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To share or not to share: Drivers and barriers for sharing data via online amateur weather networks

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SUMMARY

Increasing attention is being paid to the importance and potential of crowd-sourced data to complement current environmental data-streams (i.e. in-situ observations and RS data). In parallel, the diffusion of Information Communication Technologies (ICTs) that are interactive and easy to use have provided a way forward in facing extreme climatic events and the threatening hazards resulting from those. The combination of these two trends is referred to as ICT-enabled 'citizen observatories' of the environment. Nevertheless, the success of these citizen observatories hinges on the continued involvement of citizens as central actors of these initiatives. Developing strategies to (further) engage citizens requires in-depth understanding of the behavioral determinants that encourage or impede individuals to collect and share environment-related data. This paper takes the case of citizen-sensed weather data using Personal Weather Stations (PWSs) and looks at the drivers and barriers for sharing such data via online amateur weather networks. This is done employing a behavioral science lens that considers data sharing a decision and systematically investigates the influential factors that affect this decision. The analysis and findings are based on qualitative empirical research carried out in the Netherlands, United Kingdom and Italy. Subsequently, a model was developed that depicts the main drivers and barriers for citizen participation in weather observatories. This resulting model can be utilized as a tool to develop strategies for further enhancing ICT-enabled citizen participation in climatic observations and, consequently, in environmental management.

1. Introduction

According to the 2015 report on the state and outlook of the European Environment, floods, droughts and other weather-related extreme events are among the key risks that endanger the biodiversity, ecosystem, infrastructure and citizen's well-being in Europe (European Environment Agency, 2015). Europe suffered from more than 100 major floods between 1998 and 2004; around 700 deaths, displacement of 500,000 people and a minimum estimated insured economic loss of €25 billion are the results of these events for European countries (European Commission, 2014). Furthermore, it has been predicted that the number of people who are affected by floods (mainly driven by climate change) and also the annual monetary damage resulting from that will double during the next 70 years (Ciscar et al., 2009). Based on UNECE's report, in the best case scenario, there are four water-stressed countries in Europe, namely Cyprus, Spain, Malta and Italy; this means that around 20% of Europe's population (approximately 113 million inhabitants) live in water-stressed countries (UNECE, 2011). Water supply and wastewater operations can also be highly affected by extreme weather conditions. In such situations, water services systems (such as dams, canals, pipelines and wastewater treatment plants) can turn into elements that pose significant threats to citizens' and environment's health (Sinisi and Aertgeerts, 2011). The adverse effects of such events may not be limited to a specific location and sometimes not even the country's borders; moreover, these consequences may not be reversible or might entail huge economic investments.

In the face of such diverse weather-related hazards that are expected to be intensified by climate change (Pachauri et al., 2014; Tol, 2014), continuous and widespread observations of the weather are of crucial importance to equip authorities and citizens in at-risk locations with essential information as they have to deal with more frequent and/or more intense weather-driven hazards. Yet there are two major flaws in the traditional means of observing the weather such as Remote Sensing (RS) using satellites and in-situ observations of hydrological and

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meteorological variables. The first one is that the data acquired using these methods is not always publicly available at high resolution and density and the second one is the passive role that they stipulate for citizens in terms of understanding their environment (Lanfranchi et al., 2014). Increasing understanding of the potential of 'citizen science' in gathering data, and the rapid diffusion of Information Communication Technologies (ICTs) that are interactive and easy to use, provide a way forward in facing extreme weather events by tapping into an immense source of passion, devotion and good will but also expertise from the general public. The combination of these trends has gained popularity in many disciplines, including the environmental management domain, and is often referred to as citizen observatories through e-Participation (Wehn et al., 2015).

An example of these ICT-mediated citizen observatories are online amateur weather networks. Amateur weather observation is not by any means a new practice; in fact meteorological science was initiated thanks to the enthusiasm and interest of amateurs (Eden, 2009). The introduction of instrumental measurements in the 17th and 18th centuries and establishment of several official meteorological organizations in the 18th and 19th centuries turned these official organizations into the most widely preferred bodies for measuring and reporting weather conditions and forecasts. During the past two decades, however, the aforementioned paradigm shift towards citizen participation in environmental observations and increasing availability of user-friendly and affordable weather stations (Bell et al., 2013) once more resurfaced amateur weather observers. This was facilitated through the formation of what nowadays are called online amateur weather networks. Currently, several such networks exist and they are evolving rapidly both, in terms of the number of users as well as data visualization and reporting features. The so-called citizen contributed data that is collected using Personal Weather Stations (PWSs) and shared via these platforms can have various applications; there have already been instances of using these data to improve severe-weather warnings (Blum, 2013), event identification and separation of baseflow for small watersheds (Koskelo et al., 2012), and to verify surface precipitation (Apps et al., 2013). However, the increase in use and success of these applications are dependent on continuous and widespread involvement of citizens, the active role of citizens as the main actors of these initiatives and also trust that their efforts are valued by decision makers[1]; which in many instances are yet to be achieved.

The main objective of this paper is therefore to investigate what drives citizen participation in gathering and sharing weather-related data in order to help maximize their active and continued involvement in citizen observatories. We build on previous research in the behavioral sciences to investigate the influential factors that may affect citizens' willingness to participate in these initiatives. This paper is structured as follows. Section 2 presents a review of relevant theoretical contexts and introduces the framework used in this study. Section 3 is dedicated to details of the methods used in conducting the empirical research in the three case studies. The results of this study and the discussion of the findings are provided in Section 4. We conclude the paper in Section 5 with concrete recommendations on how to improve the current state of citizen participation in amateur weather observations.

2. Theoretical context

Collecting and sharing weather data using Personal Weather Stations is a citizen-centered and voluntary behavior that is facilitated by the diffusion of ICTs. The first step in understanding behaviors such as this, that are under an actor's direct influence, is to understand the decision making process behind it. Several decision making theories exist in the domain of behavioral sciences that may be utilized to conceptualize and understand such behaviors, namely Prospect Theory on decision making (Kahneman and Tversky, 1979), the diffusion of innovation theory (Rogers, 1968), the Technology Acceptance Model (TAM) (Davis et al., 1989), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) and the Theory of Planned Behavior (TPB) (Ajzen, 1985).

A relevant theoretical framework for our research needs to be able to systematically investigate and explain the conditions under which citizens are willing and able to collect and share weather-related data. Prospect Theory on decision making (Kahneman and Tversky, 1979) could help us explains *how* people make decisions about their prospect and what choices will most probably be made by an idealized rational individual, but it is not able to explain the reasons behind making those decisions. The diffusion of innovation theory (Rogers, 1968) has been criticized for its so-called 'pro-innovation bias' or the idea that eventually every member of the society has to adopt the innovation (Dijk, 2005), that in this case are PWSs and online platforms. Another criticism that is closely linked to this is that the aforesaid theory may not provide the basis to explain the reasons why an innovation is rejected or not diffused (Wehn de Montalvo, 2003b). The Technology Acceptance Model (TAM) (Davis et al., 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) are both based on the Theory of Planned Behavior (TPB). Both of these theories are simpler and more specific compared to the TPB in the sense that they have been developed to analyze the technology acceptance area; however, they both suffer from a fragmented and less comprehensive form of encompassing the 'perceived behavioral control' component of the TPB. This component helps explain behaviors that are not fully under volitional control and require factors such as resources or skills. Based on research on data sharing more generally, we already know that this component comes into play (Wehn de Montalvo, 2003b). The Theory of Planned Behavior (TPB) on the other hand is well-grounded and has been implemented previously and tested in numerous studies in diverse areas of research such as health related studies (Conner et al., 2003; Nguyen et al., 1997), environmental psychology (Koger and Winter, 2010; Stern, 2000), entrepreneurship (Kautonen et al., 2013), environmental innovation (Montalvo Corral, 2002), the ICT domain (Ambali, 2014; Kim and Shin, 2015; Teresa and María Arántzazu, 2013) and most relevant to this research, data sharing (Ngo Thu and Wehn, 2016; Plengsaeng et al., 2014; Wehn de Montalvo, 2003a,b). Despite its successful application in many studies, the TPB is sometimes criticized for being a rational choice theory that excludes implicit attitude such as affection and emotion (Bagozzi and Kimmel, 1995; Conner and Armitage, 1998; Sabini, 1995). Arguably, emotion and affection can be expected to come into play a strong role for ad hoc behavior but less so, or not at all, for planned behavior such as data sharing. The behavior of interest in our research, i.e. sharing PWS data via online platforms, is a specific case of spatial data sharing. Wehn de Montalvo (2003b) applied the TPB to study spatial data sharing behavior at organizational level as perceived by key individuals. This study resulted in development of a detailed model of spatial data sharing. Our unit of analysis, in this research, is individuals, thus we employed the basic model of data sharing as the framework for our study (see Fig. 1).

According to the basic model of data sharing, the behavioral intention of an individual to share spatial data is based on three main constructs; 'attitude' towards sharing the data that is linked with expectations about the outcomes resulting from performing that behavior; perceived 'social pressure' or beliefs about the

[1] We thank an anonymous reviewer for this addition.

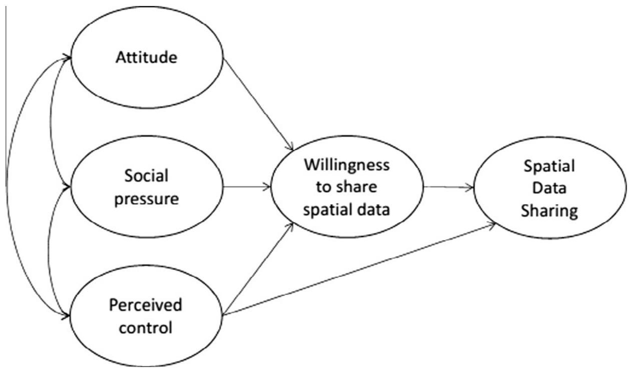

Fig. 1. Basic model of spatial data sharing (Wehn de Montalvo, 2003b).

expectations of others and their (dis)approval of data sharing and, finally, the 'perceived control' or perceptions about the absence or presence of specific factors that impede or facilitate data sharing (Wehn de Montalvo, 2003b). A combination of these beliefs 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.

3. Methodology

This research was carried out within the scope of the WeSenseIt project that is one of the EU-FP7 projects in the area of environmental monitoring utilizing Citizen Observatories (funded 2012–2016). Empirical research was conducted in three countries in which the WeSenseIt case studies are located namely UK, Italy and the Netherlands. The willingness to share PWS data via online platforms was studied within two major groups of citizens: (1) Personal Weather Station data-sharers; i.e. citizens who already own relevant equipment, observe the weather and share the resulting data via at least one online platform and (2) the general public or other members of society who either do not have the equipment or have a PWS but do not share the data it generates via web-platforms. Based on our theoretical framework, we aimed to identify the range of beliefs that may facilitate or impede sharing personally-collected weather data via web-platforms. To achieve this, we needed to acquire an in-depth understanding of citizens' beliefs about this activity and therefore chose a qualitative empirical research approach. The results and findings from this were further complemented by a review of secondary literature as recommended by Wehn de Montalvo (2003b). Encompassing the findings of the previous studies that tried to understand the behavior of the participants in crowd-sourcing activities and knowledge sharing in online communities enabled us to, on the one hand, ensure the consistency of the terminology used and, on the other hand, complement the empirical research results with the findings of these studies, where applicable. Table 1 presents the list of this secondary literature and their relevance to the topic of this research.

An online semi-structured survey with open ended questions (Gharesifard, 2015; Gharesifard and Wehn, 2015) was used to collect data about the PWS data sharers for practical reasons; i.e. their geographically diverse locations and potential privacy issues since the PWSs are usually located at their home. The second group (non-PWS data sharers) could be reached more easily and therefore was interviewed either face-to-face (11 interviews in the Netherlands and 10 in the UK) or via phone/Skype (9 interviews in the Italy case) using the same questions. Furthermore, in each of these countries, one location with a low concentration of PWSs

Table 1
Secondary sources consulted for constructing the model and their relevance.

Title/Reference	Research focus/theory used	Key findings of relevance for PWS data sharing model
'To give or to receive? Factors influencing members' knowledge sharing and community promotion in professional virtual communities'/(Chen and Hung, 2010)	Knowledge sharing in virtual communities/Social Cognitive Theory (SCT)	Interpersonal trust
'Understanding knowledge sharing in virtual communities: An integration of social capital and social cognitive theories'/(Chiu et al., 2006)	Knowledge sharing in virtual communities/Social Cognitive Theory (SCT)	Community-related outcome expectations
'Testing an integrative theoretical model of knowledge-sharing behavior in the context of Wikipedia'/(Cho et al., 2010)	Knowledge sharing in virtual communities/Theory of Planned Behavior (TPB)	Altruism
'Social network, social trust and shared goals in organizational knowledge sharing'/(Chow and Chan, 2008)	Knowledge sharing/Theory of Reasoned Action (TRA)	Social trust
'Knowledge sharing in online environments: A qualitative case study'/(Hew and Hara, 2007)	Knowledge sharing in virtual communities/N/A (based on a collective view on knowledge sharing studies)	Altruism Technical skills
'Acceptance of blog usage: The roles of technology acceptance, social influence and knowledge sharing motivation'/(Hsu and Lin, 2008)	Online knowledge sharing/Theory of Reasoned Action (TRA)	Trust
'Knowledge sharing behavior in virtual communities: The relationship between trust, self-efficacy, and outcome expectations'/(Hsu et al., 2007)	Knowledge sharing in virtual communities/Social Cognitive Theory (SCT)	Outcome expectations
'More than fun and money. Worker Motivation in Crowdsourcing – A Study on Mechanical Turk'/(Kaufmann et al., 2011)	Crowdsourcing/Self-Determination Theory (SDT)	Technical skills
'Determinants of successful virtual communities: Contributions from system characteristics and social factors'/(Lin, 2008)	Social characteristics of virtual communities/Information Systems (IS) Success Model	Trust
'Fostering the determinants of knowledge sharing in professional virtual communities'/(Lin et al., 2009)	Knowledge sharing in virtual communities/Social Cognitive Theory (SCT)	Reciprocity Trust
'It is what one does": Why people participate and help others in electronic communities of practice'/(McLure Wasko and Faraj, 2000)	Participation in virtual communities/N/A (based on a collective view on Knowledge Management studies)	Technical skills
'Understanding citizen science and environmental monitoring: final report on behalf of UK Environmental Observation Framework'/(Roy et al., 2012)	Citizen science and environmental monitoring/N/A (based on a synthesis review of 234 citizen science projects)	Opportunities
'Mapping the determinants of spatial data sharing'/(Wehn de Montalvo, 2003b)	Data sharing/Theory of Planned Behavior (TPB)	Outcome expectations Skills Resources Opportunities

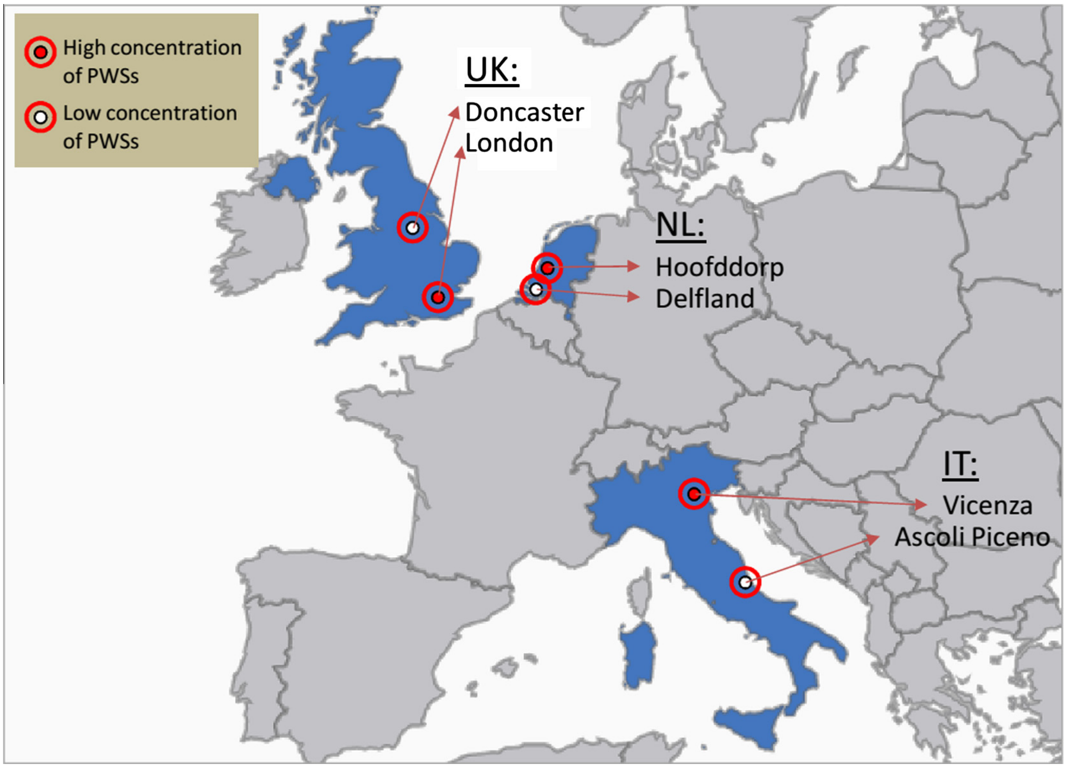

Fig. 2. Selected locations with high/low concentration of PWSs in the Netherlands, UK and Italy.

and another one with a high concentration of these stations were selected for conducting the interviews with the general public. This strategy was adopted to enable us include the dominant facilitating or impeding beliefs that the general public might have towards sharing PWS data via online-platforms. Accordingly, we first calculated the density of PWSs that share their data on weather networks in different regions of each country by overlapping the coordinates of a number of PWSs that, at the time of conducting this research, had available contact information with the administrative divisions of each country using ArcMap. Availability of the contact information of the PWS owners was vital for conducting the online survey since subsequently we needed to be able to contact these potential respondents; this led to choosing most of these potential respondents from the list of CWOP[2] and WOW[3] stations, however many of the chosen stations also shared their data on other major networks such as WU,[4] EWN,[5] PWSweather[6] and WeatherLink.[7] After generating these maps, Delfland in the Netherlands, Doncaster in UK and Ascoli Piceno in Italy were identified as locations with low concentration of PWSs while Hoofddorp in the Netherlands, London in UK and Vicenza in Italy were selected as administrative areas with high concentration of stations (See Fig. 2).

In total, 30 interviews were conducted with participants from the general public and 43 valid responses were received from the PWS data-sharers in the Netherlands, UK and Italy. Table 2 presents the number of interviews with the general public and online survey responses from PWS-data sharers per case study.

Table 2
Overview of interviews and responses to online surveys.

Case study	Interviews with the general public	Valid responses to online surveys (PWS data sharers)
NL	11	13 [RR[a]: 13%]
UK	10	14 [RR[a]: 14%]
IT	9	16 [RR[a]: 16%]
Sum:	**30**	**43**
All three cases	**73**	

[a] RR: Respose Rate.

While conducting the interviews among the general public, in all case study areas, general factors such as the interviewees' age and gender were taken into account and random samples were taken within each age/gender group. Moreover, interviews were conducted in different locations such as shopping centers, parks, train stations and restaurants at various times of the working day and also during the weekends in order to create equal chance for different members of the public to be selected for the interviews.

For the PWS data-sharer group, per case study, 100 invitation emails to participate in the online survey were sent to the potential respondents. The main criteria that were considered while 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. Only 7% of all survey responses came from PWS owners younger than 35 years old. Furthermore, only one female respondent (in the UK case) was among the participants in the online survey. Although the sample size and composition are not representative of the whole population, given the above mentioned criteria for selecting respondents, this may nevertheless provide an indication of the state of the PWS data-sharer community in terms of age and gender in these countries.

[2] Citizen Weather Observer Program (http://wxqa.com/).
[3] Weather Observations Website (http://wow.metoffice.gov.uk/).
[4] Weather Underground (http://www.wunderground.com/).
[5] European Weather Network (http://euweather.eu/).
[6] Personal Weather Stations Network (http://pwsweather.com/).
[7] Davis WeatherLink network (http://www.weatherlink.com/).

4. Results and discussion

4.1. Attitude towards sharing personally-collected weather data via web-platforms

'Attitude' is one of the main components argued to affect the intention to share data (Wehn de Montalvo, 2003b) and in our case is based on the perceived (positive and/or negative) outcomes or consequences of sharing personally collected weather data via web-platforms. Based on the collected data during the empirical research, beliefs about the outcomes of sharing in all three cases can be clustered into four domains: 'tangible personal outcomes', 'intangible personal outcomes', 'societal outcomes' and 'interpersonal trust'. Table 3 summarizes the elicited beliefs based on the views of both engaged (i.e. data sharers) and non-engaged citizens.

'Tangible personal outcomes' that is identified as the first domain of attitude, refers to the actual or approximate gains and/or losses that a person perceives to incur as the result of sharing personally collected weather data via web-platforms. The usefulness of the collected data for personal purposes such as business, education, sports and leisure was mentioned by both PWS data sharers and the general public as a motivator for citizen's engagement in sharing the data. On the other hand, especially for those whose daily activities are not very much dependent on the weather and who also have no interest in the subject, the availability of, as they say, 'enough official data' seems to create a sense of ignorance about the necessity to collect and share weather-related data by citizens. This is the negative perception about the tangible usefulness of the collected data and this was elicited only from respondents among the general public. The second category of tangible personal outcomes focuses on privacy and security issues. One of the main concerns of both PWS owners and the general public was the fear of theft. The equipment needed for collecting and sharing data must be installed outdoor in the backyard, garden, roof, etc. and therefore cannot easily be protected at all times. These devices may cost from a couple of hundred to more than a thousand Euros. Due to the fact that the location of any station is easily retrievable using the web-platforms and Google Earth, the issue of security is certainly a tangible outcome that may hinder participation in online data sharing. This argument is also true for the privacy-related issues and the possibility of being located by any other unwanted visitor, such as marketers, vendors and researchers. There were also concerns about potential cyber security issues since the data sharer needs to open more ports and run some software 24/7.

'Intangible personal outcomes' refer to intrinsic gains in the form of self-actualization or inner satisfaction that one may gain from sharing personally-collected weather data. A sense of belonging to a community of friends with shared interests/visions can be one of the intangible outcomes of sharing this type of data via web-platforms. 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. This generates a sense of self-actualization that may be a good motivation for those who value this. Previous studies also recognize shared vision and common interest as a 'bonding mechanism' among virtual communities (Tsai and Ghoshal, 1998; Chiu et al., 2006, p. 1878). Learning from each other is another form of intangible personal outcome and pertains to the sense of enjoyment derived from sharing knowledge with others and learning from them. This generates a reciprocal sense of satisfaction for both the sharer and recipient of the information. The process of learning can happen via one to one communications between the virtual community members or via group interactions in online fora, Facebook pages, etc. Respondents from the general public and PWS-owner participants seemed to perceive value in learning from other society members (as it builds social capital[8]) and thus considered this as a source of motivation. Interest in the weather refers to the sense of excitement, enjoyment, and satisfaction that one gains from observing the weather and sharing the data on web-platforms. This was elicited as another intangible outcome of getting engaged in online PWS data sharing. Not surprisingly, this was mentioned in the positive form by the PWS owners and in the negative form by the general public. The first group mentioned the sense of excitement as a driving force while the second highlighted their lack of interest in the weather observation as a preventing factor and mentioned that they simply get bored by this activity. An example mentioned by one of the PWS owners 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". A number of PWS owners mentioned another form of intangible negative outcome of sharing personally-collected weather data that is labeled as recognition. This category refers to the fact that those engaged in the activity find themselves worthy of receiving some sort of commendation and acknowledgement from other members of the society, especially those who enjoy this service; an expectation that is not fulfilled in most cases and therefore translates into a sense of disappointment and considered as a negative outcome. This came up during the online surveys where PWS-owners stated that other sites may use their data without permission and acknowledgement or the national weather services use these data for free without any sort of gain for the data sharer. On the other hand, a sort of commendation and recognition may be considered as an intangible outcome of data sharing and motivate participants to engage more in this activity. In this regard, some PWS data-sharers mentioned that valuation of their efforts does not have to be monetary per se and intangible values are just as important.

The third domain of the attitude component is the 'societal outcomes'. Relevant secondary literature about participation in crowd-sourcing activities and online communities also had indicated 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; Hsu et al., 2007); 'community interest' (McLure Wasko and Faraj, 2000). Some have also mentioned 'altruism' which can be considered as a subset of the 'societal outcome' domain (Cho et al., 2010; Hew and Hara, 2007). In the case of sharing personally-collected weather data, both groups of respondents could only perceive positive societal outcomes for this activity. The first elicited societal outcome relates to the potential contribution of the data to monitoring and forecasting activities, thus helping to reduce or mitigate environmental risks. Some respondents considered these risk prevention applications as a source of motivation for their participation. As an example, one of the respondents from the general public in the UK case stated that; "I believe that the overgrowing problem of global warming should encourage citizens to share their data so we can get a better understanding of this phenomenon". Benefiting society at large by improving knowledge about the weather is the second behavioral belief of this domain that was mentioned frequently by the respondents. Some of the relevant examples that were mentioned during the interviews and online survey are contribution to citizen values and well-being, creating collective knowledge about the weather and climate that is not possible individually, 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 society at large and creating an alternative source of data for research purposes.

[8] We thank an anonymous reviewer for this interpretation.

Interpersonal trust is the last elicited domain of attitude in this study. Several studies on knowledge sharing in online communities have recognized the importance of trust as a determinant of the intention to participate in these communities (Chow and Chan, 2008; Hsu and Lin, 2008; Lin, 2008). Due to the fact that in our study the main actors are citizens, we identified interpersonal trust as one of the domains that influences the perception of citizens about sharing personally-collected weather data via web-platforms. Chen and Hung described 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 and Hung, 2010, p. 228). The issue of trust and its relation with attitude in this case can be articulated as the expectations regarding the sharers' competence and the objectives of sharing promoters. In other words, it 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 and also the intentions of promoter groups and organizations. The stronger this trust is, the more inclined people are expected to be towards sharing PWS data online. Views on the weather-related competence of citizens and the reliability of the data that they produce as well as the reasons (agenda) of data sharing promoters, as shown in Table 3, were highly diverse both among the PWS data sharers and the general public respondents.

4.2. Social pressure to share personally-collected weather data via web-platforms

'Social pressure' is the second main component of the basic model of data sharing (Wehn de Montalvo, 2003b) and in this study refers to beliefs about the perception of relevant individuals, groups or institutions (referents) about sharing personally collected weather data via web-platforms and whether they will approve or disapprove this behavior. These beliefs are referred to as normative beliefs (Ajzen, 1985). Based on the data collected, the normative beliefs about the referents' views in the three cases can be represented by five different domains: 'Public/private organizations', 'scientific community', 'weather enthusiast community', 'other society members' and 'moral norms and altruism' (see Table 4). The social pressure domains are highly dependent on the behavior in question and less extendible from relevant secondary literature in comparison with attitude domains (Wehn de Montalvo, 2003b); therefore this section is mostly based on the findings from the empirical research.

With respect to the domain of Public/private organizations, new weather-related commercial actors such as PWS manufacturers and application developers (who are the emerging providers of weather-related products and value-adding services) were perceived to approve PWS data sharing because of the direct benefits that they obtain from the diffusion of the technology that is a prerequisite for this activity. On the other hand, there were opposing perceptions regarding the pressures by traditional weather-related commercial actors (long-established organizations such as news agencies/channels and private weather forecast organizations), weather-related (inter)governmental organizations and other industrial sectors (such as agriculture, energy, tourism and transport sectors). Respondents mainly based their judgment on whether these organizations or companies may gain or lose their 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 personally-collected weather data via web-platforms. Furthermore, in some cases, one respondent could perceive both positive and negative pressure from the same organization or company. This is due to the fact that they might gain in some respects (such as gaining knowledge) while losing in others (authority or power).

In the scientific community domain, scientists were perceived to be supporters of sharing such data by a number of respondents from both groups. They believed that scientists and researchers appreciate this additional source of freely available data and that they consider it a complementary source of data to available official observations, therefore welcoming and supporting data sharing. On the contrary, some respondents from the general public perceived scientists as opponents of sharing personally-collected weather data, questioning the capability of the general public to collect qualitatively-sound data. In case of educational institutes, a consensus existed among both groups of respondents, perceiving them in favor of sharing since such institutes may use the data for educational purposes.

As their label suggests, communities of weather enthusiasts support sharing personally-collected weather data. Respondents from both groups elicited 'weather enthusiast individuals' as independent members of society who may motivate each other and the general public to further engage with this activity. According to the PWS data-sharers, actual and virtual 'weather networks' and 'weather-related hobby clubs' (such as ham radio clubs, aviation clubs and sailing clubs) are also specific groups that approve collecting and sharing weather-related data by citizens.

The forth domain of the 'Social pressure' component is pressure from other society members. These are individual citizens who may not gain or lose directly from data sharing but still may approve or disapprove this behavior for different reasons. There were a few respondents who mentioned beliefs about the (dis)approval of (anti)environmentalist community, family members and peers. The reason why (anti)environmentalist groups and individuals may approve or disapprove this behavior is rather self-explanatory and relates to the benefits and losses that they may perceive about the availability of more environmental data. Family members, neighbors and friends of those who share data may also support this activity or stand against it based on their personal opinion. Furthermore, critics of Citizen Science/Big Data were frequently mentioned as a source of negative pressure on those who engage in data sharing. Concerns about the competence of citizens to collect and share data of acceptable quality as well as concerns about privacy and security issues resulting from sharing personally-collected weather data were mentioned as the main reasons why critics of Citizen Science/Big Data were perceived to hold this stand.

Morality can be considered as moral obligations to perform or not perform a behavior (Sabini, 1995) and therefore may be categorized as a 'Social pressure' antecedent. The use of shared PWS data to reduce risks and benefits for society at large are the two reasons for sharing PWS weather data online mentioned by respondents from both groups.

4.3. Perceived control over sharing personally-collected weather data via web-platforms

Perceived Control is the third main component of basic model of data sharing and also a function of beliefs. In our case, these beliefs are related to perception of citizens about the absence or presence of factors that may impede or facilitate PWS data sharing via online amateur weather networks. According to the theoretical framework, these factors can be further divided into two groups based on their relation to the individual who performs the behavior; internal factors or external ones (Ajzen and Madden, 1986; Wehn de Montalvo, 2003b). During our study, four different control domains were identified, namely 'technical skills', 'knowledge self-efficacy', 'resource control' and 'opportunities'. Based on the nature of these domains, the first two belong to the internal factors category while the last two are considered as external ones (see Table 5).

The first domain of the 'Perceived Behavioral Control' relates to control beliefs about the presence or absence of technical skills of the individual who wants to share personally collected weather data via online-platforms. Studies in the areas of crowd-sourcing and knowledge sharing in online communities have highlighted the importance of technical skills (Hew and Hara, 2007; Kaufmann et al., 2011; McLure Wasko and Faraj, 2000). This is very much relevant in the case of using PWSs to collect and share weather-related data in the sense that there are a range of technical skills whose presence may facilitate citizen's participation while their absence is likely to impede data sharing. During our empirical research, technical skills for setting up and maintaining their PWSs and also general (hardware and software) IT skills were mentioned by the respondents as factors that – if present – facilitate sharing personally-collected weather data and – if absent – make it difficult.

The second elicited Domain of the Perceived Behavioral Control is knowledge self-efficacy. 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, p. 257). Previous studies have identified self-efficacy as one of the main subordinates of Perceived Behavioral Control (Armitage and Conner, 1999; Manstead and Van Eekelen, 1998). In the case of sharing personally-collected weather data via web-platforms, self-efficacy 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 and Hung, 2010, p. 228) related to the weather. In this respect, the perceived need for a basic understanding of meteorology science appeared as an inhibiting factor for a few respondents; however, unfamiliarity with data collection methods was more frequently elicited by both groups of respondents (PWS sharers and interviewees from the general public) as a barrier for sharing data.

Having control over resources such as the following were mentioned as facilitating factors: accurate, high quality and reasonably priced weather observation equipment, reliable internet connection, the initial as well as long-term availability of financial resources, having enough time, ease-of-use of the web-platforms and apps and, last but not least, the availability of an appropriate location to install the PWS station outdoors. On the contrary, the absence of any of these resources was perceived as a barrier for citizen participation.

Opportunities are the last series of 'circumstantial factors' whose absence is not expected to affect the behavior (Wehn de Montalvo, 2003b) but their presence may serve to facilitate sharing

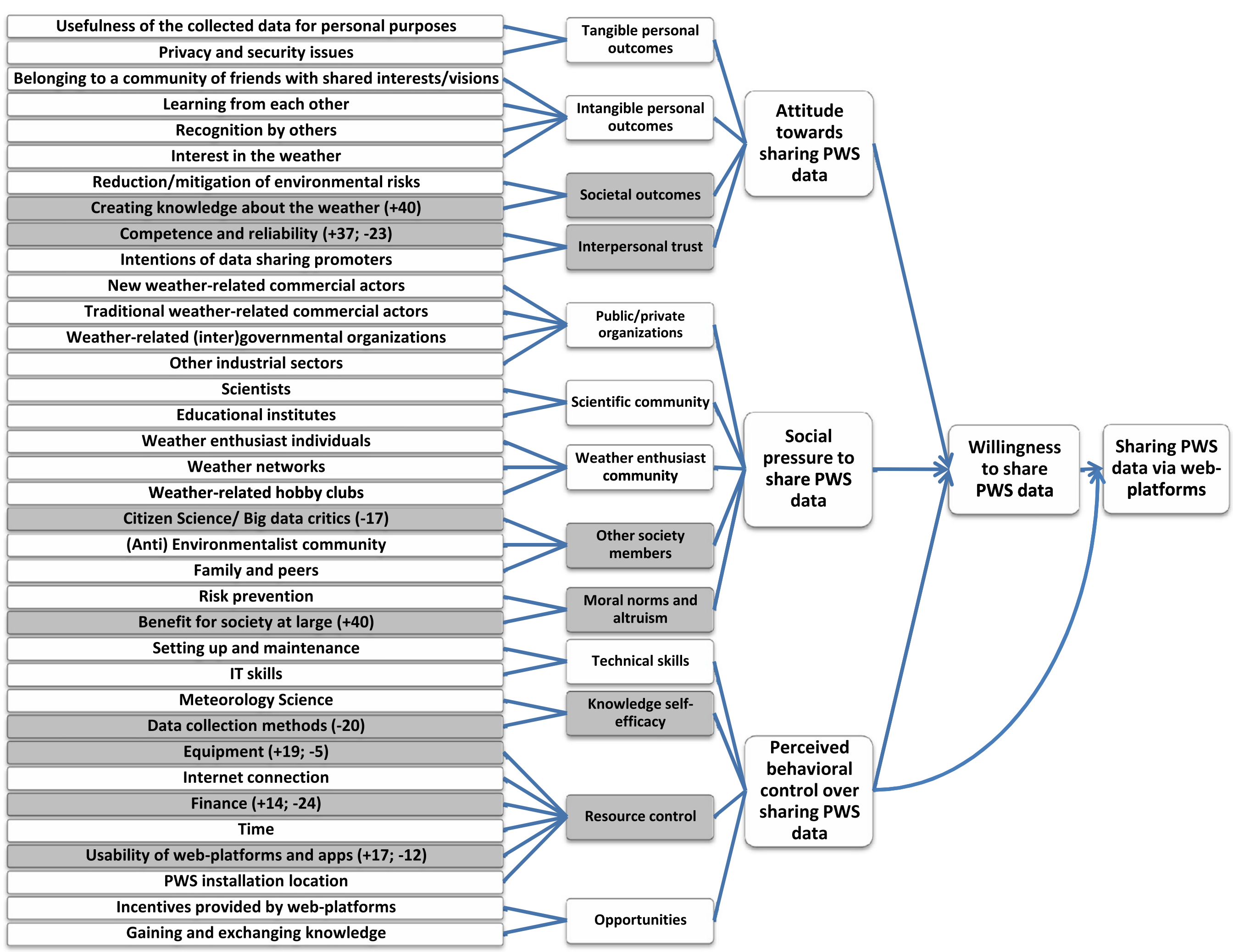

Fig. 3. The model of sharing personally-collected weather data via web-platforms (NL, UK and IT). Note: The numbers represent the frequency (occurrence) and (±) signs represent the direction of key factors, i.e. as drivers or barriers.

personally-collected weather data. Beliefs about opportunities seemed to exist only among PWS owners as it was not elicited by any member of the general public in neither of the cases. A number of respondents from this group identified several incentives that may be provided by web-platforms such as receiving feedback from the web-platform operators about the data shared by their station (in terms of quality, possible errors, etc), certificates that indicates they have provided this data for a certain period (e.g. after one year), excursions to official weather stations in their locality and a small annual retainer fee for those who joined a certain platform. Opportunities to gain and exchange knowledge was another cluster of opportunities that was mentioned by PWS data sharers. This knowledge exchange can take place through various channels, such as group discussions on online fora/social media, direct contact between PWS owners or guidelines provided by weather enthusiasts on their personal Webpage.

4.4. Summary – key drivers and barriers for citizens to share PWS data via online-platforms

The model presented in Fig. 3 summarizes the full range of elicited drivers and barriers that appear to influence the willingness of citizens to become (and remain) engaged in sharing their personally-collected weather data. The drivers and barriers elicited from the general public and the PWS data-sharers showed a great deal of overlap across all three cases (with negligible marginal differences); thus a common model was developed to depict the factors influencing the citizens' willingness to share personally-collected weather data. The highlighted beliefs and domains in this model represent the key drivers and barriers (i.e. the most frequently mentioned drivers and barriers based on our interviews and online survey results as presented in Tables 3–5) for sharing PWS data via web-platforms identified from all three case study areas.

With regards to the identified outcome-oriented beliefs, societal outcomes and trust-related factors appeared as the most salient factors. Societal outcomes, especially benefiting society at large by creating knowledge about the weather, were frequently elicited as drivers for sharing PWS data. Trust-related issues were also identified as an influential factor on willingness to share PWS data by several respondents. Furthermore, one of the most contested beliefs was the competence and reliability of citizens to participate in this activity. Considering the social pressure component, the most frequent negative pressures were perceived from critics of Citizen Science/Big Data, while moral obligations to share data were mentioned by many respondents from both groups as a driving force. Finally, to summarize the control factors, previous experience with collecting weather-related data was perceived as a major facilitator of sharing PWS data. Also, the presence of resources such as equipment, short/long term financial means

Table 3
Summary of the beliefs about the outcomes of getting engaged in sharing personally-collected weather data.

Perceived outcomes	Positive outcomes	Negative outcomes
Tangible personal outcomes	• Usefulness of the collected data for personal purposes (GP8, PWS8)	• Uselessness of the collected data for personal purposes (GP7) • Privacy and security issues (GP5, PWS6)
Intangible personal outcomes	• Sense of belonging to a community of friends with shared interests/visions (GP6, PWS5) • Learning from each other (GP3, PWS2) • Excitement from observing the weather (PWS10)	• Boredom, no Interest in the weather (GP7) • Not being recognized (PWS6)
Societal outcomes	• Risk prevention applications (GP4, PWS9) • Benefit the society at large through creating knowledge about the weather (GP15, PWS25)	
Interpersonal trust	• Trust in citizens' competence and data reliability (GP15, PWS22) • Trust in intentions (GP9, PWS4)	• Mistrust in citizens' competence and/or data reliability (GP11, PWS12) • Perceiving doubtful intentions (GP3, PWS1)

Notes: GP ... = The frequency (occurrence) of similar responses received from interviewees from the general public PWS... = The frequency (occurrence) of similar responses received from PWS data sharers during the online surveys.

Table 4
Summary of the sources and nature of perceived pressures to share personally-collected weather data.

Social pressure by key referents	Perceived pressure	
	To share	Not to share
Public/private organizations	• New weather-related commercial actors (GP2, PWS2) • Traditional weather-related commercial actors (GP5, PWS3) • Weather-related (inter)governmental organizations (GP9, PWS8) • Other industrial actors (GP8, PWS6)	• Traditional weather-related commercial actors (GP2, PWS6) • Weather-related (inter)governmental organizations (GP3, PWS2) • Other industrial actors (GP6, PWS2)
Scientific community	• Scientists (GP5, PWS3) • Educational institutes (GP2, PWS5)	• Scientists (GP5)
Community of weather enthusiasts	• Weather enthusiast individuals (GP5, PWS5) • Online weather networks (PWS10) • Weather-related hobby clubs (PWS5)	
Other members of society	• Environmentalist community (GP1) • Family members and peers (GP1, PWS1)	• Critics of Citizen Science/Big Data (GP9, PWS8) • Anti-environmentalist community (GP1, PWS1) • Family members and peers (GP1)
Moral norms and altruism	• Risk prevention (GP4, PWS9) • Benefit for society at large (GP15, PWS25)	

Notes: GP ... = The frequency (occurrence) of similar responses received from interviewees from the general public PWS... = The frequency (occurrence) of similar responses received from PWS data sharers during the online surveys.

Table 5
Summary of the perceived control over getting engaged in sharing personally-collected weather data.

Social pressure		Perceived control factors	
		Easy/present	Difficult/absent
Internal factors	Technical skills	• Technical skills to set up and maintain the PWS (GP2, PWS8) • Relevant IT skills (GP4, PWS7)	• Lack of technical skills to set up and maintain the PWS (GP3, PWS8) • Lack of relevant IT skills (GP7, PWS8)
	Knowledge self-efficacy		• Lack of knowledge about meteorology science (GP1, PWS2) • Unfamiliarity with data collection methods (GP10, PWS10)
External factors	Resource control	• Weather observation equipment (type, accuracy, quality and price) (GP13, PWS6) • Reliable Internet connection (GP5, PWS5) • Financial means (GP5, PWS9) • Time (GP6) • Easy to use web-platforms and apps (GP7, PWS10) • Appropriate PWS installation location (GP1, PWS2)	• Unavailability of equipment that is accurate, high quality and/ or at a reasonable price (GP3, PWS2) • Unreliable Internet connection (GP3, PWS9) • Unavailability of financial means (GP9, PWS15) • Lack of time (GP6) • Complicated web-platforms and apps (GP5, PWS7) • Unavailability of appropriate PWS installation location (PWS3)
	Opportunities	• Incentives provided by web-platforms (PWS10) • Opportunities to gain and exchange knowledge (PWS4)	

Notes: GP . . . = The frequency (occurrence) of similar responses received from interviewees from the general public PWS. . . = The frequency (occurrence) of similar responses received from PWS data sharers during the online surveys

and easy to use web-platforms and apps were widely believed to facilitate the sharing of weather data via online Amateur Weather Networks.

Comparing the findings of this research with the detailed model of spatial data sharing (Wehn de Montalvo, 2003b) reveals that there is a degree of similarity between influential factors on sharing PWS data by individuals and sharing spatial data at organizational level. Both studies identified 'societal outcomes' as a driver for attitude; 'organizational pressure' and 'moral norms' are present as social pressure domains in both models; and finally 'skills', 'control over resources' and 'opportunities' are elicited as common influential domains on perceived control over data sharing.

5. Conclusions

ICT-enabled citizen observatories are providing new modes for citizen participation in many environment-related domains. These innovative approaches can play a crucial role in facing worsening natural hazards resulting from severe weather conditions. This study contributed to investigating these initiatives and describing the dynamics behind them by performing a systematic analysis of the beliefs that citizens (both engaged and non-engaged) hold regarding sharing PWS data. These beliefs portray the drivers and barriers that appear to influence the citizens' willingness to get (and remain) engaged in sharing personally-collected weather data via online platform. The results of this study (both in terms of the range of influential factors and their frequency) can be utilized as a tool for decision makers to develop strategies for further enhancing citizen participation in weather-related observatories. This can be done by addressing the identified inputs and preconditions for citizen participation which may well result in a boost in the current level of citizen engagement in sharing PWS data.

Based on the findings of this research, a number of practical measures are recommended that may (further) engage citizens in sharing their personal weather observations. With respect to control over resources such as equipment; the availability of higher quality, more accurate and at the same time reasonably priced equipment is likely to attract more citizens. With recent advancements in production of low-cost ICTs, it may therefore be possible to focus on the production of devices that can attract a larger proportion of society to participate in weather observation. Furthermore, the production of more user-friendly and easy to use web-platforms and mobile applications will positively affect citizen's engagement by reducing entry barriers. Trust in the competence of citizens and in the quality of the data produced by them was frequently mentioned and highly contested by the respondents. Building trust in the data within society requires a number of measures such as; (a) more instances of real-life/academic applications and demonstration of these data, (b) attaching meta-data to the observations that indicate for example under what conditions the data has been acquired, type and accuracy of the equipment used, how often equipment is calibrated, etc. and (c) replacing current general reliability statements that exist on the web such as "never base important decisions on this or any weather information obtained from the Internet" with more accurate statements that actually inform the user about the reliability of the data rather than amplifying a false sense of mistrust in the data. Lastly, with regard to the societal outcomes that were mentioned to be a driver for participation, informing citizens about and demonstrating how online sharing of PWS data can benefit society at large, enhance environmental governance and help reduce or mitigate the risks of natural hazards, may serve to enhance their further involvement.

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