AquaNES

Demonstrating Synergies in Combined Natural and Engineered Processes for Water Treatment Systems

Deliverable D5.4

Guidance on citizen science approaches

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cNES	Combined natural and engineered treatment system
CS	Citizen science
ECSA	European Citizen Science Association

Executive Summary

Over the last decade, the participation of citizens in science (or citizen science – CS) has received increasing interest of scholars, professionals in the field and citizens themselves. Benefits of this method are recognized on an individual, scientific and system level. The aim of the AquaNES project subtask on citizen science is to theoretically assess whether and how a citizen science initiative might effectively support the monitoring and control activities for any of the demonstration sites characterized by natural treatment processes, such as bank filtration, managed aquifer recharge and constructed wetlands, combined with engineered pre- and post-treatment options.

Given that each demonstration site is unique in terms of, among others, technological design, location, governance and broader social context, this guidance takes the view that professionals closely involved to the sites are best equipped to answer the questions of whether, how and under which circumstances a citizen science initiative may be meaningful for their particular site. AquaNES demonstration sites are characterized by natural treatment processes, such as bank filtration, managed aquifer recharge and constructed wetlands, combined with engineered pre- and post-treatment options, and these natural elements can be part of the public domain and accessible for citizens. This guidance is meant to encourage and support professionals at such sites in undertaking a citizen science initiative. Besides guidance regarding the whether and how deliberations, it is also meant as a self-explanatory citizen science design guidance.

This guidance takes an outcome oriented approach placing the individual, scientific and system outcomes of a CS project at the forefront of the project design. The aim is to incite projects that are relevant on all three levels. This guidance is grounded in the latest research on citizen science and enriched by various examples from practice. By providing a five-step approach, professionals in the field are encouraged and guided to consider a CS project. The five steps are desire (the outcomes), define (the strategy and target public), design (the spatial and temporal scale and the CS type), develop (various protocols and a recruitment strategy) and detail (the training, manual and logistic plan). Going through these steps, this guideline offers a logical sequence of decisions to be made, as well as critical checks allowing for a reconsideration of the suitability of CS for a specific project.

For the purpose of illustration, a completely hypothetical citizen science case is included in this guidance. This case, which is loosely based on the actual cNES site Lange Erlen in Basel, Switzerland, allows to illustrate each step in the guidance, and connect it to the realm of AquaNES.

1 Guidance on citizen science

1.1 Introduction

In recent years, public participation in science (aka "citizen science") has gained considerable pace and received widespread support and recognition from policy makers, funding institutions and scientific researchers. Accordingly, in the past few years citizen science (CS) projects have grown spectacularly in number, scale and scope (Shirk et al. 2012, McKinley et al. 2017, Brouwer et al. 2018). The recent advances in communication technology, and specifically the rapid developments in online and mobile interaction, have enabled CS to become more widely practiced than ever before (Rotman et al. 2012, Kronemeijer 2015). It is fair to say that the current influx of digitalised gadgets have equipped citizens with a plethora of measuring techniques that have undoubtedly allowed for a "new dawn" of CS (Silvertown 2009, Dickinson et al. 2012, Rotman et al. 2012, Raddick et al. 2013). Indeed, although public participation in science, often practiced informally as a leisure activity, has existed for centuries, in the past few years CS has become a much more formalized process (Haywood 2016).

In simple words, CS refers to the participation of the general public, i.e., non-scientists, in the generation of scientific knowledge (Buytaert et al. 2014). CS as a concept was developed from two origins, one in the social sciences and one in the natural sciences (Kullenberg and Kasperowski 2016). Irwin (1995) defined CS in the realm of philosophy of science, describing the concept as an "arena where different knowledge claims can meet and cross-fertilize". Bonney (1996), instead, coined the concept to refer to projects involving data gathered by citizens. In this guidance, however, we follow the work of Brouwer et al. (2018), who grounded their description of CS in work of, among others, Bonney et al. (2009b), Shirk et al. (2012), and (Buytaert et al. 2014a). They describe citizen science as any form of active public participation in research processes set up to generate science-based knowledge. This can range from setting the research agenda by asking research questions, to collecting data, and/or analysing the results. As such, it is important to emphasize that CS thus can be broader than merely involving citizens in collecting data on, for instance, the performance of ecosystem services. There can be various CS types identified, including contributory, collaborative and co-created. As further elaborated on in paragraph 4.3, these types can be distinguished based on their degree of citizen participation. Whilst citizens in a contributory CS study are only involved in data collection and occasionally also data analysis, they are involved in every step of a co-created project (Shirk et al. 2012).

The participation of non-scientist in the generation of scientific knowledge comes with various advantages, for science, the larger system, the general public and for institutions and/or companies initiating and/or supporting CS initiatives. The most cited opportunity for CS relates to the idea that CS enables the public to collect large quantities of data across an array of habitats and locations over long spans of time, allowing to solve research problems that require extensive observations (e.g. mapping biodiversity) or the analysis of big data sets (e.g. classifying galaxies) (Jollymore et al. 2017).

Furthermore, it is suggested that CS may improve citizens' scientific literacy and can contribute to making science more democratic, both in terms of inclusiveness and a better alignment of science with societal needs (Bonney et al. 2009a, Strasser and Haklay 2018). In addition CS has the potential to generate more alternative or specific solutions, as well as to produce less contested knowledge (Irwin and Wynne 2003). CS can also raise public awareness for the topic of study (i.e. water or biodiversity) and (institutional) trust (Brouwer and Hessels 2019). To display the variety of CS projects, a list of examples is provided in Appendix III.

1.2 Citizen science and AquaNES

One of the overarching aims of the AquaNES project is to demonstrate the added benefits, over and above water/wastewater treatment, that could be obtained from utilising combined natural and engineered treatment systems (compared to fully engineered treatment trains). Those added benefits could be environmental (e.g. see Deliverable 5.2 for an analysis of ecosystem services) but they could also be social. The premise here is that the natural components of cNES – constructed wetlands, bank filtration, or managed aquifer recharge – may offer an array of opportunities to incorporate CS initiatives. Important ideas underlying this assumption are that natural treatment systems are often part of the public domain, allowing citizens to access them and also making their functioning a public concern. Also, natural treatment systems are often multi-functional systems, in which next to purification also enhancing the natural environment and biodiversity are considered important. Through the use of CS, the involvement of citizens and other stakeholders in the management, monitoring and/or development of these combined treatment systems could be promoted. As such, CS initiatives could potentially benefit both the cNES schemes themselves and the wider communities in which they are located.

Therefore, the purpose of the task underlying this report was to conduct an exploratory analysis of whether/how CS initiatives could be incorporated into cNES schemes, and what benefits and challenges they might raise. This guidance document is primarily based on a review of literature, combined with first-hand experience of the authors and feedback from AquaNES partners.

Although it is well possible that citizens contribute in research related to the engineered pre- and post-treatment processes, from a CS perspective, projects related to either the quality of the end product, e.g. drinking water (e.g. Brouwer et al. 2018), or especially related to the added value of the natural treatment processes may be the readiest. Indeed, projects related to the natural treatment processes resonate well with many CS projects centred around ecosystem services, i.e. the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfil human life (Daily 1997). Despite the abstract nature of assessing ecosystem services, numerous CS projects have attempted to (directly) addresses the measurement of ecosystem services in their study (Schröter et al. 2017). Most of these studies rely on measurements of simple proxies, including (invasive) species count, air quality, and water turbidity, which indirectly relate to an ecosystem service (Eraud et al. 2007, Crall et al. 2011, Overeem et al. 2013, Bulleri and Benedetti-Cecchi 2014, Jiang et al. 2016, Zheng et al. 2017). By involving citizens directly in monitoring or active management of ecosystems, CS can generate powerful matrix management efforts which has the potential to lead to positive, cumulative, and measurable impacts on the functioning of ecosystem services (Cooper et al. 2007, McKinley et al. 2015). In addition, Schröter et al. (2017) suggests that the application of CS in ecosystem services studies may promote the value of nature to larger audiences and different targets groups. Accordingly, it is conceivable that CS projects in an AquaNES context likewise promote the value and understanding of combined systems to the general public.

This guidance is, however, not prescriptive as to what specific elements of the combined natural and engineered systems are most appropriate or salient for a CS approach. In fact, it recognizes that each demonstration site is unique, and should make its own judgement in this regard. Hence, it is for individual demonstration sites to assess in which form, if at all, CS is meaningful and viable. This guidance is meant to encourage and support professionals in this process, not only in their deliberations as to whether and how a CS project might be meaningful, but also in relation to various key practical considerations in designing a CS project. This guidance does not offer direction during the actual execution or evaluation phase of a CS project, but focusses on grounded preparation and consideration on the suitability and details of CS.

A hypothetical CS initiative

For the purpose of illustration, a completely hypothetical citizen science case will be elaborated throughout this guidance. This illustration is loosely based on the actual cNES site Lange Erlen in Basel, Switzerland, btu this hypothetical initiative will not refer to actual data, reflect actual events, nor include any site representative contributions. The Lange Erlen site solely provides a geographical location and treatment characteristics. All other aspects will be hypothetical.

Site characteristics

The Lange Erlen treatment site produces drinking water for the city of Basel from the river Rhine (surface water abstraction) for over 50 years. The treatment train encompasses screening, filtration and subsequent soil infiltration. After re-abstraction the water is treated by granular activated carbon and UV-disinfection (Zawadzka et al. 2017, IWB 2018)(see Figure 1).

The site itself is covered with woodlands (180 ha), which indicates a high potential for provision of multiple ecosystem and cultural services. Although the infiltration areas are not accessible to general public, the wider area serves as a park and receives visitations from local residents. This is facilitated by footpaths and cycling paths present within the park, in a proximity to the infiltration zones. Family gardens and sports facilities are also present (Zawadzka et al. 2017).

Figure 1 **Schematic treatment scheme of the drinking water production in the demonstration site Lange Erlen (top) and impression from the infiltration basins/area (bottom).**
source: IWB website, © Christian Flierl and Rita Hochstrat)

Citizen Science project

In this hypothetical citizen science project the biodiversity of the Lange Erlen recreational site will be studied by site visitors via a mobile application for smart phones. The project will target regular visitors of the site and ask them to provide pictures, videos and sound recordings of certain proxy species, allowing for the creation of a long-term database on the biodiversity of the site. The use of CS allows researchers to tap into a large pool of data generated by regular visitors of the site. Contributing to the building of knowledge on the biodiversity of this recreational site, on the other hand allows participants to create a better understanding of the site and the ongoing treatment processes. Besides this, CS projects can engage participants on a more personal level with the site and increase their sense of ownership. Other CS projects (see Appendix III for a list of example projects) have shown that participants can become unofficial ambassadors of sites and can increase their awareness of the ecological status of the site. In this hypothetical project, interested participants can become more involved by also helping to analyse the collected data. In doing so, the project allows interested participants to become experts throughout their participation.

In setting up any CS project, several considerations have to be made regarding amongst others the level of participation of citizens (CS type), the recruitment of participants (recruitment strategy), the necessity of training, etc. This guidance will concisely illustrate all considerations to be made before starting a CS project. Each step will be illustrated by means of exploring the potential for this speculative CS project (recognizable by the brown boxes). All steps are summarized in Appendix I, in which also a summary of this hypothetical case is provided.

1.3 The principles of this guidance

The distinctive character of this self-explanatory guidance relates to two main principles: (i) it takes an outcome oriented approach; and (ii) it is primarily meant for institutional professionals, such as the associated professionals related to the different AquaNES demonstration sites. This guidance is grounded in the latest research on citizen science, and is enriched by various examples from practice.

1.3.1 Outcome oriented approach

To ensure sustained impact of a particular project on science and society, scholars such as Pahl-Wostl et al. (2008) and Armitage et al. (2009) have argued that desired project outcomes and project design need to be well interwoven with one another. In this regard, Wesselink et al. (2011) and Shirk et al. (2012) suggest that desired outcomes and context are essential indicators in determining the most appropriate degree of participation, whereby the former study categorised the outcomes of CS projects into outcomes for science, outcomes for social-ecological systems, and outcomes for individual participants, i.e. the citizen scientists themselves. Likewise, Jordan et al. (2012) and Cooper et al. (2007) emphasizes the value of reviewing the desired goals of a project, prior to developing the study itself, also distinguishing between different categories of outcomes. Nonetheless, the general tendency in CS projects differs in practice. Frequently, CS studies are treated as a regular study approach, following general steps like developing the research strategy, data collection protocol, etc. In order for CS projects to deliver impact on complex problems and to avoid unanticipated outcomes, this guidance explicitly presents an *outcome oriented* design approach. To this end, and as further developed in the next chapter, it puts the desired scientific, system and desired individual outcomes at the front of the design process.

Whereas previous valuable guides to CS developed by, for instance, Pocock et al. (2014) and Tweddle et al. (2012) underscore some considerations to be made before starting a CS project, these tend to be more practical of nature or linked to general research design considerations. For example, Pocock et al. (2014), among other things, emphasize that before starting a CS project one should consider the clarity of the research question, as well as the scale of the project, resources available, motivations of participants, the complexity of the protocol, and the desired level of engagement. Although they link the latter explicitly to the success of the overall project and accordingly to, at least one aspect, of possible desired outcomes of a project, Pocock et al. (2014) do not take an explicit outcome oriented design approach. Likewise, Tweddle et al. (2012) advice not to first identify the desired outcomes, but start their guidance with the steps of identifying a research question and choosing a CS type. This guidance, instead, argues that both choices strongly relate to the desired outcomes of a project and therefore should only be considered hereafter. Nonetheless, the desired outcomes do not need to be fixed or extensively defined. They can be revisited and expanded whilst going over the rest of the guidance.

1.3.2 Institutional design

In addition to the outcome-oriented approach, a distinguishing feature of this guidance relates to the audience targeted. Whereas many CS studies (e.g. Dickinson et al. 2010) and also some guidelines, such as the one developed by the researchers of ETH Zurich (2015), clearly take the scientific community as target audience, other guidelines target a broader, more general, audience as they aim to provide guidance to all involved in a specific project, e.g. Pocock et al. (2014) and Tweddle et al. (2012). This guidance, instead, is primarily meant for professionals – particularly those involved in planning, implementing and/or operating a cNES scheme. This approach resonates with the recognition of CS beyond scientific outcomes and the design of AquaNES. Indeed, CS projects are not only initiated by scientific institutes or citizens themselves. Increasingly, also private companies, governmental bodies and NGO's embrace CS, such as drinking water companies (Brouwer et al. 2018) or water boards (van der Meulen et al. 2018). This guidance aims to assist institutes alike with a clear link to the ecosystem they are embedded in and considering a CS approach. By guiding them through all steps of the project preparation and offering key points to be considered, this guide aims allow for CS projects with solid, credible scientific, system and individual outcomes.

1.4 Five-step approach

Based on a wide variety of grey and white literature, this guidance presents a five-step approach to assess the viability and plan the design of a CS project. As depicted in Figure 2, the approach consists of five main steps: desire, define, determine, develop and detail. The first step, already briefly discussed, entails the envisioning of desired scientific, system and individual outcomes. In the second step, both the target public and the research strategy are defined. Choices made considering these aspects, provide input for the third step, in which the temporal and spatial boundaries of the project are determined. In this step also decisions are made on the most appropriate CS type, considering both the desired outcomes and defined target public and strategy. Next, in the fourth, develop step the focus shifts towards the more practical matters, including the development of a recruitment strategy, and a credibility, engagement and data collection protocol. These, on their turn, provide input for the fifth and final step, in which the last preparations are made, before the project can be deployed. In this step details are operationalized through the potential development of training materials, a user friendly manual and a logistic plan.

As is visualized in Figure 2 by means of green arrows, the guidance provides a logical sequence or route for considering all components of the five-step approach. Besides the route, an important characteristic is the green/red check-boxes. These boxes represent four critical moments in which a project group should ask themselves: Is CS viable for our site? Is CS meaningful regarding our objectives? And is CS the best fitting approach? As, among other things, due to diverging desired outcomes, motivations, practical difficulties, a CS approach is certainly not always suitable or meaningful, these boxes provide critical moments of reflection and the opportunity to change the set-up of the project.

In the following chapters the five-step approach will be illuminated, elaborating on all individual components, their interrelationships, and checks. Each of the following five chapters, will cover one step in the approach.

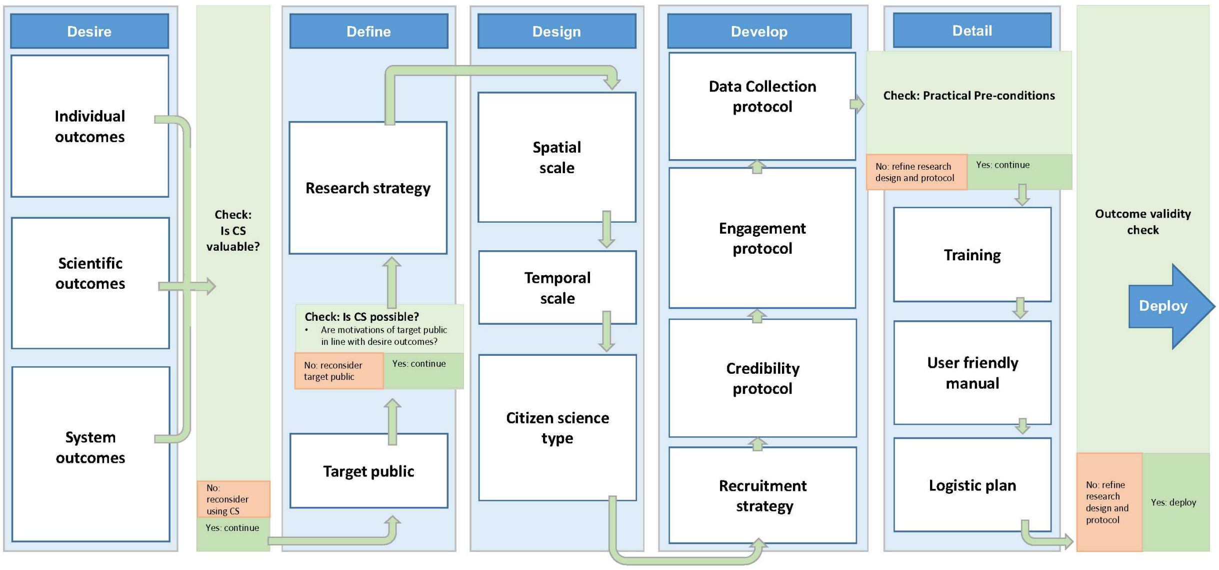

Figure 2 Five-step approach to design a citizen science project.
This figure is a simplified version of the one presented in Appendix I.

2 Step 1: Desire

In line with authors such as Jordan et al. (2012), Shirk et al. (2012) and Kieslinger et al. (2018), this guide argues that every CS design process ideally starts with identifying all desired outcomes. To this end, hereby echoing the multiple advantages of CS, this guide distinguishes between desired individual outcomes, desired scientific outcomes, and desired system outcomes. Each of these outcomes will be elaborated on in the following sections. It must be emphasized that, although these are in successive order in this guidance, no hierarchy exists between them.

2.1 Desired individual outcomes

The involvement in CS has been linked to a wide variety of individual outcomes, i.e. the outcomes for participants themselves. First of all, participants are found to have gained new skills, learning how to carry out a scientific observation or experiment (Tudor and Dvornich 2001, Bell et al. 2008, Jordan et al. 2012). Moreover participation is linked to obtaining new knowledge on the subject of study, and more generally, gaining an improved understanding of the process of scientific research, i.e. scientific literacy (Evans et al. 2005, Jordan et al. 2012, Shirk et al. 2012). CS projects are therefore commonly linked to fulfilling educational purposes (Overdevest et al. 2004, Evans et al. 2005) and fostering social learning (Jordan et al. 2012).

Additionally, the participation in a CS project is connected to an increased sense of agency amongst participants, which is linked to identification with research processes and (in the case of conservation science) the belief that the environment is a factor to base action upon (Ballard et al. 2017). Moreover, by engaging in a CS project the sense of ownership on own knowledge as well as an improved sense of place (Evans et al. 2005) has been witnessed among participants. Indeed, the engagement of citizens with their direct environment can be strengthened by participating in a CS project. Environment in this context can be considered twofold: social and physical. By participating, relationships with other community members can be build (Bell et al. 2008). In addition, participation can lead to an improved relationship with a participants' environmental surroundings (Bell et al. 2008, Jordan et al. 2012).

Desired individual outcomes hypothetical CS initiative

On an individual level, the hypothetical CS project desires for participants to increase their knowledge on the topic of study: (i) the biodiversity in the Lange Erlen recreational area; and (ii) the treatment site. Furthermore, through the project participants may develop an understanding of the value of certain proxy species. In addition, the projects aims for participants to increase their sense of ownership of the area and to potentially become an unofficial ambassador of the site.

Whereas the potential individual outcomes are many, in the design phase of CS projects the outcomes for participants often remain rather implicit (Brouwer and Hessels 2019). This guide recommends CS project teams to make the desired individual outcomes explicit beforehand. In this manner, further design configurations can be adapted, making it more likely that these outcomes will be realized. Whilst many individual outcomes are potentially present, not all will necessarily be categorized as *desired* outcomes.

Questions
Does the project aspire to expand participants' knowledge on the process of science (scientific literacy) and/or to advance new knowledge of the system studied (content knowledge)?
Does the project aim to teach participants new skills and/or to enhance their sense of agency, triggering identification with the research project, and a sense of ownership on the topic?
Does the project aspire to strengthen the relationships amongst participating individuals, or between the participant and the natural world/its environment?

2.2 Desired scientific outcomes

Scientific outcomes of CS projects can come in the form of advancing scientific understanding of the content of a project. Shirk et al. (2012) mention examples of advanced knowledge on, for instance, distribution and diversity of species, the spread of diseases and invasive species, changes in life cycle events, and impacts on human health. CS is recognized as a (cost-effective) method with the potential to create large data sets of a geographical and temporal scale hard to achieve by traditional research teams (Overdevest et al. 2004, Sullivan et al. 2009, Pocock et al. 2014). Dickinson et al. (2010) even consider CS to perhaps be the only practical manner to realize the geographical reach necessary to address large ecological questions on biodiversity and habitat development. By allowing the creation of large datasets, CS enables the detection of uncommon events over large spatial and temporal distances. Besides, in the case of long term monitoring projects, it is argued that committed participants can provide a more reliable source for gathering data than professional monitoring, as their engagement may be less subject to the availability of funding (Pocock et al. 2014).

In addition, outcomes for science might involve harnessing data from localised insights (Berkes et al. 2000, Sullivan et al. 2009). For example, Bird et al. (2003) found that local inhabitants participating in the research supplied the local knowledge necessary for effective conservation. In their study on sea turtle population degradation, a community-based project provided crucial information necessary for effective conservation of the species. Moreover, participants are sometimes found to have superior skills to the professional researchers, e.g. in species identification (Pocock et al. 2014). CS may also allow the collection of data that are otherwise difficult to obtain. For instance, Brouwer et al. (2018) report that in their study on the bacterial stability of drinking water, the involvement of CS participants enabled the collection of a large set of water samples after a night stagnation, a type of sample that for regular samplers is otherwise impossible or very difficult to collect.

Scientific outcomes hypothetical CS initiative
The project aims to create a large long term data base on the biodiversity in the Lange Erlen area. In addition, it is aimed to link the biodiversity data to the work of the treatment demonstration site by using proxy species indicating the local water quality. The aim is to get a better insight in the development of the site's biodiversity over a longer period of time.

Reviewing desired outcomes, the collection of scientific data, the collection of specific local data and the creation and collection of a large scale database seemingly are the most desired scientific outcomes. In addition, it might be useful to emphasize that scientific outcomes can be multi-faced. Also in the context of projects like AquaNES, desired scientific outcomes can reach beyond water, and for instance, also encompass outcomes related to biodiversity or specific ecosystem services.

Questions

About what subject and within what field does the project aim to advance scientific understanding?

To what extent does the project aspire to collect data which is difficult to access without the participation of citizens?

2.3 Desired system outcomes

The growth of CS initiatives relates besides its outcomes for science and individuals to the fact that CS also generates impacts on the broader social-ecological system, which this guide refers to as system outcomes. System outcomes are related to, but at the same time go beyond, the effect of participation on the individual participants. Certainly from an institutional point of view, system outcomes may be an important motivation for initiating CS initiative, even if Shirk and Bonney (2018) observe that also scientists seize to increase the impact of their studies in society and aim "to make a change in the world " (Shirk and Bonney 2018:51).

The literature mentions various potential system outcomes related to CS. Tudor and Dvornich (2001), for instance, found that a CS project can strengthen the social capital of a community, as it provides network for interactions to community members and agencies. This network cannot only foster mutual trust between the public, but also between the public and professional scientists, and between the public and institutions (Tudor and Dvornich 2001, Overdevest et al. 2004, Jordan et al. 2012). As a result, institutional trust, as well as its trust in science and scientific process can increase. Furthermore, a CS project can enhance the overall trust in the (management of) the system under study (Tudor and Dvornich 2001, Brouwer and Hessels 2019). Based on a comparative analyses of five different CS projects in the domain of water research in the Netherlands, the latter report that the public's confidence in the participating institutions generally increased (52%) or remained stable (43%). Likewise, they established that the confidence in the quality of (drinking) water, i.e. the topic under study, increased for about half of the participants (51%), and for another 44% remained unchanged (Brouwer and Hessels 2019). Even participants involved in a study that looked into the presence of microbes in the tap water, a topic generally avoided by drinking water companies as it might sparks fear amongst consumers, resulted in increased level of confidence in the involved drinking water company and the quality of water itself (Brouwer et al. 2018).

Desired system outcomes hypothetical CS initiative

On a system level this project desires to deepen the relationship of recreationist with the Lange Erlen recreational area. Besides, the project aims to increase the awareness on the potential values combined drinking water treatment systems behold.

Another possible system outcome relates to the idea that CS approach result in a higher societal acceptance of the research results. Just as participation in decision-making may increase the "ownership" of the decision (Glucker et al. 2013), which is said to lead to smoother implementation of that same decision (Irvin and Stansbury 2004), CS may increase the uptake of research results (Boon et al. 2011). This outcome relates to the idea that CS may raise the scientific literacy of society, in the sense that the experience of collecting data for use by professional scientists fosters scientific knowledge, and helps promote understanding of the potential and limitations of science, and enhances the public trust in science (Bäckstrand 2003).

CS projects may also spark political participation and civil interest in policy making. An example of this is provided by the stream monitoring initiatives in Wisconsin, US, which were found to improve political participation of citizens, as well as they strengthen informal networks and community feeling (Overdevest et al. 2004). Bird et al. (2003) observed that CS projects can foster collaboration and communication between institutes and citizens, which can benefit the creation of legislation and policy. The monitoring of a resource, for instance, can provide resource managers with feedback on local conditions, allowing for effective policy making (Bird et al. 2003). As such, CS projects allow for the participation of the community in the debate on changing policies (Bird et al. 2003, Overdevest et al. 2004).

Participating communities are found to be more engaged in taking action within their own environment. Accordingly, CS can spark increased community engagement with their surrounding environment and their valuing of certain ecological parameters, such as the presence of green space or certain species in their yard (Evans et al. 2005). Likewise, CS projects are known to have initiated local action to, for instance, implement conservation measures (Tudor and Dvornich 2001, Bird et al. 2003). In the same vein, Virapongse et al. (2016) found CS projects to be able to establish co-management of an ecological system by citizens, agencies and scientists.

Questions

Does the project aspire to enhance institutional trust and/or the overall trust in the (management of the) system under study?

Does the project wish to raise the scientific literacy of society, increase trust in scientific processes, and/or boost the societal acceptance of the research results?

Does the project seek to strengthen the social capital of the community?

Does the project aspire to increase the community valuing or engagement with their surrounding environment and/or spark local action or political participation?

Critical reflection #1

Is CS valuable?

Before continuing to the define phase of the project, it is critical to evaluate on the combined identified desired outcomes. As was mentioned before, reflecting on desired outcomes allows project managers to determine the fitting approach, which is certainly not in all cases a CS approach.

Before continuing, the project team should carefully consider the balance between individual, scientific and system outcomes. If for any of these categories no or only very vague outcomes can be determined, CS might not be a suitable approach (Shirk et al. 2012). CS employed only to achieve scientific outcomes, while at the same time (largely) dismissing individual and/or system outcomes, cannot escape the supposition that participants are only used as a cheap workforce. On the other hand, a project primarily focussing on system outcomes, also raise caution, certainly when initiated by non-research institutes. For instance, if the main focus of a project is strengthening of trust in the initiating agency, one should ask the question how such projects differs from a marketing campaign.

Critical reflection #1

These concerns are also underscored by the European Citizen Science Association (ECSA), as they place the involvement of citizens in scientific endeavours that generate knowledge or understanding, as well as the need for genuine scientific outcomes of CS projects, as the first two principles of CS (Table 3, ECSA 2015).

Besides 'checking a box' confirming the formulation of desired outcomes, this critical reflection allows reconsideration and careful formulation of these outcomes. As these outcomes form a basis on which the further study will be built, it is advisable to take time to develop these, potentially also discussing the different options with possible partners. As was argued for, we advise a combination of all three individual, scientific and system outcomes to be desired. Yet, developing these (as well as other steps yet to come in this guidance) can also be considered an iterative process, which can be elaborated on and further defined after considering additional elements of the potential project.

Question:

Does the project desire to obtain both scientific, system and individual outcomes through the CS project?

– Yes: continue to the next step
– No: Reconsider desired outcomes. If the answer remains no, try to formulate them further whilst going over this guidance. If only very few outcomes remain desired, consider whether CS is a suitable approach for your project

Critical reflection #1 hypothetical CS initiative

For the hypothetical CS project in Lange Erlen, desired outcomes are determined on an individual, scientific, and system level.

3 Step 2: Define

3.1 Define and identify target participants

Although citizen-science projects vary widely in their subject matter, objectives, activities, and scale, they have one thing in common. The involvement of participants is crucial to the success of each individual CS project. Given that citizens using their spare time contributing to science should never be seen as granted, it is advised to define and identify the target participants of any CS project in an early stage. This step involves both defining the preferred number of participants as well as the background of these participants. Both choices affect, among others, the research strategy, the recruitment strategy, and optimal CS approach.

Number of participants

The number of people engaged in CS projects varies widely, from several dozen to hundreds of thousands. For instance, the Big Garden Birdwatch project in the UK involves nearly half a million citizens every year in bird count surveys during one weekend of January (Kobori et al. 2016), whereas the Galaxy Zoo project received more than 50 million galaxy classifications during its first year by more than 150,000 people (Raddick et al. 2013). Next to these big CS projects, there are numerous projects with only several dozen of participants, including the 'Freshness of Water' project on the microbiological stability of drinking water, with 43 participants (Brouwer et al. 2018), and the DNA barcoding project, with solely 39 participants (Marizzi et al. 2018). There is no linear relationship between the number of participants and the quality of a project. When carefully designed, also small-scale CS projects have shown great potential to produce scientifically exciting results (Gadermaier et al. 2018).

Based on a 2016 large-scale explorative survey of the European CS landscape, Hecker et al. (2018a) found that the average number of participants who engage occasionally is about 7,900 per project, and the average number of citizens engaged continuously, over a long period, about 1,800. Based on these numbers, (Hecker et al. 2018a) have estimated that in Europe, at least 1.2 million people have participated once (or more) in a CS project. Today, the actual number of CS participants is undoubtedly much higher. Indeed, back in 2014 (Bonney et al. 2014) argued that even by that time thousands of scientific projects involved millions of citizens. And as the number of CS projects is growing fast, it is safe to assume that since then this number has certainly risen dramatically.

Although no conclusive answer can be given on the number of potential participants, this fact should in no way be a reason to scale back the level of ambition. There is no reason to assume that the maximum potential has been reached. In fact, based on the response rate of three CS projects in the Netherlands that invited random households to participate, it can be inferred that the potential of CS participants in the Netherlands alone may be in the millions (Brouwer and Hessels 2019).

What, however, should be taken into account when determining the preferred number of participants, is the difference between the number of registered participants and the number of active participants, i.e. participants who actually perform all the requested steps.[1] When a project runs over a longer time, one should also consider the possibility of drop out.

[1] The difference between the number of registered participants and active participants varies widely. For example, in The Clean Water Experiment project, only 36% of all registered citizens actively participated. In the Freshness of Water project, instead, this percentage was 100% (van der Meulen et al. 2018).

Questions
What is the preferred number of participants from the perspective of the desired scientific outcomes, system outcomes, and individual outcomes? Looking at similar projects or other relevant experiences, what is the expected drop-out rate along the project? What is the minimum number of participants to reckon for drop outs and to allow for statistical analysis?

Background of participants

Target participants hypothetical CS initiative
The target participants of this hypothetical project would be the people spending time in the recreational area of Lange Erlen. Within this specific group, the project aims for a diverse group of 1000 active participants. To reach this number, the project aims for 2500 downloads of the (to-be-developed) app.

As Haklay (2018) notes, *"If participation in citizen science was spread evenly across the population, about one third of participants would be expected to have tertiary education, and about 1–2 per cent to have a doctoral degree. Yet, the evidence points to a different picture"* (Haklay 2018: 55). Indeed, when looking at the educational background of CS participants, we find again and again that people with higher education are overrepresented in CS (Strasser and Haklay 2018). CS projects with over two-thirds of the participants holding a university degree are by no means exceptional. For example, in Galaxy Zoo, a project in which participants classify galaxies and help astronomers to understand the structure of the universe, 65 per cent of participants had tertiary education and 10 per cent had doctoral-level degrees (Raddick et al. 2013). Recently (Haklay 2018) have claimed that across projects, the participation of people with tertiary education is at least twice the level in the general population, and the participation of people with doctoral-level education at least three times higher.

The fact that the participants of most CS projects do not give a faithful reflection of society is related to various reasons, including the complexity of the task. What's more, it could be argued that a non-faithful reflection of society is by no means necessarily problematic. Many projects, for instance, are intentionally designed to primarily increase the quantity of data or to answer specific scientific questions and do not aim for, for instance, broadening the impact of science (Bäckstrand 2003). Projects that, however, aim for issues such as enhancing the societal relevance of science (Lamy-Committee 2017) or enhancing the public acceptance of scientific outcomes (McKinley et al., 2017) greatly depend on the condition that a diverse (representative) sample of citizens is involved in the project. Other projects may instead intentionally aim for the contribution of specific groups, such as pupils, students, women, indigenous people or other specific (underrepresented) groups (Bäckstrand, 2003).

Questions
Does the project aspire to reach a specific group? Does the project desire to broaden the impact of science, to enhance the public acceptance of scientific outcomes or to increase the societal relevance of science? In short: is representativeness diversity of participants important?

Critical reflection #2

Is CS possible?

Next to a careful consideration on the preferred number and type of participants to involve, it is important to reflect on the expectations that these participants may have in relation to the project, and more broadly, the question of why citizens may choose to volunteer and contribute their time and energy to this CS project. What are the motivations of citizens to participate? What do they get out of it?

Over the past decade, the motivations of CS participants have been increasingly taken into consideration. Based on the literature available, it is evident that citizens participate in CS projects for many different reasons (Jennett et al. 2014). For example, based on a project centred around deceased birds and marine debris on Pacific beaches in the United States, Haywood (2016) maintains that participants participate because of a “greater awareness and appreciation for the coast”, a “sense of satisfaction and contribution”, and “learning and gaining knowledge”. This finding is consistent with that of Price and Lee (2013), who claim that especially the social aspects of projects are appreciated.

In relation to the before-mentioned Freshness of Water project, Brouwer et al. (2018) come to a somewhat different conclusion. Although they indeed do find that some of the project participants are largely motivated by the prospect of fun/ interest to carry out tests/measurements, in their study, the feeling of “contributing to innovative scientific research” is the most mentioned primary motivation for participants, followed by a “special interests in drinking water”, i.e. interest in the research topic. Also other studies (e.g. Raddick et al. 2013, Haywood 2016, and Alender 2016) claim that more than just the collection of data and contributing to research is important to the participants, including learning new information, contributing to original research, enjoying the research task, sharing the same goals and values as the project, and helping others and feeling part of a team.

A recent study (Brouwer and Hessels 2019) suggests that the motivation of citizens to participants in CS projects relates to both age and educational level. Based in a number of CS projects in the Netherlands water domain they claim that the interest in the particular topic of study seems more important for the more older participants, whereas younger participants seem more strongly motivated by the fun element or the opportunity to carry out measurements by themselves. In addition, they claim that citizens with the lowest and highest education levels tend to be more often motivated by the fun element.

Question:

Are the motivations of the target public in line with the desired individual outcomes?

- Yes: continue to next step
- No: Is it possible to choose a different target public with motivations better suiting to your desired outcomes? If not, CS is no suitable approach for the project.

Critical reflection #2 hypothetical CS initiative

To align the project with the motivations of the target participants, we have contemplated on four considerations. Firstly, we evaluated whether participant would be willing to be active at this specific site (go there). As our target participants are the visitors of the area, we do not expect this to be a problem. Secondly, we considered whether the study would be of interest for participants. Biodiversity monitoring has proven to be a topic of interest for already thousands of citizen scientists and can harvest high participation rates (e.g. see eBird project, Sullivan et al. 2009), therefore also this is not expected to be an obstacle. Thirdly, specific motivations to participate were evaluated. Acquiring species identification skills and participate in monitoring are main motivations mentioned by

Critical reflection #2 hypothetical CS initiative
participants in other studies (e.g. see National Institute of Invasive Species Science CS program, Crall et al. 2013). In addition, the success of the Dutch BuitenBeter project, featuring an app through which citizens can report on the street, such as dirty bus shelters, dumped garbage bags or holes in the bike path, suggests that people may be also willing to signal irregularities in the park. This function (encompassing the upload of geotag photos) will be integrated in the app as an additional feature in the hypothetical CS case.

3.2 Define research strategy

Unlike various other steps in this guidance, defining a research strategy may be a rather familiar step. Based on the desired scientific and system outcomes, a specific research topic can be determined, accompanied by a research question. After the establishment of the research question, it is important to think about the amount and type of data needed to answer this question, along with the possible research design and approach. The research strategy affects, among others, the spatial and temporal scale of the research, as well as the most appropriate CS type.

Research question

A first step to developing a research question is doing some preliminary research on the topic defined in the desired scientific outcome stage. As it is important that the research question is well connected with established theory and research (Bryman, 2008), it is advised to do a few quick searches in up-to-date journals and relevant reports to see:

- What has already been done when it comes to your topic?
- What further study is recommended?
- What questions occur to you when reading these recent publications?

Answering these questions and assessing what issues are scholars discussing helps to narrow the focus. The next step is to formulate one or more questions about the topic, obviously taking into consideration the answers on above questions, followed by an evaluation of these newly formulated questions to determine whether they would be effective research questions, or alternatively, need to be revised. Similar to other types of study, a research question in a CS study is best when it is clear, focused, and precise (Pocock et al. 2014). In addition, it should be researchable and behold the promise of adding an original contribution to the field of study (Bryman 2008).

Research design

After the establishment of the central research question, it is important to think about the amount and type of data needed to answer this question, along with the possible paths the research could take. This includes the consideration of a suiting research design. Five distinctive main research designs can be distinguished, differing mainly in their applied temporal and spatial scales: experimental design, cross-sectional/survey design, longitudinal design, case study design and comparative design (Bryman 2008). In practice, also a combination of these designs can be applied.

- Experimental design, i.e. testing the development of dependent and independent variables in a semi controlled, randomized setting. Occasionally CS studies apply a field experiment design (Dickinson et al. 2010). CS can be used to test predications or hypotheses on a local or larger coordinated scale. Schröter et al. (2017) refer to various CS studies in which an experimental design was successfully used to involve citizens in the collection and analyzation of cause-and-effect relations.

- Cross-sectional or survey design, i.e. a standardized way of collecting a small amount of data from a large sample of people. Although also this research design is not very common in CS research, some CS studies apply a survey design commonly combined with monitoring efforts (Bell et al. 2008). Moreover, participants in a CS project are commonly asked to answer survey questions themselves as to monitor the fulfilment of desired individual and system outcomes (Cooper et al. 2007, Brouwer and Hessels 2019).
- Longitudinal design, i.e. performing monitoring activities more than one time by, for instance, re-taking a sample or repeating a survey. This research design is common in CS, as participants are for instance asked to register their observations of bird over a longer period of time (Sullivan et al. 2009).
- Case study design, i.e. studying and analysing one single case intensively. When CS is applied to a specific local issue a case study design might be fitting. Case studies in CS are linked to desired outcomes such as community building and social capital creation (Overdevest et al. 2004).
- Comparative design, i.e. carrying out two or more studies with one of the other designs in more or less the same moment in time. This approach allows for the comparison of findings over geographically dispersed research areas (Bryman 2008).

Research approach

Besides the research question and design, also the method of data collection and research approach should be determined. This includes the choice for either a quantitative or qualitative research approach. In general, a quantitative research approach is linked to deductive research. The focus of this approach lays on the testing of theory and hypotheses and it originates in the natural sciences. Within CS research, a deductive strategy can, for instance, be linked to target monitoring strategies, doing observational tests of hypotheses directed at specific questions. Opposing this strategy, qualitative research often applies an inductive approach, focusing on the generation of new theory emerging from the data and is commonly linked to the social sciences. The presence of quantification is frequently used as a simplified manner to distinguish between the two (Bryman 2008). Nonetheless this seemingly strict division between quantitative and qualitative research, within CS projects the appliance of both a inductive and deductive approach are commonly linked to a quantitative strategy (Dickinson et al. 2010). For example, surveillance monitoring is related to a inductive strategy, observing without a hypothesis in mind, collecting data to answer multiple potential questions (Dickinson et al. 2010). While targeted monitoring in CS projects can be used to evaluate hypotheses, surveillance monitoring allows for addressing unanticipated developments of the observed units (e.g. threats to biodiversity) (Dickinson et al. 2010).

Research strategy hypothetical CS initiative

The main research question of the project is What are the long term biodiversity developments in the Lange Erlen recreational area and how are these related to infiltration activities at the demonstration site? To answer this question, the project aims to combine the data collected through CS with data provided by the demonstration site owner. To collect the relevant data, between 6-10 proxy species will be selected signalling biodiversity and potentially also water quality. These species will be animals (birds), plants and fungi. The study will have a quantitative and deductive nature, applying a longitudinal design.

Questions
What is the central research question?
What is the amount and type of data needed to answer this question?
Based on the above, what is the optimal research design?
Does the project aspire to test a hypothesis? – Yes: apply a deductive research approach and determine based on your research question if a qualitative, quantitative or mixed method is most suitable. – No: apply an inductive research approach in which you develop theory. Determine based on your research question if a qualitative, quantitative or mixed method is most suitable.

4 Step 3: Determine

4.1 Determine the optimal spatial scale

Based on the desired outcomes and research strategy of the project, the optimal scale can be determined. CS projects operate at multiple spatial scales (Cooper et al. 2007, Hecker et al. 2018b). Projects can span local (Brouwer and Hessels 2019), regional (Bird et al. 2003) or (supra)national boundaries (Sullivan et al. 2009).

Spatial scale hypothetical CS initiative
The spatial scale of this CS project is clear. As the project aims to map the biodiversity development within the Lange Erlen recreational area, this will also be the spatial scale applied.

Within CS a distinction can be made between two main spatial models: projects at one-single location, i.e. community level CS (Bird et al. 2003) and projects taking place at various locations, i.e. geographically dispersed CS (Sullivan et al. 2009). The choice for a specific model might be influenced by the research strategy and established outcomes of the *desire* phase. CS focusing on a specific community level is more tailored to add specific local knowledge to a study, hereby adhering to one of the desired scientific outcomes. On the other side of the spectrum, CS on a geographically dispersed scale allows for the creation of a large data set (scientific outcome), and, for instance, cultural exchanges and global citizenship (system outcome).

Questions
Are data gathered on one single local or regional scale sufficient to answer the project's central research question? Do the desired system outcomes require a local, regional or (supra)national scale? What is the optimal scale based on both the research design and the desired system outcome?

4.2 Determine the optimal temporal scale

Temporal scale hypothetical CS initiative
As the project wishes to study biodiversity development over a long time period, we opt this CS project to have a minimal lead time of 5 years, potentially longer.

Next to the spatial scale, also the optimal temporal scale of the project has to be determined. CS projects can span the entire temporal range of scientific enquiry, from once-only measurements, requiring single moment participation of members of the public, short-term initiatives, lasting several days, weeks or months, to long-term projects lasting several years, and requiring longstanding commitment of participants (Dickinson et al. 2010, Hecker et al. 2018b).

The optimal temporal scale is first and foremost determined by the research strategy. Once-only or short-term initiatives are often connected to, for instance, to map litter, invasive species, or to address other current issues. Long-term projects often involve monitoring activities, for instance related to the weather or animal populations (Hecker et al. 2018b). An important challenge to take into account when considering a long-term project, is the obvious fact that such projects need the ongoing collaboration of participants, and consequently, additional and long-term efforts to inform, motivate and engage participants (Hecker et al. 2018c). One can imagine that drop-out rates may increase with longer-term projects, affecting the number of participants as established in the *define* phase.

Questions
Does the research require long-term data series? – Yes: design a long-term project, and invest in the ongoing collaboration of participants – No: Is a once-only measurement sufficient? – Yes: design a once-only project – No: design a short-term project, lasting between several days to several months. The optimal length is determined by the required number of measurements in combination with the required intervals.

4.3 Determine the most appropriate type of Citizen Science

An important step in every CS design trajectory is to decide on the most appropriate type of CS. Over the years, there has been considerable debate among scholars between the different types of CS based on the variety of forms in which it is practised (Buytaert et al. 2014). Such typologies are typically based on the varying degrees of participation in the research project. The degree of participation has been measured in various ways, but can be captured by the following definition: the extent to which individuals are involved in the process of scientific research: from asking a research question through analysing data and disseminating results (Shirk et al. 2012). Other indicators for quantifying the type of CS include the number or types of participants and the duration, or the effort of involvement from members of the public.

Bonney et al. (2009a) have arguably made the most influential categorisation of types of CS projects. They classified CS projects based on the degree of participation and distinguished between so-called *contributory*, *collaborative*, and *co-created* CS projects (Bonney et al. 2009a). *Contributory* projects are those in which citizen merely collect data for scientists to use in their research, in *collaborative* projects citizens also assist scientists with the analysis of this data, whereas *co-created* projects are characterised by the fact that the study is entirely designed and executed by citizens and scientists (Bonney et al. 2009a). Shirk et al. (2012) further expanded on this framework by adding two new typologies on either side of the spectrum. They distinguished *contractual* CS projects, in which the public consults the scientific community to answer specific research questions but is not involved in the data collection itself. On the other side of the spectrum, they identified *collegial* projects, in which members of the public are fully in control of a study (Shirk et al. 2012).

Table 1 provides an overview of the three most common types of CS projects. The table makes a distinction between the involvement of the public in the various research steps. The briefly discussed *contractual* and *collegial* approaches are omitted, as the degree of participation in these forms is either very small (making it difficult to distinguish this form from 'ordinary' science), or very large (and hereby beyond the scope of this guidance for professionals).

Table 1 **Typology and description of (the involvement of the public in) citizen science projects** (Table based on Bonney et al. 2009b). The letter 'P' indicates that the public participates in this step of the research process,(P) that the public *may* participate, whereas the letter 'I' indicates that the public executes this step independently

Type of project	Contributory	Collaborative	Co-created
Role of citizens	Contribute samples or data to a research project	Collect data and analyse results together with scientists	Work together with scientists to develop and execute a research project
Choose/define research question			P
Develop hypotheses			P
Design methods for data collection		(P)	P
Data collection	I/P	P	P
Data analysis	(P)	P	P
Interpret data & draw conclusions		(P)	P
Dissemination & Implementation		(P)	P
Evaluation			P

In practice, the distinction between the various types of CS are often difficult to pin down, also because in reality, some projects use a combination of approaches (Cornwall 2008). In fact, contributory projects may still allow participants to analyse the data (Tomasek 2006), and many co-created projects only have a select number of participants that are involved in the project as a whole, while others keep their role limited to certain tasks (Shirk et al. 2012). These final points are linked to an arguably even more important characteristic, namely the *quality* of participation in CS projects (Shirk et al. 2012). The quality of participation indicates to what extent the project meets the "needs and interests of the public" (Shirk et al. 2012). This implies that a project with a very low degree of public participation (e.g. the public only contributes data) may still be classified as high-quality, whereas a project with a high level of public participation can be low-quality if the research question is not relevant to the public. This characteristic of CS projects, again, emphasizes the need to carefully consider desired outcomes at the start to enable the selection of most appropriate choices.

Table 2 summarizes the various advantages and disadvantages that have been suggested for the different types of CS that may provide guidance into determining which type of CS optimal within a given context.

Table 2 Overview of advantages and disadvantages for different types of citizen science
(Compiled from (Lawrence 2006, Bonney et al. 2009b, Conrad and Hilchey 2011, Shirk et al. 2012)

Type	Contributory	Collaborative	Co-created
Advantages	– May create long-term data sets – Large quantity of data – Technical skills for individuals – Increased knowledge of system for individuals	– Some learning opportunities for all partners, both for skills and knowledge – High data quality – Increased trust among partners – May change attitudes of participants –	– Most responsive – Diverse and profound learning opportunities for scientists and individuals – Increased trust among partners – Contacts with other viewpoints may change attitudes of participants – No external funding may be needed – More societally-relevant research questions
Disadvantages	– Decisions may be slow – Low participant diversity – Limited learning opportunities – Medium time investment from all partners – Lower generation of trust between partners – Retention of participants most difficult	– Difficult to replicate – Decisions may be slow – Medium time investment from partners – (Partial) choice between scientific progress and science education	– Medium data quality – High time investment from individuals, low for scientists after set-up involving extensive training – Difficult to replicate – Commitment to intensive consensus model required – Slow process – Mostly aimed at social outcomes rather than scientific – May have non-diverse participants

To date, the most commonly applied CS approach for CS is the *contributory*, in which participants are asked to collect data, mostly in the form of observations (Tweddle et al. 2012, Pocock et al. 2014, Ramirez-Andreotta et al. 2015). Currently, this approach is also increasingly applied in the analytical phase of a research, asking participants to perform more labour intensive analytical tasks, demanding human expertise in pattern recognition. In literature this is referred to as the crowd sourcing of data interpretation (Tweddle et al. 2012). Crowd sourcing enables participants to perform simple or small tasks on a computer (e.g. classifying images). This contributes to the analysis of large datasets, not achievable by a 'normal' research team (Pocock et al. 2014). Another development in the *contributory* approach, is the increasing use of sensors, generating data automatically or with minimal management. Scientists analyse the data collected by participants using these sensors.

Citizen science type hypothetical CS initiative

Reviewing the established research design, as well as the desired outcomes, a contributory CS project seems most fitting. The largest group of participants will contribute to the data collection at the site. This will happen mainly independently, as participants will report their observations through the app. From the active participants, a small enthusiastic group will be asked to help analysing the data. This latter group will be more closely involved and would also receive training.

While a *contributory* approach allows the engagement of a variety of participants and data collection over a wide geographical scale, participants are found to be less involved and the project itself might not be relevant for the targeted audience. In *co-created* projects, on the contrary, the relevance of the project for the target audience is central, as they are involved from the very beginning. This approach is supported by Bradbury and Reason (2006), who state that the project design should not be determined by researchers alone. Instead, they advance that a participatory method should be used during early project planning phases. Increased participation has the potential to open doors to a wider range of (potential) outcomes, thus enhancing the level of impact of the project (Shirk et al. 2012). Selecting a *co-created* approach thus includes a re-assessment of the pervious steps discussed in this guidance. It implies the assemblage of a mixed project group, including participants, which together formulates the desired outcomes and re-follows the steps of this guidance. As such, this project form thus requires the inclusion of participants in every stage of the project. It demands the willingness to share goals, to listen and adapt and to stay committed to the project (Tweddle et al. 2012).

Determining the optimal CS type should be done carefully, as it strongly influences the further setting up of the project. As was mentioned before, the formation of a combination of types is not uncommon. It is recommendable to first assess what type fits best in relation to both the research strategy and the desired outcomes, and next to compare the relative cost and benefits. The following questions can guide a project group while determining where the project fits on the spectrum between *contributory* and *co-created* projects.

Questions

Does the project aspire to collect large amounts of data that are difficult/inefficient to collect using other methods?

- Yes: A contributory project can be of interest for you as it allows for the collection of data over wide geographical scopes or in very fine resolutions (Tweddle et al. 2012).
- No: A co-created project allows for the close involvement of a small number of participants, in which a consensus can be reached (Tweddle et al. 2012).
  If your project not requires a very large database and also allows for the inclusion of participants in more than one stage of the research a collaborative project might fit your needs.

Does the project aspire to collect context dependent local knowledge?

- Yes: A co-created project allows for a very local focus, having the local community closely involved and answering a locally-relevant question (Tweddle et al. 2012).
- No: In a contributory project the involvement of participants is less intense compared to co-created or collaborative, therefore this method is less suitable to extract specific local knowledge. It does allow for the monitoring of specific developments in an area, for instance the occurrence of specific (non-)native species (Tweddle et al. 2012).
  When your research could benefit from local knowledge, however involvement of participants in all research stages is not desired/possible, a collaborative approach might suit your project.

Questions

Does your research require repeated measures over time (by the same participants)?

- Yes: Having participants take repeated measurements over a longer period of time requires commitment. Therefore a co-created or collaborative project may be advisable in this case, as the goal sharing of participants and researchers allows for involvement over time and continuous training is possible.
- No: If you do not need participants to stay involved after the first measurements (or this is at least no necessity) a contributory project might suit.

5 Step 4: Develop

5.1 Develop a recruitment strategy

Although recruiting participants is integral to the success of each individual CS project, very little has been published about different CS recruitment strategies. An exception is the paper by West and Pateman (2016), who, to this end, draw on the volunteering literature, and an empirical based paper by Brouwer and Hessels (2019). Whereas the former distinguish between the recruitment strategies (i) word-of-mouth, (ii) the use of third party organizations, and (iii) the scattergun approach, the latter study presents in addition to these a fourth, so-called targeted strategy, i.e. the use of targeted invitations, as opposed to a non-targeted or generic invitation strategy, aligning well with the scattergun approach.

- Word-of-mouth; i.e. person-to-person communication between participants and potential new participants of CS projects, whereby existing participants act as advocates for the project. This strategy is especially effective when existing participants are particularly passionate about the project (Russell 2009). Another particularity, or perhaps disadvantage, of this way of recruiting is that this approach is likely to attract people who are already engaged in volunteering.'
- The use of third party organizations, such as volunteering agencies and educational establishments, brokering volunteering opportunities. This strategy may well function to reach specific groups, such as young people, minorities, and unemployed participants. The support of the community leader or alike is a critical success condition for this way of recruitment.
- The "scattergun approach", i.e. advertising to large numbers of people, but no one in particular. This strategy could include the use of social media, such as posts on Facebook and Twitter messages, press releases to get newspaper, television, and radio coverage, and posters or leaflets in key locations, such as libraries, universities and visitor centres. The advantage of this strategy that it is an easy approach to reach many people. However, it can be expected to create a bias towards people that are receptive to the particular media employed.
- Targeted invitations, i.e. sending out personal invitations to a random sample of the population. Brouwer and Hessels (2019) maintain that by the use of this strategy, it is possible to achieve a higher diversity in participation. Indeed, projects that recruited participants making use of targeted invitations managed to attract a significantly more citizens with lower level education and diversity in age. This is notable because CS projects are known to attract mainly highly educated participants (Overdevest et al. 2004, Brossard et al. 2005).

Recruitment strategy hypothetical CS initiative

Since the aspiration is to involve participants who are already visitors of the area, the recruitment would mainly aim at people at the site. An important element of the recruitment strategy are information boards at the entrances of the park. On these boards the project is explained and a QR-code for downloading the app is provided. Similar boards could also be placed at picnic areas or parking lots destined for visitors of the area. Moreover, the project will also be announced with signs in the tramline passing by the Lange Erlen area, asking people to join. Relating this back to the typology of recruitment strategies offered, this could be considered a scattergun approach, however with a strong spatial focus. Besides this, also a worth-of-mouth approach will be applied as students of the School of Life (closely collaborating with the utility site) will be stimulated to join.

As said, recruitment of participants to analyse the data will be done out of the pool of active participants already using the app. Every 3 months the 20 most active participants will be asked if they would like it to become more involved in the project and if so, receive an invitation for a training day.

In practice, also a combination of these approaches might be suitable. However, to establish the most relevant approach, it is advisable to consider both the determined CS type and project spatial and temporal scale, along with the preferred number of participants as well as the preferred background/diversity of these participants.

Questions

Does your research require a large number of participants?

– Yes: consider the scattergun approach. The advantage of this strategy that it is an easy approach to reach many people.

Does the project aspire to reach a specific group?

– Yes: the use of third party organizations may well function to reach specific groups, such as young people, minorities, and unemployed participants.

Is representativeness diversity of participants important?

– Yes: the targeted invitation strategy allows for the participation of a more representative group

5.2 Develop a credibility protocol

Although CS proves a successful way to collect large amounts, as well as specific types of data, the credibility of the data collected in CS projects are still every so often criticized for being biased, of uncertain quality, or of a lower accuracy (Dickinson et al. 2010, Freitag et al. 2016). Freitag et al. (2016) recognize that while CS projects desire to deliver to the same standards as academic science, they are usually subjected to different context. Participants in a CS projects for instance frequently need to be trained and monitored with only limited resources available (Freitag et al. 2016). Besides, CS approaches are scrutinized on their ability to gather large amounts of samples through the involvement of non-professionals, as this could lead to reduced data accuracy (Gardiner et al. 2012). That being said, it has also been argued that large databases, such as can be generated with CS, can accommodate a proportion of error while remaining high quality (Ballard et al. 2018). Furthermore, it has to be acknowledged that in the end of the day all data, including professionally collected data, have an error rate or some degree of variation between observers (Robinson et al. 2018). Accordingly, also the ECSA (2015) urges to consider CS a research approach like any other, including biases and limitations that should be reckoned for and handled with.

Thus, as is important in any research, paying careful attention to the insurance of the credibility of the collected data and performed analysis is crucial. In order to make the validity and reliability of the data evident, organizing institutions and CS project leaders have a responsibility to control, measure and report data (Robinson et al. 2018). In reviewing the potential threats to the credibility of a CS project, several moments of consideration can be identified. One can filter out biases during the setting up, in the field and after data collection of a project.

Research design phase

During the general research design phase, several measures can be taken to enlarge credibility. First, before drawing up a data collection and engagement protocol, it is valuable to check whether there are research standards available potentially guiding and standardizing the data collection. Using these existing protocols can ensure comparability with other studies and potentially endorsement of the research by agencies and institutions active in the same field (Freitag et al. 2016).

A second consideration lays in the selection and preparation of the participants and links to two commonly reoccurring errors: observer and spatial errors. Observer errors, or sampling biases, in which data collection is done unsatisfactory, is often related to the training of participants (Schröter et al. 2017). Guiding participants in their use of the developed protocols and logistics can enhance the credibility of their delivered data (Freitag et al. 2016). Standardized data collection methods, installing benchmarks and/or regular intervals, can also help to reduce observer errors (Dickinson et al. 2010). The second mentioned, spatial error, can occur when participants take a sample in from a location not representative for the area. Also here a careful protocol can guide adequate data collection. Nonetheless, in every project the balance must be found between the creation of a strict protocol, allowing carefully guided data collection whilst reducing the willingness of participants to participate, and flexible protocols, improving the willingness to participate while also increasing the chance of errors (Dickinson et al. 2010). A final point of interest in this regard relates to the possible failing of provided materials, testing kits or, for instance, lower-quality sensors. To ensure adequacy of measurements, it is advised to always thoroughly test the kits well in advance.

An institute aspiring a CS project may consider establish a partnership with an university or other knowledge institute. Such a partnership can provide the scientific advisory necessary to perfect the protocol (Freitag et al. 2016).

Data collection phase

When a project is put into practice and data is being collected in the field there are also several potential actions to enlarge credibility. In case of a long term project, participants of a research can be retrained throughout, improving their data collection skills and prompting involvement. This could further be encouraged through the instalment of a ranking system, by with citizens can improve their level of expertise through training and other activities (Freitag et al. 2016).

Besides this, experts, participants or external parties can be asked to oversee the data collection process and point out errors (Freitag et al. 2016). Other validation measures are the incorporation of control measurement by professionals or, for instance, by asking participants to deliver a form of proof to their observation (Tweddle et al. 2012). This could be for example a picture confirming an observation made. These pictures can be checked by experts on their conformity with the noted observation.

Finally, technological aids can be applied to support data validation and verification of collected data, as well as to ease the more challenging forms of data collection, e.g. automatic location identification (Freitag et al. 2016, Ballard et al. 2018). Given that CS participants often wish to receive rapid feedback, such technology may ease the possible trade-off between feedback time and quality control (Brouwer et al. 2018).

Credibility protocol hypothetical CS initiative

To ensure effectiveness and a user friendly app, the project will base the design of the data collection app on existing apps with a similar purpose. Favourably. The project would also contribute to international databases such as eBird or iNaturalist. Some of these, like the iRecord app, offer a single data infrastructure with local instances for specific user groups like bees, fungi, etc. (Pocock et al., 2018). By aligning our app with large projects like these, we can allow for statistical control of the collected data, as well as insight into larger scale biodiversity developments. Furthermore, also the quality of the data collected can be assured through methodical control of all data collected. We opt to have every record fed into the app classified twice by citizen analyst. If any discrepancies occur, the record will be checked by a professional. Moreover, a random sample of records (e.g. one in every 20 records made) will also be checked by a professional to filter out structural errors. Finally, a statistical check of the citizen data analysists' performances will be performed, to identify participants making numerous errors.

Data analysis phase

Finally, there are several control mechanisms to filter out errors after the data collection. The collected data can be validated through for instance statistic control. In this manner possible errors may be identified, and/or the completeness of the dataset checked. This exercise can be strengthened if the data collection protocol is standardized properly in an earlier stage, allowing for broader statistical control (Freitag et al. 2016). The eBird population monitoring project, provides an example hereof, as it enables data collection on a worldwide scale. Their enormous database allows for identification of volunteers' sampling errors, improving the credibility of the dataset (Sullivan et al. 2009).

In addition, project managers can also chose to filter out the data with certain characteristics. Filtered out data could be the samples collected by first year participants, samples by participants who have submitted only irregularly, or samples of participants who have submitted reports containing errors (Dickinson et al. 2010).

Other ways to check the validity of a projects' data is by performing a cross comparison with the data (of previous studies) collected by professional researchers (Freitag et al. 2016).

Questions

Does the project aspire to create a large data set by using citizen science?

- Yes: Check the availability of standardized data collection protocols. In addition, consider the most appropriate way of training your participants for the data collection (e.g. online training, readings etc.).
- No: Check the occurrence of comparable citizen science projects and discuss their data collection protocol. Alignment can increase the credibility and comparability of the data.

Does the research require repeated measurements?

- Yes: Consider offering participants re-training throughout the project.

Questions
Is it possible to apply technological aids to support data validation and verification of collected data? – Yes: apply and verify the results – No: incorporate alternative validation procedures Is it possible to ask participants to deliver additional proof to their observations? – Yes: apply and verify the results – No: incorporate alternative validation procedures Is it possible to include control measurements by professionals? – Yes: include in protocol and inform the participants – No: ask experts, participants or external parties to oversee the data collection? Is it possible to compare to collected data to an existing database? – Yes: Run statistical checks to filter out errors from the data. If the own collected database is large enough this can also be performed without additional data bases added. – No, but comparable studies are present: compare your outcomes with comparable (academic) studies to validate your findings. – No: Check your data base on irregularities and completeness. Checks can be installed such as the filtering out of data collected by participants who only submit data irregularly, or who have submitted data containing errors.

5.3 Develop the engagement protocol

Before engaging the participants in the actual research phase, it is advised to develop an engagement protocol to streamline the interaction with the citizen scientists. Indeed, the engagement of volunteers using their spare time contributing to science carries a certain degree of responsibility for a project team. By timely drawing up an engagement protocol it can be ensured that the rights and welfare of the participants are respected and protected. In developing such protocol two main considerations are important: (i) how to provide feedback to the participants; and (ii) how to organize the interactions with and between the participants.

Feedback

Recognizing the value of the contribution of participants in the research is considered of crucial importance for ensuring satisfaction and commitment of participants throughout a project. Providing feedback on the 'usefulness' of collected data and how these data relate to the ‘bigger picture’ is therefore vital (Bell et al. 2008, Jennett and Cox 2014, Haywood 2016). Feedback can be provided in different stages of a project. For instance, feedback can be offered to the participants during the data collection process itself. An example of this is provided by the project such as FreshWater Watch or the Clean Water Experiment where citizens are asked to submit their data into an online database, after which these data are very fast or even immediately plotted on an online map and made accessible (Pocock et al. 2018, van der Meulen et al. 2018). Providing a likewise infrastructure allows for a high degree of transparency to the progress of the study and study results, however, is not always possible/desirable. Other forms of feedback are also possible, such as organizing meetings or briefing. Through the provisioning of (real-time) feedback during participation, participants are also informed about their personal progress and the steps still needed to be taken (Jennett and Cox 2014).

In addition to feedback during the data collection phase, certainly also in following phases of the study, i.e. analysis and the interpretation of the data, the provision of feedback is key. Therefore, before starting the project, it is advised to consider how the research outcomes can best be communicated. Be careful to not only communicating the 'why' and 'how' of a project, but also the 'so what'. Participants might expect an institutional response based on the project, even when this is beyond the formal scope of a project (Pocock et al. 2014). It is also possible that certain responses to the scientific outcomes of a project are not in line with the wishes of participants, e.g. the extermination of (maybe attractive but) invasive species (Pocock et al. 2014). In this case, communicating the outcomes and managing expectations of participants must be done with caution. Communicating the study's scientific outcomes can be done in various ways, including the organization of a physical meeting to present the results, sending participants the results via post or email, or providing a platform were participants can access the results themselves. Also important in this context is the acknowledgement of the participants' efforts in the project results and publications, hereby providing participants credits for their work (ECSA 2015, ETH Zurich 2015).

Finally, feedback can be provided to the participants on impact of the study or project in the long term, including influence on policy, management changes or follow-up research. This form of feedback thus requires staying in contact with participants over a longer time period, keeping them up-to-date on the developments and aftermath of the project.

Questions
Is the provision of (real-time) feedback during the data collection phase desirable and feasible?
What is the optimal way to organize feedback on the projects result? (e.g. a physical meeting, post, email, online platform). What way suits best to the wishes of the target participants?
In what manners is it possible to acknowledge the participants' efforts in the project results?
Is feedback on the long term impacts desirable and feasible?

Communication

Besides the provision of feedback regarding the data collection, also the general communication strategy, starting with the recruitment, is something to consider in an early stage. Tweddle et al. (2012) even advise to put together a project team with experts, not only in the field of data collection and analysis, but also in the field of communication and publicity when starting a CS project. In the development of a communication strategy, several aspects previously decided upon might be of influence.

First of all, it is advisable to reach back to the desired outcomes, and to carefully consider how, especially the desired system and individual outcomes might be influenced by the communication strategy chosen. If, for example, there is a desire to spark individual action, a different communication strategy might be applied than when the creation of a community network is desired. Also the earlier identified target group and their motivations can be key in tailoring the communication throughout a project.

Pocock et al. (2014) suggest that communication messages that resonate well to the motivations of participants may increase their commitment. Besides, also the CS type of the project influences the most applicable strategy. Compared to *contributory* projects, *co-created* and *collaborative* projects generally require a closer connection and more communication.

Communication with participants can be set up in several forms: by organizing formal and informal (group) meetings, workshops or trainings, by providing participants readings, by creating an online platform for communication and information sharing, by emailing participants, etc. Several of these allow participants to also interact with each other, which may contribute to the creation of a sense of community amongst participants (Haywood 2016). Also, there are several important aspects to be communicated to the participants. If there are any risks in participation these should be carefully communicated and elaborated on (Pocock et al. 2014). ETH Zurich (2015) advises to design a consensus letter, providing citizens with information on how the collected data will be used and handled and how intellectual property rights are dealt with.

Engagement protocol hypothetical CS initiative

The project aspires to provide participants direct feedback through the app. This would include automated responses on sightings (including giving thanks, as well as praising special sightings). Also a competitive element is included in the app, providing feedback on the relative performance of the participant, as well as naming the top-5 data collectors. To protect their privacy, participants are offered the possibility to remain anonymous. In addition, every three months a newsletter will be send out to all participants reporting on the progress of the study, as well as mentioning the most interesting sightings and best performing citizen scientists. Engagement of participant is further monitored in the app by asking participants to fill in a short survey on their experiences, perceived sense of ownership and gained knowledge. Participants are asked to fill in a survey after 10, 25, 50 and 100 reports made.

To further involve motivated participants, once every three months the 20 best performing participants are invited to become data analysist. In preparation of this they will be offered a one-day training. During this training day participants learn to classify the collected data (which they can thereafter do online at home). They will also be taken on a guided excursion to the closed-of infiltration areas of the treatment site. Through this excursion they will learn more on the background of the study and the working of a combined system. Also the excursion can be seen as a reward for their efforts and a way to say thank you, as well as a moment through which participants can connect with other active participants.

Questions

Is sufficient communication expertise within the project team present, or is extension of the team necessary?

What implications have the established desired outcomes, target group, and CS type for the communication strategy?

Is a platform desirable and feasible to enable participants communicate with each other?

5.4 Develop the data collection protocol

To ensure the collection of useful data, in sound with scientific aspirations, the development of a data collection protocol is essential. In this protocol, which includes an operationalisation of the research strategy, several practical considerations should be made. To start, it is advisable to carefully consider the desired outcomes and appropriate way to collect necessary volumes of data to answer the central research question. To this end, an important step is to consider the type of data needed, and in relation to this, the availability of adequate sampling tools, such as sensors and test strips. The type of data collected in a CS project differ substantially (Pocock et al. 2014), and includes, but is certainly not limited to, the following:

- Observations, including the time and location of the observation. This is the most common type of data collected through CS.
- Images, videos or sound recordings. These types can be further analysed after submission to a data base.
- Physical samples, such as water samples. These can be further analysed by participants, possibly in combination with lab analysis.
- Sensory data, which allows the provision of data that cannot be observed directly otherwise (e.g. radiation) or quantified (e.g. temperature).
- Classifying data already collected. Crowd sourcing allows tasks, such as pattern recognition, to be performed by citizens. Crowd sourcing is considered especially interesting when tasks can be performed online.

Data collection protocol hypothetical CS initiative

In this hypothetical CS project, data will be collected through reporting sightings via an app. These reports will include pictures (of insects, fungi and plants), counting (of plants species per m^2) and voice records (of bird songs). Also some basic data will be collected when participants first enter the app. This includes questions on age, education level and postal code. This data will be stored anonymously.

The app needed to report the sightings will be available for free for both iOS and Android. No safety issues will occur, as data collection will take place in recreational areas and citizens only need to use their own phone.

The data analysis will happen online and participants can enter this through login in on the projects website. All data will be stored in a database and will preferably be compatible with existing databases.

While developing the data collection protocol, Jennett and Cox (2014) advise to assess the expertise level of participants. In this regard, it is important to realise that it may be possible to differentiate between the different tasks within a project. For instance, one may distinguish between basic contribution tasks for all participants and more advanced tasks for the more experienced volunteers. By considering the expertise level beforehand, a project can warrant to provide an intellectual challenge to participants, yet not overestimating them, which is considered vital by both Haywood (2016) and Jennett and Cox (2014).

In addition, a risk assessment should always be performed in this stage of the project, providing the project team insights into potentially hazardous situations that might occur during the sampling (Pocock et al. 2014). Furthermore, in this stage of the project it is recommended to not only consider one's own project, but also look for existing projects. Is there a potential for a partnership with another project, or the sharing of tools and participants? As was stated before, this can potentially save much costs and efforts (Tweddle et al. 2012, Hadj-Hammou et al. 2017).

The data collection protocol also encompasses information on how participants can share their data with the project team, for instance via a dedicated website or mobile application. It is not uncommon in CS projects that participants are simply asked to provide the results of a measurement in the form of numerical data or images. Other types of data provision, however, include a certain level of data interpretation of the participants. This can be in the form of open, multiple-choice or Likert-scale questions. Special consideration might be given to avoid biases in the individual questions such as the use of technical jargon and/or faulty scales (with e.g. overlapping intervals) (Choi and Pak 2005). Also biases in question formatting should be considered. The use of open questions can trigger unwillingness to give answers and too long questionnaires can trigger fatigue amongst participants (Choi and Pak 2005).

Besides the collection of data, it is also recommendable to consider the storage and potential re-distribution of data, as flaws in meta data and accessibility of CS data is commonly considered and obstacle for its usefulness outside a specific project (Dickinson et al. 2010). The ECSA (2015) even goes as far as urging for the public availability of all CS (meta) data collected and open access publishing.

Questions

What data (type and quantity) are needed to answer the central research question?

Are adequate tools (e.g. sensors, test strips) available for non-professional scientists to collect these data? If not, is it viable to design or otherwise acquire the necessary tools?

Are the available tools appropriate for the use by all target participants? Is it desirable to distinguish between basic contribution tasks for all participants and more advanced tasks for the more experienced volunteers?

How can participants share their data, and where will collected data be stored?

Critical reflection #3

Practical pre-conditions

Before moving to the next step, it is important to reflect on a few practical pre-conditions regarding budget, safety and (technical) feasibility.

Budget: although the available funding for the project may be already included in some of the considerations made up to now, after the development of the different protocols, an accurate estimation of the budget necessary to deploy the project can be made. Although the involvement of volunteer participants is the mainstay of CS, (often) substantial investments in resources, money and time are necessary to support CS (Pocock et al. 2014). Partnerships and external subsidies can provide additional funding.

Question:

Is there an adequate budget available for the project, allowing for sufficient data, tools, training of and communication with participants?

- Yes: continue
- No, is it possible to redesign and cut costs, to establish a partnership or acquire external funding?
- No: CS is not a suitable approach.

Critical reflection #3

Safety: another consideration to be made in this critical reflection is the safety of the research. During the development of the data collection protocol a risk assessment should have been performed. Critically assessing whether CS is the fitting approach to the research, bearing the safety risks at hand in mind, should be done very carefully. In addition also the impact on the environment should be kept to a minimum (ETH Zurich 2015).

Question:

Is participation in the developed project safe for the participants?

- Yes: continue
- No: CS is not a suitable approach

Feasibility: finally the (technical) feasibility of the project can be considered. Are all technical necessities available and also understandable for participants? If there exists doubt about the latter, performing a test study with a small group of participants might be advisable. Another option is to offer extensive training (see next section) to make sure the participants will be equipped to perform the data collection or analysis by themselves. Relating to the latter, also the accessibility of the chosen sampling sites need to be considered.

Question:

Is the project feasible in terms of technical equipment required and accessibility of the chosen sampling sites?

- Yes: continue
- No: If possible, reconsider or CS is not a suitable approach.

Critical reflection #3 hypothetical CS initiative

As was mentioned before, there is no technical equipment necessary to perform the data collection besides participants' own phone. Also, no safety issues are expected. Considering funding, for the sake of this hypothetical case we assume funding to be sufficiently available.

6 Step 5: Detail

6.1 Detail the training

The training of participants is often an important element in CS studies for increasing the credibility of the collected data, as well as reducing the risks at hand. Training itself can come in many forms, including face-to-face training sessions, online courses, quizzes and/or readings, and can occur single or multiple times. In designing a training, one can include several components. First, and probably most important, a training can guide participants through the steps of the data collection manual and help them use the data collection tools. Even if the manual is designed in a very user friendly way (see next section), offering additional face-to-face or video training can improve the understanding of users (Jennett and Cox 2014). Moreover a training can offer a stepwise guidance on how to prepare for the data-collection, how to perform the data collection, and how to upload or submit the collected data. Furthermore the training can include tips on how to collect the data in the most effective way and inform participants on who to contact for more information, on how to stay involved, and on how to gain access to additional supporting materials. Finally, a training can also include a way to test the participants ability to take a data sample, for instance in the form of a quiz.

In the process of setting up a training, one has to include the previous design choices. The chosen CS type, for instance, strongly influences the suitability of different training choices. While a *contributory* and *collaborative* approach often only require limited training, a *co-created* approach generally requires intense training and preparation of participants (Shirk et al. 2012). The design of a training protocol also relates to the desired individual and system outcomes. For instance, face-to-face training provides a mean to connect on an interpersonal level with the participants, allowing for the creation of community networks. Likewise, it is important to consider that the extent of the training provided can lead to drop-outs of participants when they consider the training too time consuming. Yet, on the contrary, offering training to participants also uncovers the potential to create a highly involved and committed group of participants (Pocock et al. 2014).

Training hypothetical CS initiative
As was discussed before, a one day face-to-face training will be provided to participants contributing to the data analysis. This training will be designed to prepare participants for analysing the data, as well as to increase their engagement with the project. However, also in the app training will be provided to participants collecting data. Through a video various methods of data collection will be explained and participants will be instructed on how to use the app.

Setting up any form of training requires investments of time and financial means. As was the case for the data collection protocol, also in the case of training participants, it can be beneficial to consult other projects on their developed training programs and materials (Bonney et al. 2014). Conformity can offer both financial and credibility benefits.

Questions
Which elements of the study require training (e.g. how to prepare for or perform the data-collection)?
Considering the data collection protocol and project's profile of target participants, what is the optimal form and frequency of training (e.g. face-to-face training sessions, online courses, quizzes)?
In light of the CS type and desired individual and system outcomes, what is the most adequate intensity of training?

6.2 Detail a user friendly manual

Providing a user friendly manual for participation in a CS project can be key for a careful to secure the accurate and reliable data collection data collection or analysis (Shirk et al. 2012). An adequate and user friendly manual provides the necessary support for participants to complete their tasks, and is well aligned with the capabilities and characteristics of the targeted participants and the training.

A carefully designed sampling manual might include the following elements:

- Information on the purpose of the sampling.
- An overview of the tools and equipment provided for the sampling, ideally presented as written text in combination with pictures
- A list of possible other attributes needed to successfully complete the sampling.
- A specification of the location where the sampling should take place, possibly including tips on how to select the optimal location for sampling.
- A specification on the time at which the sampling should take place.
- A description on how to limit any potential risks involved in the sampling and a warning for probable hazardous substances or precarious situations that might occur.
- An overview of the steps to be taken, plus an indication of the duration of each step.
- A detailed explanation of each step, including pictures and sources of additional information.
- Contact information in case of an error or issue while sampling. Participant might also use this to ask questions on the sampling or project in a broader sense, or pose ideas to the project team.

Last but not least, for the design of a good manual it is advisable to inform if other agencies or projects have any standardized manuals available (Freitag et al. 2016). This could reduce the funding necessary to develop the study and increase its credibility.

User-friendly manual hypothetical CS initiative
In the app itself also a user friendly manual will be included, guiding participants through all steps of reporting a sighting. Through the app participants can also access information on the set up and purpose of the CS project.

Questions
Which elements are needed to include in the manual? Are relevant previous used manuals available or is it feasible to test the clarity of the manual with a small number of participants?

6.3 Detail the logistics

After setting up a training for participants and developing a user friendly manual, the overall logistics can be detailed. Based on the selected temporal and spatial scales for the project a detailed logistic plan can be made, mapping out the important moments in data collection and analysis, training moments, project meetings and so forth. Also practical considerations can be made, such as how to deliver the manual, and if necessary toolkits, to all participants. Based on the selected type of CS, the involvement of citizens in the development of the logistic plan itself can be determined. In *co-created* projects, citizens might be involved in the development of this plan.

Logistic plan hypothetical CS initiative

This hypothetical CS project does not require a very complex logistic plan. The tools for data collection are participants' own phone and the target group are participants already present at the site. Only the organisation of the one day training sessions might need some logistic planning.

Questions

What are the important logistical moments prior, during and after the data collection phase?

What is the optimal manner to deliver the manual and possible tools to the project participants?

Critical reflection #4

Outcome validity check

The fourth and final critical reflection step provides project managers a moment to reflect on the developed project design and to return to the pre-set desired scientific, individual and system outcomes. Going over all of the choices made throughout the project design, do these desired outcomes need reconsideration? And is it plausible that these desired outcomes will be met? Also, is CS a feasible approach to reach these outcomes?

In this final stage one can, once more, assess to what extent the design meets the motivation of target participants, whether they will be able to use the selected tools, and whether the overall design is expected to produce data of acceptable quality (Haywood and Besley 2014, Jennett and Cox 2014). It is crucial to reflect in this stage if truly both scientists as well as participants benefit from taking part (ECSA 2015). By evaluating the desired outcomes in relation to the project design before deploying the project, a deliberated starting point for further evaluation at the end of the project (or intermediate evaluation) is set (Haywood 2016).

Question:

Evaluating the research design, is it expected all pre-set desired outcomes will be met?

- Yes: Deploy
- No: Do alterations of the protocol allow for desired outcomes to be met? If not the case, a CS approach might not be fitting.

Critical reflection #4 hypothetical CS initiative
In this final reflection the desired outcomes are revisited. Considering the pre-set desired scientific outcome of developing insight on biodiversity development over a longer term, the chosen monitoring of proxy species over minimal 5 years will most likely provide the relevant information. Regarding the desired individual outcome of increasing knowledge, it is aspired to educate participants through the newsletter and the app itself. Extra education is offered to participants joining the data analysis phase. To evaluate whether these outcomes are reached, participants are asked to fill in a short survey after the first 10 sightings (and after 25, 50, 100). Also the desired system outcomes to strengthen the relationship of participants with their environment are evaluated through the survey. A potential increase in the awareness of the value of a combined system is mainly expected for the participants joining the training and visiting the treatment site.

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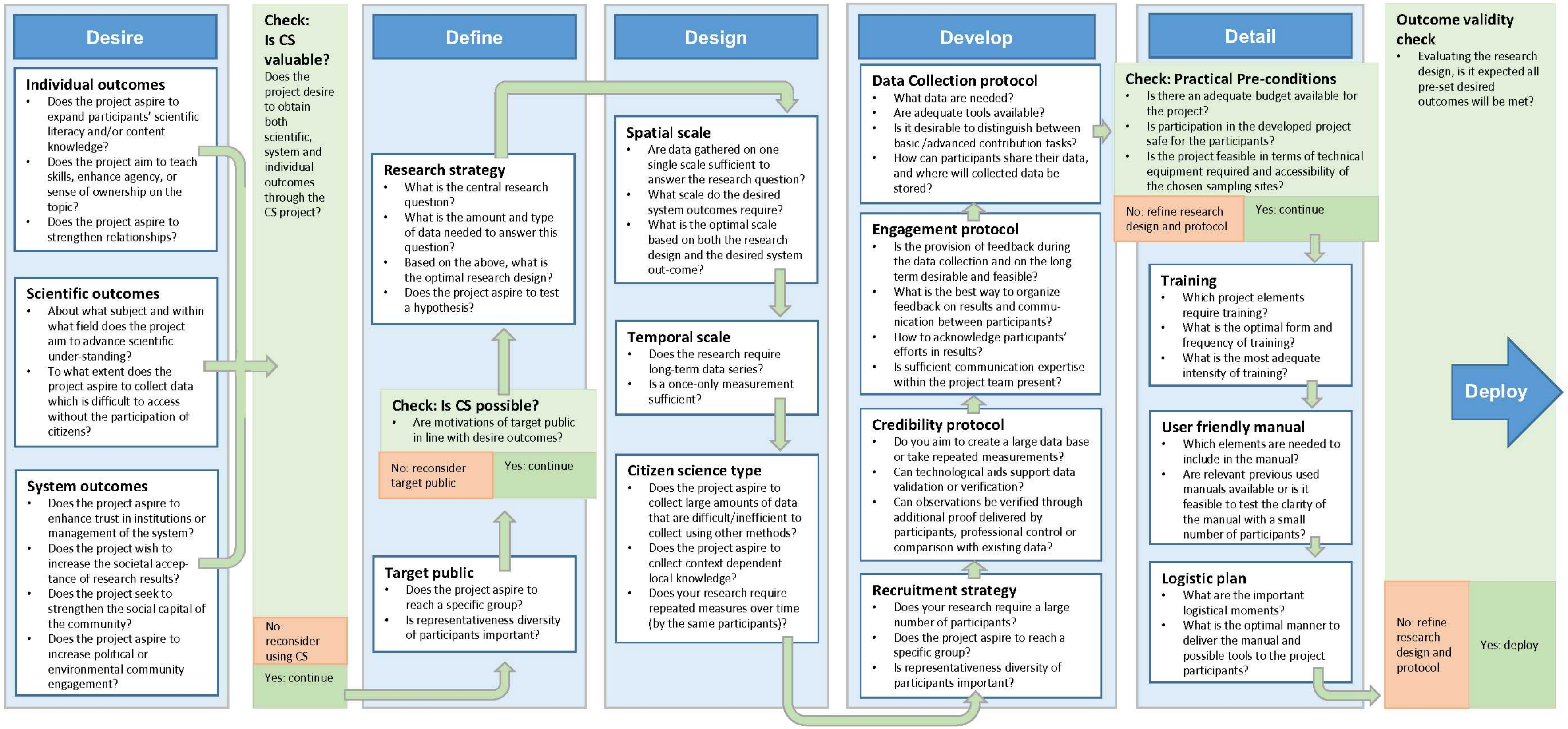
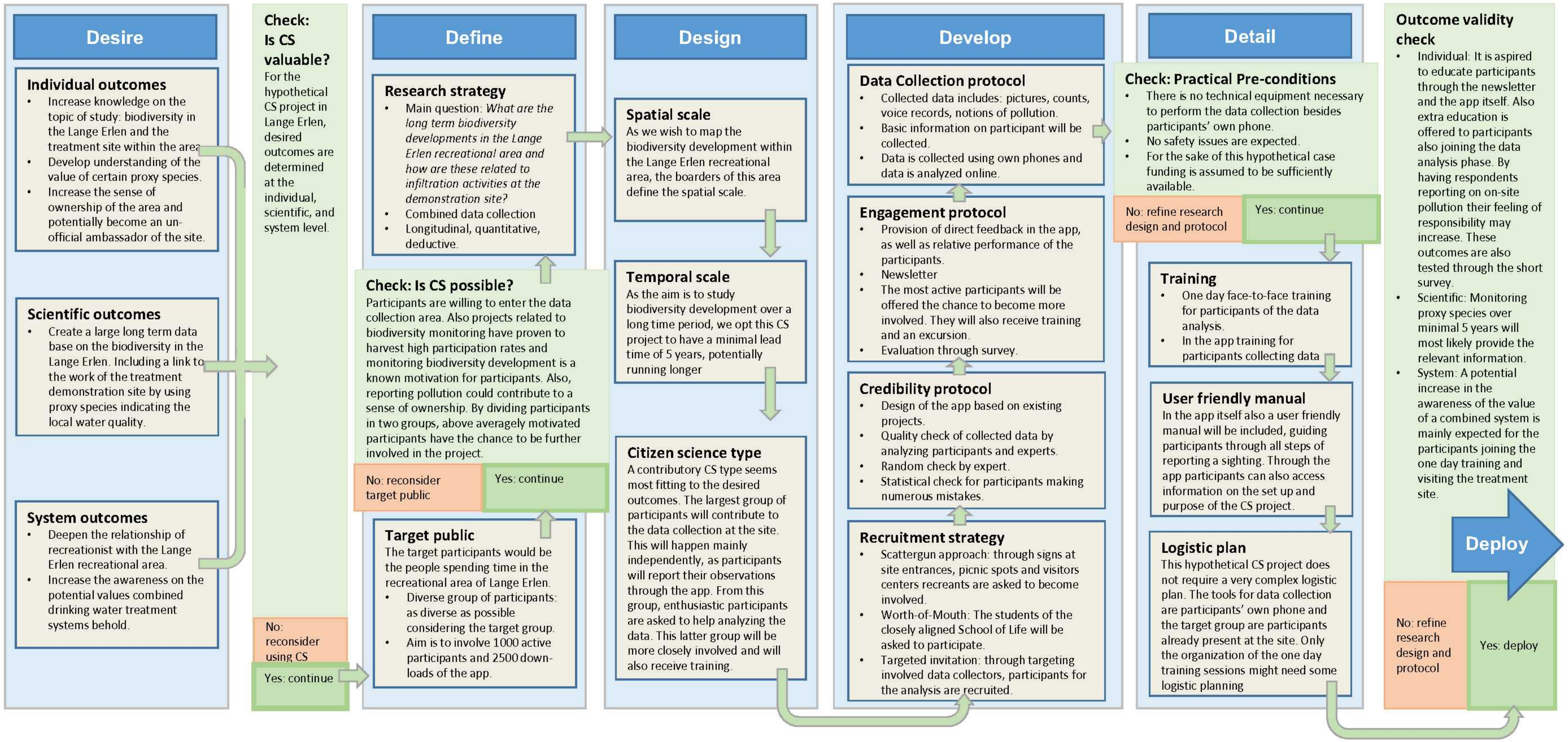
Appendix I: CS design path

CS design path



Design path hypothetical CS project Lange Erlen, Switzerland



Appendix II: ECSA Principles of Citizen Science

Irrespective of the exact form of citizen science performed, it is held to be important to keep a number of guiding principles in mind. Table 3 lists ten key principles underlying good practice in citizen science as established by the European Citizen Science Association (ECSA).

Table 3 ECSA principles of citizen science

ECSA 10 Principles of Citizen Science
1. **Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.** Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project.
2. **Citizen science projects have a genuine science outcome.** For example, answering a research question or informing conservation action, management decisions or environmental policy.
3. **Both the professional scientists and the citizen scientists benefit from taking part.** Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence e.g. to address local, national and international issues, and through that, the potential to influence policy.
4. **Citizen scientists may, if they wish, participate in multiple stages of the scientific process**. This may include developing the research question, designing the method, gathering and analysing data, and communicating the results.
5. **Citizen scientists receive feedback from the project.** For example, how their data are being used and what the research, policy or societal outcomes are.
6. **Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for.** However unlike traditional research approaches, citizen science provides opportunity for greater public engagement and democratisation of science.
7. **Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format.** Data sharing may occur during or after the project, unless there are security or privacy concerns that prevent this.
8. Citizen scientists are acknowledged in project results and publications.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
10. **The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.**

Appendix III: Example Citizen Science Projects

The list below includes several examples of CS projects throughout the world.

- eBird: https://ebird.org/home
- Zooniverse: https://www.zooniverse.org/
- Neighborhood Nestwatch Program: https://neighborhoodnestwatch.weebly.com/
- Data Observation Network for Earth (DataONE): https://www.dataone.org/
- Surfers Against Sewage: https://www.sas.org.uk/our-work/beach-cleans/
- FreshWaterWatch: https://freshwaterwatch.thewaterhub.org/
- Wild Pollinator Count: https://wildpollinatorcount.com/
- International Sea Turtle Observation Registry (iSTOR): https://scistarter.org/
- OspreyWatch: http://www.osprey-watch.org/
- Chimp & See: https://www.chimpandsee.org/#/
- Bat detective: https://www.batdetective.org/
- Galaxy Zoo: www.galaxyzoo.org
- The Shore Thing Project: www.marlin.ac.uk/shore_thing
- mySoil: www.bgs.ac.uk/mysoil
- OPAL: www.opalexplorenature.org/surveys
- None-native Species Secretary (NNSS): http://www.nonnativespecies.org//index.cfm?sectionid=81
- UK Ladybird Survey: www.ladybird-survey.org
- Clark Fork River Clean-up: https://clarkfork.org/events/2019-clark-fork-river-cleanup/
- Middle Colorado Watershed Council Water Quality Monitoring: https://www.midcowatershed.org/citizen-science-water-quality-monitoring
- Local Environmental Observation Network: http://www.leonetwork.org/en/#lat=64.86448170529478&lng=-147.75309920310974&zoom=7
- Bumble Bee Watch: https://www.bumblebeewatch.org/
- MapGive: https://mapgive.state.gov/
- Waze: https://www.waze.com/