highest academic degree?

o Professor
o Habilitated doctor
o Doctor
o Master
o Bachelor
o Undergraduate student
o Others:

13. What is your affiliation country?

o Poland
o Germany
o Italy
o France
o Others:

14. Which aspects of Single-Use Plastics are you mostly focused on? (few possible)

o Technical
o Social
o Environmental
o Economic
o Impact of COVID-19
o Others:
See Appendix Table A2.

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