What Drives Citizens to Engage in ICT-enabled Citizen Science?:
Case Study of Online Amateur Weather Networks

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ABSTRACT
In order for citizen science initiatives to pan out well, various actors need to be willing to engage in citizen science activities. The particular interest in this chapter lies with the citizens and their motivations to participate in ICT-enabled citizen science since, arguably, without citizen participation, there is no citizen science activity. The authors examine in detail what determines citizens' interest to share their weather-related data collected with Personal Weather Stations via online amateur networks and how these citizen activities could be up-scaled to address prevalent hydro-meteorological data gaps. A decision making theory is used to guide empirical research in three European countries. The results indicate no regional differences between the main drivers and incentives and raise the question whether weather observation is still a male-dominated activity in the digital age which would have implications for upscaling this citizen science initiative.

Keywords: ICT-enabled Citizen Participation, Citizen Science, Citizen Observatories, Theory of Planned Behavior, Data Sharing, Amateur Weather Networks, Personal Weather Stations, Gender

INTRODUCTION

Citizen science is being heralded as the means for overcoming many challenges: data scarcity (Muller et al., 2015), science education (Harjanne, Ervasti, Karhu, & Tuomenvirta, 2015) and citizen participation in science (Franzoni & Sauermann, 2014), in decision making and planning (Wehn, Rusca, Evers, & Lanfranchi, 2015), policy making (Haklay, 2015) and in monitoring and forecasting (Lanfranchi, Wrigley, Ireson, Ciravegna, & Wehn, 2014). Nevertheless, in order for citizen science initiatives to pan out well, various actors need to be willing to engage in citizen science activities which often start out as pilot projects before they are established and institutionalized. Depending on the particular set up, distinct actors are involved, such as spatial planners and other decision makers from various local or national authorities, policy makers, scientists in academic, educational and applied professional environments, and of course citizens, often stemming from distinct interest or contributor groups. These actors are subject to (distinct) incentives and drivers. The particular interest of this research lies with the latter – the citizens – and their motivations to participate in ICT-enabled citizen science since, arguably, without citizen participation, there is no citizen science activity. Moreover, their involvement in citizen science is typically required and desired not once, but on a continuous basis.

In this chapter, the authors examine in detail a particular case: citizens' willingness to collect weather-related data using Personal Weather Stations and to share them via online amateur weather networks. The increasing availability of user-friendly and affordable weather stations (Bell, Cornford, & Bastin, 2013) as well as online weather networks for sharing the collected weather observations appears to have given new impetus to the long-established practice of amateur weather observation.

Citizen observations of the weather are particularly relevant in view of the gradual but steady decrease of ground-based hydro-meteorological observations by national water resources government agencies since the 1980s, as observed by the World Bank (García, Rodríguez, Wijnen, & Pakulski, 2016), owing to budget constraints and related lack of maintenance as well as political turmoil that leads to the destruction of equipment, prevents readings or terminates funding. The resulting gaps in real-time and long term data records cannot be filled by satellite observations alone (García et al., 2016). At the same time, long term data records are urgently needed for policy and planning purposes and real-time data for monitoring and forecasting: for two consecutive years (2015 and 2016), the World Economic Forum has ranked water crises and the failure to address Climate Change-related mitigation and adaption as among the top three threats facing the world's population (WEF, 2015, 2016).

To better understand what determines citizens' interest to participate in online amateur weather networks and how their activities could be up-scaled to address prevalent hydro-meteorological data gaps, the lens of a decision making theory is used to guide empirical research in three European countries (United Kingdom, The Netherlands, and Italy). The findings show that there are no regional differences between the main drivers and incentives for citizens to share their PWS data; they also raise the question whether

weather observation is still a male-dominated activity (Endfield & Morris, 2012; Manley, 1952; Subkowski, 2006) in the digital age which has implications for upscaling this as a citizen science initiative.

The chapter is structured as follows. In section 2, the conceptual framework for this research is introduced, followed by section 3 in which the methods for selecting relevant locations and respondents for the empirical research are presented. In section 4, the results of the empirical research are used to analyze what influences citizens' willingness to share personally-collected weather data and how this is manifested. In section 5, the findings are discussed regarding the most/least frequently mentioned drivers; regional differences and similarities; and gender. Section 6 concludes the chapter with recommendations for citizen science initiatives.

CONCEPTUAL FRAMEWORK

The basic principle behind citizen science initiatives is not only the observation of specific phenomena (e.g. birds, the weather, flora, fauna, etc.) but the act of sharing such observations with others. Following a brief review of the literature, Müller, Thoring, and Oostinga (2010) suggested general motives for users to participate in citizen science activities, namely money, altruism, usefulness and fun. A more thorough review and subsequent survey on participation in water quality monitoring by Minkman (2015) found that altruism and fun were strong drivers while money (financial compensation) was a weak driver and lack of time a major obstacle.

For this research, and building on the authors' earlier review of decision making theories that could be utilized to conceptualize and understand the data sharing behavior of weather amateurs (Gharesifard & Wehn, 2016), the model of data sharing (developed by Wehn de Montalvo (2003a, 2003b) was selected which is based on the Theory of Planned Behavior (Ajzen, 1985) as the framework for this study. This enabled a systematic investigation and explanation of the conditions (i.e. both drivers and obstacles) under which citizens are willing and able to share weather-related data that they collected so as to gauge whether and how this citizen science activity can be scaled up. This resulted in the following definitions of the components (Box 1).

Box 1: Conceptual definitions

Behavior
The behavior to be examined by the Theory of Planned Behavior (TPB) can be defined by taking into account four elements: action, target, context and time (Ajzen, 1985, 1991). The data sharing behavior at the core of this research is defined as follows:

Action: sharing PWS data via online platforms
Target: hydro-meteorological data collected with Personal Weather Stations
Context: online amateur weather networks
Time frame: present (the period of undertaking this empirical research (November 2014 - January 2015).

Attitude
Expectations about the positive and negative outcomes of resulting from sharing PWS data via online networks (behavioral beliefs).

Social pressure
Comprised of the normative beliefs of others and their (dis)approval of data sharing via online amateur weather networks (normative beliefs).

Perceived control
Perceptions about the absence or presence of specific factors that impede or facilitate data sharing (Wehn de Montalvo, 2003b) (control beliefs).

A combination of beliefs (behavioral, normative and control beliefs) stemming from these components forms the intention or willingness to share data. In general, a combination of more positive and favorable attitudes, stronger positive social pressure and greater perceived behavioral control will lead to stronger motivations and intentions to share data. Perceived control over data sharing is stipulated to also have a direct influence on actual data sharing behavior, as illustrated in Figure 1 below, since circumstantial factors (such as a functioning Internet connection) might limit actual data sharing, even though the willingness to share may be very high. In this study, the beliefs underlying the intention to share PWS data via online platforms are investigated based on qualitative empirical research, as explained in the following section.

<Figure 1 here>

Figure 1. Basic model of spatial data sharing (Wehn de Montalvo, 2003b)

METHODS

Research design

In order to acquire an in-depth understanding of citizens' beliefs about sharing Personal Weather Station (PWS) data via online platforms, a case study approach and qualitative research methods were chosen, following Plengsaeng's et al. (2014) and Ngo Thu and Wehn's application of the TPB to data sharing (Ngo Thu & Wehn, 2016). The empirical research for this study was undertaken in three countries in which the case studies of the EU-funded WeSenseIt project (Citizen Observatories of Water; funded under FP7, (2012-2016)) are located: Delfland in the Netherlands, Doncaster in the UK and the cities of Padua and Vicenza (Alto Adriatico) in Italy.

Two major groups of citizens were targeted for the data collection: (1) PWS data-sharers (station owners who were already engaged in sharing their station data on one or more amateur weather network) and (2) the general public or citizens who either did not have a PWS or had the equipment but did not share the data. The research instruments included interview protocols (for the general public) and an online survey (to collect data from the PWS data-sharers group) that was prepared in English and translated to Italian (for the Italian case study). Both instruments contained open questions about i) advantages and disadvantages of citizens sharing their PWS data via online networks, ii) about people or organisations who push citizens or hold them back from doing so, and iii) about opportunities or constraints that render it easy or difficult for citizen to share their PWS data via online network. Other sources of primary data that fed into the analysis included, data project reports, and observations during the interviews. The results of the data collection from primary sources were complemented with findings of previous studies in the areas of citizen science and knowledge sharing in online communities. Finally, all of the above mentioned data sources were analyzed to develop a model of behavioral determinants for sharing PWS data on online weather networks.

Selection of the interview locations in each case study

A number of data collection locations were selected for each of the three case studies. One of the main selection criteria for conducting the interviews and the online surveys was to include areas with different densities of Personal Weather Stations. The intention was that this would capture diverse views about the reasons why PWS data sharing is being practiced (or not). Therefore a density map of PWS stations was developed for each country. The stations that were used to generate these maps were primarily selected from the Citizen Weather Observer Program (CWOP) and Weather Observations Website (WOW) networks; but many of these stations also contributed data to other networks such as Weather Underground (WU), Weather Observations Website (WOW), European Weather Networks (EWN), Personal Weather Stations Network (PWSweather) and Davis WeatherLink network. The final maps (Figures 2, 3, and 4) were generated by overlaying municipal administrative areas of the three cases with the coordinates of the above mentioned stations in ArcMap. In total, more than one thousand stations (149 in the Netherlands, 626 in the UK, and 292 in Italy) were included to generate these maps.

<Figure 2 here>

Figure 2. PWS frequency map of the Netherlands

(Created by authors, January 2015)

<Figure 3 here>

Figure 3. PWS frequency map of the UK

(Created by authors, January 2015)

<Figure 4 here>

Figure 4. PWS frequency map of Italy

(Created by authors, January 2015)

Based on the PWS frequency maps, in addition to the case study areas of the WeSenseIt project, an additional location with a contrasting density of stations was selected per country.

In the Netherlands case, given the low to medium density of stations in Delfland area, the only municipality with highest number of stations was selected as the alternative location for conducting face to face interviews in the Netherlands. This municipality is Haarlemmermeer that is located in the province of North Holland with four CWOP stations (see Figure 2).This region was reclaimed from water in 19th century and includes the Schiphol Airport and Hoofddorp that is the main town of this municipality.

In the UK case, South Yorkshire (where Doncaster is located) with a total number of five stations, was initially categorized as an administrative area with medium frequency of stations. However, none of these five stations were actually located in Doncaster. This meant that the second location for conducting interviews must have been in contrast chosen from locations with high concentration of stations. According to Figure 3, there are four regions that have very high frequency of stations. These regions are; the Greater London and three counties in South and South-East UK (Hampshire, Essex and Kent). Based on the importance of the Greater London in terms of its population and also encompassing the capital city of the UK, this area was chosen as the second location for conducting face to face interviews in the UK.

The WeSenseIt project locations in Italy are Padua and Vicenza (Alto Adriatico); these two cities that are located in Province of Vicenza. Based on the PWS frequency map (Figure 4), Vicenza was one of the four provinces with very high frequency of stations and therefore the second location for conducting the interviews was ideally a province with no stations. Province of Ascoli Piceno in Marche region was thus selected as the alternative location for conducting the interviews in this case.

Selection of the participants

In all three case studies, general considerations to include respondents from different age and gender groups were taken into account. Moreover, interviews were conducted in different locations such as shopping centers, parks, train stations, restaurants, etc. at various times of the working days and also during the weekends in order to create reasonable chances for different members of the general public to be approached for the interviews.

The potential respondents for the online surveys were selected from the pool of more than 1000 stations available in the Netherlands, UK and Italy. Per case, 100 invitation emails were sent and the main criteria that were considered for selecting these potential respondents were: (1) inclusion of at least some stations from the six previously mentioned interview locations, (2) a balanced inclusion of possible respondents from regions with different station frequency categories, (3) spatial coverage of the rest of the stations across the country, and (4) availability of contact information of the station owner.

Participants in the Netherlands case

For the Netherlands case, 11 face to face interviews with the general public were conducted at the two empirical research locations (6 interviews in the Delfland area and 5 in Haarlemmermeer). The bar chart presented in Figure 5 illustrates the gender frequency of different participant age groups for the face to face interviews in the Netherlands case.

In total, 13 valid responses were received from the PWS data-sharers group in the Netherlands. Figure 5 summarizes the online survey results in this case based on the gender and age group of the participants. As the table clearly represents, all of the participants are male and older than 35 years old.

<Figure 5 here>
Figure 5. Gender frequency and age groups (interviewees and online survey participants in the Netherlands case)

Participants in the UK case

In the UK case, face to face interviews were conducted with 10 respondents from the general public group (5 in Doncaster and 5 in London). Figure 6 summarizes the frequency of these respondents, based on different gender and age groups.

The total number of valid responses received to the online survey in the UK case was 14. The bar chart presented in Figure 6 illustrates the gender frequency of different participant age groups for the UK case. In this case also (similar to the Netherlands case), all of the valid responses came from PWS data-sharers older than 35 years old and only one of these respondents was female.

<Figure 6 here>
Figure 6. Gender frequency and age groups (interviewees and online survey participants in the UK case)

Participants in the Italy case

In total 9 interviews were conducted via phone/Skype in the two empirical research locations in the Italian case (4 in the province of Vicenza and 5 in the province of Ascoli Piceno). Figure 7 summarizes all the phone/Skype interviewees, based on their gender and age groups.

The total number of valid responses received in the Italian case was 16. The bar chart presented in Figure 7 illustrates the gender frequency of different participant age groups for the UK case. As the corresponding bar chart shows, in this case also (similar to the two previous cases), all of the valid responses came from male PWS data-sharers, but unlike the Netherlands and UK cases, three of the respondents were younger than 35 years old and none older than 65.

<Figure 7 here>
Figure 7. Gender frequency and age groups (interviewees and online survey participants in the Italy case)

Citizen's willingness to share personally-collected weather data: what influences it and how?

Citizens' willingness towards sharing PWS data via amateur weather networks is a function of their 'Attitude' towards this behavior (beliefs about gains and losses), the 'social pressure' that they perceive from the members of the society and also their 'perceived control over the behavior' as a result of the presence or absence of influential factors. The following sections will describe different domains that were identified by respondents from the general public and PWS data-sharers in the three case studies.

Attitude related factors

Four relevant domains of beliefs were elicited about gains and losses or the expectations of citizens about the outcome of sharing PWS data on amateur weather networks, namely: (1) 'tangible personal outcomes', (2) 'intangible personal outcomes', (3) 'societal outcomes', and (4) 'interpersonal trust'.

1. **Tangible personal outcomes**

'Tangible personal outcomes' is identified as the first domain of the attitude and refers to the actual or approximate gains and/or losses that a person perceive to have as the result of sharing PWS data on amateur weather networks.

Several other studies in the areas of public participation, citizen science activities and online communities, have identified personal outcomes as a significant influential factor on the intentions for participation. Some literatures refer to this as 'personal outcome expectations' (Chiu, Hsu, & Wang, 2006; M.-H. Hsu, Ju, Yen, & Chang, 2007); others as 'personal gains' (Hew & Hara, 2007) or 'perceived relative advantage' (Chen & Hung, 2010; M.-J. J. Lin, Hung, & Chen, 2009). McLure Wasko & Faraj distinguish between two fundamentally different types of personal outcomes: 'tangible and intangible returns'. They argue that the personal outcomes of an action can be actual and extrinsic (tangible) or in contrast intrinsic and in form of self-actualization or satisfaction (intangible) (McLure Wasko & Faraj, 2000). The earlier falls within this attitude domain while the latter is discussed in the second domain of the attitude component.

One of the first questions that might cross someone's mind when asked to spend time and money to collect weather data and share it with others via web-platforms would be; what's in it for me? With this regard; enjoying the collected data for different personal purposes such as leisure, outdoor activities, sports, weather-related businesses (e.g. farming, railways, and construction industry), possible financial gains for the data-sharers, information for car drivers, travelers and tourists were mentioned as the positive examples of beliefs. On the other hand, especially for those whose daily activities are not very dependent on the weather, and also those who have no interest in the subject, the availability of as they say 'enough official data' seemed to create a sense of reluctance about the necessity of collecting and sharing such data. This is the negative perception about the tangible usefulness of the collected data and as expected was found only in the respondents from the general public.

The second category of behavioral beliefs focuses on the privacy and security issues. One of the main concerns of both PWS owners and the general public was the fear of theft. The instruments needed for collecting and sharing data must be installed outdoor in the backyard, garden, roof, etc and therefore not easy to protect at all times. These devices may cost from a couple of hundreds to more than a thousand Euros. Due to the fact that the location of any stations is easily retrievable using the web-platforms and Google Earth, the issue of security is certainly a tangible outcome that may hinder the participation. This argument is also true for the privacy related issues and the possibility of being located by any other unwelcome visitors, for example marketers, vendors, researchers, etc. Another relevant issue that was emphasized by the respondents is often referred to as cyber security. Access to the web almost always involves increased vulnerability to cyberattacks, especially since one need to open more ports and run software 24/7 which might have security leaks. Examples that reflected concerns about cyber security were only mentioned in the Netherlands and UK cases.

2. Intangible personal outcomes

The second Domain of the Attitude component as explained in the previous section is 'intangible personal outcomes' that refers to intrinsic gains in form of self-actualization or inner-satisfaction.

A sense of 'belonging to a community of friends with shared interests/visions' was elicited as one of the intangible outcomes of sharing PWS data via amateur weather networks. As a result of the effort that the PWS owner puts into collecting and sharing the data, he or she is welcomed and included in a virtual community of citizens who share an interest or have a similar vision and this generates a sense of self-actualization that may be a good source of motivation for participation. Previous studies have also recognize having a shared vision and interest as "a bonding mechanism" (Tsai & Ghoshal, 1998) and mention that "virtual communities are groups of people brought together by common interests and goals" (Chiu et al., 2006). During the empirical research phase, a number of PWS-data-sharers and respondents from the general public identified and mentioned this belief as a source of motivation for participation.

'Learning from each other' is the second cluster of behavioral beliefs in this domain. The researchers have categorized this behavioral belief as an intangible personal outcome, because it is mainly about the sense of enjoyment from sharing knowledge with others and learning from them. A reciprocal sense of satisfaction is normally generated for both sharer and recipient of the information. This process of learning can happen through one to one communications between the virtual community members or via group communications in online forums, Facebook pages, etc. Respondents from the general public and PWS-data-sharers seemed to perceive value in learning from other society members and considered this as an incentive for participation.

The third category of behavioral beliefs is labeled as 'recognition by others'. This form of belief that was mentioned only by the station owners and in a negative form refers to the fact that PWS data-sharers find themselves worthy of receiving some sort of commendation and acknowledgement from other members of the society and especially those who enjoy this service; an expectation that is not fulfilled in most cases and therefore translates into a sense of disappointment and thus considered as a negative outcome. This category of beliefs was identified during the online surveys where PWS-owners stated that other sites may use their data without permission or acknowledgement or national weather service organizations use these data for free without any sort of gain for the data-sharer. Some respondents explicitly mentioned that valuation of data does not have to be monetary per say and intangible values are just as important.

The last category of this domain is 'interest in the weather' and refers to the sense of enjoyment, entertainment and satisfaction that one gains from observing the weather and sharing the data on web-platforms. Not surprisingly, this was mentioned in the positive form by the PWS data-sharers and in the negative from by the general public. The first group mentioned the fun factor as a driving force while the second group highlighted their lack of interest in the weather observation as a preventing factor and mentioned that they simply do not enjoy this activity. An example that was mentioned by one of the PWS data-sharers in Italy case was; "I find it very interesting to monitor and evaluate the small variations that exist in weather attributes between different areas; even if they are very close to each other, these variations still exist".

3. **Societal outcomes**

The third domain of the attitude component is the 'societal outcomes'. This belief is closely related to the definition of morality or the evaluations or implications of the behavior on the society at large. Relevant secondary literature about participation in citizen science activities and online communities had also elicited this domain as a proxy for attitude towards behavior. Different terminology is used in these literatures such as 'community-related outcome expectations' (Chiu et al., 2006; M.-H. Hsu et al., 2007); 'community interest' (McLure Wasko & Faraj, 2000); or 'Altruism' that can be considered as a subset of the 'societal outcome' domain (Cho, Chen, & Chung, 2010; Hew & Hara, 2007).

The first behavioral belief in this domain is related with the perceived applicability of PWS data for 'reduction/mitigation of environmental risks'. Several respondents from the general public and PWS data-sharer groups identified relevant examples of such applications, here are a few example: One of the interviewees from the general public in the Netherlands case mentioned that the Dutch are mostly living under the sea level and linked this to the potentials of such data for flood risk reduction in the Netherlands. In the UK case, one of the respondents from the general public stated; "I believe that the overgrowing problem of global warming should enable citizens to share their data so we can get a better understanding" of this phenomena. As the third example, an online survey participant in Italy mentioned that; "to improve the quality of life in the territory, climate change and pollution are two factors that should be monitored closely".

Benefiting for society at large through 'creating knowledge about the weather' is the second category of behavioral belief in this domain. The examples that were mentioned during the interviews and online survey are; contribution to citizen values and well-being, creating a collective knowledge about the weather and climate (that is not individually possible), creating a complementary source of data to the official observations both in terms of spatial and temporal distribution, economically efficient weather data for the government and the whole society, and creating an alternative source of data for research purposes.

4. **Interpersonal trust**

'Interpersonal trust' is the last domain of the attitude component. Several literatures in areas of knowledge sharing in online communities have recognized the importance of trust as a determinant of intention to participate in these communities (Chow & Chan, 2008; C.-L. Hsu & Lin, 2008; H. F. Lin, 2008). Due to the fact that in this study the main actors are the citizens, a specific type of trust called 'interpersonal trust' was identified as one of the domains that influences the perception of the citizens about sharing PWS data. Chen and Hung described the interpersonal trust in the context of knowledge sharing in online communities as; "a degree of belief in good intentions, benevolence, competence, and reliability of members who share knowledge" (Chen & Hung, 2010). The issue of trust and its relation with attitude can be articulated as the expectation of the trustor that his/her act will not have any harmful outcomes for him/her (Barber, 1983; Pavlou & Fygenson, 2006). Optimistically speaking, it may also refer to the assumption that the interests of trustor will be protected by the trustee (Hosmer, 1995; Pavlou & Fygenson, 2006). In the case of this research, interpersonal trust implies the extent to which society members believe in good intentions, competence and reliability of citizens as non-professionals to engage in collecting and sharing weather related data. The stronger this trust is; the more inclined people are expected to be towards engagement in this activity. Two categories of behavioral beliefs related to interpersonal trust were elicited during the face to face interviews and online surveys:

The first one is labeled as 'competence and reliability' and is related to the competence of the citizens as non-professionals in collecting and sharing weather related data and as a result; the reliability of this type of data. If interpersonal trust does not exist society members may not perceive any advantage for their engagement and this may affect their intention for participation. The issue of trust in the competence of non-professionals and the quality of the data that they produce were mentioned several times during the interviews and the online survey. Contradictory opinions seemed to exist among the respondents; some respondents trusted the official data more than the personal observations and mentioned that data contributors may intentionally or unintentionally falsify the data. Others had a sense of mistrust in the official data and therefore perceived the personally collected data as a more reliable source of information about the weather. There were also a third group of respondents who trusted in both source of data and considered the personally collected data as a complementary data stream for the official observations.

The second category of beliefs in this domain relates to the 'intentions of the data sharing promoters'. Some respondents believed in the good intentions of the data sharing promoters, while others, believed that data sharing promoters have their own reasons (agenda) for supporting PWS data sharing such as promoting specific businesses, conveying certain messages or selling their own products.

Social pressure

'Social Pressure' is the next component of the conceptual framework of this research. In the context of this research, social pressure refers to the beliefs regarding the perception of other individuals or group of individuals (referents) about sharing PWS data and whether they will approve or disapprove participating in it. These beliefs are also referred to as normative beliefs (Ajzen, 1991). The accessible normative beliefs that were elicited by respondents in this research are categorized into five different domains: (1)

'public/private organizations', (2) 'scientific community', (3) 'weather enthusiast community', (4) 'other society members', and (5) 'moral norms and altruism'. Likewise, each Domain is formed from a set of normative beliefs that will be introduced in the following sections. The normative beliefs reflect the perception of both PWS owners and the general public about the referents view on sharing PWS data via amateur weather networks and can be positive or negative in nature. The 'social pressure' domain is highly dependent on the behavior in question and less extendible from relevant secondary literature (in comparison with the 'attitude' domain); therefore this section is mostly based on the findings from this empirical research.

1. **Private/public organizations**

The first domain of the 'social pressure' relates to the perceived pressure from public/private organizations and whether they will be in favor of, or against sharing personally-collected weather data via amateur weather networks. Respondents from the PWS data-sharer group and the general public elicited several examples of public and private organizations that they believed may approve or disapprove engagement in sharing such data. They mainly based their judgments on whether these organizations or companies may gain or lose authority, power or income because of this behavior. In some cases, different respondents had opposing beliefs about the same organization or company; perceiving it in favor of or against sharing PWS data via online amateur weather networks. Four different groups were elicited by the respondents from the general public and PWS data-sharers; (1) 'new weather-related commercial actors'; such as manufacturers of the personal weather stations and application developers. This group was identified as supporter of PWS data sharing, because of the direct benefits that they have in increased engagement of the citizens; (2) 'traditional weather-related commercial actors'; this group includes long-established institutions and organizations such as news agencies/channels and private weather forecast organizations. Respondents from both group of participants in all three cases mentioned that these commercial actors may approve this behavior because they can benefit from using the data (e.g. in forecasts) and/or may disapprove it because it may affect their business by questioning its necessity; (3) 'weather-related (inter)governmental organizations'; Similar to the second category, these organizations may also approve or disapprove sharing personally-collected weather data. Several examples of these organizations were mentioned by both groups of respondents in the three cases. Here are a number of examples that were mentioned in the three case studies; KNMI (the Dutch Meteorological Institute), Waterschappen (the Dutch Water Boards), Milieudefensie (the Dutch Environmental Defence Organization), NASA (the National Aeronautics and Space Administration of the United States), ESA (the European Space Agency), Met Office (the UK Meteorological Institute), the United Nations, Italian Meteorological Service, ARPA (the Regional Environmental Protection Agency), WWF (the World Wide Fund for Nature) and Italian Military Air Force; (4) 'other industrial sectors'; these are the industrial sectors that may somehow be affected by the weather and therefore may approve and/or disapprove the behavior of sharing personally-collected weather data via web-platforms (e.g. agriculture, energy, tourism, construction, transport and insurance industries and also other industries that might harm the environment).

2. **Scientific community**

'Scientific community pressure' was elicited as the second domain of the 'social pressure' component. According to the respondents from the general public and PWS data-sharers this group may also approve or disapprove the behavior of PWS data sharing via online weather networks. A number of respondents from both respondent groups believed that the scientists and researchers will enjoy this source of freely available data and will perceive it as a complementary data stream to the available official observations and therefore will welcome and support this behavior. This also includes schools and universities that might use the data for educational purposes. On the other hand some interviewees from the general public believed that scientific community may be against involvement of general public in collection and sharing weather related data because of mistrust in the capability of general public in doing so and therefore may

disapprove it. In summary, the social pressure in this domain was perceived from two main group; scientists and educational institutes .

3. **Weather enthusiast community**

The third domain of social pressure relates to the individuals or groups of individuals who are interested in weather data for different reasons. Respondents from both groups in all three cases elicited 'weather enthusiast individuals' as independent members of the society who may motivate each other and the general public to further engage with this behavior. According to the PWS data-sharers in all three cases, actual and virtual 'weather networks' and 'weather-related hobby clubs' (such as ham radio clubs , aviation clubs, sailing clubs, etc.) are also two other groups that will approve collecting and sharing weather related data by the citizens.

4. **Other society members**

The forth domain that may influence the citizens to engage in sharing PWS data via online amateur weather networks is 'other society members'. By other society members refer to individual citizens who may not gain or lose directly like private/public and also do not belong to the scientific community and/or weather enthusiast community but still may approve or disapprove this behavior for different reasons. This group can be divided to three categories; (1) 'citizen science/ big data critics': this category that was identified by PWS data-sharers and the respondents from the general public in all three cases refers to the existing negative pressure from citizen science/ big data critics who have some sort of mistrust in the competence of the citizens to collect and share data with an acceptable quality and also are concerned about the privacy and security issues resulted from that; (2) '(Anti) environmentalist community': This group contains both positive and negative beliefs from rather self-explanatory groups within societies who perceive certain environmental-related benefits or losses for this type of data; (3) 'Family and peers' is the last group of this Domain. This includes family members, neighbors and friends of the one who shares data that may support this activity or stand against it based on their personal opinion or circumstances.

5. **Moral norms and altruism**

The last domain with regards to the 'social pressure' component is labeled as 'moral norms and altruism'. Morality can also be considered as moral obligations to perform or not perform a behavior (Sabini, 1995) and therefore may be categorized as a 'Social Pressure' antecedent. These types of beliefs, especially when related with the risks, are closely linked with altruism and may be considered as a source of inner approval to perform the behavior. This is also true when the behavior performer provides a useful for society at large. Based on the results of the interviews with the general public and online survey with the PWS data-sharers in all three cases, 'risk prevention' and 'Benefit for society at large' were elicited as the relevant sets of beliefs for this category.

Perceived Control

The final main component of the conceptual model of this study is 'Perceived Behavioral Control' (PBC), and is also argued to be a function of beliefs. These beliefs are formed based on the perception of an individual about the absence or presence of certain factors that may impede or facilitate performing the behavior and are referred to as control beliefs. The PBC component is essential while studying behaviors that are not under full 'volitional control' (Ajzen, 1991). In this study, the behavior of sharing PWS data via online amateur weather networks is being investigated and a number of circumstances and factors may interfere with the performer's control over this behavior. These factors or circumstances can be further divided into two groups based on their relation to the individual who performs the behavior; internal factors or external ones (Ajzen & Madden, 1986; Wehn de Montalvo, 2003b). Some examples of

internal factors are personal abilities, knowledge and skills while opportunity, time and dependence on other's cooperation may be categorized as external factors (Ajzen & Madden, 1986). In this study, four different domains were identified under the 'Perceived Behavioral Control' component, namely; (1) 'technical skills', (2) 'knowledge self-efficacy', (3) 'resource control' and (4) 'opportunities'. Based on the above explanations, the first two categories are internal factors while the last two are external to the individuals.

1. **Technical skills**

The first Domain of the 'Perceived Behavioral Control' relates to the control beliefs about the presence or absence of technical skills of the individual who want to participate in sharing PWS data via online amateur weather networks. Many literatures in the areas of citizen science and knowledge sharing in online communities have highlighted the importance of technical skills (Hew & Hara, 2007; Kaufmann, Schulze, & Veit, 2011; McLure Wasko & Faraj, 2000). This is very much relevant in the case of using PWSs to collect and share weather related data in the sense that a range of technical skills exists, that their presence may facilitate citizen's participation and at the same time their absence is likely to impede their engagement. Based on the empirical research results in all three cases, two different categories of technical skills were identified; technical skills about 'setting up and maintenance' of the PWSs and 'IT skills' in general that includes basic computer skills (hardware and software), using the Internet to send and receive data and in some cases managing a personal webpage.

2. **Knowledge self-efficacy**

The second elicited domain of the PBC is 'knowledge self-efficacy' that has been identified as one of the main subordinates of Perceived Behavioral Control (Ajzen, 2002; Armitage & Conner, 1999; Manstead & Van Eekelen, 1998). According to Bandura, Perceived self-efficacy is defined as “people’s beliefs about their capabilities to exercise control over their own level of functioning and over events that affect their lives” (Bandura, 1991). It is important to mention that 'self-efficacy' is different from 'controllability' that is another subordinate of Perceived Behavioral Control and Ajzen makes this distinction clear by linking the first one to the "ease or difficulty of performing a behavior" and the second one to "beliefs about the extent to which performing the behavior is up to the actor" (Ajzen, 2002). In the case of sharing personally-collected weather data via web-platforms a specific type of self-efficacy was identified that relates to the perception of the citizens about their knowledge of the methods of data collection and weather observation in general and its effect on the ease or difficulty of their participation. This is closely linked with citizens' "confidence in an ability to provide knowledge" (Chen & Hung, 2010) related to the weather. Some members of the society tend to believe that normal citizens do not have the required knowledge about observing the weather and collecting the relevant data and thus do not feel confident to participate in these activities. On the other hand others may have this knowledge self-efficacy and this may act as an enabling control factor for their participation.

Generally speaking many members of the society seem to believe that they know enough about meteorological phenomena and weather related events when they watch the news on TV or check the forecasts on websites or their mobile Apps. It even forms an integral part of some people's daily conversations, however when they imagine themselves in the position of the data provider, some of them may not be as confident as before. This perception about lack of meteorological knowledge self-efficacy was mentioned more specifically by some participants. These are two examples of the responses received in this regard; "there is a need for educating people about weather phenomena and this can even start from primary schools"; "I think 'a high level of knowledge is required to do this".

Familiarity with 'data collection methods' and the technical knowledge that may be required for that is another control belief of this domain. This is closely related to the perceived knowledge and confidence about the perception of an individual about the difficulty of these methods. An example answer that was

received during the interviews with the general public in the Netherlands case was; "citizens should be well instructed how to gain data, otherwise they will be incorrect and therefore not useful".

3. **Resource control**

The fourth domain of the PBC component is resource control. In the case of sharing PWS data via online amateur weather networks, control over resources refers to the perception of the individuals about the extent to which performing this behavior depends on their access to external resources such 'equipment', 'Internet connection', 'finance', 'time', 'usability of web-platforms and apps' and 'PWS installation location'.

The first category of resources is the required equipment to observe the weather and share the data on web-platforms. These are the hardware required for citizens' engagement. Several participants from both respondent groups mentioned this category of beliefs when asked about the factor that may facilitate or enable them to participate.

The second group of resources is the Internet connection that is essential for sharing the collected data. The majority of respondents in the Netherlands and UK cases believed that the Internet connection is not an issue and some even mentioned this in their answers, however in both cases there were participants who still believed that this may positively or negatively affect the citizens engagement and mentioned for example that: there are "there is a lack of good Internet access in some areas". This issue seemed a bit more highlighted in the Italy case as a larger proportion of the respondents from the general public and PWS data-sharer groups mentioned this as a factor that hinders their engagement. An example that was mentioned by one of the PWS owners is; "the inefficiencies in our infrastructure system (Internet for all) make it difficult to share a big amount of data".

Finance is the next cluster of resources and was elicited as an enabling (if present) or disabling (if absent) factor. This category of resources includes both initial capital investment and the ongoing operation and maintenance costs of having a PWS. This is also evident while visiting some of the personal WebPages where station owners ask for donations from their visitors; an anonymous example is provided in Figure 8.

<Figure 8 here>

Figure 8. An example of a donation request note from an amateur website

Time is the forth category of resources that were identified based on the collected responses during the interviews with the general public. The responses suggest that availability of time to collect and share the data and maintain a PWS is factor that citizens will consider before engaging in the activity.

Both PWS data-sharers and respondents from the general public in all three cases mentioned easy to use web-platforms and applications may facilitate citizens' participation. On the other hand they also identified complex and hard to understand web-platforms and applications as a barrier for their engagement.

The sixth control factor of the resource control Domain is the suitable location for installing the weather stations. This is an important issue for the ones who live in apartments or perhaps live in sheltered locations where high rise buildings and trees cause limitations for standard weather observations. As an example, one of the PWS owners in the UK case, stated that; "unfortunately my garden has high trees on the West and South elevations so my wind speed and direction is not always accurate. I do make this clear on my personal weather site".

4. **Opportunities**

The second category of external control factors and the last domain of Perceived Behavioral Control is labeled as opportunities. Absence of these series of 'circumstantial factors' is not expected to affect the behavior (Wehn de Montalvo, 2003b) but their existence may facilitate sharing personally-collected weather data. This belief seemed to exist only among PWS owners as it was not elicited by any member of the general public in neither of the cases. PWS data-sharers identified two categories of opportunities; (1) 'incentives provided by web-platforms'; the examples that were mentioned for the this cluster are; receiving feedbacks from the web-platform operators about the data shared by their station (in terms of quality, possible errors, etc.) , a certificate that indicates they have provided this data for a certain period (e.g. after one year), an excursion to official weather station in their locality, and a small annual retainer fee to those who have joined a network. (2) 'Opportunities to gain and exchanging knowledge'; as an example one of the PWS owners in the UK case stated; "I have found that sharing weather data and learning has opened up many new avenues of useful teaching experience for my students".

The model of sharing PWS data via online amateur weather networks

The model presented in Figure 9 summarizes the discussions about citizens' willingness to share personally-collected weather data, based on the findings and the theoretical framework of this research. Initially and prior to conducting the empirical research, two possible approaches were envisioned for developing this model. The first one was to develop individual models for each case (or any combination of cases) and the second one was to develop a common model for the three cases; and the choice was totally dependent on the level of differences in the findings across the three case studies. As it is further discussed in the cross case comparison section, the results did not show significant difference across the Netherlands, UK and Italy case studies, and thus a common model (Figure 9) was developed for the three cases.

<Figure 9 here>

Figure 9. The model of sharing PWS data via online amateur weather networks (in the Netherlands, UK and Italy)

DISCUSSIONS

Most/Least frequently mentioned influential factors

In this section, the most and least frequently mentioned influential factors for sharing PWS data via online amateur weather networks are presented. The discussions are based on a compilation of interview and online survey results in the three case studies. In total, 43 PWS data-sharers and 30 participants from the general public participated in this study. A tabular format is utilized to illustrate the most and the least frequently mentioned behavioral, normative and control beliefs that may positively or negatively affect the citizen's willingness to share PWS data via online amateur weather networks.

Among the identified positive beliefs about the outcomes of sharing PWS data, benefits of for the society at large through creating knowledge about the weather was the most frequently mentioned belief (see Table 1). This implies that more than 50% of the respondents from both groups (PWS data-sharers and the general public) believed that sharing PWS data will help enhance the current spatial and temporal weather databases. Furthermore, one of the most contested beliefs was the competence and reliability of the citizens to participate in this activity. There were 37 positive and 23 negative responses about this influential factor and this clearly shows the diversity of views about this issue among the respondents.

Table 1. Most/least frequently mentioned perceived outcomes

Component	Perceived outcomes	Positive/negative beliefs about the outcomes	No. of total responses	
			positive	Negative
Attitude	Tangible personal outcomes	Usefulness of the collected data for personal purposes	16	7
		Privacy and security issues	0	11
	Intangible personal outcomes	Belonging to a community of friends with shared interests/visions	11	0
		Learning from each other	5	0
		Recognition by others	0	6
		Interest in the weather	10	7
	Societal outcomes	Reduction/mitigation of environmental risks	13	0
		Creating knowledge about the weather	40	0
	Interpersonal trust	competence and reliability	37	23
		Intentions of data sharing promoters	13	4

Interestingly, the most frequently mentioned referent that encouraged respondents to participate in sharing PWS data appeared to be their inner-self (Table 2). Benefiting society at large which is linked to the moral norms and altruism domain was mentioned by more than 50% of the total respondents in all three cases. On the other hand, in general, for all three cases, Citizen Science/ Big data critics seemed to impose the most negative social pressure on the citizens, discouraging them from participation.

Table 2. Most/least frequently mentioned perceived sources of social pressure

Component	Social pressure by key referents	Perceived pressure (not) to share	No. of total responses	
			To share	Not to share
Social Pressure	Public/private organizations	New weather-related commercial actors	4	0
		Traditional weather-related commercial actors	8	8
		Weather-related (inter)governmental organizations	17	5
		Other industrial sectors	14	8
	Scientific community	Scientists	8	5
		Educational institutes	7	0
	Weather enthusiast community	Weather enthusiast individuals	10	0
		Weather networks	10	0
		Weather-related hobby clubs	5	0
	Other society members	Citizen Science/ Big data critics	0	17
		(Anti) environmentalist community	1	2
		Family and peers	2	1
	Moral norms and altruism	Risk prevention	13	0
		Benefit for society at large	40	0

Generally speaking, the presence of each control factor is perceived to make sharing personally-collected weather data easier and its absence make it more difficult. Resources such as equipment, finance, and usable web-platforms and mobile applications were among the most frequently mentioned factors, in that their absence is perceived as a barrier and their presence is perceived as a facilitator for sharing PWS data

via online amateur weather networks (see Table 3). Furthermore, with regards to the knowledge self-efficiency domain, unfamiliarity with data collection methods was frequently mentioned as an influential control factor for not participating in this activity.

Table 3. Most/least frequently mentioned perceived control factors

Component	Perceived control factors	Beliefs about (presence/absence of) control factors	No. of total responses	
			Easy/ Present	Difficult/ Absent
Perceived Behavioural Control	Technical skills	Setting up and maintenance	10	11
		IT skills	11	15
	Knowledge Self-efficacy	Meteorology science	0	3
		Data collection methods	0	20
	Resource control	Equipments	19	5
		Internet connection	10	12
		Finance	14	24
		Time	6	6
		Usability of web-platforms and Apps	17	12
		PWS installation location	3	3
	Opportunities	Incentives provided by web-platforms	10	0
		Gaining and exchanging knowledge	4	0

This study did not aim for a quantitative validation and ranking of the revealed beliefs. Future research should validate the model presented here, using a survey approach to allow respondents to rank each belief. Based on a large sample of respondents, a quantitative analysis of their responses will result in generalizable insights of the most influential beliefs and of the extent to which specific behavioral beliefs have a direct influence on sharing PWS data via online amateur networks.

Cross case comparison

The purpose of this section is to compare the findings of the research, across the three case studies, with the aim of identifying similarities and differences in the responses received from the participants. For this purpose, the results from the three cases are first compared and contrasted at the domain level to identify, the major differences (if any); and then zoomed in at the belief level to discuss the major similarities and differences in positive and negative perception about sharing PWS data via online amateur weather networks, across all three cases.

The review of the responses at the domain level clearly demonstrates that the groups of beliefs (domains) about sharing personally-collected weather data via web-platforms that were identified in the Netherlands, UK and Italy cases are basically the same. To summarize, for each case, four Attitude domains were elicited, namely: 'tangible personal outcomes', 'intangible personal outcomes', 'societal outcomes' and 'interpersonal trust'. Five different domains represented the Social Pressure component; 'public/private organizations', 'scientific community', 'weather enthusiast community', 'other society members' and 'moral norms and altruism'. Finally the Perceived Behavioral Control has four domains, namely; 'technical skills', 'knowledge self-efficacy, 'resource control' and 'Opportunities'.

The result of the analysis showed a great deal of similarities in the range of elicited beliefs by respondents from the general public and PWS data-sharers in all three cases. The behavioral and control beliefs fully matched for the Netherlands, UK and Italy cases. However, the normative beliefs in the three cases,

showed two marginal differences. Firstly, in the Italy and UK cases, some respondents mentioned that they perceive social pressure from environmentalist and individuals or groups and also from those who may harm the environment for their personal benefit (anti-environmentalists). This was not mentioned during the interviews with the general public and online surveys with PWS owners in the Dutch case. The second difference was identified in the Italy and Netherlands cases when the respondents mentioned the issue of approval or disapproval of sharing personally-collected weather data via web-platforms by family members and peers as these may consider it as a waste of time and money or, on the other hand, support it for personal reasons. This was not elicited from any of the respondents in the UK cases.

A predominantly male activity?

The bar charts presented in Figures 5, 6, and 7 for the online survey respondents reveal that only one female respondent (in the UK case) in all three case studies participated in the online surveys for this research. Given the total number of valid responses (i.e. 43 for all three cases), this represents less than 3% of the total valid responses that were collected from the PWS data-sharer community.

The qualitative nature of this study puts inherent limits on the sample size which is therefore not representative of the entire population (in each of the three countries or all of Europe). This study therefore cannot draw firm conclusions about the gender (im)balance regarding the participation in ICT-enabled amateur weather observations. Nevertheless, given the random selection procedure of the participants, this finding raises a question about the gender dimension of the larger online amateur weather observers' community in these countries.

Recent research carried out within one of the UK's amateur weather observation communities (i.e. UK-Climatological Observer Link) indicates that both, amateur and professional weather observations, are a predominantly male preserve (Endfield & Morris, 2012). Several reasons for have been suggested for this in the literature. Gordon Manley (controversially) argued long ago that "prolonged maintenance of daily observations demand an odd and uncommon type of enthusiasm" (Manley, 1952, p. 300) that is best found within the male community. Diverse factors come into such as the invisibility of female efforts in maintenance, recording and sharing the data (the so-called 'invisible technicians' (Endfield & Morris, 2012)), and the tendency of men to enjoy their "closed off universe" (Subkowski, 2006, p. 386) and to get involved in long-term and continuous data collection, analysis and storage efforts (Endfield & Morris, 2012).

With advancements in ICTs and the availability of automatic amateur weather stations as well as dedicated apps, further research is required to generate sound insights into the current situation of gender balance regarding participation in ICT-enabled weather observations, so as to inform the individuals and organizations involved in setting up and – especially - in scaling-up citizen science projects.

CONCLUSIONS

In this chapter, a decision making theory was used to serve as a framework for a systemic investigation of a specific type of citizen science activity, namely collecting weather observations with Personal Weather Stations and sharing these via online amateur weather networks. Based on empirical research in distinct locations of three European countries with a carefully selected sample of participants, the following conclusions can be drawn.

First, there appear to be no substantial regional differences between the main drivers and incentives for citizens to share their PWS data. This suggests that the reasons and obstacles for sharing PWS data via online platforms are fairly homogeneous in the studied countries. Nevertheless, while some of the drivers

and obstacles for sharing weather observations pertain across citizen science activities, others differ. The mistrust in the competence of the citizens to collect and share data of an acceptable quality is a commonly discussed concern (Bonney et al., 2014; Crall et al., 2011; Nature, 2015)which is manifested as negative social pressure, holding back participation. However, in the case of sharing weather observations, altruism and societal benefits appear to play a significant role whereas in other citizen science initiatives such as biodiversity monitoring, citizens seem to be driven more by personal returns and show greater reluctance to share the data (Ganzevoort & van den Born, 2016). It remains to be seen whether the Big Data-related anxieties regarding privacy and security uncovered here also pertain across different citizen science initiatives. This leads to the second conclusion that the reasons for participating in citizen science activities are thematically bound and therefore need to be carefully considered in context when aiming to scale up specific citizen science initiatives.

Finally, if in the digital age observing the weather is still a male-dominated activity, so is the participation in online amateur weather observation networks and communities; such gender bias would have implications (and inherent limitations) for upscaling this citizen science initiative. Similarly, despite ever advanced apps and ever easier to use weather stations, the technical knowhow and capabilities required for collecting and sharing hydro-meteorological data do matter and can constitute a tangible barrier for continued participation. Affordable equipment, training for particular citizen segments and use-friendly web-platforms and mobile applications still seem a must if citizen science is to close the data gaps.

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KEY TERMS AND DEFINITIONS

Amateur Weather Data: Weather data that are collected and shared by members of the general public (can also include experts in meteorology science) using Personal Weather Stations (As compared to official weather observations).

ICT-enabled Citizen Science: Citizen Science activities that are employing Information Communication Technologies (ICTs) such as low-cost and innovative sensor devices, smart phones and social media to facilitate data collection and sharing by the members of the general public.

Knowledge Self-Efficiency: The level of confidence that someone has in her/his own knowledge about a certain topic (in this case, about Meteorology Science and weather data collection methods).

Online Amateur Weather Network: A virtual network of amateur weather observers that hosts, aggregates and visualizes amateur weather data on an online platform.

Personal Weather Station (PWS): A set of sensors and instruments that enables the measurement of different weather attributes (often in an automated way) and which is normally installed at the user's home or work place.

Societal Outcomes: The evaluations or implications of a certain behavior on society at large, as compared to its implications for the performer of the behavior.

Weather Enthusiast Community: Individuals or groups of individuals who are interested in weather data for different and often personal reasons.