What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases

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ABSTRACT

Civic tech initiatives dedicated to environmental issues have become a worldwide phenomenon and made invaluable contributions to data, community building, and publics. However, many of them stop after a relatively short time. Therefore, we studied two long-lasting civic tech initiatives of global scale, to understand what makes them sustain over time. To this end, we conducted two mixed-method case studies, combining social network analysis and qualitative content analysis of Twitter data with insights from expert interviews. Drawing on our findings, we identified a set of key factors that help the studied civic tech initiatives to grow and last. Contributing to Digital Civics in HCI, we argue that the civic tech initiatives' scaling and sustaining are configured through the entanglement of (1) civic data both captured and owned by the citizens for the citizens, (2) the use of open and accessible technology, and (3) the initiatives' public narrative, giving them a voice on the environmental issue.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**.

KEYWORDS

Civic Tech, Digital Civics, Civic IoT, Scaling, Citizen Science, Sustainability

ACM Reference Format:
Andrea Hamm, Yuya Shibuya, Stefan Ullrich, and Teresa Cerratto Pargman. 2021. What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 17 pages. https://doi.org/10.1145/3411764.3445667

CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05.
https://doi.org/10.1145/3411764.3445667

1 INTRODUCTION

This paper investigates the emergence and sustained development of civic initiatives that use the Internet of Things (IoT) (i.e., sensors and applications) and related sensing, information, and communication technologies to improve community services, civic engagement, and citizens' quality of life. Such initiatives, here called civic tech initiatives [78], dedicated to social or environmental issues have become a worldwide phenomenon and made various invaluable contributions in terms of data [31, 32, 52, 66], community building [23, 58], and outreach [59, 82]. Meijer and Potjer [64] and Lui et al. [61] illustrated prominent examples of such initiatives. Yet, despite implementing user-centered technologies and applications, such technologies' sustained use remains low [41], and civic initiatives are often only short-lived [39, 61]. Two streams of empirical research in HCI have focused on this issue: (1) studies about the design, development, and use of civic technologies for citizen engagement and participation via data [24–26, 28, 41, 56, 57] like citizen science initiatives [29, 37, 52, 71] and (2) studies investigating the evolution of civic tech initiatives [5, 80] like studies on scale and scaling of community engagement [11, 20].

Drawing on previous work on Digital Civics in HCI, this paper explores what makes globally active civic tech initiatives sustain over time [5, 61, 80] to identify factors that ensure the long-lasting use of civic technologies and the evolution of the initiative. Knowledge about such factors may lead to a deeper understanding of the challenging and dynamic design space of Digital Civics [56, 81].

We report on a Civic IoT research project consisting of two case studies: Luftdaten, an initiative dedicated to particulate matter, and Safecast, dedicated to radiation. We have chosen to investigate these initiatives as they emerged in 2011 and 2015, respectively. Both initiatives reached a global scale while being maintained in two cities in Europe and Asia. Luftdaten includes more than 8,000 volunteers from 73 countries [79] and counts over 13,000 sensors installed worldwide. Safecast has a community of 5,000 volunteers from 102 countries and more than 5,000 sensors installed worldwide [76] (all data as of Dec 2020).

These two initiatives are issue-specific and so-called bottom-up, i.e., non-governmental and community-based organizations driven by sensor technology use, participatory design, and open data visualization. Both initiatives have assembled their own sensing devices

and provide their community members with easy-to-use tools. Furthermore, they both have engaged and still continue to engage citizens to capture and provide large amounts of Open Data, which are shared and visualized in a publicly available, browser-based map. Both initiatives are grounded in the volunteer work of people passionate about the role that technologies can play in addressing matters of civic concern and bringing about change in society [49]. As such, the initiatives here studied have not been initiated or designed by HCI researchers/designers.

We investigated these two civic tech initiatives using interviews conducted with their core team members to get insights into the initiatives' emergence and growth. We also collected and analyzed historical Twitter data by performing social network analyses and qualitative content analysis to understand better the intricacies of the community members' interaction and communication with the general public. We completed the study with a review of online and public materials, e.g., media articles and blog posts, which help to identify challenges and changes illustrating the dynamic character of the initiatives investigated.

In contrast to previous works, e.g., [5, 45, 80], we did not conduct action research [42] as we were not engaged in the design of any part of the initiative's development. Our work firstly contributes an in-depth understanding of how the civic tech initiatives examined managed to remain relevant to the public while keeping their community activated and their technologies running. Secondly, from the quantitative and qualitative data collected, we identify a set of key factors contributing to the development of long-lasting civic tech initiatives. We finally discuss our findings regarding current HCI studies on civic data, open civic tech, public narratives, and critical HCI scholarship on empowerment and power structures.

2 RELATED WORK

2.1 Civic Tech, Digital Civics, and Citizen Science

The notion of civic tech [78] (short version of "civic technologies") describes the use of technologies for civic purposes and was initially proposed by the Knight Foundation [69]. Civic tech initiatives allude to socio-technical arrangements in which technologies such as the Internet of Things (IoT) and data are put at the service of citizens and communities. They attempt to bring citizens (i.e., groups, communities, the general public) and authorities together to discuss matters of common concern [54, 61]. Such socio-technical arrangements have lately caught the attention of the HCI research community, which has, over the past years, showed an increasing interest in the design of digital technologies [78], for infrastructuring civic participation [58], and the formation of publics [40, 56]. Particularly, studies contributing to unpack the design space of Digital Civics [25, 26] have enabled to address "the needs of both citizens and civic authorities and helps establish trusted relationships between these different stakeholders." [41] (p. 2833)

By fostering democratic design models valuable for both citizens and local governments, the field of Digital Civics investigates how dynamic relational models embedded in the design of civic technologies can potentially "reconfigure power relations between citizens, communities and the state." [81](p. 1096)

For instance, Corbett and Le Dantec [25, 26] focusing on community engagement, have insightfully pointed out that communication between citizen stakeholders can also be understood from a set of everyday practices and goals that go beyond rigid transactions of service delivery. In this sense, these authors contribute to show the broader terrain of day-to-day challenges and breath of practices that makes up community engagement and informs the design of supporting technologies that mediate such practices and enable community goals [26].

We see strong ties between the design and scholarship of civic tech in Digital Civics and studies on citizen-supported environmental monitoring and citizen science [29, 37, 52, 71]. Likewise, to the aim pursuit by digital civics research and design practice, the produced local knowledge contributed by citizen science projects can be used for negotiating matters affecting their communities [46, 72]. More specifically, citizen science projects involving citizen-sensed data resonate with the civic tech initiatives we have studied concerning the value given to the data captured and shared by the involved citizens. For instance, previous works discussed the importance of citizen science data in terms of re-using shared data [83], for policy formulation and implementation [65]. Although, "citizen science data" is often criticized concerning data quality and the value of citizen participation for science, e.g. [67], citizen-sensed data can be "just good enough" [34], when the data primarily serves a civic purpose, e.g., awareness-raising or effecting changes. From this particular perspective, the primary value of citizen sensed data is that previously there has not been any data on a particular socio-environmental issue in a particular geographical place [34]. On this note, recent conceptions of "good enough" [34] or "imperfect" data [4] that are leveraged for civic purposes emphasize the potentials of citizen sensing data for public information and discourse [38], raising public awareness [34], civic action [13], or social change [4].

By studying Luftdaten and Safecast, we are dissecting these broader contexts of actors, tools, resources, knowledge, and discourses in which civic tech initiatives can emerge and last. In particular, in this paper, we focus on issues concerning the evolution of civic tech initiatives and how they sustain over time as those are still under-researched questions for the field of Digital Civics [39, 56, 81]. In doing so, we engage in the following section with previous work discussing sustained use of civic tech in relation to issues of scale and scaling.

2.2 Sustained Use of Civic Tech

Works focused on the sustained use of technologies for civic participation and why civic tech initiatives last are not easy to find, although several HCI studies [5, 41, 48, 57, 62, 80] and recent efforts in HCI [39, 74] touch upon these issues.

Analyzing the design of technologies with the involvement of communities, Taylor et al. [80] examined what steps were taken to ensure the long term viability of the deployment and what happened during the technology handover. In this context, Taylor et al. [80] contribute knowledge about how to plan and execute technology handovers when researching with communities. In detail, these authors refer, for instance, to the role played by the expectation management, the tensions around experimental technology, the

importance of iterative development, creating skills, and reaching mutual agreement [80] (p.1555f.). These insights serve, among others, to draw attention to both civic design and research aspects that inevitably configure the long life of the technology-use in the communities involved [14]. In this respect, Johnson and colleagues discussed the importance of an inclusive civic discourse and how ownership and giving control to the community positively affect the project's evolution [48].

In this light, Manuel and Crivellaro emphasize the need for a new approach enabling "citizens to use existing open-source tools developed in HCI to create a more sustainable long-term impact" [62] (p. 10). As such, these authors argue for providing open tools and documentation, so designers can support citizens and civic actors to tackle their civic purposes by technology. From this perspective, Manuel and Crivellaro point to how openness can contribute to community ownership and sustainable civic tech [62].

Moreover, it is the community's ecosystem and its social context that seems crucial for the sustainability of civic tech initiatives [23]. Balestrini et al. [5] provide a broader view of civic initiatives that includes local governments, the media, and schools. These works [5, 62] are of particular importance to our study. They help to understand the various challenges that emerge when designing civic tech interventions with communities and for the communities. We draw upon this work to shed light on factors involved in the long-term impact and sustainability of socio-technical innovations [74].

2.3 Scale and Scaling

Issues of long-term impact and sustainability of civic tech initiatives are often discussed in terms of scale that points to "how technology is used in large networks of interconnected systems, with billions of users, across diverse contexts" [20] (p. 29). Moving on from "scale," recent work has emphasized "scaling" taking into account "the variety of practices, along with the role of human and non-human agents, that contribute to the ways local initiatives proliferate across contexts and over time" [74]. In this respect, a simple "growth" in terms of user numbers or copy-pasting of technologies to other contexts falls too short. Especially bottom-up initiatives would rather work towards lasting collaborations than towards high quantities [74]. Such a lens on scale requires addressing whole infrastructures and artifact ecologies to move beyond more superficial analyses of singular systems and designs [20] (p. 30).

In that connection, Biørn-Hansen and Håkansson's [11] study on scaling up change in community organizations identifies three stages of scaling up change by distinguishing: the "sustaining" stage that refers to a relatively fixed implementation of an initiative's working routine and practice; the "growing" stage, that alludes to setting up and upgrading the technological infrastructure for a volunteer community, and the "spreading" stage that points to generating and distributing new skills and knowledge [11]. In particular, this work contributes to understanding that ICTs can play a role in each of such respective phases by: infrastructuring generic designs by allowing a range of future services in a community; supporting the long-term knowledge generation and practices so people meet and learn together, and "accepting that scaling up is not always the point" [11] (p. 10).

2.4 Summary of the Related Work

In sum, there is a significant body of work in HCI investigating the design, development, and use of civic technologies for citizen engagement and participation via data, and an increasing interest in the long-lasting of civic tech initiatives. However, little is still known about the sustained use of technologies in civic tech initiatives that have managed to grow globally and remain relevant for the involved citizens for a long time (i.e., more than five years). We argue this knowledge gap is essential to address in HCI. Longitudinal analyses of long-lasting communities involving multiple networks of actors and technologies are central to deepen our current understanding of the role that open data and open technologies play in the scaling and sustaining of civic tech initiatives [20].

3 METHODOLOGY

3.1 Case Selection

This paper presents empirical findings collected on two long-living civic initiatives Safecast and Luftdaten. We aim to understand the particularities of Safecast and Luftdaten. We have selected the cases due to their longevity (9 years of Safecast and 5 years of Luftdaten) and their global dimension (Luftdaten.info installed 13,000 sensor stations with more than 10 billion data points in more than 73 countries and Safecast 5,000 with more than 150 million data points in over 102 countries; as of Dec, 2020 [76, 79]). An unsystematic media review has identified the cases because many media reported thoroughly about them. We chose these particular cases due to several apparent similarities like environmental monitoring, sensor technology usage, citizen science, and civic engagement.

We are not part of the cases' core teams or broader communities and conducted non-participatory, observatory, and descriptive research.

3.2 Methods

To reach a more comprehensive view of the cases, we apply mixed methods by complementing each qualitative and quantitative data and method's strength, verifying and converging each method's results [35, 77].

First, we quantitatively show evidence of their sustainability over time. In detail, by using the Python package NetworkX, we conducted a social network analysis of Twitter data per year of the hashtags: #luftdaten, #airrohr, #safecast, and of the Twitter accounts @luftdaten, @airrohr, @SafecastJapan and @safecast. "Airrohr" means in English "airpipe" and is the given name to the air pollution sensor kit. The data has been crawled via the Twitter API.

Next, we applied several qualitative methods to understand better the activities, actions, motivations, expectations, identities, and transformations of the studied initiatives. More specifically, we conducted the following analyses:

- a structuring qualitative content analysis (QCA) on the API-crawled Tweet data of Twitter accounts @luftdaten (3205 Tw.), @airrohr (1098 Tw.), @safecast (2805 Tw.), @safecastjapan (1065 Tw.).
- a theme analysis of two transcribed interviews with core team members, i.e.,

  - with a Luftdaten admin (1h25min) who is a founder of the initiative and manages the database and the network infrastructure
  - with a Safecast admin (1h) who is a founder of the initiative and manages the initiative's global activities
- a review of snowball-sampled online materials (e.g., blog entries, media articles, project websites, research papers) for additional details which are helping us to illustrate the backgrounds of Safecast and Luftdaten

We drew upon Kieslinger et al. [51] for the design of the interview questionnaire, which provided valuable information on how to assess citizen-based projects for societal usefulness. The questionnaire covered different sections, including outreach, facilitation, and communication, collaboration and synergies, citizen participation, long-term planning and adaptive project management, philosophies/policies (e.g., being a platform/ transparency/ de-stigmatization). Example questions from the core team interviews are:

- How would you describe your volunteer community? Has the community evolved over the years?
- How did/does your initiative cooperate with established institutions (i.e., local government, media)? Who approaches whom?
- What are the target societal outcomes of your initiative? Have they changed over time?
- Do you see your initiative as a political actor?

When surveying people today about events that happened several years ago, interviewees might forget or reframe things from the past. For this reason, we believe that it is essential to complement the interviews conducted today with the core team with data captured in the past. In this vein, we decided to analyze historical social media data since it portrays the temporal dimension of the initiatives. In other words, by gathering social media data via API, we were able to analyze data going back from today to 2011. In this way, we conduct a retrospective longitudinal study that was suggested as a research design for studying scaling systems [20] (p. 30).

Among all of the initiatives' social media accounts, we decided to analyze their communications on Twitter for the following three reasons:

First, a comparison of Luftdaten's and Safecast's social media accounts shows that they have the highest follower numbers on Twitter compared to Facebook, Instagram, Vimeo, or LinkedIn. We assumed that the higher the follower number, the more people are targeted and reached by the initiatives' communication, and also the larger is the part of the initiatives' community that can be found on this particular platform.

Second, when accessing their Twitter feeds, we noticed that both initiatives' extensively used Twitter for their communication with the community and also the broader public and particular actors. We observed more interactions in terms of comments, sharing, or liking on Twitter than on the other platforms. Further, we could trace here the broader ecosystem of the initiative that possibly contributes to its sustainability, e.g., we saw that Luftdaten is retweeting messages from the World Health Organization (WHO), or from CNN and BBC to connect to international public discourses on air pollution.

Third, the interviewed core team members highlighted the importance of the Twitter platform for Luftdaten's and Safecast's evolutions, in particular, to recruit members, openly communicate their technological developments, and grow their communities in later phases.

The Twitter platform has certain advantages as a communication tool for civic tech initiatives. It has a lower barrier comparatively with for example, Facebook, Instagram, or Pinterest platforms, which ask people to register to read the contents. When the initiatives were founded (i.e., 2015 and 2011), Twitter was already a popular platform while others such as Instagram were not yet so wide-used in 2011. In Japan, Twitter was an essential communication tool during the Fukushima disaster [3].

3.3 Data Analysis

The data analysis was carried out by two of the four authors collectively and recursively. First, we created social network graphs of the Tweet data from account creation until 2019-12-31. Nodes of each graph were colored based on the Louvain community detection algorithm, which extracts the community structure of large networks by evaluating how much more densely connected the nodes within a community are, compared to how connected they would be in a random network [12]. We visualized the Retweet networks per year and received nine network graphs for Safecast (founded in 2011) and five network graphs for Luftdaten (founded in 2015). By comparing the yearly network graphs, we observed how the initiatives have grown over time and became sustained in their social media communication and networking. Retweet networks helped understand how effectively the initiatives reached out to the public and their community. In particular, being retweeted by Twitter accounts that have more followers would increase the initiatives' visibility.

For the structuring QCA, we directly accessed the Twitter pages and analyzed the Tweets manually within the Twitter environment (from account creation until 2019-12-31); older Tweets have been collected via the Twitter API and analyzed within a spreadsheet. We built categories and subcategories inductively from these Tweets by a systematic interpretative structuring of the contents [63] (p.63f.). We focussed on the categories that would help to explain the initiatives' longevity and sustainability. The goal of the qualitative analysis was to gain a more profound knowledge of the two initiatives by reading through their Tweeting activities and better understanding their evolution and linkages to other societal actors. In this way, Twitter gives us access to the initiatives' long-term activities and practices and functions like a documentary tool. Non-English data was translated by this study's authors, whose native languages include German and Japanese. Other languages occurring in the analysis have been translated with the help of DeepL. A sufficient and thorough category system gained from the material was the criteria for closing-off the QCA.

Still, we are aware that the Twitter analysis conducted in our study may not include all voices of people contributing to the civic tech initiatives' development (see Limitations for details). Subsequently, the transcripts of the interviews have been analyzed by theme analysis [63](p.104ff.). Based on the category system that we have constituted in the previous analysis of the Tweet contents,

we have read the interview transcripts several times to select those details that elaborate on the categories identified.

Finally, we interpreted the data on a more abstract level. We extracted the factors to make both cases to last over time from the vast data we collected. Doing so, we first extracted factors from each case, then we contrasted them and discussed their similarities collectively until the material was saturated. From those similarities, a set of key factors emerged.

3.4 Research Ethics and Positionality

The study's authors' positionality is essential for understanding and contextualizing a research paper [7]. Our international team of authors, in terms of nationalities and cultures, includes researchers with backgrounds from the cases' respective countries. We all care deeply about the social and ecological environment of the planet and are particularly interested in understanding the role that technology and data can play in bringing about change in society.

We are also aware of the resourceful economic statuses of Germany and Japan that are most likely reproducing certain privileges on the here-emerged civic initiatives compared to initiatives emerging in less privileged countries. We will address this particularity in the Discussion section.

To address ethical concerns, we asked the operators of the Twitter accounts for permission to analyze their public contents for this study, which they granted us. The initiatives' core teams are aware of our non-participatory, observatory study on the initiatives and appreciate that we selected their initiatives as research objects. For this reason, we decided to deanonymize the civic tech initiatives' names. Another reason is that both initiatives are already largely covered by domestic and international media, which is also why we found the cases. However, the names of the core team, community members, Twitter users remain anonymized.

3.5 Organization of the Results

The following sections present the results obtained from the analysis of Luftdaten and Safecast. As presenting results from two cases is always a challenging task, we follow the structure suggested by Taylor et al. [80]: We present each case separately before summarizing the results from both cases. In particular, we first introduce the initiative's background based on the review of additional online materials, and afterward, we illustrate the empirical results. The quantitative results build on the social network analysis, while the qualitative results build on the content analyses of the interviews and all Tweet data from the Twitter accounts of Safecast and Luftdaten. We structure the qualitative results according to apparent phases similarly illustrated in Biørn-Hansen and Håkansson [11].

In particular, we organize the qualitative results into three phases we have identified as emergence, growth, and sustaining. The transition from emergence to growth and sustaining is clearly defined here by the point in time when established institutions apply the initiative's data. However, growth and sustaining phases appear to be more intermingled and partly parallel. Growth is somewhat related to the amount of data, the impact, the community size and activity, and sensors installed. Whereas, the sustaining phase refers to an established network of collaboration partners, continuous funding, and other achievements that facilitate the initiative to last. Nevertheless, there can be further growth after the sustaining phase is achieved, or the initiative can grow during the sustaining phase.

4 CASE STUDY 1: LUFTDATEN.INFO

4.1 Background

Luftdaten.info (https://luftdaten.info/) is a project founded within the Code for Germany Program of the Open Knowledge Foundation in 2015. Luftdaten.info is dedicated to measuring particulate matter (PM), i.e., particles of, e.g., rubber, liquids, and dust that remain suspended in the air. On their website, we read that they identify with Citizen Science and Open Data. The civic initiative created a do-it-yourself sensor kit for about 30 EUR and started to capture PM data first in Stuttgart, later in Germany and worldwide. To communicate their data, they set up the Luftdaten map, where PM values are displayed as colored hexagons (https://maps.sensor.community/ - Luftdaten has recently been renamed to "Sensor Community"). The initiative's creative head is a communication designer who, like other core team members, has a personal motivation for cleaner air in Stuttgart [33]. The initiative was highly covered by German media and even by international media (https://luftdaten.info/presse/). Luftdaten has emerged in an already heated public discussion on air pollution, culminating after a reprimand from the EU commission. The EU commission threatened Stuttgart's government with a lawsuit before the European Court of Justice if the Stuttgart citizens are not effectively protected from the too-high PM concentrations [84]. From the beginning, Luftdaten provides their PM data as Open Data in an open archive (at https://archive.sensor.community/). Since 2017, the local news medium Stuttgarter Zeitung implemented its own PM data map sourced by Luftdaten PM data (https://www.stuttgarter-zeitung.de/feinstaub) and makes the data directly available for their readership on the medium's website.

Luftdaten appears already within the academic literature, in terms of, e.g., testing the quality of the applied SDS011 fine dust sensor [21], using the openly available PM data as a database for a hackathon [53] and a data science challenge [36].

4.2 Evolution and Reach through Social Media Networks

Following the evolution of Luftdaten's Twitter communication networks over time (see Figure 1) we found that Luftdaten.info started in 2015 with only a few engaged Twitter accounts representing a homogeneous group. In 2016, the network became organized in four smaller groups. Significant growth can be observed in 2017 when the network became much more extensive, and numerous Twitter accounts interacted with the Luftdaten initiative. Until 2019, the network shows more complexity. One can distinguish multiple subgroups that interact with each other. From 2017 to 2019, there are single nodes scattered at the outer area of the network. The largeness and diversity of active Twitter accounts in Luftdaten.info's communication are notable, indicating that over the past five years, Luftdaten.info has been successful in terms of getting new and more participants in the community and engaged in conversations with diverse actors from different publics.

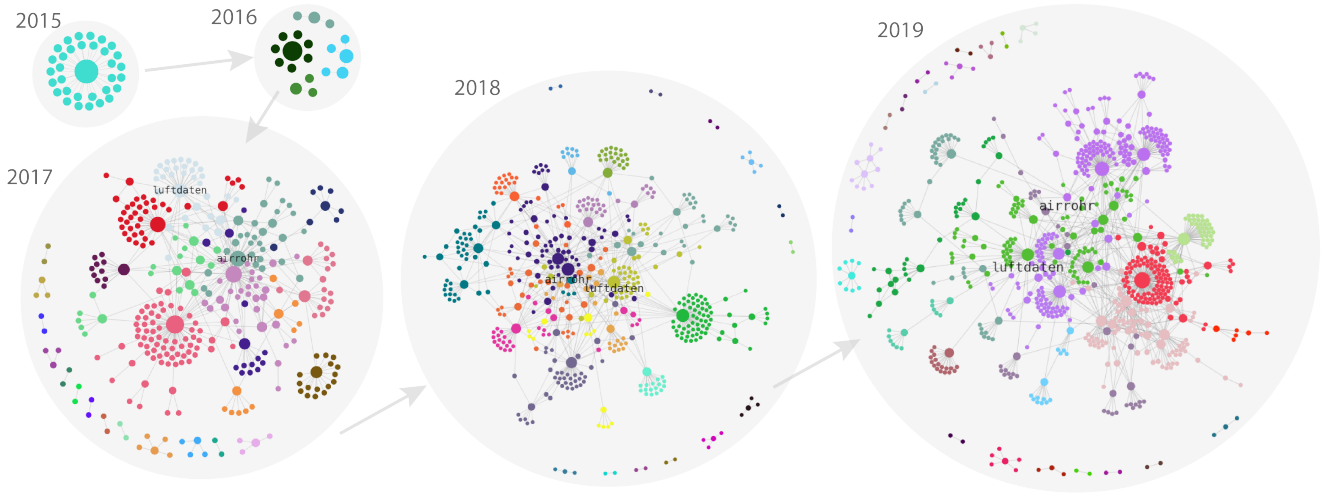

Figure 1: Luftdaten's Twitter communication network evolution. Starting with only a few people in the network in 2015 (33 nodes), year by year, the network grew significantly in 2017 (338 nodes) and became increasingly complex and more extensive until 2019 (744 nodes). As more diverse people and groups of people become involved, the visibility and reach of Luftdaten as an actor and as a topic is extended on the Twitter platform. About the network graphs: Each node in network graphs represents a Twitter account, and each edge represents a (re)tweet occurrence of the Twitter accounts related to @luftdaten and @airrohr. The node size indicates how many times this account has (re)tweeted to one of the Twitter accounts per year. The data basis for each figure is the retweet network per year. The graphs are created by the Python package NetworkX (for details see 3.3).

The combined network graphs of all years (see Figure 2) show the Twitter accounts' increment in Luftdaten's retweet network. The bigger the node, the more followers an account has. We found several accounts with more than 100K followers that are part of Luftdaten's Twitter communication network. These accounts include journalists and media, political parties, a domestic ministry, and international foundations.

4.3 Evolution Phases

In the following, the insights from the interview with a Luftdaten admin and the qualitative content analysis of the Twitter contents are combined and presented according to the initiative's three main evolution phases: emergence, growth, and sustaining.

4.3.1 Emergence. According to the Luftdaten admin, the initiative's main focus was a low-cost and easy-to-use technology to measure air pollution. "*Due to the low price, we can operate many more measuring points*" and in this way, the low-barrier technology is the basis for a potentially large community that operates the sensor kit independently. The Luftdaten admin explained their concern "*that it can always be the case in volunteer-based projects that someone [..] can no longer participate.*" For this reason, "*all the tools we develop should be as simple as possible, and they should be manageable or further developable by others.*" They decided from the beginning "*to run everything Open Source.*" As part of the Code for Germany program of the Open Knowledge Foundation, Luftdaten follows the principle of openness, i.e., Open Source and Open Data, with the intention that everybody can access the Luftdaten archive and download the data for further uses.

The first goal of Luftdaten.info was to install 300 fixed sensors to measure PM in Stuttgart. "*So we get an image of an entire area. And [...] I can make a statement [on this area] or at least check if I have a theory where the fine dust really comes from.*" Earlier, people would have relied on two official PM measurement stations in Stuttgart. However, from only two data points in a city, one could not say "*whether this is due to traffic, heating or industry. Because it is more or less arbitrarily determined where these two stations have been placed.*"

Another technology developed in the early phase is the Luftdaten map, "*which was developed relatively quickly over a weekend [...] as part of the NASA Space Apps Challenge.*" They brought their own data and used the event to work on the Luftdaten initiative. "*We said to ourselves, we already have data - we want to continue to make it available.*"

Within the emergence phase, Luftdaten did not use its Twitter account interactively and engagingly. Rather @Luftdaten communicated in one-way style as a PM info bot sharing the current air pollution values of various sensor stations in an automated way, e.g., "*2017-01-25 07:05 #finedust alert in 70186 Stuttgart! Sensor 286 = 218.63 µg/m³.*"

Nevertheless, Luftdaten started networking and reaching out to journalists very early, which led to the increasing presence of Lufdaten on public regional broadcaster SWR and national radio.

4.3.2 Growth and Sustaining. After the initial media reports, "*Stuttgarter Zeitung [a traditional local newspaper, A/N] became aware of us*" remembers the Luftdaten admin. "*They sent an editor to our meetings, about twice a month, who listened to us and asked if we could work together.*" They wrote regular reports on Luftdaten and started to experiment with Luftdaten's Open Data. From 2017, Stuttgarter Zeitung developed their own air pollution map, which shows aggregated PM data by city districts. After this, "*[w]e never had the problem that we had to go to the newspapers to report about*

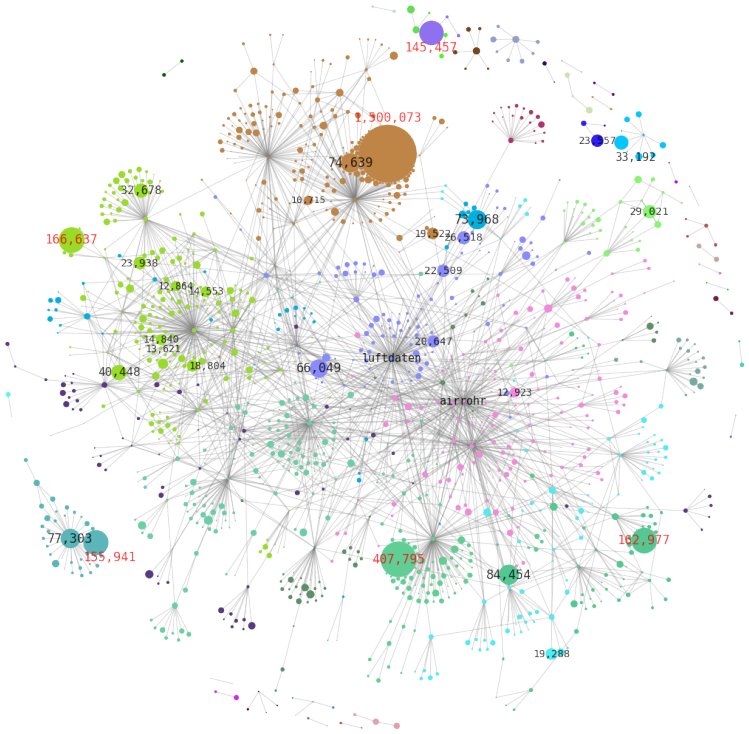

Figure 2: Network graph shows influential Twitter accounts involved in Luftdaten's retweet networks. In other words, it shows how far Luftdaten's online discourse reached. About the graph: Each node represents a Twitter account. Node sizes indicate follower numbers. If an account has more than 10k followers, the follower number is shown. The text is in red if the account has more than 100k followers. The graphs are created by the Python package NetworkX (for details see 3.3).

[us], but on the contrary [...] we sometimes had 2-3 newspapers or television teams sitting at [our] meetings."

Simultaneously, the Twitter account @airrohr was created in 2017, almost two years after the initiative began. "Airrohr" is an English-German neologism that translates to "air pipe" in English; it is the given name of the PM sensor kit that has been invented by Luftdaten. This account is dedicated to the "*most beautiful airrohr challenge*" where community members are invited to share photos of their self-made sensor kit with creative decorations under the #airrohr hashtag. This challenge seems to create a positive community feeling for the volunteers. Simultaneously, it helps increase the Luftdaten-related content on Twitter and probably the visibility of the air pollution topic.

From 2018, Luftdaten used its primary Twitter account @luftdaten for communication with the community and the public. The seemingly largest part of the Tweets is sharing content for public relations (PR) and community building. For example, they retweeted how community members set up a new sensor or posted photos from community workshops - such Tweets target the community and the public.

Luftdaten also shares media articles covering the Luftdaten initiative itself, e.g., from Stuttgarter Zeitung, The Guardian, Deutsche Welle. Also, community members share that they have seen media coverage on Luftdaten, e.g., "*video report on the #citizenScience project @luftdaten used to counter air pollution in Stuttgart.*"

Over the years, Luftdaten gained a large team of volunteer developers. If required, "*10-20 people spontaneously develop something.*" The community usually acts quickly because almost everything would be available on Github. Community members would do even translations to French, Russian, Polish, Spanish, Turkish, and other languages within a few days. On that score, the core team's workload is significantly reduced, and responsibilities are distributed among community members.

Besides the civic data collection and public visualization, Luftdaten themselves would not do much environmental simulations or modeling. For volunteers with their home computers, it would be challenging to process massive amounts of data. Preferably they search for academic collaboration. Since the beginning, Luftdaten has gathered several hundred gigabytes of data, "*we are happy if science helps out a little with data analysis.*" For example, in 2019, a German university hosted a data science challenge with the Luftdaten dataset as a basis.

Luftdaten is fully based on volunteers, also the core team works in their free time. For this reason, the regular costs would be relatively low ("*from 1.500 to 2.000 Euro for infrastructure*"). Via the

Betterplace platform, they organize donation campaigns that cover the costs regularly.

Today the core team based in Stuttgart consists of 8-10 active people responsible for different tasks. The admin states that the tasks are relatively flexible and shift from time to time: "*Well, I am actually an administrator, but I do a lot of programming in the meantime.*" People who know less about programming would try their hand at analysis, and other people would try to extend the sensor device. Nevertheless, their capacities are limited. "*So we always need people who know a little bit about it and bring in their knowledge.*"

We observed that Luftdaten uses Twitter as a tool for strategic networking and sharing information to raise awareness about a topic about which they care. They, for example, retweeted contents on air pollution by influential people that are not members of their community, e.g., from WHO officials writing, "*Women who breathe polluted air during the month right before or after they get pregnant are more likely to have babies with birth defects #AirPollution [...].*" Luftdaten retweeted not only media articles but air pollution information from internationally well-reputed institutions or projects like NASA or CopernicusEU. Further, Luftdaten shared air pollution-related contents from other local groups, e.g., in Brussels (Belgium), Münster (Germany), Bretagne (France), or Sheffield (UK). Other emergent topics were "civic tech" and "open data," or "smart city." These topics mainly appeared with events, panel discussions, or meetings dedicated to these developments, e.g., in the context of the event "Offene Stadt" (Engl. open city) in Hamburg (Germany), the organizer tweeted, "*On the road in Hamburg's #open city [...] Transparency, Open Data, Participation. With many great organizations and projects like [...] @Luftdaten [...] and many others.*" Luftdaten has several times been mentioned as a model for civic innovation in future-making smart city intentions of city planners, e.g., "*Best Practices, e.g., urban design Ulm with [...] or @luftdaten .info*"

Until 2020, Luftdaten achieved to install "*almost 400 sensors in Stuttgart,*" and it collects data from over 10K sensors installed worldwide. To extend their community, Luftdaten is networking towards other local groups interested in air pollution ("*If you know any local groups that are willing to help people with building and installing their #AirRohr [...]: we are building a "community map" so that interested people can find help nearby.*") In the future, Luftdaten would like to measure noise and nitrogen-dioxide because these topics would become more visible in public discussion.

The information provided by air pollution data from Luftdaten has a specific impact on some community members' daily lives. Luftdaten has "*several hundred if not thousands of users who have installed [the PM sensor, A/N] in their home automation systems.*" Such systems continuously analyze the sensor data, and if "*the air outside gets too dirty, please let me know or close all windows.*" According to the Luftdaten core team, members would look at the air pollution data of their balcony to decide on when to hang their laundry outside.

Luftdaten extended their activities towards student education. Together with IBM Germany, Luftdaten organized a workshop for more than 250 school students in Berlin in 2019. They showed how to acquire and assemble the sensor device, collect and upload the data to an open community portal.

5 CASE STUDY 2: SAFECAST

5.1 Background

The Safecast initiative emerged a few days after the 2011 Tohoku earthquake and the resulting Fukushima Daiichi nuclear disaster. The core team found together because they were worried about their families living in Japan, who, with the lack of radiation information, could not properly decide how to react to the disaster [75]. From this basis, they agreed on starting Safecast. It started with three people with backgrounds in programming, design, entrepreneurship, software development, and many other skills who assembled an improvised Geiger device. The device "bGeigie" was dedicated to measuring radiation in Japan in the aftermath of the disaster. Safecast visualizes the radiation data in a worldwide map that can be accessed via a browser (https://map.safecast.org/). A detailed description of the device and its updated versions, the datasets, and the map can be found in Brown et al. [19] (p. 84-89). The civic initiative has been driven by a quick mobilization of existing professional networks to set up the device, the data collection and visualization [75]. The role of academia has to be emphasized as a location that essentially facilitated the emergence and functionality of Safecast [75].

Safecast has been studied and portrayed in academic literature; these works helped us structure and make sense of the material we collected. For example, Brown et al. [19] describe the full volunteer and low-hierarchy structure as a crucial foundation of Safecast (p.89) as well as the vital outreach via social media and the public communication of their "message through many major media outlets in Japan and abroad" (p.91). Further, it is stated that "transparency and credibility are recognized as essential for the success of the Safecast project" (p.92). Another study looked at the societal impacts of Safecast. Abe [1] has contextualized Safecast as a "socio-technical system" pointing out that the collected data is not useful for knowledge production until people create narratives on the data. Further, it is the public communication of these narratives that would be necessary to reach the people. We build upon these works by examining Safecast's communication on social media and receiving insights from one of the founders.

5.2 Evolution and Reach through Social Media Networks

Safecast started with a relatively large range of actors in 2011 and has kept core parts of these networks for more than nine years (see Figure 3). Safecast began with diverse actors as an event-driven group after the Fukushima nuclear power plant incident in 2011. Over time, Safecast's communication has been mainly initiated by core members and sustained not only by core members but also by diverse international volunteers, organizations, journalists, and supporters.

We found several accounts with more than 100K followers that are part of Safecast's Twitter communication network (see Figure 4). These accounts include journalists and media, politicians, famous actors, famous academics, and worldwide-known museums.

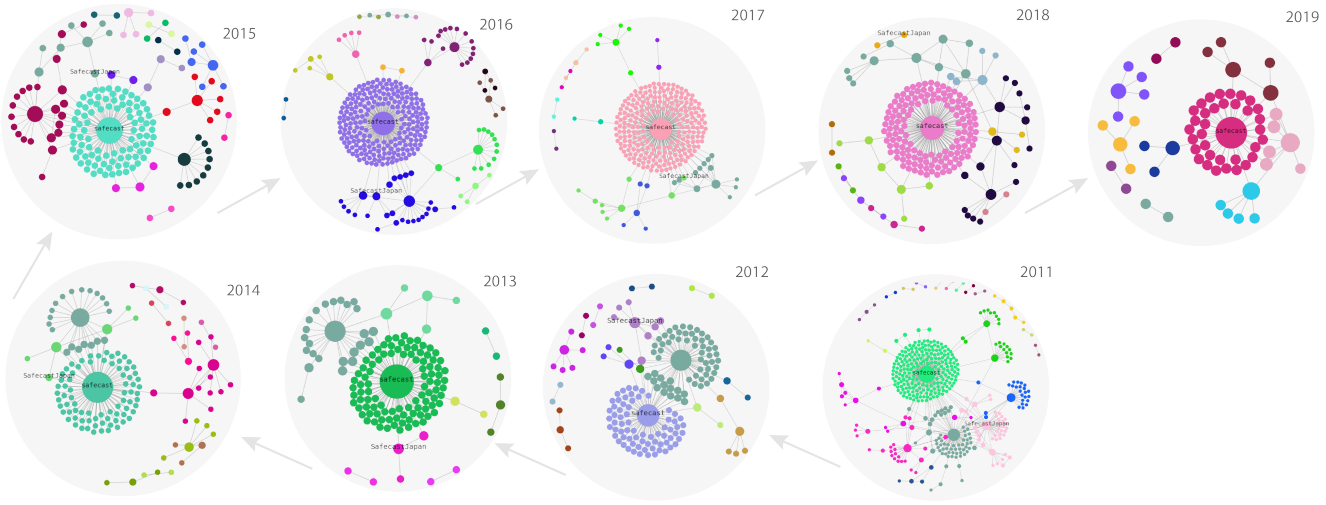

Figure 3: Safecast started with a relatively wide range of actors in 2011. From 2012 until 2019, the Twitter networks' size decreased continuously down to a stable core network. About the network graphs: Each node in network graphs represents a Twitter account, and each edge represents a (re)tweet occurrence of the Twitter accounts related to the civic initiative. The node size indicates how many times this account has (re)tweeted to one of the Twitter accounts per year. The data basis for each figure is the retweet network per year. The graphs are created by the Python package NetworkX (for details see 3.3).

5.3 Evolution Phases

In the following, the insights from the interview with Safecast and the qualitative content analysis of Safecast's Twitter accounts are combined and presented accordingly to initiative's evolution phases: emergence, growth and sustaining.

5.3.1 Emergence. Safecast's core team was using Twitter from the beginning as a tool for project management, i.e., directly contacting people via Twitter, sharing updates and technical news, and asking for donations and contributors. The communication here appears to be business-like and goal-oriented, e.g., Tweets like "*We're up and we need your help to gather up-to-date sourced information!*" or "*Thanks for the kind words. A Japanese version is in the works and will launch as soon as possible.*" They also reach out to find more contributors via Twitter in the initial phase to quickly set up their data collection, e.g., "*Looking for a technical contact who could provide an RSS/XML/JSON feed of their U.S. monitor data. Scraping HTML isn't fun.*" At the same time, Safecast acts from the beginning as a distributor of media activities and articles on the Fukushima Daiichi Nuclear Disaster, e.g., "*Press conference on NHK World: [LINK]*" or "*25 economies restrict food imports from Japan over radiation fears [LINK].*" After some time, Safecast emerged as a player within the disaster-caused radiation discourse in Japan.

Safecast adhered from the beginning to the value and principle of openness. "*We open every single thing up [...] so that we're not relying on us alone. Even if we don't have a lot of money if we publish the plans for the devices, other people out in the world can still make them and they can still start collecting data and publishing data.*" Safecast provided all resources for the volunteers, and this accessibility to the equipment and materials "*allows lots of things to happen even without our specific direction on it.*" With all materials open, Safecast believes that they are more trustworthy, which is useful to attract new community members, collaborators, and network partners. This decentralized form of running Safecast has helped them build resilience "*because our community is so strong, even if we have a lot of problems internally, the community keeps things moving.*"

In the early phase, Safecast's core team published on-the-ground reports. They visited disaster-stroke regions in Fukushima prefecture and shared their experiences, photos, and radiation values via their blog and Twitter. Quickly, local politicians in Fukushima were interested in the activities of Safecast, which helped them identify places for measurements, organize capacity-building workshops, communicate with residents in Fukushima, and connect them to other politicians and authorities. "*[V]ery early [...] the local governments became strong allies [...]*" and recognized that Safecast could collect the lacking information on what happened after the disaster.

The large parts of the initial funding came from the Knight Foundation [15], a foundation dedicated to quality journalism, media innovation, social responsibility, and the arts, to strengthen democracy. Later, we observed that Safecast's donation campaigns were extraordinarily successful at the beginning of the initiative, "*The Kickstarter we launched this morning was successfully funded in under 12 hours.*" or "*Only a few hours left for 200% donation matching. Please pass this on! Thank you!.*"

5.3.2 Growth and Sustaining. Civic authorities applying Safecast's data mark the transition from emergence to growth and sustaining phase. The authorities recognized Safecast's unique radiation data relatively early. Only about six months after the incident, the Fukushima Government has created a worldwide map of radiation measurements on their website, of which Safecast provided the

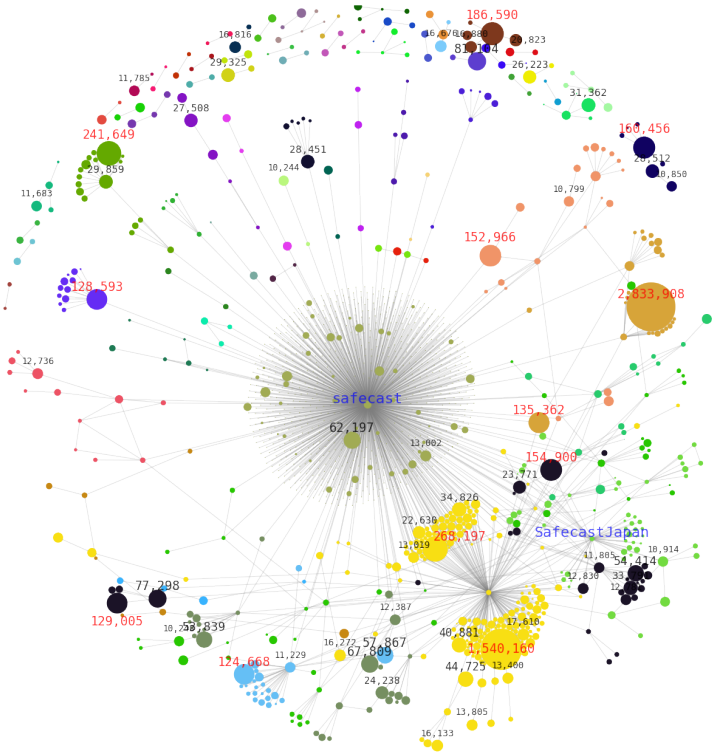

Figure 4: Network graphs show how influential twitter accounts have been involved in retweet networks. In other words, it shows how far Safecast's online discourse reached. Each node represents a Twitter account. Node sizes indicate follower numbers. If an account has more than 10k followers, the account name and the follower number are shown. The text is in red if the account has more than 100k followers. The graphs are created by the Python package NetworkX (for details see 3.3).

data. Also, Safecast has been invited since 2014 to The International Atomic Energy Agency (IAEA) to present their works [17, 18].

Safecast emphasized the importance of "*interaction with the community.*" Over more than nine years of Safecast history, they have held multi-scale events, from educational workshops for children to large international conferences. They organized numerous meetings and workshops in the Tokyo FabLab, the MIT Media Lab, different hackerspaces, and their Tokyo office. The symposiums and conferences aimed to have "*conversation in public*" with a broader online community in the background (i.e., more than 1,000 volunteers). The technological evolution of Safecast "*has always been based on feedback from the community.*"

From early on, Safecast saw talking to the media as one of the core tasks. They had an open policy to talk to anybody who approaches them regardless of their opinions or political positions, "*[...] hoping them to spread the word about our efforts and [...] what we are trying to promote: Openness and sharing the information and community self-alliance.*" Besides, they have leveraged various tools (e.g., blogs, medium, Twitter, Facebook, Linkedin) to diffuse their efforts and be visible, which may have helped them to be reachable.

Safecast is equally confident and open about their self understanding as they write on Twitter "*We're not a political organization, we collect & publish data. We've done more of that than all other orgs in Japan combined.*" Such an attitude would allow them to contribute arguments, i.e., radiation data, to the public discourse, but not acting as a political stakeholder around the socio-environmental issue. Referring to the lack of data, Safecast writes clearly on Twitter that "*The only way most people have data is because of us. Our data is open and transparent on every level [...].*"

To ensure long-term funding, Safecast used its Twitter networks to mobilize donors. Safecast managed their regular donation campaigns on the Kickstarter donation platform and advertised these campaigns on Twitter, e.g., "*We're at 92 backers on Kickstarter. Who will be #100???.*" Finally, Safecast received many donations from people outside Japan.

To remain relevant to the public and keep the initiative vivid, Safecast has widened its initial concerns about the environment over the years by adapting the current public discourse. From their Twitter data, we find that they became engaged in air pollution in Los Angeles and they carried out student education events. According to the interview data, Safecast has not expanded their purposes randomly. Instead, they evolve by adjusting with citizens' concerns or the community needs. Also, they expand purposes based on keeping their core ideas. e.g., Safecast provides all their data and information openly, so people could use it to make their own informed decisions. For example, we learned that residents in the

Fukushima Prefecture had used Safecast data to make decisions on their daily life, i.e., they decided where to move based on lower radiation values in a location [47].

In the next section, we summarize a set of key factors identified from the activities described in each of the phases observed. The quantitative analysis of the Twitter networks allowed us to take a temporal perspective on the cases, most often missing in the HCI literature. And, through the analysis of the qualitative data, our work provides an in-depth understanding of the multiple and diverse actors, technologies, and activities characterizing the emergence, growth, and sustaining phases of Safecast and Luftdaten.info. Building on these results, we developed a nuanced understanding of their evolutions, which can inform the study and design of scaling and sustaining civic tech initiatives.

6 SUMMARY OF KEY FACTORS FOR THE CIVIC TECH INITIATIVES' SCALING AND SUSTAINING

In the following, we explain the key factors identified from our retrospective longitudinal mixed-methods analysis of the scaling and sustaining phases of Luftdaten and Safecast.

With the set of key factors here identified, we do not intend to provide a checklist, implying that any civic initiative will be sustainable once all points are checked [5]. Instead, we stress that civic tech initiatives are complex and dynamic socio-technical arrangements embedded in specific cultural, geographical, and political ecologies, as well as structures of power [27]. As it is usual for case studies, the findings represent specific and situated cases.

Issue of public concern. Both cases had started their initiative when the tackled issues (Fukushima Daiichi disaster, air pollution, and emission scandals in Stuttgart) were part of the current media agenda and public discussion. There was a lack of data on this specific, critical issue potentially affecting people's health; the public needed this information in both cases. The social value given to both civic initiatives was associated with the central role they played in providing tools, capacity building, and communication space to discuss pressing issues regarding the city residents' wellbeing.

Competent core team. The human basis of the civic initiatives is a small team of well-organized, tech-savvy, and personally motivated people, i.e., freelancers, designers, entrepreneurs, and engineers. The core teams of both cases are geographically connected and have an emotional affective motivation towards the issue, their care about their cities, families, and future generations. Furthermore, they share values on transparency and openness, providing information and data to the public discourse. In both cases, most of the core team members who started the initiatives are still actively involved with the initiative; only a few people dropped out. The core teams carried out the necessary tasks and achieved the first milestones, on which the initiative grew. They set up community meetings and the community's infrastructure, assembled the prototypes, provided information materials, communicated the initiative's goals, and contacted potential collaborators.

Initial background network and further networking. Safecast and Luftdaten did not occur spontaneously. Both cases show that the initial background network, i.e., the foundations and academic networks supporting the initiatives, played a role in gathering expertise and spreading the word. Further networking - especially with established institutions and stakeholders - was a key factor related to trustworthiness and has led to external application of the collected data, which ensures a continuous relevance of a civic initiative. Besides, improving the quality of the data, the data analysis, the data visualization, and the devices involved was advantageous to connect to science and research institutions.

Access to material resources and openness. The core members of both initiatives relied on material resources such as available meeting rooms or labs from universities or foundations being part of their initial network. Openness here means that newly created resources have been made accessible. Sharing values regarding transparency in terms of Open Data, Open Source, or Open Knowledge, i.e., providing all data, plans, materials, and devices, allowed the initiatives a way to evolve, while not relying on being managed in a top-down manner.

Low-barrier technology. The core teams of both initiatives developed the actual IoT and communication technologies, which combined with commercial components, formed an ecology of artifacts that enabled the initiative to capture data, coordinate itself, and become publicly visible. Such technologies are in particular: (1) a do-it-yourself, easy-to-use, relatively low-cost sensing device, (2) the underneath network architecture and an open database, (3) an intuitively understandable and publicly available data map, (4) communication technologies, which is mainly social media-based communication. The low-barrier technology was vital to find participants and attract a large community (also less tech-savvy people). If the technologies needed too much expert knowledge to use them, it would have been hard to spark people. Despite being do-it-yourself and easy-to-use, the technologies need to be "good enough" [34], so the data can be used for informing the public and serve as arguments in public discourse.

Data applied by established institutions. Both initiatives have successfully captured, shared, and communicated citizen data reused by other established institutions. In the case of Luftdaten, the air pollution data is applied by a traditional local news medium in Stuttgart. In the case of Safecast, it is the local government in Fukushima Prefecture that applied the radiation data. These institutions show and distribute the initiative's data via their websites until today. This continuous use and re-use of the data implies a certain trust towards these civic initiatives. At the same time, we see how the initiatives' data reaches out to the general public and ensures their societal relevance.

Attracting new community members. Finding new participants while keeping the community active is probably the primary key factor for making a civic initiative growing and scaling. We found out that organizing events for students, participating in networking social or cultural events, or business-like meetings helped to attract new people and potential new community members. We also find other practices that represent openness and help to attract new members, such as retweeting, establishing a partnership in terms of co-ownership, and translating into different languages.

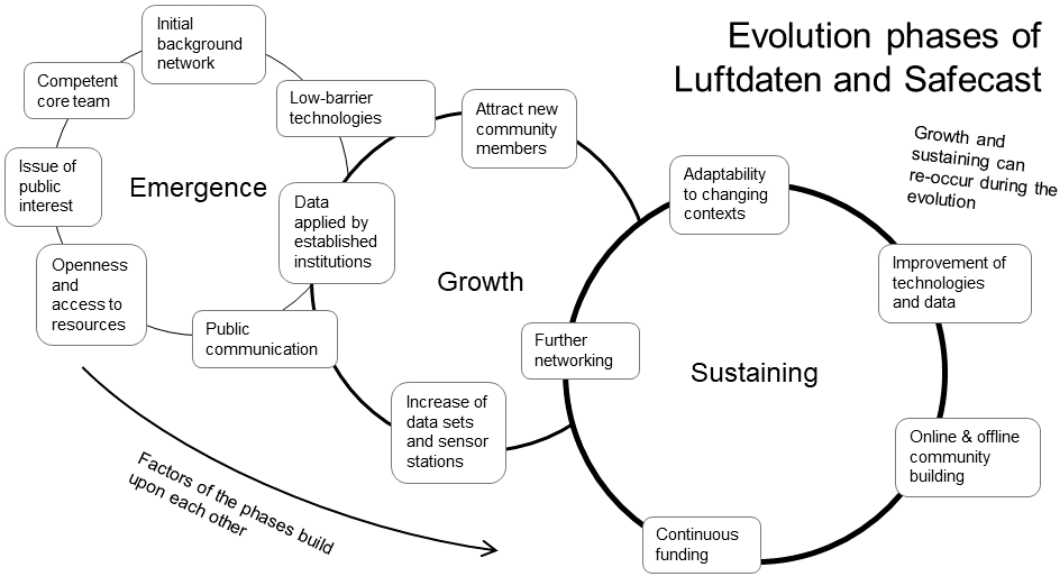

Figure 5: Evolution of Safecast and Luftdaten cases. The factors that are key for a sustainable initiative are placed around the evolution phases emergence, growth, and sustaining.

Increasing data sets and sensor stations. The increase of data sets and sensors stations is interconnected with attracting new community members. Simultaneously, few community members have been very engaged and set up many sensors just by themselves.

Continuous funding. One of the basic needs of sustaining is funding. We assume that the public willingness to donate money is relatively high as long as the issue, e.g., air pollution or radiation, is part of the public discourse. These initial donations collected by the platforms Kickstarter and Betterplace allowed the initiatives to grow a lot initially. Later the initiatives took efforts to remain in public discourse and to reach people that would be potential donors.

Public communication. Public communication is crucial to become a part of the public discourse on environmental issues and reach people by sharing their own data-driven narrative. It includes the continuous and interactive use of social media and working with traditional media, i.e., inviting journalists or giving interviews. Both cases also maintained two-way dialogue on Twitter with the community and the public that led to attracting new volunteers or distributing the core team's workload. The social media accounts likewise contributed to keeping the issue-related public discussion ongoing, e.g., by addressing famous people or officials of large organizations like the World Health Organization (WHO). Also, giving comments to issue-related media articles contributed to increasing public communication on the initiative.

Online and offline community building. A civic initiative lives from its community and vice versa. The communities brought many inspirations into their initiatives. For example, we observed how the communities were involved in photo challenges on social media, organizing meetings, workshops, and events, identification with citizen science and open data communities, sharing experiences, telling on-the-ground stories, and playing with data visualizations. Further, the community used Twitter to discuss their measurements or inform the public and the community if they recognized exceptional high values in their neighborhood.

Adaptability to changing contexts. Both cases have evolved from their initial purposes. They have worked with other sensors or evolved towards the educational sector or health communication. These extensions did not happen randomly, but they were reactions to community members' demands or towards the current public discourse. Reacting such demands by transforming the initiative helped the initiatives remain relevant for people and attractive for media coverage. Likewise, it helped to gain new donors and network partners.

Figure 5 summarizes the set of factors that are key for the civic tech initiatives examined. The bubbles' overlaps refer to the fact that the phases are not easily separable, and the factors are interlinked and building on each other.

7 DISCUSSION

From dissecting the emergence, growth, and sustaining of Luftdaten and Safecast over time (i.e., from 2011 and 2015), we discuss in this section how the factors identified have contributed to the Luftdaten and Safecast scaling and sustaining. In doing so, we draw particular attention to the role played by the initiatives' civic data, the use of open civic tech, and the involved citizens' public narratives on the environment for the long-lasting of both civic tech initiatives. We end this section with a note on pre-existing inequities and power structures embedded in the civic tech initiatives here studied.

7.1 Civic Data and Impact

Gathering data about air pollution and radiation has an impact on local people's daily lives. We learned about such influencing effects in relation to the captured sensor data, and what kinds of decisions are made based on this data, e.g. where people move, when they ventilate, or hang their laundry outside.

We, therefore, emphasize the term "civic data" to draw attention that such data is both captured and owned by the citizens for the citizens. More specifically, civic data is different from, for example, citizen science data as they are not primarily aiming at generating data for scientists concerned by contributing scientific knowledge. Instead, civic data aims at providing citizens means and knowledge to act upon the local pressing environmental issues affecting them and future generations.

While for civic data, scientific quality is not the first priority, enabling public discourse and social action rather are. The civic attribute of data echoes the social value of "imperfect data" underscored by Alvarado Garcia and colleagues [4] regarding the power of data in informing citizens, requesting action, and building capacity.

Although Safecast's and Luftdaten's data is not free from errors (e.g., [30]), it is definitely "just good enough" [34] for the emergence, growth, and sustaining of civic tech communities aiming at bringing about societal change via own's public narratives about the environment. Such imperfect, good enough civic data data is instrumental in creating high media attention, bringing established institutions to become involved and apply the citizen-collected data for their public information services, and engaging people worldwide.

7.2 Open Civic Tech

Because people need access to become involved in civic data, the civic tech initiatives required accessibility. The key factors "openness and access to materials" and "low-barrier technology" describe the open technology that includes principles of open source and open data. In this way, Luftdaten and Safecast are based on the ability to transmit not only within their respective communities but also to a globally networked data community. This ability depends on the existence of methods for interoperability [22, 83] like application programming interfaces (API) to open and machine-readable data [73]. Using APIs, Github, and other tools, civic initiatives can provide many materials, i.e., technologies, codes, data, and plans, openly and accessible for people with necessary technical skills. The sensor kits are relatively inexpensive compared to professional devices. It is a strength of Luftdaten and Safecast, that they make their materials and resources not only available but also accessible for people with basic technical knowledge [50, 62] and limited financial resources. We learned that they are even translating their materials in various languages, which allows them to attract and include non-English speaking people. Through their toolkits, extensive documentation, and regular workshops and educational events, the civic tech initiatives provide capacity building for their communities and interested people.

Apart from this, we understand that the shared value of openness is an essential condition for the initiative's rapid growth and scaling. The open design of the technologies, codes, and data is a fundamental decision that ensured that the initiatives' evolution was (and is) not dependent on specific individuals. Both initiatives' core teams have in common that they are less a managing team that gives top-down commands to the community, but they rely on the community's input and skills to evolve. Skills and capacities are built in the way of self-management and self-education by the community members. People can join Safecast or Luftdaten independently from the core team and bring in their own skills. This decentralized nature helps keep the community ongoing and stable, and the initiative flexible [43], which relates to the key factor "Adaptability to changing contexts". We learned that Luftdaten and Safecast became more professionalized and more visible over time as the core teams participated in strategic events around topics like Civic Tech, Open Data, Nuclear Energy, or Smart City. Doing so, they not only adapted their activities and communication to other contexts, e.g., urban planning, innovations, energy technology, or digital markets, but also met potential network partners, like IT companies, living labs, or hackerspaces.

Factors such as "Online and offline community building", "Attract new community members" and "Increase of data sets and sensor stations" illustrate that the low-barrier sensor kits have been assembled in participatory and joyful events. For example, with school students and community members who proudly share photos of their running sensor station in their homes or gardens. At the same time, these people become aware of the environmental issue they measure while oscillating from playfulness to seriousness and vice-versa [68] (pp.1-11). In this respect, the use of low-barrier and low-cost technologies by networks of actors in the community can allow overcoming digital exclusion that is still identified as a shortcoming in data-enhanced city scenarios [28, 62].

7.3 Public Narratives on Environmental Issues

Luftdaten's and Safecast's scaling and sustaining are not only about the role played by the open sensor technology, the civic data, and the communities built around them; but also about the public narrative contributed by the citizens (i.e., individuals, the academic institutions, the press media, the authorities, etc.) involved in the initiatives (i.e., gathering environmental data, analyzing it, programming tech, running educational workshops data, etc.). As Abe [1] has argued, Safecast is a "socio-technical system" whose collected data is not useful for knowledge production until people create narratives based on such data. In the case of Luftdaten, we observed the same. Citizens' narrative about the data captured and the sensors' use is an essential part of reaching out, networking, and generating attention within and outside the communities. Based on our findings, such a public narrative is particularly linked with the key factors "Public communication", "Attract new community members," "Data applied by established institutions," and "Further networking." From early on, the use of social media, by both initiatives, especially via strategic retweeting, helped them to initiate and maintain a two-way dialogue on air pollution and radiation while constructing community identity and agency vis-à-vis the general public. Such a dialogue led to attracting people, donors, and networking partners that led to public visibility and community engagement, and further key collaboration (e.g., with journalists, scientists, local politicians).

We see similarities to "data stories" previously conceptualized by Gabrys and colleagues [34]. Public narratives on the respective environmental issues are mediated via the initiatives' public communication with the media, their consistent use of blogs, and social media interactions. By sharing their respective angles on civic data and open tech, the various actors constituting Luftdaten's and Safecast's public narratives contributed "their stories" enabling them to have a say on public discourses on the Fukushima disaster and air pollution in urban areas.

Building on the communities' captured civic data and their use of open tech such civic techs' public narratives facilitated civic engagement and raising awareness of the environmental issue tackled by Luftdaten and Safecast. Moreover, the public narratives fell on a fruitful ground because when Luftdaten and Safecast joined the public discourses, the media had already reported on these environmental issues and people already discussed these issues on social media. In this regard, we learned from these cases that the public narrative facilitated by social media and close cooperation with traditional media (i.e., journalists) is part and parcel of the socio-technical arrangement embedded in these civic tech initiatives. Such a narrative (contributed in different languages) helped Luftdaten and Safecast scale-up and endured by having a voice in the public (i.e., local and international) environmental discourse.

Finally, through the citizens' participation in the public discourse, diverse actors become interested and engaged with the initiatives, and in doing so, infrastructuring that new issue-based publics can be designed [55] from a local to a global scale.

7.4 A Note on Empowerment and Embedded Pre-existing Power Structures

Luftdaten and Safecast have been founded on the premise that they would not accept the non-existence of data regarding particulate matter in the air and radioactively contaminated areas. For this reason, they started collecting the data by themselves in an activist way. They shared their knowledge with the broader public. They attempted to design technologies and analyses of civic data fully transparent and open to potential contributors (i.e., individuals, universities, the press, organizations, local authorities). As already pointed out by [81], such social and technical configurations can have democratic value. Ordinary citizens could empower themselves by joining the data collection and, in doing so, tackling issues of their concern [6, 44] to make informed decisions for their everyday lives.

However, while conducting this study, we noticed certain particularities linked to power imbalance or inequities (re)producing influence and power. Such particularities are recently discussed in critical scholarship on civic technologies e.g. [9, 10]. From such a socio-critical perspective, we are cognizant of Luftdaten's and Safecast's specific "socio-political and economic landscapes" [8] that have structurally helped to make them grow and sustain. In this context, we argue that we cannot fully understand the identified factors without linking them to their landscapes' economic power and socio-political influence. Coupled with pre-existing power and influence are especially early key factors "Competent core team", "Initial background network," "Access to material resources and openness," as well as later factors "Further networking," "Continuous funding" and "Data applied by established institutions." The technical skills and competencies of Luftdaten's and Safecast's core teams and the communities' high education status play an important role in the scaling and sustaining of the initiatives located in resource-rich Germany and Japan. We also observed the reproduction of existing gender imbalances in IT (e.g., [2]) in the full male founding teams of Luftdaten and Safecast.

Furthermore, the initiatives' positionalities are shaped by their initial background networks, including prestigious research institutions (in the case of Safecast) and global activists' networks (in the case of Luftdaten). These networks enabled them to quickly grow globally while bringing their message to an international public but also facilitated attracting highly skilled people to join the initiative and contribute to their activities and actions. In turn, such partnerships allowed more convenient access to technical knowledge, equipment, and other materials and resources. In this regard, we are aware of the role played by powerful local institutions for sustaining the initiatives (i.e., their data being applied by local government or news media). For instance, social media campaigning and social networking are not equally advantageous for every civic tech initiative since such communication strategies are deeply interlinked with the initiatives' positionality.

Compared to less resourceful civic initiatives (e.g., [9, 70], we presume that Luftdaten and Safecast can be viewed as part of something like a civic tech elite that benefits from the social capitals [16] of established actors in their networks in highly developed countries. Such pre-existing capital, prestige, and power can configure the initiatives' digital space, which further shapes the social field [60]. In that connection, we understand that civic tech initiatives emerging in less resourceful environments ([9, 70] where background networks are less powerful, education standards and access to technology are less developed; it is much harder to reach endurance and sustainability over time.

8 LIMITATIONS

As we build this paper on case studies, one cannot take the key factors and apply them to other cases. The reason is that the respective ecosystems (e.g., geography, culture, politics, economy) that the studied civic tech initiatives inhabit have strongly shaped the analyzed cases. For example, Safecast has emerged because of the tragic Fukushima Daiichi nuclear disaster in Japan. Only after this, the interplay of its privileged ecosystem and Safecast's own strategic decisions have led to their sustainable and robust initiative. The same applies to Luftdaten.info, which is tightly embedded in the German city Stuttgart's comparatively rich economic context and specific cultural and geographical features.

Another limitation of our work is that we are approaching the research question by primarily using the lenses of the initiatives' core teams. As such, we are aware that the choice of analyzing the core team and their Twitter accounts entails that other voices from the community are missing. Particularly, the Twitter analysis is missing members of the community who are not on Twitter and consequently, other social aspects that while contributing to the evolutions of the civic tech initiative, have not left any traces on Twitter.

There might be some important voices that are not uncovered during our analysis. We only have studied the initiatives through the founders and core team members and official social media and online contents. But there might be other actors or residents who know about the public issues at hand and have a different or even critical take on Safecast and Luftdaten (e.g., [30]).

In this respect, we might have missed additional key factors that cannot be identified by our pragmatically methodological choices. Possibly, some key factors could have been different if we would have selected cases from other socio-political and economic landscapes.

9 CONCLUSION

Drawing on previous HCI works in Digital Civics [81], we have studied two civic tech initiatives in Germany and Japan that reached a global scale and that include several thousands of volunteers and sensor stations, and millions of data points. We were able to identify the initiatives' evolution phases (emergence, growth, sustaining) and a set of key factors that helps them endure (see all key factors in Fig. 5). We could generate these findings by combining the core teams' lenses with a retrospectively designed longitudinal study of historical Twitter contents. Such a pragmatically developed mixed-method design can inform HCI research on scaling [20]. Finally, replying to what makes civic tech initiatives last over time, we argue that, in these cases, the entanglement of civic data, open tech, and the initiatives' public narrative plays a central role in the scaling up and sustaining of such socio-technical arrangements. Notwithstanding, we acknowledge issues of power [27] and inequities since the here-studied cases could take advantage of their resourceful environments and pre-existing privileges.

ACKNOWLEDGMENTS

We would like to thank Prof Ina Schieferdecker and Prof Hideyuki Tanaka who made this collaboration possible. We are also grateful to Gopinaath Kannabiran from the IT University of Copenhagen, and the anonymous reviewers who provided us with helpful comments on our work.

This work has been partially funded by the Federal Ministry of Education and Research of Germany (BMBF) under grant no. 16DII111 ("Deutsches Internet-Institut").

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