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RESEARCH ARTICLE

# Citizen science's transformative impact on science, citizen empowerment and socio-political processes

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**Abstract**
Citizen science (CS) can foster transformative impact for science, citizen empowerment and socio-political processes. To unleash this impact, a clearer understanding of its current status and challenges for its development is needed. Using quantitative indicators developed in a collaborative stakeholder process, our study provides a comprehensive overview of the current status of CS in Germany, Austria and Switzerland. Our online survey with 340 responses focused on CS impact through (1) scientific practices, (2) participant learning and empowerment, and (3) socio-political processes. With regard to scientific impact, we found that data quality control is an established component of CS practice, while publication of CS data and results has not yet been achieved by all project coordinators (55%). Key benefits for citizen scientists were the experience of collective impact ("making a difference together with others") as well as gaining new knowledge. For the citizen scientists' learning outcomes, different forms of social learning, such as systematic feedback or personal mentoring, were essential. While the majority of respondents attributed an important value to CS for decision-making, only few were confident that CS data were indeed utilized as evidence by decision-makers. Based on these results, we recommend (1) that project coordinators and researchers strengthen scientific impact by fostering data management and publications, (2) that project coordinators and citizen scientists enhance participant impact by promoting social learning opportunities and (3) that project initiators and CS networks foster socio-political impact through early engagement with decision-makers and alignment with ongoing policy processes. In this way, CS can evolve its transformative impact.

**Keywords** Participatory research · Research data management · Data quality · Social learning · Political uptake · Recognition

## 1 Introduction

Today, society is facing complex socio-ecological challenges such as the climate crisis, biodiversity loss and global health issues. Finding solutions to these complex problems requires creating sound scientific evidence while enhancing societal ownership and embracing different knowledge domains. Here, citizen science (CS) can act as a transformative change agent by fostering participatory, societally relevant knowledge generation (Bela et al. 2016, p. 997). CS projects can prepare and legitimize decision-making by mobilizing different stakeholders to participate in research design, data collection and interpretation (Dillon et al. 2016, p. 451; Singletary et al. 2022, pp. 235–236). The development of CS has been guided by visions of transformative impact in three central dimensions: (1) scientific impact through large-scale data generation and new scientific understanding (Hecker et al. 2018a, p. 41; Strasser et al. 2018, p. 54);

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(2) participant impact through enhanced action-based learning and collective engagement (Harlin et al. 2018, p. 411; Peltola and Arpin 2018, p. 379); and (3) socio-political impact through jointly created evidence for decision-making processes (Lepenies and Zakari 2021, p. 18; Owen and Parker 2018, p. 284). These CS impact potentials are framed in international policy documents (Socientize 2015, p. 10) and CS strategies for several European countries (Manzoni et al. 2019, p. 7; Bonn et al. 2022, p. 11). CS has been framed explicitly as an important participation and research avenue in the German coalition contract (2021, p. 24) and as "offering enhanced levels of participation in assessing (and determining) the success of EU environment policies" by the European Commission (2013, p. 4).

In this study, we define citizen science (also termed community science, see Cooper et al. 2021) as "participation of individuals in scientific research activities who are not institutionally bound in that field of science. Participation can mean anything from short-term data collection to intensive use of free time and a high level of expertise" (Bonn et al. 2022, p. 11). The most compelling motivations for citizens to participate in CS projects are the desire to contribute to scientific discoveries or to environmental protection, to learn something new, and to have fun while being outdoors or meeting other people (Richter et al. 2021, p. 5; West et al. 2021, p. 8).

While CS has evolved rapidly over the last 2 decades, visions for CS impact have not always been fully realized (Theobald et al. 2015, p. 243; Turbé et al. 2019, p. 10). Arguably, CS is still an emerging research approach and it is therefore time to take stock and to assess the realization of these visions. Comprehensive evidence on the scientific, participant and socio-political impact of CS is required to inform CS practice and to improve CS infrastructures and support mechanisms. Since CS is a very heterogeneous field, when studying its impacts, it is important to consider different objectives (i.e., science-, policy- or transition-driven CS, Dillon et al. 2016, pp. 450–451) and forms of participation (i.e., contributory, collaborative or co-creative projects, Shirk et al. 2012, p. 6).

To review and discuss recent CS achievements and challenges, we build on the visions and recommendations from the Green Paper Citizen Science Strategy 2020 for Germany (Bonn et al. 2016, pp. 21–31), which were developed over a 2-year multi-stakeholder dialogue process. For developing the White Paper Citizen Science Strategy 2030 for Germany (Bonn et al. 2022), we reviewed the current status of CS with about 120 members of the German, Austrian and Swiss CS communities during two online CS dialogue forums. As an outcome of the discussions, the team of authors (consisting of over 40 CS researchers and practitioners from various organizations such as research institutes, NGOs, private associations, museums, governmental agencies and archives) developed a framework of quantitative indicators to evaluate the present status of CS in its (1) scientific, (2) participant and (3) socio-political dimensions (Fig. 1 and Table 1). These three indicator dimensions, which we describe in the following sections, align well with the outcome dimensions of CS developed by Shirk et al. (2012, p. 8) and with the CS evaluation dimensions proposed by Kieslinger et al. (2018, p. 86). Thus, the framework resulting from our collaborative stakeholder process supports the call from previous studies for more standardized evaluation in these central CS dimensions.

### 1.1 Citizen science impacts on science

CS can create new scientific knowledge and understanding by engaging both scientific and civil society actors and integrating diverse knowledge domains (Dickinson et al. 2012, p. 291; Hecker et al. 2018a, p. 42). Science-driven CS projects often encourage the development of spatio-temporally large-scale datasets (Dillon et al. 2016, p. 450) and can make important contributions to the monitoring and implementation of the Sustainable Development Goals (Fraisl et al. 2020, p. 1747; Fritz et al. 2019, p. 925). High-quality data and publications in peer-reviewed journals (and other media such as online data repositories) are key requirements for reaching scientific targets (Bowser et al. 2020, p. 12; Kosmala et al. 2016, p. 551). Data management plans can be used to systematically plan and document the whole research data life cycle, from data collection to archiving. The selection of data quality metrics depends on research goals and context. There are a multitude of mechanisms to ensure CS data quality. These include quality assurance before and during data collection, e.g., by training citizen scientists and by using standardized protocols, as well as data quality control after data collection, e.g., by comparing CS data with expert data or by using automatic data filtering tools (Wiggins et al. 2011, p. 6). Nonetheless, CS is frequently viewed with skepticism with regard to data quality (Burgess et al. 2017, p. 6; Lukyanenko et al. 2016, pp. 447–448; Theobald et al. 2015, p. 242). It remains unclear to what extent different approaches for data quality assurance and control are currently implemented in CS projects and evidence of data management practices in CS projects is scarce (Bowser et al. 2020, p. 2; Hansen et al. 2021, p. 2).

### 1.2 Citizen science impacts on participants

CS can create meaningful opportunities for participants to gain and share new knowledge as well as scientific skills (Kloetzer et al. 2021, p. 294; Peter et al. 2021a, p. 1). The process of learning about the study subject and about how science works is an integral part of CS. According to Phillips et al. (2018, p. 4), 92% of CS projects on SciStarter aim

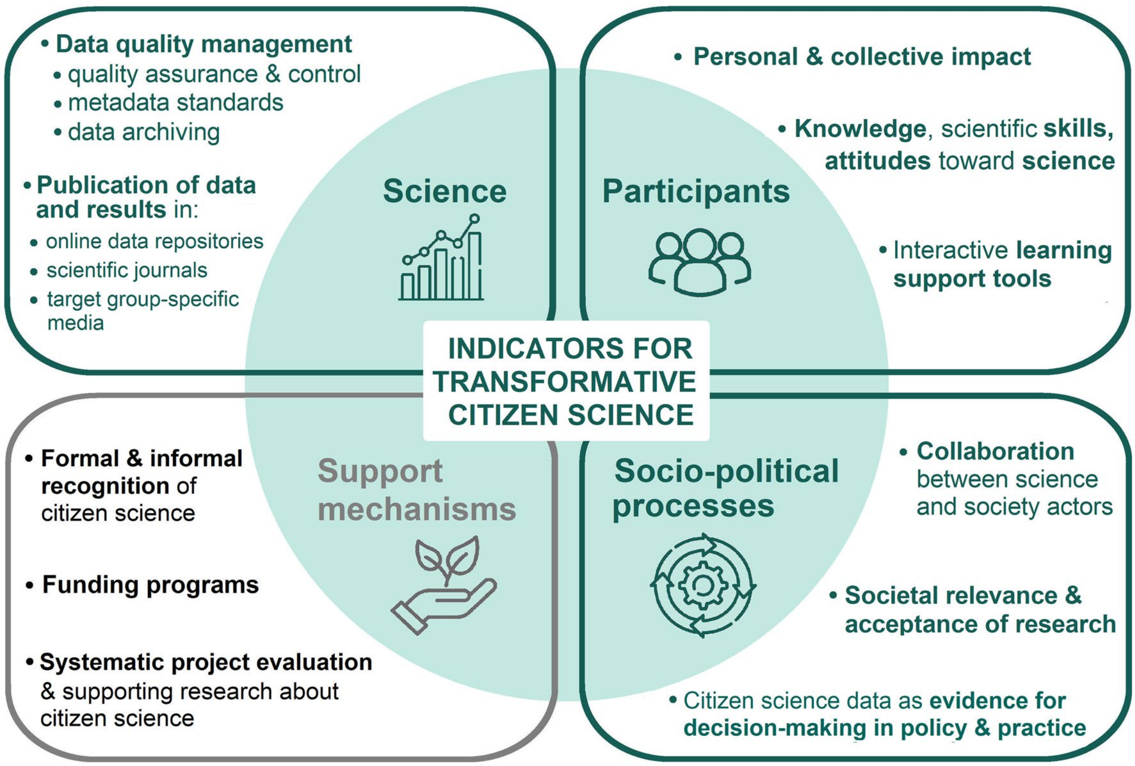


**Fig. 1** Indicators for transformative citizen science in the scientific, participant and socio-political dimensions. The gray box shows important support mechanisms for citizen science

to achieve learning outcomes for their participants. Many CS projects encourage participants to engage in scientific inquiry and propose their own unique research questions (Dillon et al. 2016, p. 452; Jordan et al. 2012, p. 308). CS can thus increase trust and improve attitudes toward science (Bruckermann et al. 2021, pp. 1192–1193). In addition to promoting scientific literacy (Ballard et al. 2017, p. 10; Bonney et al. 2009, p. 977), CS can also foster pro-sustainable and pro-environmental behavioral changes (Haywood 2016, p. 16; Jørgensen and Jørgensen 2021, p. 1345; Lewandowski and Oberhauser 2017, p. 106). Research has shown that policy- or transition-driven CS projects (Dillon et al. 2016, p. 450) that encourage rigorous data collection and offer interactive, place-based forms of learning for participants (Haywood et al. 2016, p. 476), can develop the participants' belief of making a personal and collective impact in the field of their CS project (Jordan et al. 2016, p. 493; Phillips et al. 2018, p. 6). Opportunities for social interaction and community building have been shown to motivate citizen scientists to remain committed to CS projects and to engage in environmental protection (Chase and Levine 2018, p. 8; Agnello et al. 2022, p. 7; Asah and Blahna 2013, p. 872). Nonetheless, evidence on collective action outcomes or empowerment through CS outside the biodiversity research area remains scarce (Groulx et al. 2017, p. 45).

### 1.3 Citizen science impacts on socio-political processes

CS projects can enhance the societal relevance and acceptance of research and political decision-making by mobilizing diverse actors to collaborate in research projects (Conrad and Hilchey 2011, p. 277; Kelly et al. 2019, p. 7). CS projects that generate sound evidence and good quality, often large-scale data, can provide important information for policy development and evidence-based land management strategies (Danielsen et al. 2010, p. 1166; Schade et al. 2021, p. 351; Turbé et al. 2019, p. 6). For example, CS can provide an essential source of information in biodiversity and water quality monitoring (Chandler et al. 2017a, p. 280; von Gönner et al. 2023, p. 10). Politically, the seminal CS study on insect biomass trends in Germany (Hallmann et al. 2017) has triggered the adoption of the new German Insect Protection Law (BMUV 2019). Evidence is lacking, however, on how the CS community evaluates the overall societal and political impact of their projects. Information on networking activities within the CS community and on ongoing cooperation with high schools and universities is equally scarce.

**Table 1** Indicators to evaluate CS impacts in the dimensions of science, participants, socio-political processes and support mechanisms. For detailed survey questions based on the presented indicators, see SI6

| CS dimension | Definition of indicators | References |
|---|---|---|
| Science | Percentage of overall CS community reporting systematic data quality assurance and control; publication of data and results in scientific journals | Wiggins et al. (2011, p. 4) and Theobald et al. (2015, p. 237) |
| | Percentage of CS data managers reporting use of metadata standards; data stored in scientific archives | Wilkinson et al. (2016, p. 5) |
| Participants | Percentage of citizen scientists reporting increased content knowledge; scientific skills; interest in science; motivation for long-term participation in CS; experience of making a personal and collective impact in CS project field, behavioral intentions to actively engage beyond CS project activity; changes in attitudes toward science | Kieslinger et al. (2018, p.86), Phillips et al. (2018, p.7) and Brossard et al. (2005, p. 1100) |
| | Percentage of citizen scientists and CS project coordinators reporting use of learning support tools (such as on-site training or mentoring) | Kieslinger et al. (2018, p.86), Peltola and Arpin (2018, p. 369) |
| Socio-political processes | Percentage of CS project coordinators and school teachers reporting practice of CS in high schools; percentage of researchers reporting practice of CS in universities | Schuttler et al. (2019, p. 1), Wyler and Haklay (2018, p. 168) |
| | Percentage of researchers reporting increase in visibility, societal relevance and acceptance of research through CS | Hecker et al. (2018a, p. 7) |
| | Percentage of researchers reporting CS contributions to the development of management strategies; more effective implementation of research results through CS | Fritz et al. (2019, p. 924) and Turbé et al. (2019, p. 5) |
| | Percentage of overall CS community reporting that CS data are used as evidence for societal and political decision-making | Fritz et al. (2019, p.928) and Turbé et al. (2019, p. 12) |
| Support mechanisms | Percentage of overall CS community reporting recognition of CS engagement in science and society; adequate CS funding programs (including start-up, follow-up and low-threshold formats) | Kieslinger et al. (2018, p.86) and Land-Zandstra et al. (2021, p. 253) |
| | Percentage of CS project coordinators reporting systematic internal or external CS project evaluation | Kieslinger et al. (2018, p. 86) |

### 1.4 Citizen science support mechanisms

We determined three essential support mechanisms for CS (gray box, Fig. 1). First, formal recognition for CS engagement in the science community and acknowledgement within the CS community are essential to motivate continued participation in CS projects (Capdevila et al. 2020, p. 5; Wehn and Almomani 2019, p. 345). Second, adequate CS funding is needed for CS projects to establish contact and earn trust of relevant stakeholders in project scoping phases, conduct research activities and evaluate data (quality) in establishment phases. Third, systematic CS project evaluation is needed to determine if project specific CS goals are reached (Schaefer et al. 2021, p. 496). At the same time, supporting, cross-project research on CS is important to produce generalizable findings on CS project implementation and impacts (Altmann et al. 2022, p. 126).

Based on these indicators (Fig. 1), we explore how the German-speaking CS community in three countries assesses the current status of CS with regard to (1) scientific practices and outcomes, (2) participant outcomes and learning support tools and (3) socio-political processes. In addition, we analyze the extent to which the identified CS support mechanisms are currently established and how CS stakeholder groups differ in their assessment of CS.

## 2 Methods

### 2.1 Study design, target groups and data collection

The study was based on a cross-sectional online survey among the CS community in Germany, Austria and Switzerland. The three dimensions of CS, the support mechanisms and their respective indicators identified during collaborative writing sessions at our online CS dialogue forum (see Fig. 1,

Table 1) served as a framework to develop the online survey questions. We define indicators as quantitative measures based on verifiable data, which reduce complexity and can be used to communicate condensed information, to monitor changes in status quo and to inform decisions (Haase et al. 2014, p. 419).

The survey was anonymous and consisted of two sections (see Supplementary Information SI6). The first section contained group-specific questions for each of the following CS stakeholder groups: CS project coordinators, citizen scientists, researchers interested or actively involved in CS, members of NGOs and the extracurricular education sector, school teachers and members of CS funding organizations. To reflect the reality of multiple actors and roles in the field of CS, respondents could select up to three stakeholder groups.

The second survey section targeted all respondents and contained questions on generic aspects of CS and sociodemographic items. The survey featured a collection of closed-ended questions (i.e., single-, multiple-choice and Likert-type) to generate quantifiable data as well as open-ended questions to supplement the results with qualitative data (see SI6, SI7). We revised certain questions after receiving feedback on the pretest version of the survey by a panel of 73 CS practitioners from Germany, Austria and Switzerland and two experts of the Leibniz Institute for the Social Sciences (GESIS). The survey was implemented using SoSciSurvey software (version 3.2.44, SoSci Survey GmbH, Munich, Germany). Members of the German, Austrian and Swiss CS networks and large NGOs were invited to participate in the online survey through an open call. A snowball sampling technique was used to distribute the survey within the wider CS community via direct emails, social media channels, newsletters and webpages of numerous research institutes and universities, NGOs and foundations, and the three national CS platforms. The survey was open for 5 weeks (28.09.2020 to 30.10.2020).

### 2.2 Sample description

We collected 421 survey responses and took into account all responses that completed the first survey section containing the stakeholder group-specific questions (i.e., 50% of all questions, $n = 340$). The distribution of valid responses was fairly even among important CS stakeholder groups ($n = 113$ citizen scientists, 92 members of NGOs and the extracurricular education sector—hereafter referred to as “NGO members”—, 79 CS project coordinators and 75 researchers active or interested in CS, for demographic details see Table SI1.1). In addition, we received valid responses from 19 representatives of CS funding organizations, 18 high school teachers and 58 other individuals interested in CS. The majority of the respondents were affiliated with CS projects in biology, environmental sciences, or agricultural sciences and geography (Tables SI1.2–3). Our survey showed that CS is also frequently practiced in other disciplines (e.g., medicine, history, social sciences and astronomy). Respondents were mostly based in Germany (84%, see Fig. SI1.1), with a smaller number based in Austria (7%) and Switzerland (8%). We used the same recruitment approach in all three countries, and we assume that participation rate was much higher in Germany than in Austria and Switzerland because the German CS community in particular wanted to support the authors’ goal to collect evidence for the White Paper Citizen Science Strategy 2030 for Germany.

Most respondents had an academic background, with more than 80% holding a master’s or doctoral degree. Several other studies have also shown that the majority of participants in CS projects have an academic background (Chase and Levine 2018; West et al. 2021; Cooper et al. 2021) as CS projects often do not yet seem to effectively reach and mobilize people from non-academic backgrounds. In this respect, our respondent sample reflects the general composition of the CS community.

Most of the responding citizen scientists (67%) were active in contributory CS projects (i.e., projects that involve participants in data collection), while 33% were engaged in collaborative, co-creative or collegial projects [i.e., projects that enable citizen participation in several or all phases of the research process, see Shirk et al. (2012); Fig. SI3.1]. Respondents indicated a variety of motivations for engaging in CS (Fig. SI4.1). The respondents’ length of engagement in CS varied considerably from 0 to 63 years and, interestingly, only 41% were active in CS networks (Fig. SI4.3). This shows that we reached a diverse spectrum of CS actors, many of whom were not connected to CS networks, as CS is often local and independent. Respondents took an average of 18 min to complete the survey, and response rates to different survey questions varied (also due to filter questions). Consequently, the analysis is based on the actual response rates ($n$) specified for each question.

### 2.3 Data analysis

Data analyses proceeded sequentially. First, we conducted an exhaustive descriptive analysis and summarized the results for all (group-specific and generic) single-choice, multiple-choice and Likert-type questions. Second, we examined potential differences between the four main stakeholder groups’ responses (citizen scientists, project coordinators, researchers and NGO members) to the generic questions. We used Chi-square tests to compare the four groups’ response frequencies in single and multiple-choice questions, with subsequent Chi-square post hoc tests with Bonferroni correction to check significant results. For the multiple-choice questions, Chi-square tests were computed separately for every item. We used Wilcoxon rank-sum tests to check for differences in the four main stakeholder groups' ratings of the ordinally scaled Likert-type data. The responses of respondents who had assigned themselves to two or three stakeholder groups ($n=66$ and $n=24$, respectively) were taken into account in each of the respective groups. To check whether double or triple group affiliations had a significant effect on the results, we repeated the analysis of the generic questions with adjusted group samples. For this analysis, we defined unique group affiliations for each respondent by prioritizing group affiliations in the following order: coordinator, researcher, NGO member and citizen scientist. Since this analysis did not reveal any relevant differences compared to the original results, this study reports the findings based on the original dataset.

Third, using ordinal logistic regression models, we investigated associations between the citizen scientists' received forms of learning support as well as reported CS project types and their self-reported learning outcomes. We used the same approach to examine potential effects of the citizen scientists' gender, age, educational attainment and length of CS engagement on their self-reported learning outcomes. Ordinal regression models for each learning outcome were fitted using a stepwise approach: Initially, we fitted models containing one potential predictor each. All predictors with $p \leq 0.1$ were then carried forward to multiple regression models, which were reduced through backwards selection until the best fitting model was reached. We checked the independence of predictor variables for the ordinal regression models using Chi-square tests.

We checked the influence of missing data for example by comparing dropout numbers (i.e., number of respondents who didn't complete the survey) between the four main CS stakeholder groups (see SI1, p. 2). Data analyses and visualizations were conducted using R (Version 4.0.3).

To analyze the qualitative survey results, we mapped responses to the open-ended questions to general topics and subtopics in Table SI7.1.

## 3 Results

### 3.1 Citizen science impact on science: data quality control and scientific publications

With regard to scientific rigor and impact, almost all project coordinators (94%, $n=77$) and the majority of overall respondents (77%, $n=309$) reported that their CS projects applied systematic measures for data quality assurance and control. These measures covered a wide spectrum and were applied slightly more frequently during and after data collection than prior to data collection (Table 2, $\chi^2=7.17$, $df=2$, $p<0.05$). Most respondents stated that their projects

**Table 2** Measures of data quality assurance and control in the surveyed CS projects

| Preparatory measures | Accompanying measures | Retrospective measures |
|---|---|---|
| Project specific data quality guidelines (21%) | Standardized monitoring, e.g., through protocols (24%) | Expert appraisal of CS data or samples (24%) |
| Training participants (21%) | Collection of evidence, e.g., photos or samples for re-examination (24%) | Manual data filtering (18%) |
| Testing participants' knowledge or skills (6%) | Accompanying and supporting participants during data collection (23%) | Systematic data storage and archiving (16%) |
| | Collection of metadata (14%) | Comparison of CS and expert reference data (15%) |
| | Manual data filtering (11%) | Metadata examination (10%) |
| | Standardization via calibrated measuring devices (10%) | Comparison of CS data with known (measured) current status (9%) |
| | Repeated sampling or measuring (10%) | Automatic data filtering (7%) |
| | Automatic plausibility- or completeness control with data entry tool (8%) | Normalization of CS data with statistical methods (4%) |
| | Self-assessment of data quality by participants (7%) | Triangulation of CS data, i.e., complementing with other sources such as remote sensing data (3%) |
| | Automatic data filtering (4%) | Automatic text, image or sound recognition (3%) |
| | Automatic text, image or sound recognition (3%) | Ranking of the participants' performance (3%) |

Percentages of respondents ($n=309$) for the respective answers are shown in brackets. Items are based on Wiggins et al. (2011, p. 6). For details on differences between the four main stakeholder groups' answers, see Table SI2.1A-B ensured data quality with manual techniques, e.g., through expert appraisal of CS data or samples (Table 2). A minority of respondents (8% or less) indicated that their CS project used automatic tools to ensure data quality (Table 2; Table SI7.1). Around a third of the researchers, NGO members and project participants did not know which data quality assurance and control measures were used in their CS project (Table SI2.1A). While about half of the CS coordinators indicated that they used data management plans, only 28% of the researchers reported this about the CS projects they were involved in ($\chi^2 = 38.17$, $df = 6$, $p < 0.001$, Fig. SI2.2). A few of the CS data managers employed metadata standards (19%, $n = 98$).

Less than half of all respondents (39%, $n = 309$) declared that the data and results produced in their CS projects had already been published, while 26% said that publication was planned (see Fig. SI2.1 for group specific percentages). According to the respondents, CS data and results were published more frequently on project websites than in scientific journals (Fig. 2, $\chi^2 = 7.97$, $df = 1$, $p < 0.01$). The majority of CS data managers reported archiving their data on university servers, scientific repositories or archives, libraries or collections. Meanwhile, a third reported that data were stored on servers restricted to internal or private use, and another 15% reported that the data were not systematically archived (Fig. SI2.4). Among the respondents who wished for more advice on CS project implementation, more support with and resources for data quality control and management was one of the most frequently expressed requests (Fig. SI2.5; Fig. SI5.5).

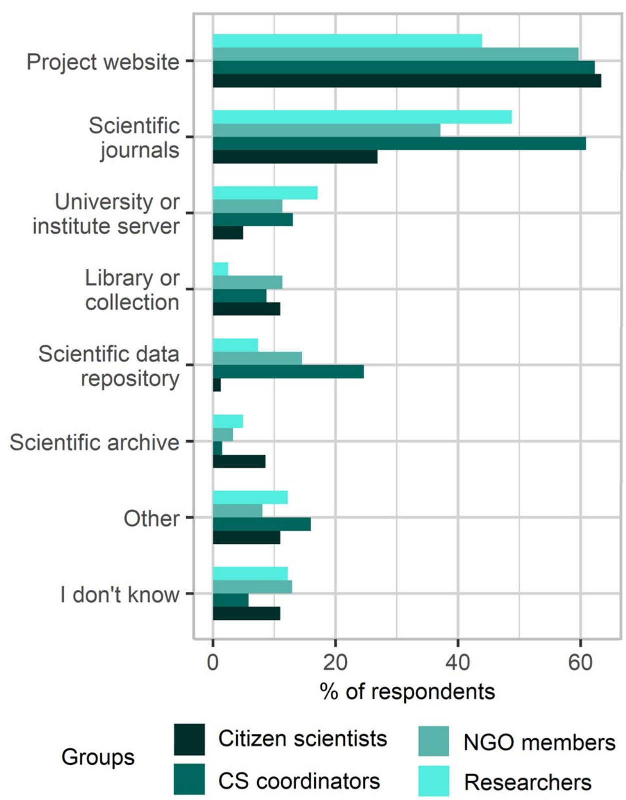


**Fig. 2** Publication media of CS project data and results. Multiple-choice question ($n = 77$ coordinators, 67 researchers, 81 NGO members, 105 citizen scientists)

## 3.2 Citizen science impact on participant learning and empowerment

When asked what impact their CS engagement had on their personal development, most citizen scientists answered that they felt enabled to "make a difference together with others" and to "personally achieve something" in the field of their CS project (Fig. 3). Feeling able to make a collective impact was reported significantly more often by citizen scientists who received systematic feedback on their CS activities (coeff = 0.83, SE = 0.36, $t = 2.28$, $p < 0.05$) or who benefited from personal mentoring by fellow citizen scientists (coeff = 0.97, SE = 0.43, $t = 2.27$, $p < 0.05$, Fig. 4). We also observed that citizen scientists active in collaborative, co-creative or collegial projects were more often convinced of making a personal and collective impact than those engaged in contributory projects (see Table SI 3.2.5–6 for results of multiple ordinal regression models).

In addition, a majority of citizen scientists reported that their CS activities helped them to acquire project specific content knowledge and two thirds indicated having gained new scientific skills (Fig. 3). Again, citizen scientists who had received systematic feedback on their CS activities rated their content knowledge gain (coeff = 0.90, SE = 0.38, $t = 2.37$, $p < 0.05$) and acquisition of scientific skills (coeff = 0.95, SE = 0.35, $t = 2.68$, $p < 0.01$) more positively than citizen scientists who had not received feedback (Fig. 4). Similarly, citizen scientists who benefited from personal mentoring (coeff = 1.14, SE = 0.41, $t = 2.77$, $p < 0.01$, Fig. 4, Table SI7.1), or had opportunities to take responsibility for challenging tasks in their CS projects (coeff = 1.30, SE = 0.44, $t = 2.94$, $p < 0.01$), reported significantly higher competence acquisition than citizen scientists who did not receive these learning support forms.

Opportunities for citizen scientists to take responsibility for challenging tasks and to engage in personal mentoring programs were significantly positively related to reported increases in science interest and in long-term project motivation as well as changes in attitudes toward science among citizen scientists (Tables SI3.2.3–4; 2.7). The citizen scientists' age, gender, educational attainment and length of CS engagement were generally not associated with their self-reported learning outcomes (for exceptions, see Table SI3.2.1–8).

With regard to learning support tools offered in CS projects, a majority of project coordinators reported offering

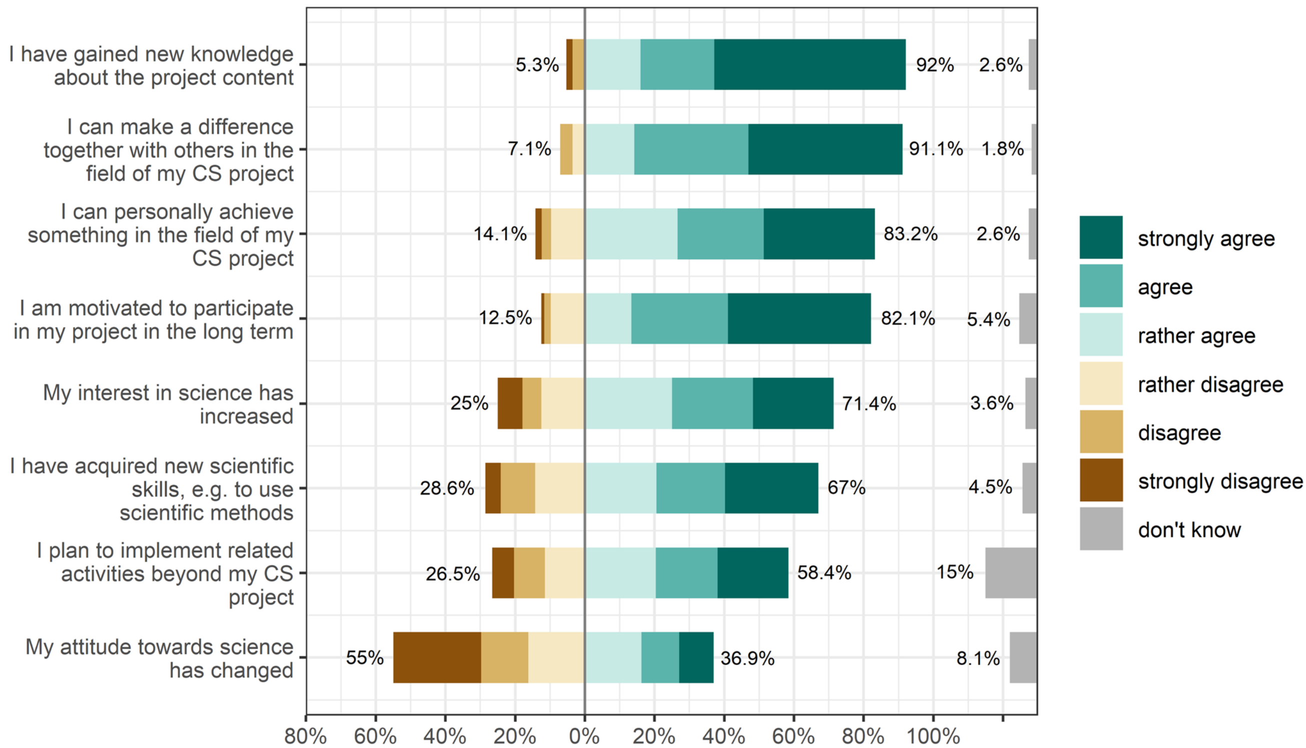


**Fig. 3** Self-reported impacts of CS activities on citizen scientists' learning and personal development. Percentages of agreement are indicated with green bars on the right side; percentages of disagreement are shown on the left side with bars colored in brown ($n = 113$ citizen scientists)

written information material, e.g., booklets or websites, and two thirds offered on-site training (Table SI3.1). In contrast, only half of the citizen scientists reported that they benefited from written information material. In fact, fitting ordinal logistic regression models, we found no significant relationship between the two most frequently used forms of learning support, written information material and on-site training, and the citizen scientists' self-reported learning outcomes (Table SI3.2.1–8, Fig. SI3.5C-D). Citizen scientists indicated that training could be improved by addressing the analysis of CS data and use of the results as well as the principles of scientific work in more detail (Fig. SI3.6).

## 3.3 Citizen science impact on socio-political processes

Survey respondents rated personal exchange with colleagues (from other organizations and their own organizations) as the most important tool for building their expertise in CS. Only about a quarter of all respondents chose conferences or scientific articles about CS as important means to develop their CS expertise (Fig. 5). Most respondents indicated that CS advisory services should be organized as a decentralized network or as contact points in local organizations (Fig. SI4.5).

With regard to the integration of CS in universities, less than 10% of the responding researchers stated that CS was currently offered in university courses, and only one third of the researchers stated that their colleagues were open to adopting CS as a research approach (Fig. SI4.6–7, Table SI7.1). Regarding collaboration with educational institutions, 35% of the CS coordinators reported working with high schools.

As reasons for engaging in CS, 75% of the researchers stated increased visibility and societal acceptance of their research, and two thirds agreed that CS actually improved the societal relevance of their research. About half of the researchers indicated that CS led to more effective implementation of research results, and a third stated that CS currently contributed to filling data gaps to tackle urgent environmental or societal problems (Fig. SI4.8).

A majority of respondents (88%, $n = 281$) valued CS as an important tool for political and societal decision-making processes, with no significant differences among the four main stakeholder groups ($\chi^2 = 10.19$, $df = 9$, $p = 0.34$, Fig. SI4.4). In contrast, less than 20% of all respondents agreed that policy-makers actually used CS data as evidence for decision-making processes (Fig. SI5.1, Table SI7.1). Here, CS coordinators were more optimistic than researchers, citizen scientists and NGO members ($p < 0.01$, $r = 0.22$; Table SI5.1).

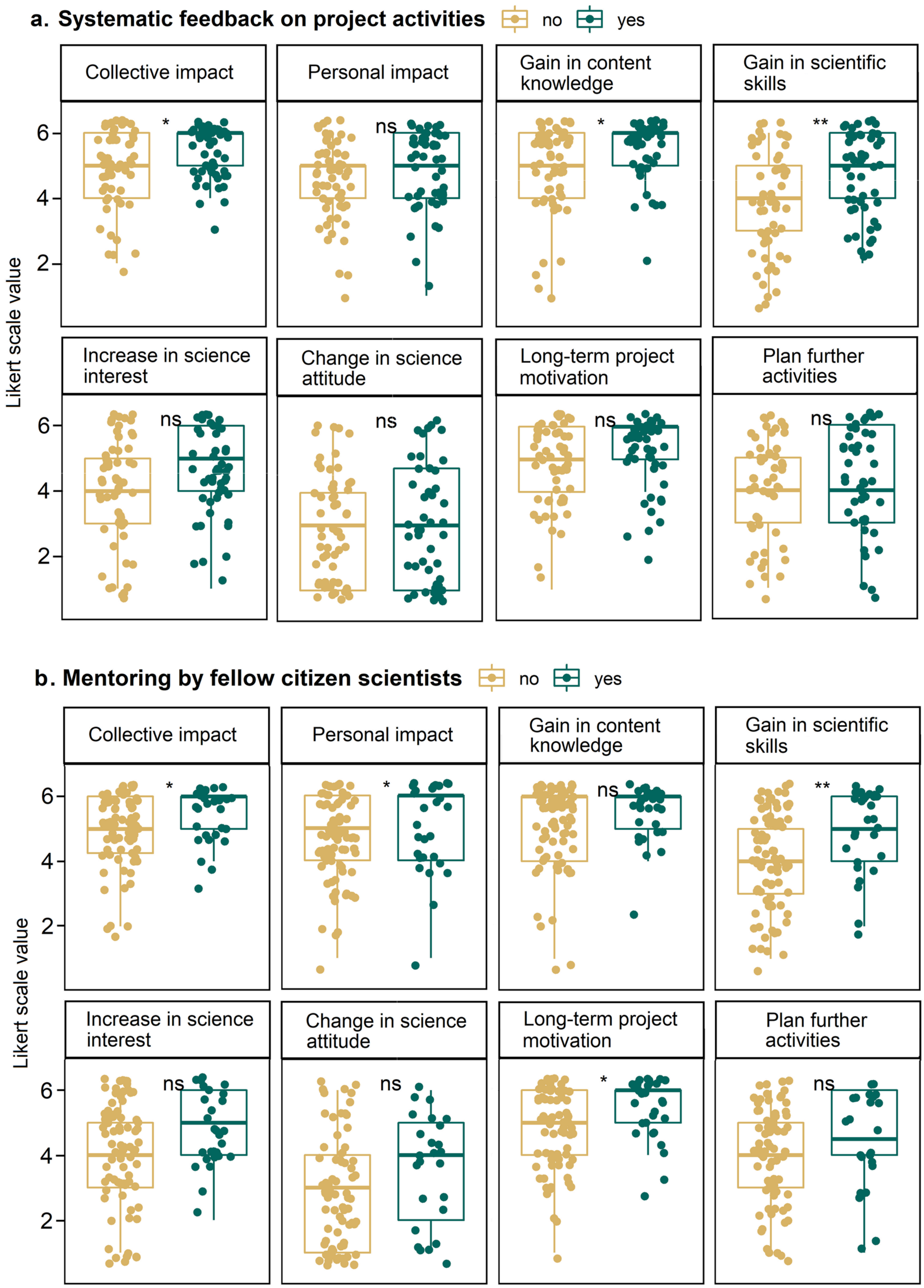


**Fig. 4** Self-assessment of learning outcomes among citizen scientists in relation to different forms of learning support. Citizen scientists ($n=113$) were asked to rate their learning outcomes on a 6-point Likert scale (6 = strongly agree, 1 = strongly disagree). Differences in self-reported learning outcomes between citizen scientists who received feedback (**a** $n=51$, green boxplots) or mentoring (**b** $n=29$) and those who did not receive these support forms ($n=60$ and $n=82$, yellow boxplots) were examined using ordinal logistic regression models. Significance levels are indicated with asterisks (ns = not significant; $*p<0.05$; $**p<0.01$). See Fig. SI 3.5.A-G for details on other forms of learning support

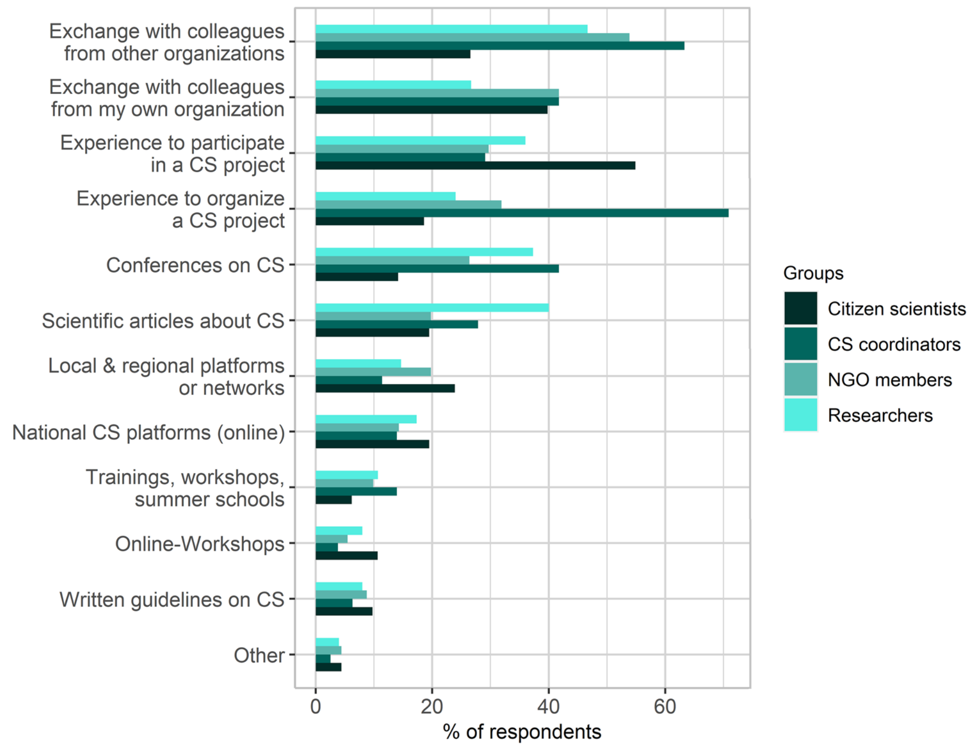


**Fig. 5** Self-reported effectiveness of support instruments for gaining expertise in citizen science. Multiple-choice question with a maximum of 5 answers ($n = 79$ coordinators, 75 researchers, 91 NGO members and 113 citizen scientists)

## 3.4 Implementation of support mechanisms for citizen science: recognition, funding and evaluation

While half of all respondents rated recognition of CS in strategic papers and project calls positively, the majority of respondents reported a low level of external recognition for CS engagement (for group-specific answers, see Fig. SI5.1, Table SI5.1). Only a minority stated that the CS engagement of researchers was adequately recognized and that CS contributions were indicated appropriately in scientific and non-scientific publications. For a ranking of important recognition tools for citizen scientists from the respondents' perspective, see Fig. SI5.2.

A quarter of all CS project coordinators did not receive any external funding and reported working on a voluntary basis. Few respondents thought that there were enough CS funding programs, including funding for CS scoping studies, follow-up and low-threshold funding (i.e., programs with simple application procedures that are accessible to citizen initiatives and associations with little staff capacity) (Fig. SI5.3).

Regarding project evaluation, about 40% of the CS project coordinators stated that their project was evaluated by internal (14%) or external (5%) evaluators or a combination of both (23%). A third of the CS project coordinators declared that their project was evaluated informally and another third reported not being evaluated at all. Stratified by the availability of external funding, project coordinators with external funding conducted systematic evaluations more often (49%; $n = 51$) than project coordinators without external funding (10%; $n = 19$, $\chi^2 = 7.11$, $df = 1$, $p < 0.01$).

# 4 Discussion and recommendations for action

By analyzing 340 survey responses from a broad range of CS stakeholder groups and research disciplines, our study provides detailed insights into the current status of CS in central Europe with a focus on Germany, Austria and Switzerland. Our findings provide evidence for all three outcome dimensions of the framework for public participation in scientific research (Shirk et al. 2012) that guided previous CS research in an international context. Therefore, we expect our results to be inspiring and useful for practitioners and researchers around the world working in similar contexts, as other CS communities are likely to face similar challenges.

Key findings of our study for science outcomes are that data quality assurance and control is well established in CS projects, while only about half of the responding CS project coordinators had already published CS data and results. For the citizen scientists' learning outcomes, opportunities for social learning, e.g., systematic feedback or personal mentoring, were essential. The CS potential to influence policy processes was considered very high, while only a minority of respondents thought that CS data and results were actually used by decision-makers. Overall, our findings underscore the importance of close collaboration among citizen scientists, researchers and other stakeholders for community building and promoting individual empowerment or collective action.

Drawing upon these key findings, we derive recommendations for action (Fig. 6) to strategically foster collaborations among different CS stakeholders and take CS to the next level of transformative impact in its scientific, participant and socio-political dimensions.

### 4.1 Science impact: established practices and professionalization needs in citizen science data management and publication

Regarding CS contributions to science, awareness for data quality assurance and control was very high in the surveyed CS community, and CS projects reported a broad range of project-specific data quality control measures. This shows that data quality control is a firmly established practice in CS that is considered essential by practitioners to generate valid CS data sources in different research disciplines (Bowser

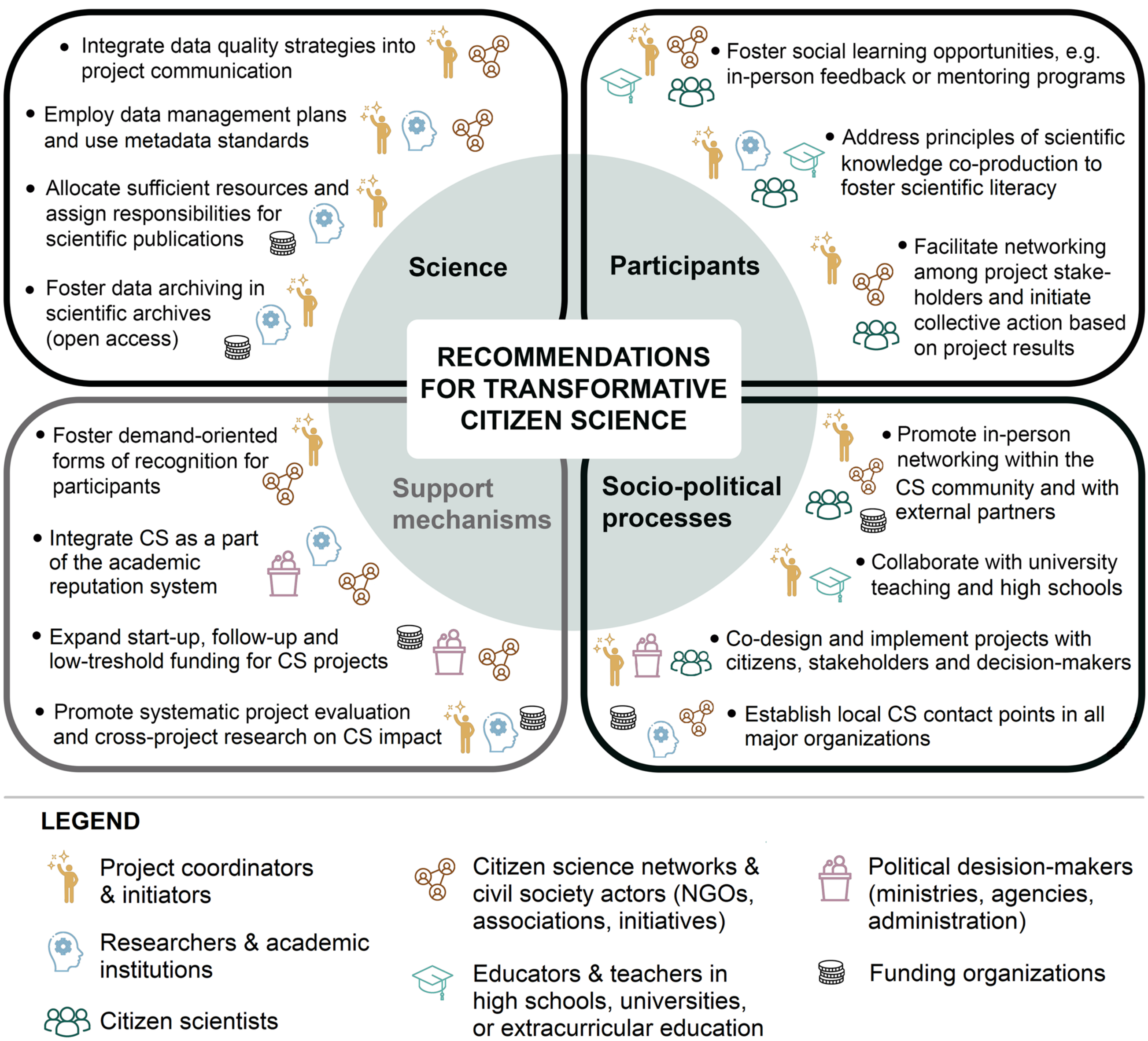


**Fig. 6** Recommendations for action to strengthen the transformative impact of CS with corresponding target groups marked in the form of icons. The black boxes show recommendations for action in the scientific, participant and socio-political dimensions of CS. The gray box shows recommendations to strengthen support mechanisms for CS. Each of the recommendations for action is based on survey results for the corresponding CS indicators described in Table 1. The importance of each target group for implementing the recommendations is shown by the icon order (from left to right and from top to bottom)

et al. 2020, p. 1; Kosmala et al. 2016, p. 551). Nonetheless, there is potential for further improvements to data management, as currently, automatic data quality control tools are only used to a limited extent and knowledge is lacking about project specific data quality management strategies among researchers, NGO members and project participants. Complementing manual techniques with automatic data quality control tools, e.g., through AI-based visual or acoustic signal pattern recognition (Mäder et al. 2021, p. 1335) or statistical methods for data filtering and normalization (Lotfian et al. 2021, p. 7), can further improve data quality assurance and control, saving staff resources in the long term, especially in large-scale monitoring projects. As one respondent described it, *"data acquisition and generation is almost completely automated in our project through a digital data entry form and so it's hardly possible to enter nonsense data. In addition, sampling is done repeatedly so that independent comparison data sets exist."*

To enhance transparency and trust in CS data quality (Burgess et al. 2017, p. 6) and to raise awareness for potential errors during data collection among participants, project coordinators need to clearly communicate data quality strategies to participants and project stakeholders (Fig. 6). Open discussion about CS data quality strategies is a valuable tool for CS projects to promote scientific literacy and to exchange ideas with project participants about data quality control.

Important data management practices, such as using data management plans and meta-data standards or systematically archiving CS data, are not yet established in the majority of CS projects (see also Bowser et al. 2020, pp. 11–12), but arguably also not yet in all other academic science projects. Therefore, systematic data management needs to be explicitly included and prioritized in CS project plans, so that project staff can allocate resources to implement this important task in day-to-day project work. Developing a data management plan at the very start of the project facilitates structured CS data collection and helps define quality control approaches to produce FAIR (Findable, Accessible, Interoperable, Reusable) CS data (see Wilkinson et al. 2016, p. 4) corresponding to the processing objective, e.g., fit for specific databases, GIS or modeling. The fact that metadata standards are only employed in a small proportion of CS projects limits data reusability and complicates data identification for potential data users. To document the exact context and purpose of data collection as well as measures for data quality control, CS projects could either apply metadata standards designed specifically for CS (Public Participation in Scientific Research Common Conceptual Model, see https://core.citizenscience.org) or use suitable domain-specific metadata standards from established research disciplines (Lemmens et al. 2021, p. 165, Fig. 6).

Publication rates of CS data and results currently fall short of the scientific goals for CS. Similar to Turrini et al. (2018, p. 179), we found that only about half of the surveyed project coordinators had already published their CS data and results (other studies found even lower publication rates, e.g., Kullenberg and Kasperowski 2016, p. 12; Theobald et al. 2015, p. 236). Sharing new scientific knowledge by publishing data and results is a core element of any research and also applies to CS. Publications are an important outcome for CS projects to gain recognition and credibility in the science system (Burgess et al. 2017, p. 6; Robinson et al. 2018, p. 34). If CS data and results are not published in scientific journals, they are not subjected to scientific peer review and the efforts of project participants and stakeholders may never be formally acknowledged by the scientific community. Therefore, project initiators, coordinators and researchers should allocate sufficient resources for project design to obtain publishable results and then assign responsibilities for scientific publishing (Fig. 6). In addition, publishing data and results on project websites, in target group specific media or as preprints, is important to provide feedback on project results to participants and the public. To advance citizen participation in data analyses and archiving, citizens could be granted access to data from different CS projects and analysis tools (e.g., through open data portals including reuse metrics for indicating how often certain data have been used).

Sharing data via scientific archives and data repositories (such as the Global Biodiversity Information Facility-GBIF or the Fireball data repository of the International Meteor Organization) is not yet common practice in the CS community. Since CS is driven by the commitment of engaged citizens and systematic CS data archiving is crucial to make CS data accessible in the long term, collected CS data and results should be made easily available to the public (see Fig. SI2.6, Robinson et al. 2018, p. 29). As our survey showed, appropriate digital infrastructures, resources and support for CS data management, publishing and archiving are not always available or accessible for CS projects. Therefore, (inter)national research data management platforms such as the National Research Data Infrastructure in Germany (NFDI.de) should provide user-friendly interfaces and user training to facilitate the archiving of CS data. In addition, establishing a support network of data science experts and disseminating existing guidelines or tutorials on CS data management (see for example CSA Metadata Working Group 2021, Wiggins et al. 2013) are further important steps to promote FAIR CS data production and increase CS publication rates.

### 4.2 Participant impact: role of social interaction for participant outcomes in citizen science

Imparting content knowledge and scientific skills is an essential success factor for many CS projects (Bela et al.

2016, p. 996; Peter et al. 2021a, p. 7). Here, we found that CS already has a positive impact, as two thirds of the citizen scientists reported having increased their scientific skills through participating in CS project activities. Still, CS projects often lack the capacity (or target objective) to explicitly engage participants in the principles of scientific research and rather focus instead on specific data collection skills development, such as species identification (Haywood et al. 2016, p. 477; Stylinski et al. 2020, p. 1). For CS projects aiming to specifically strengthen participants' scientific skills and literacy (especially in times of scientific skepticism and conspiracy theories), it is important to explicitly address scientific principles during CS trainings and research activities (see Bonney et al. 2016, p. 5; Peter et al. 2021b, p. 25, see Fig. 6).

Social interaction among fellow citizen scientists and engagement with the CS project researchers and staff were key determinants for participants' perceived gains in content knowledge and scientific skills (see also Peter et al. 2021b, pp. 19–21). For citizen scientists to become more confident in their abilities, systematic feedback on project activities as well as mentoring programs is particularly helpful (Peltola and Arpin 2018, p. 376; Sforzi et al. 2018, p. 432). For example, van der Wal et al. (2016, p. 10) showed that beginners can quickly gain taxonomic and ecological skills if they receive detailed feedback on their species identifications. This was also evident in the responses to open-ended questions: *"What helped me a lot in feeling competent as a citizen scientist was the practical field work together with experienced butterfly experts, and the exchange with fellow citizen scientists."*

In-person feedback from experts can also serve as a form of recognition and appreciation for engaging in CS and can motivate participants to commit more effort to acquire necessary skills (Peter et al. 2021b, p. 21). Our findings also indicate that CS projects that enable active participation (e.g., by inviting participants to take responsibility and bring in their own expertise) increase their development of scientific skills. In contrast, the most commonly employed support tools, written information material and on-site training, were rated as much less effective. As our results indicate, CS project coordinators could enhance the participants' learning outcomes by organizing training in more interactive ways (Peter et al. 2021b, p. 19) and by addressing the scientific aspects of CS data analysis and use together with the citizen scientists.

The belief of being able to make a difference through one's own or group-based actions ("self-efficacy" and "collective efficacy") was one of the most important impacts on the participants' personal development and has been shown to be an important precursor of actual individual and collective environmental action (Fritsche et al. 2018, p. 28; Philips et al. 2018, p. 8). Importantly, this indicates that CS could serve as an important tool to generate insights for transformative change. Our results suggest that collaborative, co-creative and collegial CS projects, which initiate social interaction and close collaboration between participants, researchers and other stakeholders, are particularly suitable for developing participants' beliefs that they make individual or collective impacts in the field of their CS project.

One of the most frequent aims of environmental CS projects is to initiate pro-environmental behavior or community actions that contribute to environmental conservation or to sustainable transformation (e.g., Bela et al. 2016; Grossberndt et al. 2021; Haywood et al. 2016; Jordan et al. 2011). In our study, nearly 60% of the citizen scientists (many of whom participated in environment-related CS projects) declared planning to take action in the field of their CS project. Previous research suggests that CS-related behavioral changes mainly concern communication activities (i.e., talking about the project with family, friends or even local politicians, Jordan et al. 2011, p. 1152; Lewandowski and Oberhauser 2017, p. 109; Peter et al. 2021a, p. 13). Participants often do not seem to perceive any direct link between their CS activities and the potential for more general civic engagement or lifestyle changes (Peter et al. 2021a, p. 13). Action-based CS research (e.g., Haywood et al. 2016; Chase and Levine 2018; Groulx et al. 2019; Jordan et al. 2019) has shown that initiating community building, e.g., by offering regular networking events for project participants and stakeholders, can be an effective tool to foster pro-sustainable and pro-environmental behavioral changes (Fig. 6). Such events can incentivize CS participants and other stakeholders to develop and discuss concrete approaches for individual and collective action based on lessons learned through the project (e.g., sowing insect-friendly plants in gardens and parks, collecting plastic rubbish or restoring riverbanks). Therefore, CS coordinators may actively seek opportunities to enable collective action based on CS project processes and results to realize expectations for community-based CS impacts.

In our survey, many CS projects successfully evoked the citizen scientists' interest in science and long-term project motivation, which are key to success in many CS projects. An increase in participants' interest in science through CS activities has so far been observed mainly in relation to specific CS research topics, e.g., certain species or environmental issues, rather than in relation to science in general (Peter et al. 2021a, p. 12; Toomey and Domroese 2013, p. 59). Motivation of participants depends on several factors, particularly on individual values, social networking opportunities, successful project coordination and participant recognition (Richter et al. 2018a, p. 741; Richter et al. 2021, p. 10; West et al. 2021, p. 13).

An important goal of participatory research is to improve attitudes toward science, defined here as science-related beliefs and evaluative dispositions of science (Bruckermann et al. 2021, p. 1181). Yet, research to date has shown that CS projects often seem to be able to improve the participants' attitudes toward the specific project content, but not necessarily their attitudes toward science in general (Chase and Levine 2018, pp. 4–5; Bruckermann et al. 2021, pp. 1192–1193). Similar to other studies (Crall et al. 2013, p. 1; Druschke and Seltzer 2012, p. 182; Jordan et al. 2011, p. 1151), changes in attitudes toward science were only reported by a minority of citizen scientists in our study. This could partly be because some citizen scientists already had positive attitudes toward science before joining their CS project (Table SI7.1, p. 2). Future studies might therefore aim to assess attitudes based on survey data collected both before and after citizen scientists engage in CS projects.

Overall, our survey findings illustrate that opportunities for social learning and active participation in research play an essential role in promoting participants' learning outcomes. This finding points to a discrepancy between the supply and actual effectiveness of the most frequently offered learning support tools, i.e., written information material and on-site training. We highlight the value of actively including social, interactive learning opportunities, such as personal feedback on project activities or structured mentoring programs, into CS projects (see also Bell et al. 2008, pp. 3449–3451; Peter et al. 2021b, p. 19; Singh et al. 2014, p. 5; Unell and Castle 2012, p. 1). Likewise, social learning opportunities can be created by initiating data collection in teams, by asking participants to check each other's data, or by providing face-to-face meetings between participants and researchers. These learning formats can be an avenue for project coordinators to strengthen participants' science knowledge and competence gains, their feeling of being "part of a larger endeavor" (Peter et al. 2021b, p. 20) and their motivation to engage in conservation actions (Haywood et al. 2016, p. 485).

### 4.3 Socio-political impact: vision-reality gap for citizen science

Our results highlight the importance of in-person networking and exchange within and beyond the CS community to develop CS competencies (Richter et al. 2018b, p. 275, 278). Surprisingly, other formats of exchange were rated less important for capacity building. Consequently, project initiators, coordinators and CS networks should actively schedule opportunities for personal exchange into everyday CS project life (Fig. 6).

Although universities and high schools are important CS partner institutions for fostering societal transformation, our survey shows that CS is not yet sufficiently established in either of these institutions. Their huge potential for mainstreaming and anchoring CS among young learners could be realized by providing best practice examples for successful cooperation with schools (e.g., Kiessling et al. 2021; Schuttler et al. 2019), by soliciting the active support of university and high school administrators and by reinforcing capacity building activities (Fig. 6, see for example the Austrian CS funding program "Sparkling Science", University of Vienna 2019, 2022).

One of the main proclaimed benefits of CS to policy development is the improvement in political decision-making and policy implementation, as evidenced by a qualitative content analysis of 43 international policy documents (Hecker et al. 2019, p. 8). Our survey, however, points to a large gap between the CS community's vision and perceived current socio-political CS impacts. Although CS data and results already contribute to the fulfillment of national and international reporting obligations in nature conservation, for example, through the European Farmland Bird Indicator (e.g., Butler et al. 2010) or the Grassland Butterfly Indicator (e.g., Van Swaay and van Strien 2005), CS results have until now rarely been incorporated into political decision-making processes outside this area (Hecker et al. 2018b, p. 5; Hyder et al. 2015, p. 115; Nascimento et al. 2018, p. 220). The potential attributed to CS in political strategy papers (e.g., European Commission 2019; 2020) is in contrast to the lack of consideration and use of CS data and results in policy-making.

To enhance citizen-driven, participatory decision-making processes at the municipal, state and federal level, CS practitioners could learn from best practice examples. These include CS projects that have already had a measurable impact on policy formation and implementation, like the air quality monitoring project "Curious Noses" (Van Brussel and Huyse 2019, p. 15). To achieve genuine political impact, CS project initiators and coordinators should clarify relevant policy fields early on and co-design projects together with citizens and decision-makers to contribute policy-relevant data and fill evidence gaps. Thus, CS can generate in-person contacts to make CS projects visible to decision-makers and clarify data quality standards with authorities or agency members (Veeckman and Temmerman 2021, pp. 11–12).

Both in-person exchange among different CS actors, and the acknowledgement and use of CS data by political decision-makers could be further promoted by decentralized CS contact points (Fig. 6, Bonn et al. 2022, p. 98) stemming from universities, research institutes, NGOs, agencies or city administrations. Such CS contact points could harness CS expertise within organizations and provide information and advice for both CS practitioners and decision-makers on the integration of CS data and results into policy-making. They could also provide advice and training on adequate CS project design and networking strategies, as well as on the procedures and outcome planning for successful participation in political decision-making processes.

### 4.4 Support mechanisms for citizen science: in need of development

To strengthen and to develop sustainable CS project design and implementation, CS support mechanisms need to be reinforced. These include formal and informal recognition of CS, enhanced and adequate funding programs as well as systematic CS evaluation.

CS projects require substantive personal commitment and communication effort from coordinators, researchers and citizens to integrate different aims and perspectives into a coherent joint research process (Bonn et al. 2022, p. 43; Cunha et al. 2017, pp. 7–8). Therefore, recognition is essential to motivate participants, project coordinators, involved researchers and other CS practitioners (Capdevila et al. 2020, p. 5; Richter et al. 2021, p. 10). To prevent a lack of recognition, as reported in our findings, from becoming a barrier to CS engagement, project coordinators and CS networks should strengthen existing recognition instruments and establish new, demand-oriented forms of recognition (Fig. 6). Based on our findings, valuable *informal* and social forms of recognition can be opportunities for personal exchange between CS participants and researchers or policy-makers; free interactive qualification or training; and fostering collective impact through joint development of management strategies with CS participants and decision-makers. One respondent stated: *"As a reward for my voluntary engagement, I would appreciate more insights and participation in the work of the research team. Currently it is a black box, I hand in the results and don't know how they proceed with it."*

Important *formal* recognition instruments for CS participants may include a standardized format for indicating CS contributions in data repositories, reports and scientific publications, and possibly the provision of certificates for CS engagement. In addition, for researchers, CS expertise needs to become a valued part of academic reputation. In this context, establishing a social impact indicator could be an effective way for academic institutions to assess and reward the societal impact of CS research (Fig. 6, Bonn et al. 2022, p. 59).

Despite efforts to strengthen CS in national and international research funding in recent years (e.g., BMBF 2019), our results and the very low CS funding rates (3.3% in BMBF program 2019) indicate that existing funding is insufficient to successfully develop and implement CS projects. Actively engaging citizens in project conception, throughout the entire research process and also in the evaluation and processing of the data and results is often not feasible within a traditional 3-year funding phase. Moreover, creating policy impacts via CS is a long-term objective that manifests gradually over time. Empirical results suggest that CS projects often reach their maximum policy uptake after 6–8 years (Chandler et al. 2017b, p. 171). To enable adequate CS scoping and establishment phases, especially if co-created, funding organizations should establish appropriate funding terms, as well as facilitate start-up and follow-up financing (Fig. 6). Importantly, funding needs to be diversified and application procedures need to be simplified to successfully transition to CS as a mainstream research approach and to allow diverse participation including bottom-up, citizen- and NGO-led projects (see Table SI7.1).

For effective management and improvement in CS processes, evaluation is essential (e.g., Kieslinger et al. 2018). Less than half of the CS project coordinators in our survey, however, reported systematic internal or external evaluations. Supporting research on CS and systematic project evaluation are core management instruments to refine CS activities (Groulx et al. 2017; Stylinski et al. 2020). Therefore, increasing resources and introducing systematic project evaluations as a requirement for project funding could be useful avenues to strengthen evaluation activities according to existing CS evaluation frameworks (e.g., Kieslinger et al. 2018; Phillips et al. 2018; Fig. 6). An openly accessible and systematic documentation of CS evaluation best practices (e.g., Greving et al. 2022) could promote mutual learning and facilitate greater implementation of CS evaluation frameworks.

## 5 Conclusion

Based on 340 survey responses from the German-speaking CS community in Germany, Austria and Switzerland, we provide a synthesis of the current status of CS and its scientific, participant and socio-political impacts. For scientific impact, our findings show that data quality assurance and control are well established in CS projects. Both systematic data management and publishing of CS data and results, however, need to be enhanced to meet the CS core aim of jointly generating new scientific advances together with citizens.

Citizen empowerment in CS projects is achieved through enabling personal and collective efficacy and new knowledge gains, which were identified as key outcomes of CS engagement by citizen scientists in our survey. Our results suggest that these participant outcomes can be developed further through social learning opportunities, such as systematic feedback on project activities or mentoring programs.

Regarding CS policy impact, our survey results point to a vision-reality gap. While several policy strategies attribute a high impact potential to CS, the broader uptake of CS results in policy and practice seems yet underdeveloped from the CS community's perspective, apart from a few excellent examples cited.

Based on these findings, we recommend specific actions for different CS actors to strategically advance the transformative impact of CS: (1) increasing capacities for systematic CS data management and scientific publications, (2) promoting in-person, social learning opportunities for CS participants to encourage collective action, (3) encouraging personal interaction among CS actors to foster mutual learning and (4) strengthening pathways for uptake of CS produced evidence by policy and practice. The latter can be facilitated by joint engagement of CS project stakeholders to align project goals and methods with current decision-making processes and policy relevant indicators. To support these aims, (5) funding organizations will need to create and expand funding programs tailored to CS specific needs. In addition, to turn CS from an emerging to an established research approach, (6) CS expertise and success need to be integrated into the academic reputation system, and adequate recognition established for all participants.

These needs could be effectively achieved by establishing local CS contact points in all major institutions, e.g., research institutes, NGOs, museums and government agencies, who can build, secure and share CS expertise, and provide in-person advice at the regional and local level.

If CS practitioners and funders succeed in harnessing these opportunities, we envision that CS can play an increasingly important role in addressing the complex socio-ecological problems of the climate, biodiversity and health crisis. By providing sound and community-led evidence for societal challenges, citizen science can unleash its impact potential as a transformative change agent for science, citizen empowerment and socio-political processes.

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**Author contributions** All authors contributed to the study conception and the development of indicators and survey questions. Julia von Gönner, Susanne Hecker and Aletta Bonn coordinated and led the survey conception. Julia von Gönner implemented the online survey, managed, analyzed and interpreted the data, drafted the manuscript, incorporated co-author feedback and led the submission of the manuscript. Thora M. Herrmann, Till Bruckermann, Michael Eichinger, Susanne Hecker, Friederike Klan, Julia Lorke, Anett Richter, Ulrike Sturm, Silke Voigt-Heucke and Aletta Bonn contributed to writing and critically revising the manuscript. Till Bruckermann helped analyze the data and contributed to figure design. Aletta Bonn supervised the project. All authors read, commented and approved the final manuscript.

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**Data availability** The data supporting this study is available at https://doi.org/10.5281/zenodo.7476627.

## Declarations

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Ethics approval** The questionnaire and methodology of this study were approved by the legal department of Helmholtz Center for Environmental Research (UFZ Leipzig, Germany), which reviewed ethical aspects of this study and confirmed that it was conducted in accordance with the ethical standards (file number RA-461/20).

**Consent** Informed consent was obtained from all individual participants included in the (anonymous) online survey study.



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