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ASSESSING THE VALUE OF EARLY WARNING APPS FOR DISASTER COST REDUCTION

A FRAMEWORK TO FACILITATE INVESTMENT DECISIONS TO PROTECT PRIVATE PROPERTY

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ABSTRACT:
The Bayesian theory highlights the role of information in the decision process and its value for economic agents to reduce uncertainty. We apply this principle to app-based early warning information in the context of natural disasters. Modern societies are increasingly threatened by a wide range of such hazards. Their economic effects have been receiving growing attention and leading researchers have started to investigate their impact on modern societies to develop new economic theories. Globally, the direct overall losses from natural disasters in 2014 had a volume of around US$ 110bn. In recent years, Early Warning Systems (EWS) to protect lives and property were developed. While many approaches exist to assess the value of products, technologies and innovative companies, methods to assess the value of systems like EWS are missing. This paper presents a disaster-independent concept with dynamic investment calculations that show the benefits of EWS for private households. Specific value to existing approaches is based on its advanced focus on behavioral and financial aspects. The presented approach provides an innovative analytical framework for future investments in warning technologies and supports decision-making. Its utilization is illustrated by a heavy precipitation scenario.

KEYWORDS:
Disaster costs, early warning systems, investment decisions, quantitative assessment model.

1. INTRODUCTION

Modern economic theory highlights the contribution of information in the decision process and its value for economic agents to reduce uncertainty (Bayesian decision theory, Johnson and Holt, 1987). We apply this principle to app-based early warning information in the context of natural disasters. Modern societies are increasingly threatened by a wide range of such hazards and their economic impact has been receiving growing attention from the World Bank, WHO, OECD and UN (see e.g. Guha-Sapir and Santos, 2013). Furthermore, leading researchers started to investigate this impact to develop new economic theories (see e.g. Cavallo, Cavallo and Rigobon, 2014, Cavallo, Galiani, Noy and Pantano, 2013 and Cavallo, Cohen and Werker, 2008). Globally, the direct overal losses from natural disasters in 2014 had a volume of of around US$ 110bn (see Munich RE, 2015a). Between 1990 and 2014 single flood events caused damage of up to US$ 43bn (see Munich RE, 2015b) and the damage of single winter storm events in Europe, for example, exceeded US$ 11.5bn in the same period (see Munich RE, 2015c). Turoff, Hiltz, Banuls and Van Den Eede (2013) show that emergency preparedness and management and resulting activities like investments in infrastructure are not functioning as they should in modern societies. 'Given the large number of threats that are possible in the next decade', they show the need for 'far more efforts at planning for emergencies'. One way to enable populations to cope with all these risks is the use of advanced Early Warning Systems (EWS) that can warn a large number of users within a very short time frame with specifically targeted localized or personalized alerts. However, implementing such advanced systems requires quite significant investments. While many approaches exist to access the value of products, technologies and innovative companies, methods to assess the value of systems like EWS are missing. In addition, Perrels, Frei, Espejo, Jamin and Thomalla (2013) identified a need for information in a related field. There is a rising interest around the world to better understand the economic value added of weather services to prepare the population for disasters. This paper proposes a disaster-independent approach to assessing the benefits of EWS for private households. It builds on Klafft and Meissen (2011), Wurster and Meissen (2014) and Wurster, Klafft and Kühn (2015). Specific value is based on its advanced focus of lead time aspects, human behavior and financial estimations.

2. EXISTING APPROACHES TO ASSESSING THE VALUE OF EARLY WARNING SYSTEMS

While the traditional toolbox to evaluate potential investments includes static and dynamic approaches and the value of innovative companies can be estimated by the discounted cash flow method, multiplied evaluation, market-based approaches and combined concepts, EWS investment decisions are embedded in a specific context. Foundations for their evaluation consist of return on security investment (ROSI) calculations (ENISA, 2012), cost avoidance analyses (see Klafft and Meissen, 2011) and economic analyses of weather information (examples are, for example, given by Perrels et al., 2013 and FMI, 2012).

This paper is based on the cost avoidance approach. This method uses statistical analyses and cost estimations to determine the amount of damage that can be prevented if a warning system is in place, and compares these benefits with the investments needed to build and operate the system (see Klafft and Meissen, 2011). The models include approaches that focus on one type of disaster as well as models that work independent of specific disaster types. Wenzel, Baur, Fiedrich et al. (2001) present an early model that is specifically focused on earthquake warnings and does not include human aspects of system use. Meissen and Voisard (2008) developed a complex model that was used to calculate the benefits of a meteorological warning system in practice, but it lacks the consideration of behavioral and psychological effects on system use, too. The EU FHRC Model (FLOODsite, 2009) helps to assess flood warnings, but social and behavioral aspects are not analysed. Based on survey data, Parker, Tunstall and McCarthy (2007) showed the validity of the model and found that people, who had been warned, could save £821 (≈ $1,620 in 2013, adjusted for inflation and purchasing power) more than those who had not. Many people in the survey received warnings via telephone. By stressing contextual changes due to new warning technologies, the authors unveil a research gap. Likewise, Krenz, Hellriegel and Klafft (2014) point towards the lack of consideration of modern communication technologies in present studies. Another advanced model is proposed by Klafft and Meissen (2011). Similar to Meissen and Voisard (2008), its advantage is that its use is not limited to one type of disaster. However, personal influences such as the situational assessment of a warning and acquired problem-solving skills through previous experiences (Krenz et al., 2014), the physical and situational ability to implement a recommended action and the contribution of volunteers are not considered. An extended overview of additional models is given by Klafft and Meissen (2011). However, no existing model includes an in-depth consideration of human behavior after receiving a warning or unveils the additional benefits offered by volunteers who use EWS. In addition, a need to compare EWS with social media has emerged recently (see Ridler-Ueno, 2013). This paper helps to close all of these gaps.

3. EXISTING APPROACHES TO ASSESSING THE VALUE OF EARLY WARNING SYSTEMS

According to Knorr and Naderer (2014), warning systems consist of three major components: the input data, the decision-making process by the warning personnel, and the distribution of alerts. Ghersetti and Odén (2014) identified three stakeholders of such processes: authorities, the media and the public. Based on this context, the effectiveness of an EWS for private households can be described by five groups of factors.

1. Asset-related factors comprise variables related to the asset value of the relevant households. Specific financial figures and additional factors allow for the calculation of the ***potential amount of loss,*** which forms the basis of the potential damage reduction.

2. Disaster-specific factors include ***the probability of the occurrence of a specific disaster per time unit in the warning area*** as well as ***specific disaster-related variables*** like the wind speed in the context of storms and the inundation depth in the contexts of flood events and heavy rain.

3. Personal factors influence how a warning is processed by the recipients and if and how it is then translated into protective actions. In addition, numbers of subscribers are highly important for evaluating EWS. Like Parker et al. (2007) we model the variable ***'proportion of households that subscribe to the service'***. With regard to weather information that are part of the EWS warning, Johanson and Holt (1997) refer to a 'cost-loss situation', in which a decision-maker must choose one of two actions: protect an activity or operation at a known cost or face the risk of, perhaps catastrophic, loss. A stylized individual decision model illustrating the central concept of the Bayesian decision theory can be developed as follows: subjective probabilities, along with the assumption that agents can assign a unique utility ranking to all possible outcomes, are key in the theory (Johnson and Holt, 1997). In private households, relevant actions may include, for example for meteorological threats, closing windows, securing loose items outside and driving the car into a garage. The actions largely depend on how the underlying risk is perceived (see Klafft and Meissen, 2011). Based on our research four factors are relevant:

Situational Likelihood of willingness to respond: The state of research offers the variable 'likelihood that a recipient is willing to perform a certain protective action' (Klafft and Meissen, 2011). In addition, Thieken, Kreibich, Mueller and Merz (2007) show the relevance of situational responsiveness. Therefore, we define the variable ***'situational likelihood that the relevant person is willing to perform a specific protective action in case of a warning for the specific disaster'.*** Bubeck, te Linde and Aerts (2013) provide a meta-analysis of factors that influence private flood mitigation behavior and, therefore, help to specify this variable. These factors include: flood experience, feeling of worry or fear, damage suffered, perceived probability and perceived risk of property damage.

Physical and mental ability to perform the action: An important issue to assess possible reactions to an alert is whether at least one person who is physically able to perform the relevant measure belongs to the household. The relevant measures are often simple like e.g. securing loose items and closing doors. Exceptions exist i.e. when transporting furniture or installing water pumps is necessary. The latter also requires good technical understanding. This is reflected by the component 'mental capacity'. Therefore we define the meta-variable ***'likelihood that one person is physically and intellectually able to perform the relevant protective action'.*** Bubeck et al. (2013) show the influence of both abilities by introducing four variables: age, gender, education and flood experience. Furthermore, according to Dressel and Pfeil (2014), disabled and language deficient people, the area of residence as well as families with smaller children must also be taken into account.

Psychic ability to perform the action: Severe situations lead to three typical behaviors. Unlike normal reactions, hyperactivity and apathy reduce the likelihood of efficient behavior (ANZ, 2000). Therefore, we define the variable ***'probability that at least one person, who is present, is mentally capable of performing the specific action'*** but consider Dombrowsky's (1982), Mawson's (2005) and auf der Heide's (2004) findings that the likelihood of panic is relatively low in the context of floods, storms, thunderstorms and heavy precipitation events.

Spatial distance: Consistent with Parker et al. (2007), who found it significant whether or not at least one person is at home, we define the variable *'probability that at least one person is available in time to take appropriate action'*.

4. Warning-related factors comprise seven variables. The first one, ***prediction accuracy,*** is crucial in every early warning process. Two kinds of errors have to be avoided: missing alerts ('false-negatives') and false alerts ('false-positives') (see Jacks and Ferree, 2007). In addition, the noticing as well as the credibility of a warning is an important prerequisite for carrying out the intended activities. Klafft (2013) shows that the time-lag of noticing an alert is subject to strong fluctuations. On this basis, we model the variable ***'probability of noticing in due time'.*** The likelihood of successful notice by an EWS subscriber is determined by two variables: (a) the likeliness to have a chargeed up and ready for reception mobile phone on one's person (see Haeder and Haeder, 2009) and (b) the likeliness to notice the transmitted message within the given time frame according to Dinardo (2014). The factor ***lead time of the EWS*** describes the time gap between issuing a warning and the appearance of the disaster. It determines the scope and complexity of protective actions that can be taken by warning recipients. Its relevance is, for example, shown by Day (1970). Klafft and Meissen (2011) outline the lead times for different disaster types. Natural disasters like storms, thunderstorms and local flooding enable EWS-based loss prevention. In addition, calculating the benefits of EWS has to take into account that the target groups can receive alerts in alternative ways. ***Lead time****human* refers to the fact that they might have taken the same protective action even without an EWS (e.g., because they notice an upcoming thunderstorm visually). In addition, ***lead times based on the use of other media*** needs consideration. The key advantage of advanced EWS is the fast information transmission, which is specified through the geographical defined areas and connected with specific recommendations for action. Television and radio cannot issue warnings when switched off at night. This applies also to receiving messages on a PC. Advantages of smartphone warning apps compared to social media include the opportunity to offer personalized warnings and specified information at the city or regional level (see Ridler-Ueno, 2013). Likewise, Dressel and Pfeil (2014) stress the importance of behavioural advice in all messages delivered to avoid any commotion. Advanced EWS warnings often build on behaviour research and modern psychological principles. Furthermore, Chatfield and Brajawidagda (2012) describe disadvantages of warning systems based on social media regarding speed of communication and information quality. Based on the three lead time-related variables, the variable '***increased likelihood that a protective action will be completed due to an EWS-generated warning'*** shows their additional contribution compared to noticing one's self or through other media.

5. Action-related factors focus on the protective measures. The realisation of the relevant damage reduction through the use of EWS can be affected by bottlenecks. Measures for flood protection, for example, can be hindered by living in a one-story house or a lack of storage space. Therefore, the variable '***absence of bottlenecks'*** (AoB) is created (see Wurster et al., 2015). Regarding the effectiveness of protective measures, Fielding et al. (2004) analyze the effectiveness of moving cars and valuables in the context of a flood event and provide a percentage rate of effective measures. One weakness of their study is that easy measures, such as closing doors and windows, with which success is very likely, are not considered. We will show later specific formulas for loss prevention measures in the context of heavy precipitation events that consider the effectiveness aspect. Therefore we do not define a specific variable in this context. According to Rechenbach (2012), the effectiveness of EWS is increased by ***multiplier effects*** (e.g., recipients pass the warning to neighbours), which has also been the subject of other studies such as Nagarajan, Shaw and Albores (2012), Parker, Priest and Tapsell (2009) or Parker and Handmer (1998). Since we focus on systems that offer volunteers the opportunity to register as a multiplier, this effect is especially important. The variable shows how many additional households are warned on average by one multiplier.

4. FRAMEWORK FOR DETERMINING THE VALUE OF EARLY WARNING SYSTEMS

Calculating the benefit of an EWS requires, in particular three kinds of information: the value of relevant assets, possible damage, and avoidable losses withthe help of the EWS and its users. Based on these requirements, a scheme to determine the EWS-based benefit was created. It consists of two stages comprising eight steps: 1. calculating the EWS-based loss avoidance and 2. extrapolation of the EWS-based benefit (see Figure 1 and Figure 2).

The value of the variables depends on the regional, economic and cultural context. Regarding the asset value of private households, for example (Figure 1, box 1), an estimation for Germany is presented by Emschergenossenschaft and Hydrotec (2004). Additionally, Deutsche Bundesbank (2013) assesses the value of all private property in Germany, including inventory, at around €5.7bn, from which an average value per property can be derived and used in the same manner. A similar approach is shown by Rodriguez and Zeisler (2001), which differentiates between singlefamily, doublefamily and multi-family homes. An assumption of what type of housing is predominant in the respective area considered can be based on CEDIM (2014).

Possible disaster types (box 2) are, for example, storms or heavy rains while a period of one year may provide an appropriate temporal context. Regarding flood events, for example, Rodrigues and Zeiler (2001) and Emschergenossenschaft and Hydrotec (2004) describe various formulas to calculate the resulting damage, depending on the water level, which allow for an assessment of the total potential damage targeted by EWS-based measures.

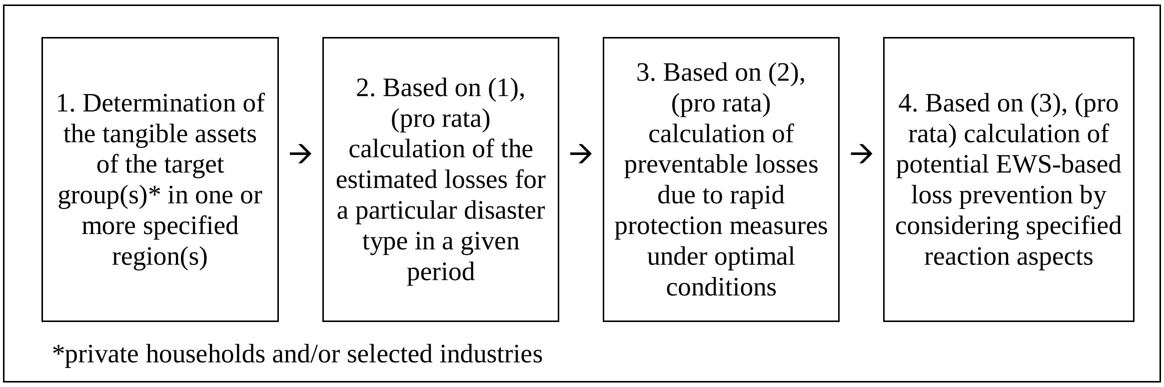


Figure 1: Scheme to determine the EWS-based loss avoidance

These formulas distinguish between the types of housing, especially between those with and without a basement. Instead of focussing on the damage of specific disasters or disaster scenarios, Petak and Atkisson (1982) conduct ‘risk’-based calculations. Calculated as Hazard * Value at Risk * Vulnerability, the risk variable replaces the potential damage and estimated losses by taking specified hazard types into account. Use of this variable allows for more specific, future-oriented calculations. The estimation of preventable losses (box 3) may build on expert interviews. In addition, there are events, such as flood catastrophes, for which specific formulas exist (see e.g. Schröter, Ostrowski, Velasco et al., 2008). The calculation of the possible damage reduction with the help of the EWS (box 4) takes, in particular, different reaction-specific aspects into account. They include, for example, the receipt of the warning, the willingness to respond and the ability to react.

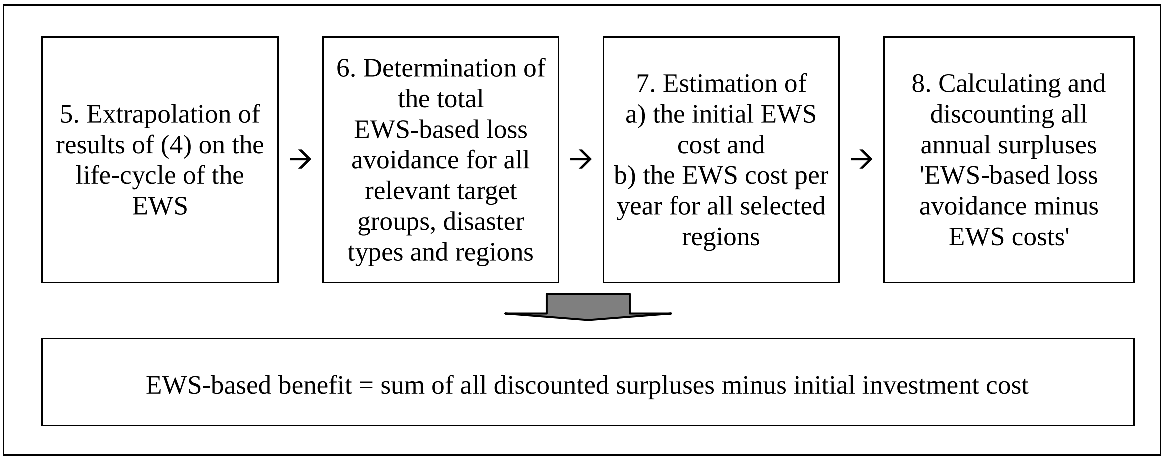


Figure 2: Extrapolation of the EWS-based benefit

In stage 2, the EWS-based benefit (Figure 2, last box) is calculated based on cost avoidance extrapolations (boxes 5-6) and EWS cost estimations (box 7). In addition, it builds on the sum of all discounted annual surpluses: 'EWS-based loss avoidance minus EWS costs' (box 8) minus the initial cost of investing in the EWS.

5. FORMULAS TO ASSESS THE BENEFITS OF EARLY WARNING SYSTEMS

Based on Figure 1, a formula for assessing the benefit of EWS is proposed. The formula is a modification and extension of previous work of Klafft and Meissen (2011) and Wurster and Meissen (2014) and builds on the following variables:

AH	: assets of the households in the warning area
d_{AH}	: potential damage of the households in the warning area
D_i	: disaster of type i
$P(D_i)$	: projected number of type i disaster per time unit in the warning area
H	: number of private households in the warning area
S_i	: share of households in the area under consideration typically struck by a disaster of type i, with $0 < S_i \leq 1$
h	: private household
$R_{i,h}$	: relevance of protective actions to protect private households in case of a disaster of type i, with $R_{i,h} \in [0;1]$
$AoB_{i,h}$	: absence of bottlenecks with regard to protective actions in household h with $AoB_h \in [0;1]$
$bfit_{prot,i,h}$	: potential monetary benefit of protective actions performed by a household
bfit	: total system benefit caused by additional successful protective actions
t	: time span of economic assessment (EWS life-cycle time)
$LHood_{able,i,h}$	: likelihood that members of the relevant household are able to perform protective actions on their own or by the help of family and friends, product of $LHood_{a\ ble\text{-}l,i,h,}$ $LHood_{able\text{-}ph,\ i,h,}$ and $LHood_{able\text{-}ps\ i,h}$
$LHood_{able\text{-}l,i,h}$	: likelihood that members of the relevant household or family and friends are able to be at the location in due time
$LHood_{able\text{-}ph,i,h}$	: likelihood that the members of the relevant household are physically and intellectually able to perform relevant protective actions on their own or by the help of family and friends
$LHood_{able\text{-}ps,i,h}$	: likelihood that the members of the relevant household are psychically able to perform relevant protective actions, if necessary by the help of family and friends
$sLHood_{willing,i,h}$	: average situational likelihood that members of the relevant household are willing to perform protective actions in case of a warning for disaster i
$P_{Pred}(D_i)$	: probability that a disaster of type i is (correctly) predicted
$LHood_{subscr,h}$	: likelihood that a household member uses the EWS
$LHood_{notice,i,h}$	: likelihood that a household member notices an incoming warning message via the EWS in due time
$LHood_{outage,i}$	: likelihood that the EWS is inoperational (e.g., due to adverse effects of the disaster of type i)
M	: multiplier effect, induced by volunteers who disseminate the warning information
$T_{Lead,EWS(Di)}$	: typical lead time for an EWS warning for a disaster of type i
$T_{Lead,human(Di)}$	: typical lead time in which humans can detect upcoming disasters of type i themselves
$T_{Lead,othermedia(Di)}$	: average maximal lead time for disasters of type i based on warnings by other media (social media, TV and radio) in addition to $T_{Lead,human(Di)}$
$inc_{prot,i,h}$	: increased likelihood that protective actions will be completed in case of a disaster of type i due to an EWS-generated warning in due time, depends on $T_{Lead,EWS(Di)}$, $T_{Lead,human(Di)}$ and $T_{Lead,othermedia\ (Di)}$.

In a first step of the calculation, the likelihood that a warning is received and translated into protective actions in case of a disaster of type i in a private household ($LHood_{action,i,h)}$ can then be described as:

$$LHood_{action,i,h} = LHood_{subscr,h} \cdot (1 - LHood_{outage,i}) \cdot LHood_{notice,i,h} \cdot Ri,k,h \cdot sLHood_{willing,i,h} \cdot LHood_{able,i,h} \cdot AoB_{i,h}$$

The equation above includes factors like the reachability ($LHood_{subscr,h}$), possible communication loss ($LHood_{outage,i}$), attention ($LHood_{notice,i,h}$), as well as the situational willingness ($sLHood_{willing,i,h}$) and ability ($LHood_{able,i,h}$) of the household members to take relevant protective actions in case of an early warning. Benefits resulting from protective actions depend to a large extent on the alert accuracy and the disaster frequency. Considering the life-cycle time t of an advanced multi-hazard EWS, the benefit ($bfit_H$) for private households created by additional protective actions initiated by the EWS can be calculated as:

$$bfit_H = \sum_i \left[t \cdot P(D_i) \cdot P_{Pred}(D_i) \cdot M * LHood_{action,i,h} \cdot bfit_{prot,i,h} \cdot H \cdot S_i \cdot inc_{prot,i,h} \right]$$

The equation above summarizes the benefits ($bfit_{prot,i,h}$) of all types of additional ($inc_{prot,i,h}$) protective actions taken by private households (H) in the considered area to protect private property ($LHood_{action,i,h}$) as a result of warnings distributed via the EWS. Of course, benefits only materialize for those households that have actually been struck by a disaster (S_i), and in case of disasters that have been correctly predicted ($P(D_i)$), $P(P_{Pred}(D_i))$ over the EWS life-cycle time t. After calculating the overall positive impact bfit of the EWS, this impact needs to be set into relation to system-induced costs. Klafft and Meissen (2011) give detailed instructions on how to calculate them. Below, we show the EWS-based savings for households based on the example of a heavy precipitation event in the German city of Hamburg and the given data for the analytical steps 1-3. Specific emphasis is put on step 4.

6. EXAMPLE

Although most heavy precipitation events go unnoticed, some cause severe damage and illustrate the importance of timely alerts, just like the one in the German city of Hamburg on June 6th 2011: up to 81.3 l/m² of rain teemed down within 70 minutes, flooding basements, underground parking lots and many other buildings (see Fein, 2011), causing an estimated overall damage of €27M to €46M including a damage of €9M to €28M in private households (damaged cars not included). This amount is based on damages in 1,000 cellars with average losses between €9,000 and €28,000 ($12,200 and $38,000) (see HWWI and Ecologic, 2012). East-Hamburg was hit particularly hard with 50 to 100 mm of rain within six hours (see de Paus, Riecke, Rosenhagen and Tinz, 2011). The following calculation is based on the aforementioned event and examines the benefit of an app-based EWS. With regard to $LHood_{subscr,h}$ there is potential that 10% of the population are subscribed to such a service in Germany (see Rechenbach, 2012). Breakdowns of complete mobile phone networks, which are relevant for $LHood_{outage,i}$ can be estimated at less than 5%. Based on an empirical study by Haeder and Haeder (2009), the likeliness to have a mobile phone powered and ready to receive on a person was estimated to be 70.89% after three hours. In addition, Dinardo (2014), among others, suggests that 95% of received messages are read within the first 5 minutes.

To specify these values in the EWS context, OptiAlert (2014) issued warning messages in a field test at 6:33 p.m. Thirty percent of the test subjects not only received a warning but also confirmed the receipt within five minutes. In contrast to that experiment, the app in our example will issue specific sounds to facilitate the noticing of the message. For the purpose of this study, we will therefore use the combined value of Haerder and Haerder’s (2009) and Dinardo’s (2014) findings. Based on their findings, it is most likely that almost all transmitted messages are read within a 3-hour lead time. Combining both estimations and determining the average yields a value of 70.73% for $LHood_{notice,i,h}$.

Klafft and Meissen (2011) analysed the willingness to respond to a warning and to conduct specific protective actions by a survey. The willingness to close windows, to secure loose items outside and to drive cars into garages reached the highest results of between 93 and 100%. As shown before, there are many kinds of potential protective actions. Warnings may also allow for conducting multiple activities. For the purpose of this study the willingness to respond in general is set at 95%, supported by the assumption that people are very responsive in protecting their private property.

Concerning the likelihood that the target group is at home in due time, five aspects are important: a) working activities, b) free time, c) sleeping, eating, personal care, d) weekends and e) holidays. Regarding Germany, studies indicate that the place of employment of most German workers (76%) is less than 30 minutes away from their homes (Winkelmann, 2010, Figure 2). We define the relevant period as consisting of 8 h plus 1 h break and 30 + 30 min. to commute, 10 h in total. Based on these assumptions, 76% of the German workers spend 10 out of 24 hours per day close to their home due to their working activities. We add an additional 10 h for sleeping, eating, personal hygiene etc. Regarding free time, SFZ (2013) found that Germans prefer spending time at home. Concerning additional activities (sport, etc.) we estimate that the distance between the relevant places and the homes of the citizens is comparable with the distance to the place of work or even closer. Specific estimations for weekends, holidays and people who do not work are shown in Table 1. In total we estimate $Lhood_{able-I,i,h}$ to be 77%.

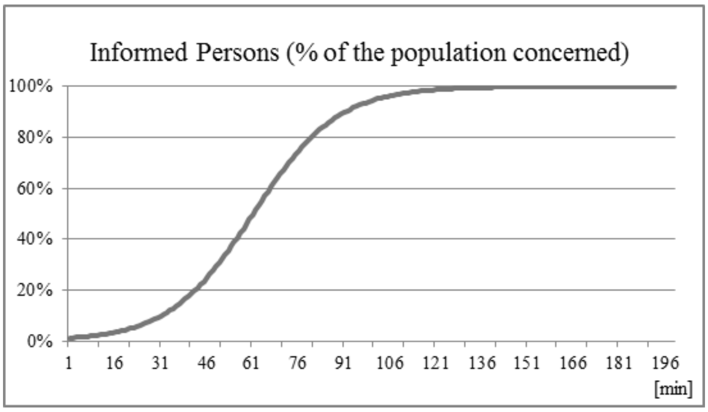
Carsell, Pingel and Ford (2004) determined the share of households whose members are able to move or transport items from their homes or have friends or relatives who can do it. They estimated that 80% of all households are able to conduct these activities alone or with the help of family and friends. Many other protection measures like closing windows or doors are simple and do not require specifc fitness. In addition, Dombrowsky's (1982), Mawson's (2005) and auf der Heide's (2004) found that the psychic ability to perform a protective action is seldom affected by precipitation events. Therefore, we estimate the product $LHood_{able\text{-}ph,i,h}$ * $LHood_{able\text{-}ps,i,h}$ to be 90% and $Lhoodable_{i,h}$ 69.3% (90% * 77%).

Table 1: Probability of German citizens to be at home in due time to protect their property in the context of the heavy precipitation event

Citizens and activity per type of day	Probability to be at home in due time per activity (a)	Total hours per activity and day (b)	Percentage per day (c) = (b)/24	Probability to be at home in due time: probability per day (d) = (a) * (c)	share of the relevant days per year (e)	probability per year (f) = (d) * (e)
WORKFORCE[1]						
Working day						
Working and commuting	76%	10	42%	32%		
Sleeping, eating, personal care	95%	10	42%	40%		
Free time	90%	4	17%	15%		
Interim result				86%		
Percentage of days per year					61%	
Share of the ability to be at home in due time per year						53%
Comment: 76% of all Germans need less than 30 minutes to commute between home and their place of work; the places of most free time activities (sport clubs, etc.) are less than 30 minutes away from their homes. In Germany, the number of annual working days depends on the Federal State. Our calculation uses 253 days minus 30 days of holiday. Values for 'sleeping, eating and personal care' also include business trips. Days of illness (which are often spent at home) are not considered separately.						
Weekend						
Sleeping, Eating, Personal care	90%	10	42%	38%		
Additional free time	75%	14	58%	44%		
Interim result				81%		
Percentage of days per year					29%	
Share of the ability to be at home in due time per year						23%
Comment: weekend days = 2/7 of 365 days						
Holidays and Public Holidays						
Total	10%	24	100%	10%		
Interim result				10%		
Percentage of days per year					10%	
Share of the ability to be at home in due time per year						1%
Total probability to be at home in due time per year and group of citizens						77%
STUDENTS Total probability to be at home in due time per year and group of citizens						77%
Comment: For simplicity's sake we use the values of workers						
PART-TIME WORKERS, SENIORS, DISABLED PERSONS AND UNEMPLOYED PERSONS Total probability to be at home in due time per year and group of citizens						77%
Comment: We estimate that these citizens spend more time at home than the workforce. For simplicity's sake we use the same values.						
TOTAL PROBABILITY OF THE CITIZENS TO BE AT HOME IN DUE TIME PER YEAR						77%

1 According to Destatis (2009), 61% of the 81.8 Mio. German citizens (48.8 Mio.) are between 20 and 65 years old. 20% (16 Mio.) are 65 and older. According to eurostat (2014), Germany's labour force includes 77.1% of all citizens between 20 and 65.

As for the multiplier effect, a simulation of the dissemination warnings via mobile phones at Fraunhofer FOKUS, showed that after 3 hours 98.7% of the people concerned received a warning, which is 9.87 times the initial 10% that subscribed to the service. The simulation assumes that the warning is triggered during ordinary working hours (more precisely, shortly before noon). The associated graph of the simulation is depicted in Figure 3.



Source: simulator of Fraunhofer FOKUS

Figure 3: Simulation of the EWS-based dissemination of a disaster warning

Based on the data from HWWI and Ecologic (2012), we consider two scenarios to estimate the potential minimum and maximum benefit of the EWS in the given context. They build on a total potential damage of €9.4M in the first case and of €28M in the second one.

7. CALCULATIONS ACCORDING TO SCHRÖTER ET AL. (2008) AND DAY (1970)

Schröter et al. (2008) and Day (1970) both offer a way to derive $bfit_{prot,i,h}$ from the damage potential of an event and the provided lead time by an EWS. While Schröter et al. (2008) distinguish between private households and industrial buildings, Day (1970) provides a single formula.

The calculations in Table 2 for the event in Hamburg imply a damage potential of €9.4M to €28M (see HWWI and Ecologic, 2012) and a lead time of three hours (which, in reality leads to a reaction time of one and a half hours on average, taking into account that some people react immediately and some only at the very end or not at all).Schröter et al. (2008) assume a linear relationship between the provided lead time and the potential savings: $y = 0.007*x + 0.18$, whereas x represents the lead time and y the percentage reduction of the potential damage. It therefore suggests a reduction of 18% without any lead time at all, which can be interpreted as the potential of all instantaneously implementable savings.

Additional 0.7% can be achieved with any additional hour of lead time. Since we only consider the additional benefit of an EWS, the initial savings of 18 % are omitted for this calculation. In the case of Day (1970), the same relationship of lead time and potential damage reduction through protective measures is described as non-linear with a declining slope and a saturation limit of 35%. The associated formula was approximated to be $y = 35 - 5040/(23*x + 144)$. According to Schröter et al. (2008), effectiveness aspects are already included in their formula. Therefore, our calculation concept does not include an additional effectiveness variable. The research framework, which led to the Day curve requires the same procedure. Table 2 shows the chosen parameters and two scenario calculations based on Schröter et al. (2008) and Day (1970) reflecting an optimistic and a pessimistic view.

According to Table 2, the EWS-benefit based on Schröter et al. (2008) and Day (1970) varies significantly. Under the given assumptions, the calculated benefit according to Day (1970) is 6.44 times higher than the one according to Schröter et al. (2008). One could suppose that these results change for particularly high lead times, but this only happens for an unrealistic long period. Based on its empirical (European) background, we regard Schröter et al.'s (2008) newer formula as more relevant to Hamburg’s context than the U.S.-based Day curve.

Although the Day curve leads to 'better' results, another disadvantage is that it only considers measures to protect movable property.

Table 2: Damage reduction according to Schröter et al. (2008) and Day (1970)

					Scenario 1 foundation: optimistic damage calculation	**Scenario 2 foundation: pessimistic damage calculation**
$LHood_{subscr,h}$	10%	Ri,h	1	dHA [€] / h	9,400	28,000
$LHood_{outage,i}$	3%	AoBi,h	1	$bfit_{prot,i,k,Schröter}$ [€]	98,7	294
$LHood_{notice,i,h}$	71%	P(Di)	1	$bfit_{prot,i,h,Day}$ [€]	636	1,894
$LHood_{able,i,h}$	69%	PPred(Di)	89%	H*Si	1,000	1,000
$sLHood_{willing,i,h}$	95%	M	9.87	$inc_{prot,i,h}$	95%	95%
		$T_{Lead,EWS(Di)PLUS}$	1.5	$Bfit_{H,Schröter}$ [€]	37,042	110,338
				in US$**	43,849	130,615
** exchange rate of January 12, 2015				$Bfit_{H,Day}$ [€]	238,647	710,863
				in US$**	282,503	841,498
Sources: $LHood_{subscr}$: Rechenbach (2012), $LHood_{notice}$: Haeder and Haeder (2009) and Dinardo (2014), PPred(Di): Klafft and Meissen (2011), d_{AH}; H*Si: HWWI and Ecologic (2012), $bfit_{prot}$: Schröter et al. (2008), Day (1970), all other data: own estimations						

It is important to highlight that Table 2 shows only the savings related to one incident. As shown in Figure 2, more calculations are necessary to estimate the benefit for the period of one year as well as the estimated life-cycle of the EWS. After calculating the benefits for all potential disasters and subtracting the EWS costs, the value of the EWS is visible. The costs of the German EWS KATWARN are for example shared between insurance companies and the administrative districts that use the EWS. The cost related to the technical infrastructure, the operation of the system and additional R&D activities are borne by the first stakeholder group. Based on this, each administrative district that wants to use the system pays an initial fee of €15,000 for installation, customization, initial training and marketing. Maintenance costs per year are €3,000. Additional costs are energy costs as well as communication costs for warnings via SMS. App-based systems as presented in this paper avoid such communication costs.

8. SUMMARY AND OUTLOOK

This paper presented a formula to assess the economic benefits of EWS with regard to the property of private households. The relevance of key variables is stressed by Parker et al. (2007). Additional validation activities in accordance to Merz, Kreibich, Schwarze and Thieken (2010) will be an important part of future activities. Collecting additional data related to the relevant behavioral variables is planned. The limitations of the two concepts from Schröter et al. (2008) and Day (1970) were described above and show the need for more research in this regard. In addition, the present formula only includes the additional benefit realized by the dissemination of information by volunteers. Formulas for the benefits of EWS for companies and the practical help of volunteers will be developed in the project ENSURE. Another evaluation method, the cost-loss approach is proposed by Johnson and Holt (1997) for valuing weather information. The authors suggest surveys of users in which the respondents estimate subjectively the value of specific information services. Surveys are also an option to calculate the value of an EWS. Citizens of Hamburg affected by the disaster of June 6, 2011 could, for example, be asked to determine the potential loss avoidance with the help of an EWS. After the introduction of such a system in a specific region, it is also possible to ask the users which EWS-based benefits they gained in the context of a given disaster. Analyses of future disasters may also include comparisons of the damage and cost savings of EWS users and of those citizens who do not subscribe to such a service.

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REFERENCES

auf der Heide, E. (2004). Common Misconceptions about Disasters: Panic, the "Disaster Syndrome," and Looting. In: O'Leary, M. (ed). The First 72 Hours. A Community Approach to Disaster Preparedness. iUniverse Publishing, 337–378.
ANZ (2000). Psychologie des Verhaltens der Bevoelkerung in extremen Situationen. Workshop report. http://ec.europa.eu/echo/civil_protection/civil/act_prog_rep/psych_aspects_inf_pub_de.pdf.
Bubeck, P., te Linde, A., Aerts, J. (2013). Assessment of upstream flood risk in the Rhine Basin. KfC 100/2013.
Carsell, K.M., Pingel, N.D., Ford, D.T. (2004). Quantifying the Benefit of a Flood Warning System. *Natural Hazards Review*, **Volume: 5, Issue:3,** 132-140.
Cavallo, A., Cavallo, E., Rigobon, R. (2014). Prices and Supply Disruptions During Natural Disasters. *Review of Income and Wealth,* **Volume: 60, Special Issue: Selected Papers from the 32nd IARIW General Conference, Boston, Massachusetts, 2012,** S449–S471.
Cavallo, E., Galiani, S., Noy, I., Pantano, J. (2013). Catastrophic Natural Disasters and Economic Growth. *Review of Economics and Statistics,* **Volume: 95, Issue:5,** 1549-1561.
Chatfield, A. T., Brajawidagda, U. (2012). Twitter tsunami early warning network: a social network analysis of Twitter information flows. Proceedings of the 23rd ACIS Conference, 1-10.
CEDIM (2014). Project description. http://www.cedim.de/english/1018.php.
Cohen, C., Werker, E.D. (2008). The Political Economy of "Natural"" Disasters, *Journal of Conflict Resolution*, **Volume: 52, Issue:6,** 795-819.
Day, H. J. (1970). Flood warning benefit evaluation-Susquehanna River Basin (urban residences), ESSA Technical Memorandum WBTM Hydro-10, National Weather Service, Silver Spring.
de Paus, T., Riecke, W., Rosenhagen, G., Tinz, B. (2011). Meteorologische Referenzdaten fuer die Metropolregion Hamburg,
http://klimzug-nord.de/index.php/page/2011-08-01-Projekt-des-Monats-August-2011.
Destatis (2009). Bevölkerung Deutschlands bis 2060. Begleitmaterial zur Pressekonferenz am 18. November 2009 in Berlin. 12. koordinierte Bevölkerungsvorausberechnung.
Deutsche Bundesbank (2013). Vermögen und Finanzen privater Haushalte in Deutschland: Ergebnisse der Bundesbankstudie,
http://www.bundesbank.de/Redaktion/DE/Downloads/Veroeffentlichungen/Monatsberichtsaufsaetze/2013/2013_06_phf_studie.pdf?__blob=publicationFile
Dinardo, J.N. (2014). Send2mobile+, US patent 20140156407 A1,
http://www.google.com/patents/US20140156407
Dombrowsky, W.R. (1982). Panikmache: Über echte und falsche Gespenster, *Zivilverteidigung. Forschung, Technik, Organisation, Recht,* **Volume: 3,** 41-53.
Dressel, K., Pfeil, P. (2014). Bridging the Gap between Crisis Management and its Recipients – Key Findings from a European Study on Socio-Cultural Factors of Crisis Communication. Klafft, M., ed., Current Issues in Crisis Communication and Alerting, Fraunhofer Verlag, 12-19.
Emschergenossenschaft, Hydrotec (2004). Hochwasser-Aktionsplan Emscher.
http://www.eglv.de/fileadmin/EmscherGenossenschaft/2.3_Flussgebietsmanagement/Karten_Anlage/Methodik_der_Schadensermittlung/methodik_schadensermittlung.pdf
ENISA (2012). Introduction to Return on Security Investment. Helping CERTs assessing the cost of (lack of). security. http://www.enisa.europa.eu/activities/cert/other-work/introduction-to-return-on-security-investment/at_download/fullReport.
Eurostat (2014). Arbeitskräfteerhebung. Erwerbstätigenquote der 20- bis 64-Jährigen in der EU28 im Jahr 2013 auf 68,3% gefallen. Gegenläufiger Trend für 55- bis 64-Jährige.
http://ec.europa.eu/eurostat/documents/2995521/5176298/3-19052014-BP-DE.PDF
Fein, J. (2011). Niederschlagsrekord fuer Hamburg. http://www.wetterspiegel.de/de/nachrichten/

Fielding, J., Burningham, K., Thrush, D., Catt, R. (2007). Public response to flood warning. R&D Technical Report. Environment Agency April 2007.
FLOODsite (2009). Developing models to estimate the benefits from flood warnings. Project report. http://www.floodsite.net/html/publications2.asp?by=documentTitle.
FMI (2012). EWENT. D5.2 Economic value of weather forecasts on transportation – Impacts of weather forecast quality developments to the economic effects of severe weather. Project Report.
Ghersetti, M., Oden, T.A. (2014). Communicating Crisis Through Mass Media. In: Klafft, M., ed., Current Issues in Crisis Communication and Alerting, Fraunhofer Verlag, 24-41.
Grayman, W.M., Males, R.M. (2002). Risk-based modeling of early warning systems for pollution accidents, *Water Science and Technology*, **Volume: 46, Issue: 3,** 41-49.
Guha-Sapir, D., Santos, I. (ed.) (2013). The Economic Impacts of Natural Disasters, Oxford University Press.
Haeder, M., Haeder, S. (2009). Telefonbefragungen über das Mobilfunknetz: Konzept, Design und Umsetzung einer Strategie zur Datenerhebung. VS Verlag für Sozialwissenschaften.
HWWI and Ecologic (2012). Gutachten zu den oekonomischen Folgen des Klimawandels und Kosten der Anpassung fuer Hamburg, http://www.hamburg.de/contentblob/3815154/data/.
Jacks, E., Ferree, J. (2007). Socio-Economic Impacts of Storm-based Warnings. AMS Second Symposium on Policy and Socio-economic Research. http://ams.confex.com/ams/pdfpapers/120849.pdf
Johnson, S.R., Holt, M.T. (1997). The Value of weather information. In: Katz, R. and Murphy, A.H. (eds.), Economic Value of Weather and Climate Forecasts, Cambridge University Press, 75-108.
Klafft, M. (2013). Diffusion of Emergency Warnings via Multi-Channel Communication Systems - An Empirical Analysis. Proceedings of the 11th Internat. Symposium on Autonomous Decentralized Systems, 295-299.
Klafft, M., Meissen, U. (2011). Assessing the Economic Value of Early Warning Systems. Proceedings of the 8th Internat. ISCRAM Conference, Lisbon, 2011.
Knorr, D., Naderer, C. (2014). Possibilities of Individual Severe Weather Alerts Depending on Geographical Location of Recipients – A Case Study from Austria. In: Klafft, M., ed., Current Issues in Crisis Communication and Alerting, Fraunhofer Verlag, 2014, 43-59.
Krenz, K., Hellriegel, J., Klafft, M. (2014). A Concept for the Simulation of Alert Message Propagation in the General Population. Current Issues in Crisis Communication and Alerting, Klafft, M., ed., Fraunhofer Verlag, 76-97.
Mawson, A.R. (2005). Understanding Mass Panic and Other Collective Responses to Threat and Disaster, *Psychiatry*, **Volume: 68, Issue: 2,** 95–113.
Meissen, U., Voisard, A. (2008). Increasing the Effectiveness of Early Warning via Context-aware Alerting. In: Fiedrich, F., Van de Walle, B., Proceedings of the 5th Internat. ISCRAM Conference, Washington, 2008, 431-440.
Merz, B., Kreibich, H., Schwarze, R., Thieken, A. (2010). Review article "Assessment of economic flood damage", *Nat. Hazards Earth Syst. Sci.,* **Volume: 10,** 1697-1724.
Munich RE (2015a). Review of natural catastrophes in 2014: Lower losses from weather extremes and earthquakes.
https://www.munichre.com/site/corporate/get/documents_E1073674437/mr/assetpool.shared/Documents/0_Corporate%20Website/6_Media%20Relations/Press%20Releases/2015/Munich-Re-Press-release-natcat-2014.pdf
Munich RE (2015b). Loss events worldwide 1980 – 2014. 10 costliest events ordered by overall losses
http://www.munichre.com/site/corporate/get/documents_E-567437233/mr/assetpool.shared/Documents/5_Touch/_NatCatService/Significant-Natural-Catastrophes/2014/10-costliest-events-ordered-by-overall-losses.pdf
Munich RE (2015c). Loss events in Europe 1980 – 2014. 10 costliest winter storms ordered by insured losses.
http://www.munichre.com/site/corporate/get/documents_E2089112740/mr/assetpool.shared/Documents/5_Touch/_NatCatService/Significant-Natural-Catastrophes/2014/10-costliest-winter-storms-ordered-by-insured-losses.pdf
Nagarajan, M., Shaw, D., Albores, P. (2012). Disseminating a warning message to evacuate: a simulation study of the behavior of neighbours. *European Journal of Operational Research*, **Volume: 220, Issue: 3**, 810–819.
OptiAlert (2014). Deliverable D8.3. “Field test results”.
http://www.opti-alert.eu/assets/files/Deliverable%208-3.pdf.
Parker, D.J., Handmer, J.W (1998). The role of unofficial flood warning systems. *Journal of Contingencies and Crisis Management*, **Volume: 6, Issue: 1**, 45–60.

Parker, D.J., Priest, S.J., Tapsell, S.M. (2009). Understanding and enhancing the public's behavioural response to flood warning information. *Meteorological Applications,* **Volume: 16, Issue: 1**, 103–114.
Parker, D., Tunstall, S., McCarthy, S. (2007). New insights into the benefits of flood warnings: Results from a household survey in England and Wales. *Environmental Hazards,* **Volume: 7, 2007**, 193–210.
Penning-Rowsell, E.C., Green, C. (2000). New Insights into the Appraisal of Flood-Alleviation Benefits: (1). Flood Damage and Flood Loss Information. *Water and Environment Journal,* **Volume: 14, Issue: 5**, 347–353.
Perrels, A., Frei, T., Espejo, F., Jamin, L., Thomalla, A. (2013). Socio-economic benefits of weather and climate services in Europe, *Adv. Sci. Res*., **Volume: 10**, 65-70.
Petak, W. J. and Atkisson, A.A. (1982). Natural Hazard Risk Assessment and Public Policy. Springer.
Rechenbach, P. (2012). Warnung der Bevoelkerung – Erfahrungen mit KATWARN in Hamburg. Ergaenzendes Informationssystem fuer Großschadenslagen und Katastrophen. *Brandschutz,* **Volume: 2012, Issue: 10,** 772-775.
Ridler-Ueno, S. (2013). An ‘App’ for everything; But can Apps for Disaster save lives? Presented at the TIEMS Berlin Conference, Berlin, 2013.
Rodriguez and Zeisler [Ruiz Rodriguez + Zeisler] (2001). Übersichtskarte der Überschwemmungsgefährdung und der möglichen Vermögensschäden am Rhein. Abschlußbericht für die Internationale Kommission zum Schutz des Rheines (IKSR),
http://www.iksr.org/fileadmin/user_upload/Dokumente_en/Reports/bericht_nr_131.pdf
Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., Mifflin, E., et al. (2006). HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment, *Nat. Hazards Rev.,* **Volume: 7, Issue: 2**, 72–81.
Schröter, K., Ostrowski, M., Velasco, C., Torres, D.S., Nachtnebel, H.P., Kahl, B., Beyene, M., Rubin, C. Gocht, M. (2008). CRUE Research Report No I-5: Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE). http://www.crue-eranet.net/calls/ewase_finalreport.pdf
SFZ (2013). Die beliebtesten Freizeitaktivitaeten der Deutschen, http://www.freizeitmonitor.de /de/zahlen/daten/statistik/freizeit-aktivitaeten/2013/top-10-freizeitaktivitaeten.html.
Thieken, A. H., Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., Maiwald, H., Merz, B., Müller, M., Piroth, K., Schwarz, J., Schwarze, R., Seifert, I., Seifert, J. (2008). Methods for the evaluation of direct and indirect flood losses. Proceedings of the 4th International Symposium on Flood Defence, Toronto, 2008.
Thieken, A. H., Kreibich, H., Mueller, M., Merz, B. (2010). Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002. *Hydrological Sciences Journal,* **Volume: 52, Issue: 5,** 1016-1037.
Turoff, M., Hiltz, R., Banuls, V., Van den Eede, G. (2013). Multiple Perspectives on Planning for Emergencies: An Introduction to the Special Issue on Planning and Foresight for Emergency Preparedness and Management, *Journal of Technological Forecasting and Social Change,* 80, 1647-1656.
Wenzel, F., Baur, M., Fiedrich, F., Ionescu, C., Oncescu, M. (2001). Potential of Earthquake Early Warning Systems. *Nat. Hazards,* **Volume: 23,** 407-416.
Winkelmann, U. (2010). “Manche pendeln weit“– Berufspendler im Bundesländervergleich. Statistisches Monatsheft Baden-Württemberg 4/2010, 40-43.
Wurster, S., Meissen, U. (2014). Towards an Economic Assessment Approach for Early Warning Systems: Improving Cost-Avoidance Calculations with Regard to Private Households. In: Hiltz, S.R., Pfaff, M.S., Plotnick, L., Robinson, S., eds, Proceedings of the 11th ISCRAM Conference, Pennsylvania, May 2014, 439-443.
Wurster, S., Klafft, M., Kühn, M. (2015). Beyond Saving Lives: Assessing the Economic Benefits of Early Warning Apps for Companies in the Context of Hydrological Hazards, Proceedings of the ISCRAM Conference 2015.