Engagement of Online Communities Within a Citizen Science Framework for Improving Innovative Participation Models: Insights from Hydrology and Environmental Monitoring

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Abstract. Citizen science is a set of methodological approaches aimed at engaging general public in the processes of co-production and sharing of scientific knowledge to face societal needs and environmental challenges. Its main fields of application concerns environmental sciences, earth observation and urban planning, by introducing human and socio-cultural perspectives into technical and scientific tasks. New developments in Information and Communication Technologies (ICT), remote sensing and data processing pave the way to new crowdsourcing activities for social engagement, volunteers' recruitment and organization. In particular, social media systems allow rapid sharing of information at low cost connecting and organizing people within online communities. Citizen science can constitute an innovative theoretical framework within which online communities can be engaged for production of new forms of knowledge and for giving innovative perspective in organizational processes. The aim of the paper is to pose general reflection to build a conceptual transdisciplinary framework for the integration of online communities as part of citizen science projects integrating insights deriving from its application for hydrology and water resources management.

Keywords: Citizen science · Online communities · Public engagement · Knowledge co-production

1 Introduction

Citizen science is a set of methodological approaches aimed at increasing public participation in scientific research activities through the co-production of knowledge and useful

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tools for data collection, data processing and dissemination of results [1]. Its main fields of application concerns environmental sciences, earth observation and urban planning, by introducing human and socio-cultural perspectives into technical and scientific tasks. In this way, citizen science support expert researchers in the definition of practical solutions that intercept research questions with social needs [1–5]. Citizen Science involves the use of crowdsourcing models and participative approaches for the sharing of ideas, the development of projects and the organization of volunteers in research projects [6].

New developments in Information and Communication Technologies (ICT), remote sensing and data processing pave the way to new crowdsourcing activities for social engagement, volunteers' recruitment and organization [7, 8]. In particular, social media systems allow rapid sharing of information at low cost [9] connecting and organizing people within active communities [8, 10]. Citizen Science can constitute an innovative theoretical framework within which online communities can be engaged for production of new forms of knowledge and for giving innovative perspective in organizational processes. Citizen science, firstly, encourages dialogue and the exchange of information between citizens and experts, in order to increase awareness on public interest issues and in decision-making processes [1, 2, 11, 12]. Dialogue and information exchange are also functional to collaborative modelling of tools and processes [13, 14]. Volunteers' engagement and participation in a citizen science framework is not limited to data collection only but extends to the shared definition of research problems and the co-production of results for understanding the phenomena [1, 15].

Despite the developments and integration of ICT and new recruitment methods through social media systems in participatory approaches to scientific research and environmental monitoring, the engagement of online communities in citizen science activities constitutes a research gap. This gap is found both at theoretical and empirical level, where citizen science initiatives are generally conducted on field activities coordinated by experts. The use of ICT and digital technologies, in this context, is usually supportive. Yet, the role of online networks and digital communication tools is increasingly pervasive in the information gathering and exchange between people aimed at knowledge co-production through cooperation and organized collective action [10].

Starting from this gap, the aim of the paper is to provide a conceptual framework for the integration of online communities as part of citizen science projects integrating insights deriving from its application for hydrology and water resources management [3, 16]. The research method adopted is a theoretical literature review on the concept of citizen science and its implications related to engagement of online communities. Finally, this contribution presents three illustrative cases from hydrology and water resources management to contextualize practical and organizational issues in citizen science projects to hypothesize possible scenarios for the engagement of online communities. Starting from Shirky's [10] indications regarding the organizational issues posed by online networks and digital communication tools, this contribution tends to outline possible potential scenarios of online communities' engagement in a citizen science framework aimed at co-production of knowledge through information sharing, cooperation and collective action between users. The paper is structured as follows: in Sect. 2, authors introduce theoretical concepts related to citizen science and explain ideal typical users' attitudes within an online network. In Sect. 3, authors illustrate research gap in

investigating the role of online communities in a citizen science framework. Sections 4 and 5 are focused on insights derived from application of citizen science principles in hydrology and water resources management from theoretical contributions and practical applications. Then, in Sect. 6 authors will provide final considerations focused on possible organizational scenarios for enhancing the role of online users in a collective action towards achievement of social and environmental goals, by application of citizen science principles.

2 Theoretical Framework

A common and statutory definition of citizen science is still missing [17] and its application in research tasks usually reflect empirical concerns. Definition of methodologies, protocols and research methods is the result of dialogue and shared points of view between experts and engaged volunteers [2, 18]. Citizen science aims to promote peer collaboration between experts and citizens, even if first group often leads research projects because of its level of expertise on scientific topic [1]. In fact, experts refer to professional researchers involved in academic context. While volunteers represent a heterogeneous group, within which individuals can differentiate themselves by level of education, cultural and social background, professional expertise, motivations and interests [13, 19].

Furthermore, volunteers can represent different interest or social groups. Expert researchers often engage generic volunteers through call to action or crowdsourcing techniques [7, 20, 21]. In other cases, volunteers' engagement aims at representatives of local communities, bearers of social and territorial needs, such as bottom-up associations, neighborhood committees or ethnic and linguistic minorities [2].

These aspects are crucial for achieving common research objectives, defining shared research design, adopting, and implementing suitable tools for data collection and processing aimed at the co-production of knowledge and scientific activity. Starting from these theoretical assumptions, citizen science is usually structured in (1) contributory, (2) collaborated, and (3) co-created typologies according to the level of engagement and tasks assigned to volunteers [22–24]. This tripartition can represent ideal types on which setting up participation strategies. From a contributory perspective, experts maintain their leading role, controlling all stages of the research process. The role of volunteers is limited to the collection and sharing of data useful for research purposes [22, 23, 25]. From a collaborated perspective, volunteers' engagement includes refining tasks of research question, activities and roles set by experts [22, 23, 25]. Participants act in cooperation to experts in order to give them insights to analyze under scientific lens. Finally, co-created typologies constitute the highest level of citizen science, in which co-production between experts and volunteers is more evident. Co-created citizen science implies participants' engagement in all stage of research process [22, 23, 25]. Volunteers' participation is expressed in a call to action in which participants act as peer with experts [26].

Based on this ideal–typical tripartition, an organization involved in citizen science activities has a complex and circular structure (Fig. 1). The complexity derives from the coexistence and co-participation of different types of actors, coordinated by experts.

Circularity depends on constant dialogue between actors that interact as peers. Circularity guarantees a constant flow of information between participants at the basis of feedback actions and in support of collective actions within the processes of knowledge co-production, co-management of public and scarce resources (such as water, land, woodlands and food systems), co-assessment of related risks (floodplains, rainfalls, drought, soil erosion) supporting for concerted and shared decision-making processes.

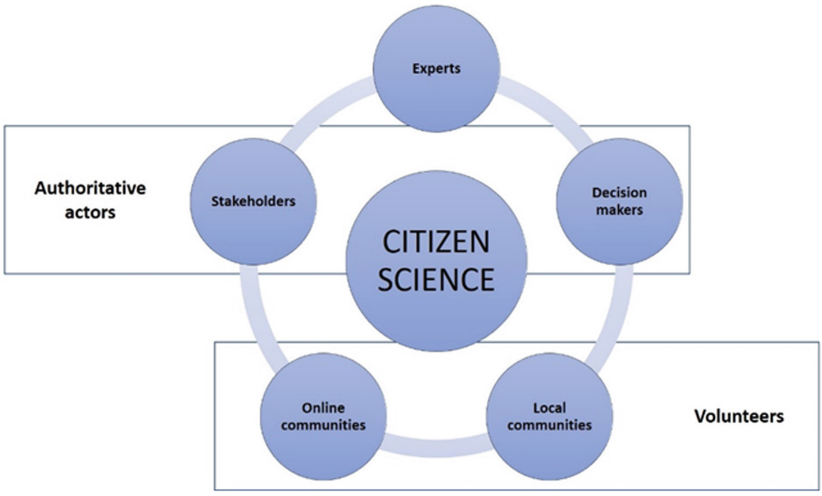

Fig. 1. Cyclic configure of citizen science participation (Source: Authors)

Advances in Information and Communication Technologies (ICT) and digital technologies open new scenarios of knowledge co-production by expanding research tools and methods to social media [9, 18, 27]. In this context, online communities come into play as a new actor for the co-production of information and data useful for knowledge, innovation and creative solutions [28, 29] for organizations enrolled in scientific research [16]. The engagement of online communities, thus, transfers the participatory modalities of citizen science within digital platforms in which volunteers can share data and information, organize themselves and take collective actions [30, 31]. Virtual platforms to share creative ideas to organizations and also to interact between users and experts, building social networks and establish a sense of community [29]. Online technologies support unformal communities in organizing tasks for common efforts [30–32]. According to Shirky (2008), online interactions among users differentiate in three kinds of effort: sharing, cooperation and collective actions [10].

Sharing represents the simplest way to interact within an online community or to take advantages from social media tools [10]. Participants' behaviors are similar to contributory citizen science because their tasks are limited to data or information sharing [15, 22, 33]. Cooperation represents a second intermediate level of engagement in an online community. It implies changing in individual behaviors because participants need to synchronize their action in order to create a group identity [10, 27]. Cooperation

presents strong similarities with collaborated citizen science because it stimulates dialogue and conversation between participants around issues that defines research question and design, opening new way of knowledge and tools co-production [15, 22, 33]. Collective action is the highest level of engagement in an online community. It requires that participants act as a single entity in achieving a specific goal [10]. Decisions are binding and individual behaviors must reflect a general attitude [10]. Participants not only share information and awareness but also responsibility of their action. Collective action is the base of co-production. In this way, it can pose at the base of co-created citizen science because group actions define research scope, methodologies and tools to adopt [15, 22, 33].

These similarities, therefore, lay the foundations on which to set framework models to conceptualize the engagement of online communities in a citizen science framework bringing insights from theoretical and practical application in hydrology and water resources management as an application field of knowledge co-production, as summarized in Fig. 2.

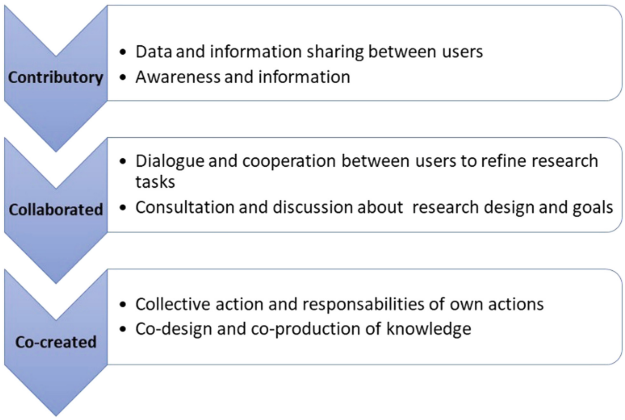

Fig. 2. Summary of main synergies between citizen science ideal types and online communities' attitudes, according to Shirky's tripartition (2008) (Source: Authors)

3 Research Gap

Despite the growing pervasiveness of digital technologies in hydrogeological research and ecosystem management that leverage Volunteerd Geographic Information (VGI) [34] and User-generated contents (UGC), there is a gap with the application of citizen science methodologies with the involvement of online communities. User-generated content data collection usually follows the application of crowdsourcing principles [21, 35] and the involvement of volunteers at a first level of data sharing under the supervision of experts or according to involuntary and anonymous data sharing methods [3, 6, 21]. In recent years, however, there have been several attempts to create active communities as part of citizen science-based research activities [26, 36]. Studies on this topic focus

not only on identifying profiles of participants [36, 37] but also seek to investigate the knowledge acquired by volunteers and the level of awareness on the issues addressed [38–40]. Research on the latter aspect puts volunteers in a perspective of greater interaction between themselves and with experts in the definition of research projects and evaluation of results [40, 41]. Investigating acquired knowledge and awareness projects volunteers towards the development of skills is useful to undertake collective actions and intervene on all phases of the research process with the support of experts [40]. The development of digital platforms therefore allows to contextualize the actions of the participants in a virtual context, often different from the field surveys [40].

Investigating on application of citizen science in hydrological science and water resources management provides several insights to develop a conceptualization of the engagement of volunteers in scientific research processes and in organizational issues related to participatory approaches supported by digital tools and social media contribution. Practical applications in hydrological research and monitoring provide terms of comparison and cases-studies to engage online communities in co-production of shared knowledge, co-design of monitoring tools and in promotion of collective action based on users and online communities' contributions enhanced by means of digital platforms and social media contents. Practical applications from hydrology and water resources management give conceptual and theoretical insights to reduce gap in the enhancement of online communities' contributions into citizen science.

4 Insights from Citizen Science in Hydrology and Water Resources Management

The application of citizen science offers to the hydrologists and water management scientists new research skills for implementing analytical models through the integration of traditional data collection methods with information provided by volunteer citizens, using their own personal mobile devices [3, 21, 35, 42]. The advantage offered by personal mobile devices is the ability to offer a continuous flow of data, constantly updated and with a widespread geospatial coverage, at low cost [2, 35, 43].

Studies on citizen science in hydrology and environmental sciences is mainly focused on the development of organizational and participatory models for the collection and integration of crowdsourced data [14, 18, 44]. These models are usually based on stakeholders' participation and cooperation in terms of increasing participation of general public, reducing social conflicts, building consensus and promoting negotiation between participants and experts on topics of common interests such as management and sustainable uses of water resources [14] or risk and flood hazards communication [18]. The adoption of computer-based models – by means of software platforms, suitable smartphone applications for technical data collecting and processing and communication tools – is functional to (1) support communication efforts directed to general public or specific community groups and to (2) analyze social networks patterns in order to identify potential stakeholders to involve, defining roles and tasks within the organization [45–47]. Social network pattern analysis allows not only a mapping of organized groups of online users but also to investigate interactions between members of an online community [48] and between users and their context of interaction [49, 50]. Context

of interaction is composed not only by peer volunteers but also by stakeholders and institutional actors, such as local authorities and research centers that conduct and coordinate scientific activities or commission research based on co-production of knowledge and co-design of tasks and goals [45]. Introduction of social media tools in citizen science investigation is reshaping socio-spatial networks of participation, projecting the engagement of volunteers from community-based approaches towards virtual contexts [51].

Some peculiar factors stem from literature review supporting engagement and organizational processes in the application of citizen science in hydrology, both in physical and virtual context. These factors can be summarized in (1) the simplicity of the procedures adopted in the engagement of volunteers through simple instruction to carry out [18]; (2) development of suitable tools for data collection and processing – such as, smartphone applications or surveys by means of social media – functional to perform technical tasks in an intuitive and immediate way [18]; (3) development of communication strategies aimed at organizing users and optimizing communications and information exchange between participants [18, 51]; (4) stakeholders' analysis to assign roles and tasks within the organization and define levels of participation and collaboration [14].

User participation is an interactive and iterative process that involves different types of volunteers depending on the level of education, expertise, motivations and interests [14, 19]. These aspects are strategic factors for durability of citizen science projects and the organizational structure of a cohesive and active community [2, 52, 53]. Stakeholder's analysis determines the level of engagement of volunteers within an organization. Their engagement includes different level from participation in terms of information, awareness and consultation to active collaboration in public discussion for definition of research design, co-production of knowledge and co-decision making [14]. Motivations and interests can vary from personal interest to gaining power within a community by means of knowledge [22]; from improving social relationship to social learning [2, 13]; from promotion of joint action to civic participation in co-management of common resources, such as water or agricultural services [54]. From a technological perspective, keeping high motivation relies on development of dashboard of data visualization and digital interactive tools to make user aware on volunteered contribution in research activity. Frequently call to action and feedbacks by email can enhance user's role within online communities, making them feel part of a group [2, 13].

Several studies investigate on novel tools offered by the use of digital technologies and the role of social media in gathering data and information for implementing hydrological and water resource management models [18, 21, 55, 56], monitoring flood risk and disaster risk reduction [7, 9], measuring streams flow and water levels [55, 56]. Expert researchers assimilate information observed by users for the implementation of hydraulic models based on time-series and large geospatial coverage of contributions [57]. However, many applications of this kind rely on crowdsourcing activities that are often involuntary, where the production of data is not the result of deliberate actions within a citizen science research purpose [7, 44]. This issue often occurs in the cases where contribution derived from social media contents, where users are not directly involved or engaged in scientific activities [44]. The illustrative cases in the next paragraph show how the development of digital and web-based platforms is functional

not only to offer technological solution to data collection but also to the construction and enhancement of online communities engaged in water resources management and hydrology under supervision and coordination of experts.

5 Digital Platforms for Engaging Communities in Hydrology and Environmental Monitoring

Several citizen science initiatives on community-based approaches focus mainly on the topic of water management with particular attention to atmospheric phenomena that affect the water cycle and water quality intended as an essential ecosystem service for functioning and social well-being [2, 35]. In this sense, such initiatives tend to create active communities around water management and monitoring through the development and implementation of digital platforms and the use of suitable and ready-to-use apps. The development of online platforms is part of citizen science's progress towards new conceptual, technological and communicative paradigms aimed at widening interactions between users in a common and shared effort [58].

Spotteron, CitSci.org and AnecData represent three illustrative cases that exemplify the application of citizen science in environmental research and monitoring through engagement and enhancement of online communities. The purpose of these platforms is not only to collect data, but also to create operating communities that can constantly share and update personal and collective opinions and experiences in relation to topics of scientific interest, highlighting their impacts on daily experiences. The Spotteron platform offers, for example, advanced digital tools (such as digital maps) for the collection and mapping of information by citizens on various topics of scientific interest. As part of hydrology and water management Spotteron has developed the CrowdWater app [59] in order to collect information on water level and estimate water flows [59]. The application has been used in several studies since the estimation of flows [55, 56] to monitor microplastic pollution of waterways [60]. The involvement of citizens takes place through training and gaming phases in order to build a community attentive, educated and sensitive to the purposes of research and above all to keep the motivations of citizens within the community high through rating and ranking systems of the information received [56, 61]. Through the training and gaming system, the researchers wanted to set up the construction of a community attentive to water management issues in order to obtain active citizens as sensors on a specific geospatial context to provide data and at the same time improve their perception of water resources and the risks related to them for greater sensitivity in terms of water use and consumption.

CitSci.org platform supports collaboration between researchers and citizen scientists in research and decision-making activities [62]. Users can freely access to the platform defining research questions, shared issues and scenarios, developing shared research plans and activities with a view to promoting online collective action initiatives [23, 62]. Users can also build models, collect data and view results according to a shared participatory model in order to create inclusive and participatory management protocols [23].

The AnecData platform provides tools for crowded data collection and interpretation towards the solution of common issues addressed within Citizen Science [58, 63].

Available tools include datasheets, image uploads, charts, and data mappings [58, 63]. Communication tools underpin the potential to create cohesive and active communities through online channels [58, 63]. The platform supports collective actions aimed at solutions to collective problems by creating networks between experts and citizens. Its function is not only limited to the production of knowledge but also to promoting class actions [58, 63].

Digital platforms – like those illustrated above – provide technological support to citizen science projects with wide range of features and advanced tools. Social community extensions – such as newsfeeds, forum, comments, liking and user following, data visualization and summary – constitute many advanced functionalities that facilitate interactions and information exchange at the base of communication strategies, community building processes and new forms of distributed collaboration [64, 65]. Scope of citizen science platforms is to generate measurable results for scientific research and evidence-based decisions [65]. Data quality extensions offers tools for analyzing and validating of citizen observation and for reducing errors and biases [65].

6 Final Considerations

In this contribution, authors have examined the main characteristics of citizen science as a theoretical framework for the engagement of online communities in the processes of scientific knowledge co-production in support of innovative and shared solution for water and hydrological resource management and assessment. Authors have, therefore, examined three illustrative cases aimed not only at investigating the technological aspects, but above all at focusing on the methods of creating communities in order to identify essential and peculiar characteristics that can integrate online communities in a citizen science framework. Finally, the contribution aims to provide insights for the engagement of an online community to support citizen science initiatives across a transdisciplinary application between social and hydrological sciences with the support of digital and information systems.

The role and potential of online communities in a citizen science framework is currently still little explored.

The theoretical insights and practical examples shown in this contribution offer general guiding principles for setting up the organization of online communities in a participatory scientific research process. Digital platforms, such as Spotteron and CitSci.org, offer interesting digital solution to be replicated in several study contexts for the construction of active communities around environmental issues to support scientific research and decision-making processes. These platforms constitute not only a digital solution for a large-scale data collection, but also lay the foundations for the construction of communities engaged in the monitoring and management of socio-environmental processes. In some cases, the team of researchers experimented with the use of dashboards and gaming for long-term engagements of participants and to evaluate the effectiveness of volunteered observations. These solutions can constitute long-term monitoring tools to verify and quantify the contribution provided by volunteers not only in terms of data provided but also for measuring validity, effectiveness and temporal continuity.

The online communities can broaden the recruitment area of volunteers by the support of digital technologies and social media. Digital solutions facilitate the communications within the organization offering the ideal medium to involve non-expert volunteers using user-friendly and intuitive tools. Citizen science provides the theoretical framework on which experts can set up participatory research works and develop participatory processes aimed at the co-production of scientific contents not only and not so much to solve academic research questions, but above all to find concerted solutions to contemporary challenges, such as consequences of climate change or assessment of scarce resources.

In this context, social media (1) implies the adoption of new data collection methods; (2) offer new tools for communication and rapid online interaction between experts, stakeholders and citizens; (3) they constitute investigation tools to identify attitudes and behavioral patterns at the basis of the organizational structures of groups of volunteers.

In the light of the examination of the literature and illustrative case reported, three possible scenarios for integrating online communities into citizen science framework can be outlined. The first scenario is of a collaborative type, in which users contribute to the co-production of knowledge by sharing data deriving from direct observation of phenomena. In this context, users act as widespread human sensors, autonomous in their action with a low level of interaction. The second scenario is cooperative, in which users' actions are synchronized within an organizational structure coordinated by experts. In this context, data collection activities and interactions among users are guided according to specific goals fixed by experts. The third scenario is collective. It represents the highest level of integration of online communities into citizen science processes. In this scenario, the community building is completed. Users share common values and visions at the base of joint action with experts.

Citizen science initiatives in hydrology and water resources management are usually based on community-based approaches and crowdsourcing activities. Community-based approaches not necessarily imply the use of digital and web-based technologies and crowdsourcing activities are often unintentional and not specifically aimed at full engagement of volunteers in scientific research processes. Engagement of online communities in citizen science would make systematic data collection in a context of continuous and active monitoring aimed at intercepting collective social and environmental needs and directed towards concerted solutions to problems related to urban planning and environmental management. Another peculiarity is the virtual interaction of online communities. This aspect allows the replicability of organizational and communication models on different geographic large-scale application contexts and case studies, not only limited to assessment of environmental and water resources but also extended to other fields such as public sector accounting, assessment of public services (transportation, health, education), ecosystem and agro-food systems assessment, co-management of network services and infrastructures.

Despite the wide availability of publications, application cases, tools, techniques and digital platforms related to citizen science, the impacts of this approach at the level of human behavior and cultural change represent a field of investigation that is still little explored and in an experimental phase. Further studies on the topic will have to be directed to shed light on the ability of citizen science to create cohesive and organized

communities and on behavioral changes both individually and collectively. The study of these aspects will be able to shed more light on the motivations and interests underlying the involvement of citizens in the production of scientific knowledge and in decision-making processes. Aspects that complement and integrate with the collection of data and observations and their validation through the implementation of traditional analysis models.

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