Deliverable D5.9

D5.9 Crowdsourced EEW services

Deliverable information	
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Summary

Citizen seismology involves millions of people globally and its role is increasingly important in the mitigation of the seismic risk and for improving people awareness during and after seismic events. This deliverable summarises the progress made by the Earthquake Network (EQN) citizen science initiative in providing useful services to the European and to the global population living in seismic areas. Started in 2012, the initiative implements the first smartphone-based earthquake early warning (EEW) system. Thanks to a smartphone app, the devices made available by citizens are exploited to create a network for the real-time detection of earthquakes. When an earthquake is detected, an alert is sent to the smartphones with the app installed and published on social networks (Twitter and Facebook) and on Telegram channels. Main aims of EQN are to possibly alerts people before strong ground shaking begins and, more generally, to improve people's awareness of seismic events happening in their area.
For many years, EQN run without any proper assessment of its detection capabilities and efficacy in alerting people. The RISE and the TURNkey H2020 projects have been the opportunity for EQN to be studied in details by seismologists and scientists who, for the first time, had access to the EQN detection logs. The following sections detail the findings about EQN on the following questions:

1. Which earthquakes are detected by the EQN smartphone network?
2. Which is the network detection delay?
3. Did EQN ever provide a forewarning to people exposed to high shaking levels?
4. How EQN users react when they receive a real-time alert?
5. How did EQN perform during the Turkish-Syrian earthquake of February 6, 2023?

Technical details are demanded to the scientific articles in the reference list and published as part of the RISE and TURNkey projects.

1. EQN detection capabilities

The relevance of question 1. is related to the fact that smartphones are not seismometers nor scientific-grade instruments specifically designed for the detection of earthquakes, and the smartphone network is subject to both false alerts and missed detections (Yannick Massoda and Finazzi, 2023). Also, a smartphone network employed in a EEW system does not necessarily need to detect all earthquakes down to small magnitudes.
In Finazzi et al. (2022), EQN detection logs and earthquake catalogues have been used to fit probabilistic models able to provide the probability of detection for a generic earthquake given the earthquake parameters and the geometry of the smartphone network. Specifically, it was discovered that the detection probability mainly depends on how smartphones are clustered within the network, on the number of smartphones in each cluster and on the earthquake intensity at the nearest cluster from the epicentre (i.e., the cluster where the detection usually occurs). Additionally, a country effect has been observed when comparing three countries where EQN is popular, namely Italy, Chile and the United States (US).
Figure 1 shows how the probability of detection changes with respect to the number of smartphones in the nearest cluster and to the shaking intensity at the cluster location. Not surprisingly the probability is practically equal to one when the intensity is high and/or the number of smartphones is high. This suggests that EQN is suitable for EEW, where the aim is to alert people when strong earthquakes hit.
The Italian EQN subnetwork appears to behave differently with respect to Chile and the US, with probabilities of detections that tend to be lower when the cluster is small or the intensity at the cluster is small. However, the Italian data set only included 18 of the 508 EQN detections available for the three countries and this country effect might disappear when considering larger data sets.

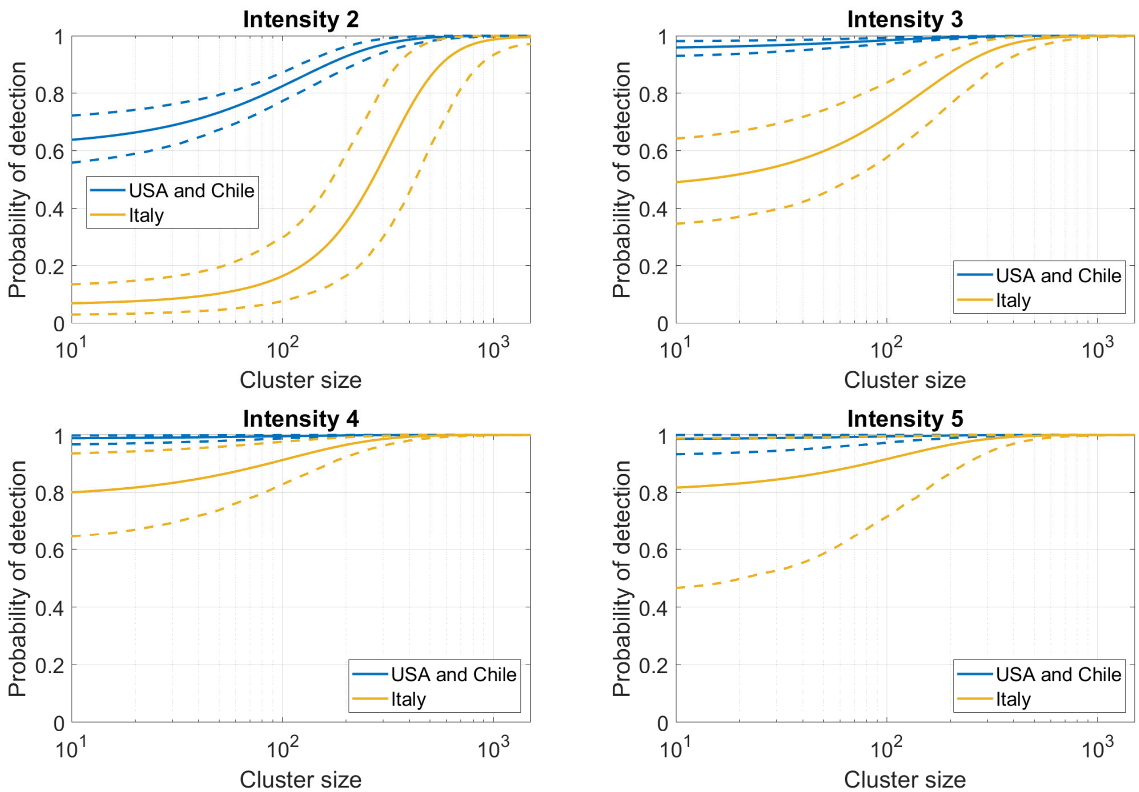

Figure 1. EQN earthquake detection probability (solid lines) and 95% confidence bands (dotted lines) as a function of the size of the cluster nearest to the epicenter and the earthquake intensity at the cluster location assuming an earthquake depth of 10 km and a distance of 20 km between the epicenter and the cluster location.

2. EQN detection delay

EQN detection delay is affected by the network geometry and by the detection algorithm. The random delay induced by the detection algorithm has a small variability and it is usually between 1 and 3 seconds. This delay mainly depends on the behaviour of each individual smartphone, on the Internet latency and on the detection logic implemented on the EQN central server.

On the other hand, the delay related to the network geometry has a larger variability and it mainly depends on the distance between the earthquake hypocentre and the nearest cluster of the smartphone network. Figure 2, which is based on the data analysis of Finazzi et al. (2022), shows the expected EQN detection delay for Western US, Chile and Italy assuming a given network geometry and an earthquake of magnitude higher than 5 at 10 km of depth. The detection delay practically mimics the population spatial distribution, which determines the network geometry and the number of smartphones in each cluster. EQN detection delay tends to be more uniform in areas where the population is evenly distributed and does not present large gaps.

Table 1 compares the EQN and the ShakeAlert detection delay (with respect to origin time) for some seismic events detected by both systems. When EQN detects the earthquake at short distance from the epicentre, the two systems have comparable delays. This is a remarkable result given that EQN has nearly zero operational costs.

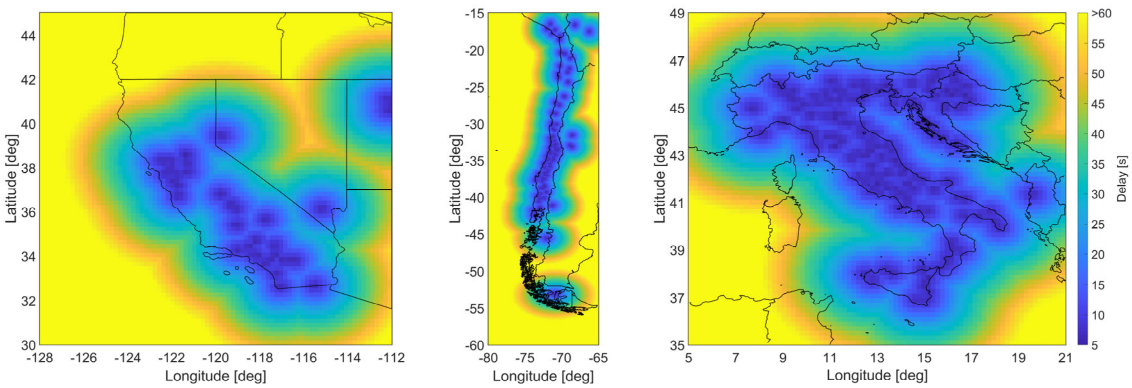

Figure 2. EQN expected detection delay for a generic earthquake assuming a magnitude >5, a depth equal to 10 km and that the detection is triggered by the P phase. The delay is based on the EQN smartphone network geometry observed at 3 a.m. local time on 15 January 2020.

Table 1. Detection delays for the 4 earthquakes detected by both ShakeAlert and EQN.

Magnitude	Origin time	ShakeAlert detection delay	EQN detection delay	EQN detection distance
7.1	July 6th, 2019 03:19:53.04	6.9 s	40.0 s	188 km
4.5	October 15th, 2019 05:33:42.81	5.6 s	7.2 s	3 km
3.8	December 5th, 2019 08:55:31.65	5.7 s	5.4 s	10 km
3.9	December 12th, 2019 08:24:32.6	6.8 s	10.4 s	20 km

3. EQN warning time

Warning time is the difference in time between the EEW alert and the beginning of the ground shaking. In the EEW context, the interest is on the warning time for people exposed to high and dangerous shaking levels. In Bossu et al. (2022), the warning time offered by EQN has been computed for 53 significant earthquakes with magnitude >4.5 occurred between December 15 2017 and January 31, 2020 and detected in real-time by EQN. Specifically, the warning time has been computed for people exposed to intensity 4, 5 and 6 of the modified Mercalli intensity scale. As depicted in Figure 3, the warning time is affected by the earthquake magnitude. However, a large magnitude does not necessarily implies a positive warning time for all of the three target intensities. If the earthquake epicentre is located offshore or in a uninhabited area, the EQN detection occurs far from the epicentre (at the nearest town or village with enough smartphones). In this case it may not be possible to send a EEW to areas where the intensity is 5 or 6.
The data analysis showed that, in two cases, EQN was able to send a EEW to people exposed to intensity 6. In particular, a 7 second forewarning was sent to people involved in the M6.4 earthquakes that hit Albania in November 26, 2019, with 51 casualties and more than 14,000 buildings destroyed or damaged.

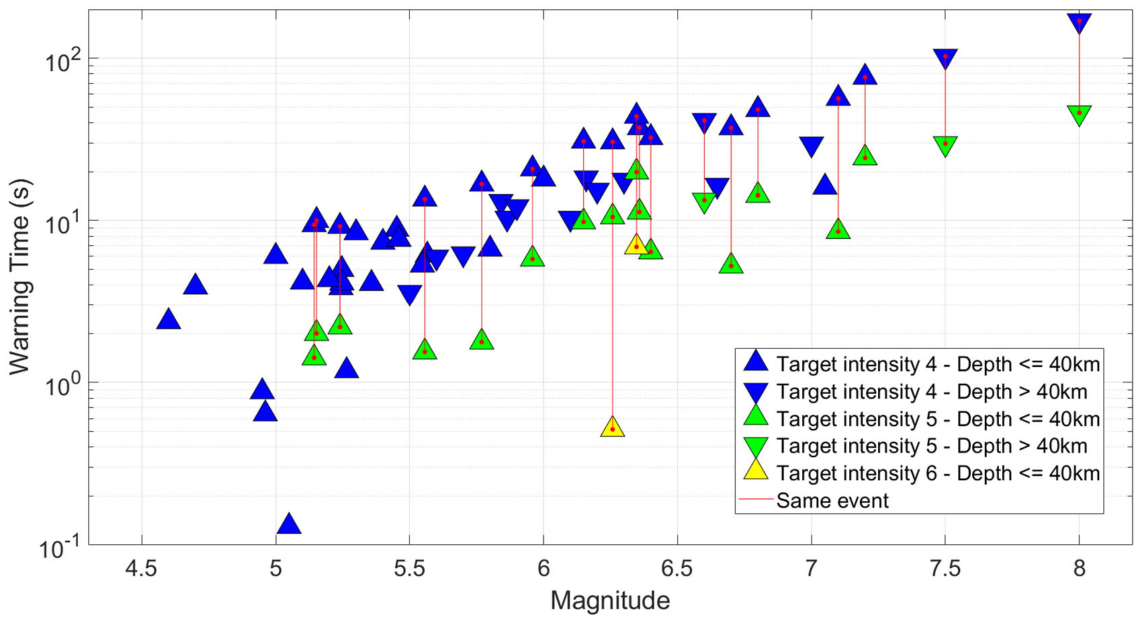

Figure 3. Estimated warning times for the 53 earthquakes detected worldwide with magnitude equal or greater than 4.5 with positive warning time. Blue, green, and yellow triangles depict warning times for target intensities 4, 5, and 6, respectively. Crustal and deep earthquakes are shown by triangles and inverted triangles, respectively. Warning times related to the same event are connected by red lines. For sake of clarity, magnitude is altered by a random shift of +/-(0.03, 0.06) for earthquakes sharing the same magnitude.

4. EQN's participants reactions to EEW

Assuming that an earthquake is detected in real-time and that a EEW is received on smartphones, it is of interest to understand how EQN users react. To this end, Fallou et al. (2022) analysed users' reaction to a warning sent by EQN on May 26th, 2019 when a M8.0 earthquake hit northern Peru at 02:41 a.m. local time, with a focal depth of 120 km. The earthquake was largely felt 1000 km from the epicentre and more sporadically up to 2000 km from the epicentre, a felt area that covers several nearby countries, including Colombia, Ecuador, and Bolivia. Two people died, and about 30 were injured. The EQN alert was sent to more than 54,000 EQN participants over the felt area. Table 2 reports part of the results of the survey submitted to them. Only 34.7% of the participants who received the alert before the shaking reacted by moving to a safe place or by running outside the building. Most of the participants spent the time between the alert and the shaking warning their relatives, either nearby or on social media. This suggests that sending an early warning does not necessarily lead to the desired result and that future study on EEW should also focus on sociological and psychological aspects.

Table 2. EQN's participants reactions to the EEW alert. Several answers possible. The survey base was the EQN participants who received the alert before the M8.0 earthquake (n=570).

What did you do when you received the alert?	
I warned my relatives physically present with me	54.6%
I waited for the first vibrations of the earthquake	35.4%
I went to a safe place in my house (under a table…) dropped, covered and hold on	25.1%
I warned my relatives through social media, SMS…	22.1%
I ran outside	9.6%
Nothing	2.8%
Other	2.8%

Additionally, the survey allowed to study the EQN participants' experience during the M8.0 event. Table 3 reports what was experienced by the participants in terms of shaking and EQN warning. 34.3% of 1662 participants who had the EQN app installed at the time of the event received an early warning, 34.6% received a late warning, 10.6% received the warning but did not feel the shaking while 14.1% felt the shaking but they did not receive the alert.

Table 3. EQN participants' experience of EEW for the M8.0 earthquake. The survey base was the EQN participants who had the app installed before the M8.0 earthquake (n=1662).

		Received the warning			Total
		Yes		No	
		Before the quake	After the quake		
Felt the earthquake	Yes	**Accurate early warning** **34.3%**	**Late warning** **34.6%**	**Missed warning** **14.1%**	83.0%
	No	**Perceived false warning** **10.6%**		**Accurate absence of warning** **6.4%**	17.0%
Total		79.5%		20.5%	100.0%

5. EQN's performance during the Turkish-Syrian of February 6, 2023

Before the major Turkish-Syrian earthquake (TSE) of February 6, 2023, Turkey was the 6th country in terms of EQN active users. This means that the EQN smartphone network already had a good coverage in the country, though mostly on the west of Turkey.

The TSE detection by EQN occurred at around 30 km from the epicentre with a delay of 11 seconds from origin time. An alert for strong earthquake has been instantly sent out to EQN users in the area. Figure 4 shows the warning time distribution among the population exposed to different levels of ground shaking assuming that the alert was sent to everyone living in the impacted area (in practice, only EQN users received the alert). The result, which is based on the macroseismic intensity map provided by USGS and on the Gridded Population of the World data base provided by the Socioeconomic Data and Applications Center of NASA, shows that people exposed to shaking intensities equal or higher than VIII could have received an early warning up to 32 seconds.

Figure 5, on the other hand, shows the warning time for 807 EQN participants who are known to have received the real-time alert from EQN. For each user, warning time and macroseismic intensity are computed using the last known spatial location of the smartphone before the TSE. Four participants who experienced shaking intensity between 8.5 and 9 received a 5 seconds warning, while two participants a warning between 20 and 30 seconds.

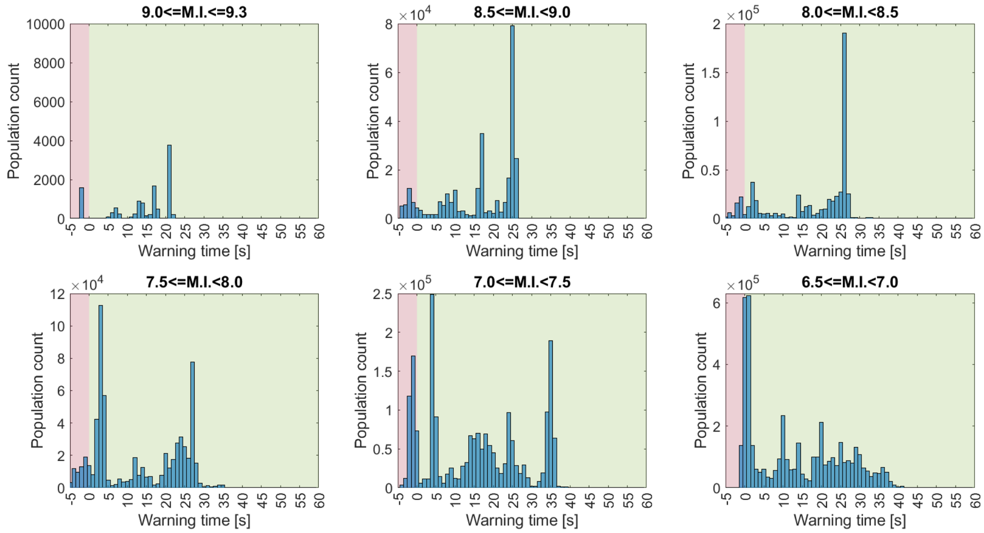

Figure 4. Potential warning time distribution with respect to the population exposed to macroseismic intensities (M.I.) between 6.5 and 9.3 during the Turkish-Syrian earthquake of February 6, 2023. Positive warning time means early warning.

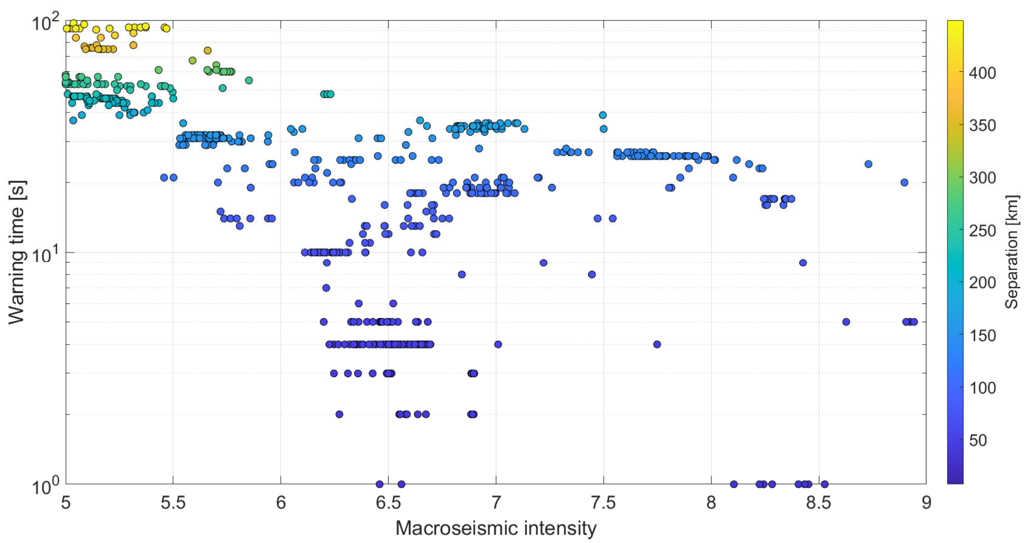

Figure 5. Warning time for 807 EQN participants impacted by the Turkish-Syrian earthquake of February 6, 2023. Each dot is a participant.

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