Are sirens effective tools to alert population in France?

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Abstract. *In France, sirens have been the principal tool in France designated to alert the population in case of danger. However, their efficacity has not been objectively tested. Using a geographical information system, questionnaires, and surveys, we analyzed (1) the spatial distribution of the sirens network in relation to: the covered population, the hazards threatening different areas and the actual number of disasters that have occurred in the past, (2) the political dilemma of activating sirens, and (3) the population trust in sirens, as well as its understanding of expected behavior in case of an emergency. Results show that, with a few exceptions, siren coverage in France is primarily determined by population density, not by the expected hazards or the cumulative number of past disasters. Sirens are also rarely used by the authorities. However, surveyed members of the population identify sirens as the most effective alert system over other alternatives such as cell phone-based alerting tools. In a 'mock' emergency most members of the public did not know how to respond in case of an emergency, and even most of those who correctly identified the appropriate response prior to the exercise didn't react upon later hearing the siren. To improve the effectiveness of the French siren network, we recommend: (1) relocating sirens to optimize their efficiency, (2) complementing the sound of sirens with a clear and unified message, (3) reorganizing the competencies to activate siren alerts, and finally (4) improving public education on different alert tools and expected behavior during an emergency.*

Key words: Alert, risk management, sirens, France.

1. Introduction

Sirens are among the most widespread tools to alert a population to danger (Sorensen, 2000; Bean et al., 2016; Sättele et al., 2016; Stokoe, 2016; Mathews et al., 2017; Goto and Murray, 2020; Bopp and Douvinet, 2020). Sirens are intended to adequately warn citizens of threats or dangers to life or property, such as sudden mass hazards (earthquake, tsunami), rapidly occurring natural hazards (wildfire, flash flood), industrial accidents (toxic gas releases, explosions), or terrorist attacks, and can be implemented at the scale of entire cities (Singapore, Bombay or Mexico City) or countries (e.g. Japan, France). Sirens theoretically present several advantages. They produce collective as well as individual reactions (Cazanave, 2010). They should allow authorities to quickly advise people and to implement countermeasures in a short response time (Douvinet, 2020). They are effective in alerting an entire

population, day or night (Zunkel, 2015; Mathews et al., 2017; Landry et al., 2019) provided that the distribution of sirens is dense enough to be heard by all. Sirens leave no time for hesitation and require immediate reactions (Reed et al., 2010; Cain et al., 2021; Fekete et al., 2021). But their effectiveness is based on the implicit assumption that the population understands what is expected from them during the alarm (Sorensen, 2000; Linsday, 2011). For example, in regions of North America prone to tornadoes, a siren during tornado season is understood to indicate an impending event, and it is assumed that the alerted population knows the need to take shelter (Mathews et al., 2017). Mexico City has used sirens emitting a characteristic sound to alert residents when earthquake shaking is imminent (Coleman et al., 2011). These outdoor sirens are then a relevant part of the warning dissemination process, since one siren may alert thousands of people, even if they are not watching or listening to any type of mass media broadcast. However, where the population is less informed about risks (e.g., from flash flooding) or where sirens can be activated for different risks, they may be less effective, and the behavior expected from the people (to stay, to shelter, to leave…) might be more ambiguous (Douvinet, 2018).

In France, despite changes at the head of the Ministry of Interior over the past 60 years, since the end of World War II priority remains allocated to the sirens for alerting people. A first network of sirens, the *National Alert Network* (NAN), was designed, as attested by an order signed in 1954 by General de Gaulle. Electronic sirens were foremost deployed to alert people to aerial threats, and a few years later, the order of January 7th, 1959 defined responsibilities of the authorities responsible for the NAN activation (mayors, prefects and the Ministry of Interior). The decree of May 8th, 1973 expanded NAN use in the event of nuclear, bacteriological and chemical risks, in relation to the development of the nuclear program in France in the 1970s. In 2010, 4,189 NAN sirens were deployed in 2,568 municipalities across France (Deloitte, 2014). But due to their age and failures in the activation, the French Ministry of Interior decided in 2010 to create a new network, presented as "more modern" and "more responsive": the so-called SAIP (*Système d'Alerte et d'Information des Populations*), with a final target date of 2022. The distribution of the future SAIP sirens is based on the concept of risk area, "taking into account the population density, the speed of the process-creating hazards, the nature of risk, and specific circumstances (concentration of chemical industries for example)", but no maps and statistics are available to confirm how these concepts were applied to develop the distribution of sirens. The distribution of the 5,531 SAIP sirens was planned according to two priority levels (Vogel, 2017). Six hundred and forty high-priority areas are covered by 2,832 sirens, and 1,103 lower-priority areas are covered by 2,699 sirens (table 1). The siting of new SAIP sirens was guided by three objectives: 1) to connect sirens together; 2) to create a unique software; 3) to improve the sirens location to reach a maximum number of people. But the areas and populations covered by the sirens is not publicly available information.

Several studies have raised doubts about the effectiveness of sirens and criticized the heavy investment in this technology in France (Hirel, 2002; Vinet, 2010; Garcia and Fearnley, 2012; Beccerra et al., 2013; Pappenberger et al., 2015; Daupras et al., 2015; Vogel, 2017; Douvinet, 2018; Courteau, 2018). Monthly testing of sirens (e.g., in France, the 1st Wednesday of each month) have served to remind residents of the existence of sirens (Creton-Cazanave, 2010), but a national study indicated that only 22 % of the population recognized the sound of alert sirens well enough to guide behavior (Deloitte, 2014). While sirens continue to receive new funding (83 million euros in 2010), the protocol for activating them remains largely unapplied (Vogel, 2017). Over the period 1959-2020, sirens were activated only

73 five times: 1) during the 2014 Vidourle flash floods (3 casualties); 2) during the 2017 wildfires around Vitrolles, near
74 Marseille (no victims, but 2,400 hectares burned areas and a cost exceeding 1.3 million euros); 3) during the industrial
75 fire in Lubrizol, near Rouen, on September 26th, 2019 (there were only 2 sirens located in less than 500 meters around
76 the fire); 4) during flash floods near Cannes, on October 23rd and 30th, 2019 (5 casualties). Nevertheless, many disasters
77 did not result in sirens being activated, for example during the 1969 dam failure in Malpasset (421 victims), or in the
78 situation of numerous flash floods, such as in Nîmes in 1988 (9 casualties), in Vaison-la-Romaine in 1992 (31
79 casualties), in Draguignan in 2010 (25 casualties), in Cannes in 2015 (20 casualties), in Trèbes in 2018 (5 casualties)
80 or near Nice in 2020 (13 casualties). Siren activation is also limited when we consider all the dangerous situations that
81 could require it (i.e. 3,226 municipalities have been the subject of a natural disaster decree per year for floods over the
82 period 1982-2018 for example; CCR, 2019). In part, this may reflect a reluctance to use sirens because of liability that
83 may arise from a false alarm (such as occurred in Bastia in 2005, in the situation of a possible tsunami) and the related
84 administrative penalties to officials who incorrectly sound the alarm (2 years imprisonment and a fine of 30,000 euros).

85

86 **Table 1.** Number of sirens in the NAN network, and in the SAIP project expected in 2022 (data from Vogel, 2017)

Priority level	Number of risk areas	Number of sirens in the SAIP project				
		NAN sirens	New sirens	Municipalities' sirens	Chemical risk areas sirens	Total number
Level 1 (2017-2020)	640	1,286	932	614	0	2,832
Level 2 (2020-2022)	1,103	191	854	533	1,121	2,699
Total (after 2022)	1,743	1,477	1,786	1,147	1,121	5,531

87

88 Underlying the reliance on sirens also makes the assumption that people are able to identify, recognize, and deal
89 with hazards or threats, whatever their origins or how quickly they occur (e.g. flash floods). Other studies have
90 demonstrated that few individuals are able to identify and understand dangers only by hearing sirens in France (Lutoff
91 et al., 2016; Daupras et al., 2015). The sound of the siren is "one sound on top of others" (Dedieu, 2009), and is added
92 to the ambient noise, particularly in urban areas. Decision-making becomes complex under stress, because it involves
93 cognitive and perception barriers (Becerra et al., 2013, Creton-Cazanave, 2010; Daupras et al., 2015). The
94 interpretation of sounds depends on the knowledge and past experiences of each person, as well as the knowledge of
95 those responsible for deciding to activate the alarm (Cain et al., 2021). In addition, these elements play a key role in
96 the decision time, before the reaction time (Colbeau-Justin, 2002, Daupras et al., 2015). It is impossible to produce a
97 signal that triggers automatic behaviors (Roux, 2006) and the adoption of reflex takes time. A strong difference also
98 remains in behavioral skills, between *"I know what to do if something happens"* and *"I really apply the safety
99 instructions when a danger occurs"* (Weiss et al., 2011), and these lags prevail, independently of the type of the risk
100 involved and of the types of alert messages (Cain et al., 2021).

101 In light of the limitations mentioned above our main research question is: Are sirens effective tools to alert people
102 in France? To answer this question, we have analyzed: (1) technical aspects related to the spatial distribution of sirens

103 (*Where are the sirens located? Do they cover the targeted population?*), (2) the institutional context of using sirens in

104 France (*What is the role of sirens in emergency management in France? How are they used? Are they used?*), and (3)

105 cognitive and behavioral aspects related to the sirens *(Do people trust sirens? Do people understand what is expected*

106 *from a siren alert? Do people adopt appropriate behaviors after a siren alert?).* To gain insights into these questions,

107 we conducted a review of relevant literature in multiple fields, created a geographical information system (GIS) to

108 analyze spatial distribution of sirens in relation to population densities and location of potential hazards, and conducted
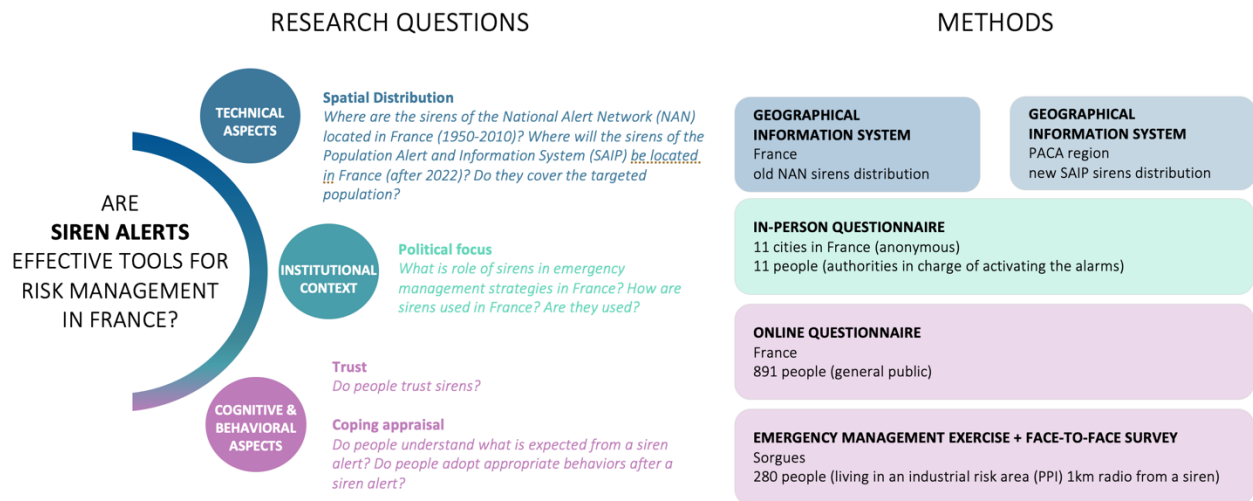
109 surveys (figure 1).

111 **Figure 1** Research questions and methods

2. Data and methods

113   Data and methods developed in this article draw upon research conducted since 2016. However, all tables and

114 figures in this article are original. In previous research, the method to calculate the number of residents living around

115 sirens (Douvinet, 2018) and the questionnaire addressed to prefects and mayors (Bopp et al., 2021) were yet addressed,

116 at a local scale, while this article coupled new results obtained at the national scale. Combining quantitative research

117 and displaying results in new tables and figures allowed us to have a more comprehensive assessment of the situation

118 of siren alerts in France.

119   First, to assess the spatial coverage, we applied tools that combine data collected using a GIS, with information

120 collected for each municipality (the number of inhabitants in 2014, the number of natural disasters over the period

121 1983-2019, and the number of registered risks). We created a geodatabase to provide an overview of the siren coverage

122 and to assess various factors that could explain the location of the current and the future siren system. This allowed us

123 to identify areas equipped and unequipped with sirens, and estimated populations covered. Second, to analyze the

124 political dilemma (activating or not the siren), we analyzed operational reports and created an in-person questionnaire

125 to evaluate the functionality and usability of sirens for authorities in charge of "turning them on" (prefects and mayors).

126 Third, to assess if population trust to sirens, and to evaluate effectiveness of the alarms in relation to perception and
127 behavioral aspects, we created an online survey and observed applications of safety guidelines during an emergency
128 exercise.

2.1. Spatial distribution of sirens in France

2.1.1. Where are sirens located in France?

131 The location of the 4,189 NAN sirens was provided by the French Ministry of Interior in a shapefile format in
132 2017. Then, we located the 2,568 equipped municipalities, and we used the municipal population census of 2010
133 (provided by INSEE, 2014) to obtain a first estimation of the population living in equipped or unequipped cities. Such
134 figures are not an ideal choice as neither the patterns of location of people at finer scale, nor influence of environmental
135 factors in the sound propagation (Mathews et al., 2017), nor mobility of residents are considered. But with these first
136 estimates, we wanted to identify which kind of areas were equipped (urban cities? rural areas?), and which were not,
137 to detect over- or under-endowed cities, and to calculate at national scale the part of residents theoretically covered.
138 We compared the number of natural disasters and the number of risks, both provided by the Ministry of Environment
139 (for 2014), for the equipped and unequipped cities, to evaluate the influence of risks or past disasters on the distribution
140 of sirens. The number of natural disasters, registered in the national CatNat database (1983-2010), is a potentially
141 relevant variable because a municipality that has suffered important damage as a result of a natural phenomenon may
142 request classification of the event as a "natural disaster" in France (Vinet, 2010; Douvinet and Janetr, 2017). The
143 number of risks, registered in the DDRM database (available in each prefecture), refers to the idea that a municipality
144 needs to map and to inform the population about risks in the living zone. We used the Spearman correlation coefficient
145 as a measure of a positive or a monotonic relation. This is the first time that such an analysis using this spatial
146 information has been reported in France.

147 Due to the confidential nature of databases, we cannot present maps expected for the future SAIP network over all
148 of France. However, we have the consent of the French Ministry of Interior to address this analysis in the PACA
149 region, in southern France, covering 31,400 km^2 with an estimated population of 5,029,214 inhabitants in 2016
150 (INSEE, 2018). The population has doubled since the 1960s (2,414,958 inhabitants in 1954) mainly due to tourism,
151 immigration from elsewhere in France and abroad. Two thirds of residents live in four major urban cities (Marseille,
152 Nice, Toulon, and Avignon). Eighty percent of the population is located in coastal areas, while mountainous and rural
153 areas in the Alpine regions are sparsely populated. The precise location of the future SAIP sirens was provided by the
154 French Ministry of Interior in a shapefile format in 2019. Then, we located the future 254 SAIP sirens and compared
155 them with the older 304 NAN. We thus analyzed the previously NAN equipped municipalities (without SAIP sirens),
156 the new equipped (with SAIP), and areas where NAN sirens will be included in the future SAIP network, and estimated
157 the evolution in covered population. One indicator, the Gini index (Atkinson, 1970), was estimated to detect levels of
158 inequality between municipal estimates. These Gini values may vary between 0 (a perfect equality with identical
159 values for the overall population), and 1 (extreme inequality, with values equal to 0, except for one individual), and
160 between 0 and 1, the higher the Gini index, the greater the inequality. In addition, the Moran index was also calculated
161 (Moran, 1950). Negative Moran indexes indicate a negative spatial autocorrelation and values range from -1

162 (indicating perfect spatial dispersion) to 1 (perfect correlation). A zero value is significant for a perfectly random
163 spatial pattern.

2.1.2. Do sirens cover the targeted population?

165 Sirens may broadcast a similar sound in France, but with various intensities (from 114 dB to a maximum of 126
166 dB), various frequencies, and various powers (from 1 up to 7kW). Siren locations were available in a shapefile, but
167 power of the sirens was indicated for only 32% of sirens, and the date of installation was available for only 28%.
168 According to the manufacturers, sirens should be audible in all directions (360°) over a distance of 4.5 km with a
169 power of 7 kW, but our field tests indicated that the siren sounds could not be heard beyond 1 km (Douvinet, 2018).
170 The actual radius of audibility around sirens is a function of sound propagation, which besides strength of the emitted
171 sound also depends on factors like the strength and direction of winds, temperature, air density, nature of materials
172 used for construction, and the ambient sound (Zunkel et al., 2015; Mathews et al., 2017). While the audibility distance
173 for a siren with a power of 7 kw is considered to be up to 3 km, sirens may also be inaudible beyond a distance of
174 800m from the source point even under ideal conditions. Audibility would be much less for weaker (1 kw) sirens.
175 Energies between two sirens can be disturbed if they are not far enough apart: for example, for a 4-kw siren the spatial
176 distance needed to be respected is 2.1 km in a calm urban environment, while 0.57 km in a densely urban area (Deloitte,
177 2014). In selecting a constant radius of audibility to use in our spatial modeling, we chose a 1.4-km radius based on
178 prior studies (Bopp, 2021; Reed et al., 2010; Zunkel et al., 2015; Mathews et al., 2017), assuming a 7kw siren, and
179 accounting for attenuation and ambient sound volume (Aumont et al., 2017). Using the population density with a
180 square mesh with tiles of 200m sides (provided by INSEE, 2014), we calculated the population covered in the 1.4-km
181 optimized radius. The population included in the radius of a siren was proportional to the area of the related circle
182 (Matthews et al., 2017). This new estimate of population covered could be compared to the total population living in
183 the cities equipped with sirens.

2.2. Institutional Context: Assessing the siren activation dilemma

2.2.1. What is the role of sirens in emergency management in France?

186 We compiled and reviewed literature (including operational reports) on major disasters in France over the period
187 2000-2020, especially after the flash floods occurred in 2010, 2015, 2018, 2019 and the industrial accident in Lubrizol
188 in 2019, to ascertain why sirens were used (or not) during such events. We took into account political heritage, social
189 practice, the nature of the risks, and how well sirens were adapted to their environment (Donaldson,1996). Many
190 studies have shown that use of sirens is contingent on political, economic, social and environments (IBZ, 2017; Bopp
191 et al., 2021). But what about organizational aspects such as procedures, type, number of actors or responsibilities to
192 disseminate the alert, hazard-detection modes, communications modes and interactions with crisis? (Bopp et al.,
193 2021). To answer this, we studied two ideas: 1) the siren activation depends on the structure and inherited political
194 governance, more than the nature of risks or the impacts of disasters; 2) the location of SAIP sirens (in progress since
195 2010) still depends on political choice, more than risk awareness and type of disasters.

2.2.2. Governance: How are sirens used in France? Do authorities really use them?

197　　　In addition, to complete the responses to the previous hypotheses, in 2020 we conducted semi-directive interviews
198　　(N=11), by phone (due to the COVID-19 context), with prefects (4), and with actors (7) representing mayors in France.
199　　The 4 prefects were selected with the support of the French Ministry of Interior, and the other actors via scientific and
200　　operational relations. All of them gave their consent to participate in the study, on a basis of anonymity, following the
201　　requirements of the French GDRP (General Data Protection Regulation) adopted in 2016. Interestingly, these actors
202　　play different roles in accordance with the level of government administration, at the national, departmental, regional
203　　and even at the municipal level. The sample (so-called S1, see worksheet in Appendix A) focused on the same topics
204　　identified in our review of literature and operational reports: the organizational objectives (*what were the objectives*
205　　*of sirens and which steps must be undertaken for their use?),* the alerting structure (*how does the approval process*
206　　*work and who triggers the siren?*), the tools actually used (*for which hazards sirens are used, and did the authorities*
207　　*use them?)* and the operational culture (*how efficient are the sirens and what factors lead to the activation?*). Indeed,
208　　we wanted to collect their opinions on the place of sirens in their emergency alert strategies, and to compare them
209　　with the operational review we carried out in the first step. This qualitative analysis was mainly focused on further
210　　exploration of unique and specific findings in relation to the roles, functions and contributions of actors during the
211　　alerting process, but the small sample size did not lend itself to statistical analysis.

212　2.3. Behavioral aspects: Measuring awareness and trust in sirens for citizens

213　*2.3.1. Do people trust sirens?*

214　　　A second sample (S2) involved 891 respondents (441 women; 434 men), aged 18-80 years old (M=39.90,
215　　SD=14.81), who completed an online questionnaire in 2019 (see Appendix B). We created this questionnaire to predict
216　　whether the Location-Based Alert System (LBAS, like cell broadcast or location-based SMS) could be useful in France
217　　(Bopp and Douvinet, 2020). Relevant to the present paper, the questionnaire asked respondents to rate a range of
218　　warning devices (including sirens) from 1 (not effective) to 10 (very effective). We analyzed results according to
219　　respondents' social characteristics (age, socio-professional category, having experienced a disaster or not) and
220　　territorial factors (type of urban area), using a ANOVA (parametric data). All the 891 persons gave their prior consent
221　　to taking part in this research, respecting the GDPR protocol. The profile of the respondents indicates an over-
222　　representation of higher-graduate (with Master's degree) diploma (+29.5%), students (+11.0%) and individuals aged
223　　from 25 and 54 years old (+ 13.4%) according to data currently available in France, and an under-representation of
224　　retired people (-18.6%), lower-graduate diploma (-10.6%) and people without professional activities (-9.2%), which
225　　could be attributed (at least in part) to the use of Internet for such survey (Divard, 2009). The age distribution of
226　　participants presented (138 were 18-24 years old, 321 were 25-39 years old, 247 were 40-54 years old, 122 were 55-
227　　64 years old, and 50 were > 65 years old) is similar to the age distribution of the country as a whole (INSEE, 2014).
228　　The largest group of respondents (508, 61%) lived in large urban areas, while 124 were from medium urban areas,
229　　128 were from small urban areas, and 118 were from rural areas. We used the Gini Index to indicate the level of
230　　inequality in the distribution of values.

231　*2.3.2. Do people understand what is expected, and adopt appropriate behaviors after a siren alert?*

To answer this question, we followed a civil security exercise in December 2016 in Sorgues, a small city immediately north of Avignon (figure 2) (see worksheet in Appendix C). We administered a questionnaire to assess the perception and the understanding of the alert to 280 persons (147 women and 133 men), aged 19-81 years old (M=55.67, SD=12.25), who were present in this risky area (so-called the *Plan Particulier d'Intervention* perimeter in French) during the civil exercise. All the participants gave their written consent prior to taking part in this exercise. We asked each participant, *"What they think to do in case of an industrial accident"* (Q1), and just a few minutes later, we asked them *"What they had just done after hearing the siren sound at 9am that morning?"* Some students (12) observed the exercise and addressed the questionnaire in some places (10) located around the industrial site, in less than 1-km radius of the sirens, which were activated at 8:45 and 9:15am. We analyzed responses quantitatively and estimated the correlations between signal detection and reaction variables using bivariate analysis. This sample (S3) was not conducted to assess a representative survey on behaviors during sirens, but it enabled us to quantify the differences between knowledge of appropriate behaviors ("*I know what I have to do*") and the real reactions people have a few minutes after the activation of alerts *("I do what I really understand about the situation")*.

2.4. Methodological limitations

Methodologically, the techniques for collecting surveys by teleconference (due to the COVID-19 context) and in-depth interviews created opportunities for data bias. While respondents described their perception of sirens, the interpretations are collected after events and not before, so this may introduce bias. It was also impossible to seek a demographically representative sample of the population using online and face-to-face questionnaires. Moreover, wording and order of questions play a role in the way individuals respond (Budd, 1987; Davis, Venkatesh, 1996; Harrison and McLaughlin, 1991). Furthermore, there is commonly a bias between what individuals report and the reality. We have already proven a recurring mismatch (Douvinet, 2018, 2020) between behavioral duties (what individuals declare they know how to do) and the behaviors actually observed in times of crisis, agreeing with other work conducted in psychology (Weiss et al., 2011). In addition, this study focused on the spatial location of sirens but fine-scale studies of responses to siren activation for recent events was precluded by ongoing judicial procedures.

3. Results

3.1. Prioritizing densely populated cities

3.1.1. Spatial inequalities in the current NAN sirens coverage

The mapping of the 4,189 NAN sirens (figure 2) showed a strong relationship between the siren location and densely populated cities. 41% of large densely urban areas were covered by at least one siren (1,299 municipalities over 3,171) and numerous sirens were located in the Ile-de-France region (Paris), equipped with 82 sirens, in Strasbourg (60 sirens), Marseille (57), Lyon (28), Toulouse (27) or Nice (26). 15 cities (out of 22) with more than 100,000 residents were equipped with more than 10 sirens. The percentage of equipped rural cities with sirens was the smallest (1.4%), and the rate in small urban areas (4.7%) was likewise low. The small number of NAN sirens in

peri-urban areas (4.1%) probably reflects the proliferation of such areas in France, but this suggests that the NAN siren coverage was poorly adapted to the evolution of urbanization as it sprawled over the last sixty years. Sirens were mounted on top of town halls (26%, 67% in dense urban areas), on roofs of churches (14 %, 5% in rural areas), on other administrative buildings (28%), and on poles placed along streets or buildings (32%).

Consequently, the NAN coverage was spatially unequal: 7.4% of the total number of municipalities are equipped (table 2). Of the 52.6% of the French population living in an equipped municipality, most were located in dense large urban areas: 77.3% of this urban population (30 million people) were covered. Of the French population living in medium-sized urban areas, only 54.4% were covered by sirens, while only 20.4% of those in small rural areas were covered, and only 4% of the population registered in rural areas really live within sound of a siren (table 2). The low percent coverage in peri-urban areas around major cities (14.7%) reflects the difference between the NAN location, and the progressive evolution of urban settlement over the last sixty years. Unfortunately, other statistical analyses are impossible, as the date of siren installation is only known for 32% of NAN sirens.

Table 2. Overview on equipped and unequipped municipalities, and populations living in equipped areas by the 3,171 National Alert Network (NAN) in France in 2010, in relation to different urban density areas (INSEE, 2014).

Urban typology (INSEE)	Municipalities			The NAN siren coverage		Municipal population		
	Total in France (n)	NAN equipped (n)	NAN equipped (%)	Total in France (n)	Average number of siren per municipality	Total (in millions)	People covered (in millions)	People covered (%)
Large, dense urban areas *	3,171	1,299	41.0%	2,461	1.89	37.7	29.1	77.3%
Peri-urban areas around major cities **	15,519	644	4.1%	968	1.50	15.8	2.3	14.7%
Medium urban area + peri-urban parts ***	1,181	151	12.8%	219	1.45	2.1	1.2	54.4%
Small urban areas****	7,990	373	4.7%	453	1.21	5.9	1.2	20.4%
Rural areas*****	6,980	100	1.4%	118	1.18	2.9	0.1	4.0%
Total	**34,842**	**2,568**	**7.4%**	**4,189**	**1.55**	**64.5**	**33.9**	**52.6%**

A group of municipalities, in a single block, consisting of an urban unit center with more than 10,000 jobs.
*** Peri-urban municipalities in which at least 40% of the employed residents work in large and densely urban areas.*
**** Urban units with 5,000 to 10,000 jobs and rural urban areas in which at least 40% of the residents with a job work in urban areas.*
***** A group of municipalities, in a single block, consisting of urban units with 1,500 to 5,000 jobs, or rural areas where at least 40% of the residents work in urban areas.*
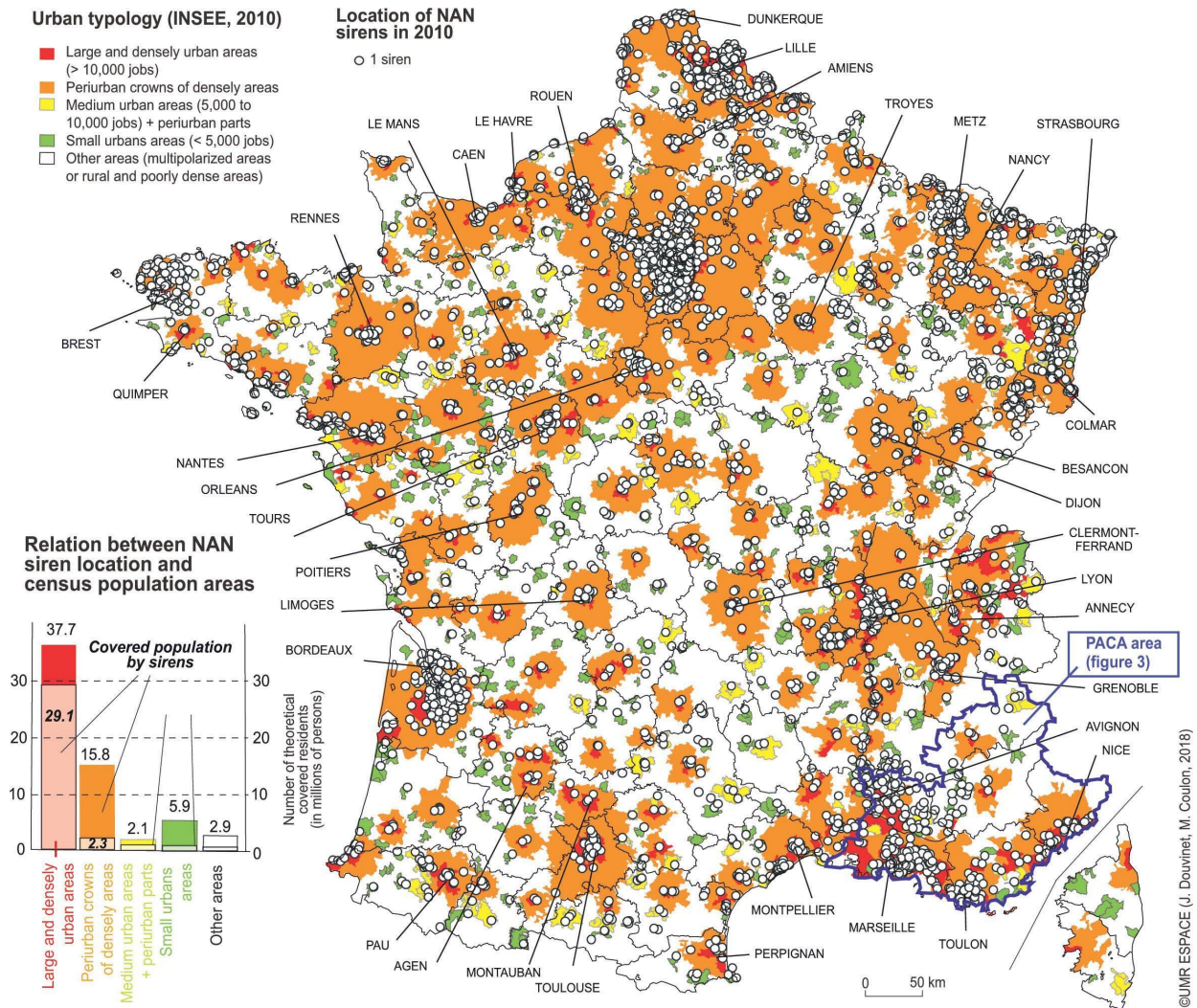****** Municipalities outside urban areas.*

Figure 2 Distribution of the 4,291 sirens of the National Alert Network (NAN) in France related to the urban areas.

When studying the relationship between the number of NAN sirens and the part of the population covered by a siren, a few medium-sized cities appear over-equipped (27 sirens in Mulhouse, 26 in Saint-Etienne, 20 in Colmar…), as well as several small rural cities (figure 3). Among the small municipalities equipped, 64 present a population of less than 500 persons. Three sirens were located in Broye-Aubigney (Haute-Saône), a village with only 477 inhabitants, but exposed to earthquake and flood risk, or at Bricy (Loiret), a village with 557 inhabitants, exposed only to flood risk (located in figure 3). In these villages, the low population would not normally justify the presence of alert sirens, but the gravity of risks was evidently the basis for locating sitens there. In contrast, several densely populated cities, for example Lyon (2 sirens for 515,685 inhabitants), Bordeaux (1 siren for a city of 252,040 inhabitants), or Argenteuil (1 siren for 110,468 residents), appear to have been inadequately provided with sirens (figure 3). Thus, while the NAN spatial coverage was influenced first by population density, with a priority to larger urban areas, this was not the only consideration accounted for. Other factors influenced the NAN coverage, such as proximity to strategic military sites (explaining the high number of sirens near Brest and Toulon for example, figure 3), proximity

10

306 to frontiers (near Germany or Belgium, with sirens first deployed after the Second World War), concentration of
307 industrial areas in several valleys (along the Rhine and the Rhone River valleys for example). And locally, or for small
308 villages, the existence of sirens is identified as a result of choices that are not very explicit (Kuligoswki et al., 2017;
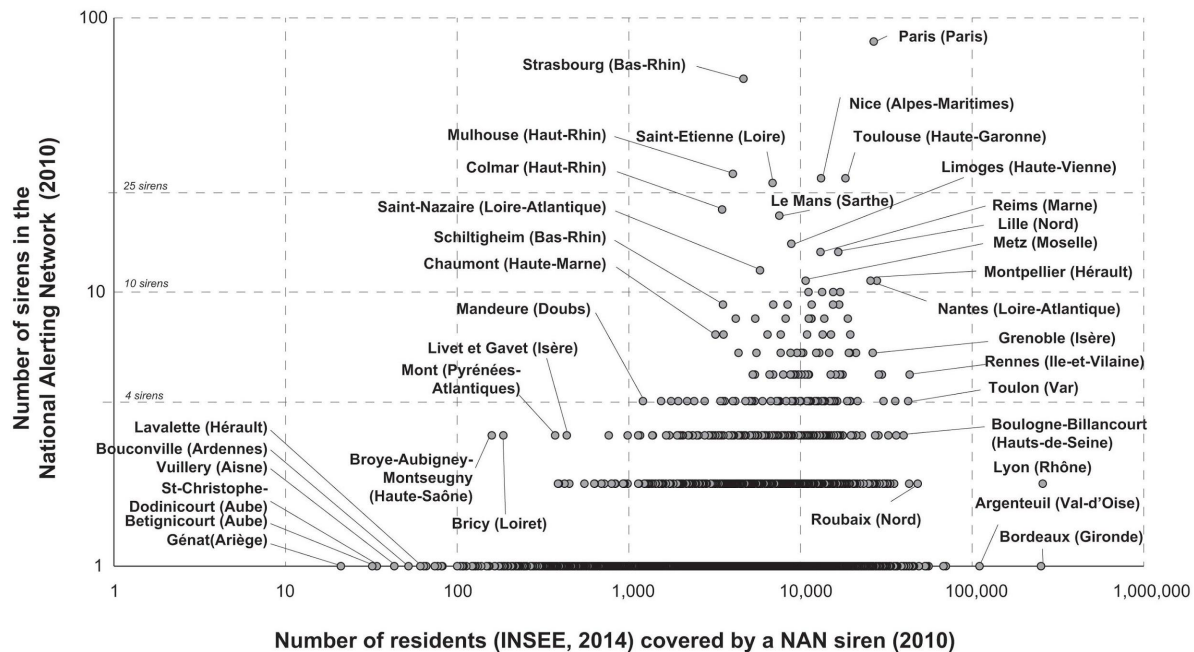309 Matthews et al., 2016).

310

311 **Figure 3** Number of NAN sirens by municipalities and average number of inhabitants served by each siren

312

3.1.2. Spatial inequalities reinforced in the PACA region with the new SAIP network

314   Mapping the spatial evolution induced between the NAN sirens (304) and the future SAIP sirens (254) in the
315 PACA region confirms that the relocation of sirens is evolving even more in favor of densely populated, large cities.
316 The number of sirens decreases in some urban areas, but at the same time, they have been relocated to even more
317 populated cities (figure 4A), around Marseille (+12 sirens), Toulon (+ 6 sirens), Etang-de-Berre (+13 sirens), or Saint-
318 Tropez (+ 5 sirens). Interestingly, the number of residents living in equipped cities will not significantly decrease: the
319 SAIP sirens will cover 58.54% of the population, with 254 sirens, against 59.54% covered with the 304 older NAN
320 sirens. The 101 new SAIP sirens will benefit the 2 most populated departments in the PACA region: Bouches-du-
321 Rhône (+44) and Var (+40). However, the decreasing number of NAN sirens appears important in several outlying
322 urban areas, especially in the hinterlands of Marseille and Nice region, and in the Vaucluse (-58, against +1 new SAIP
323 siren). In this department, the previous NAN network, composed of 85 sirens (which covered about 386,100 residents
324 within a 3-km radius), will be replaced by only 27 SAIP sirens, covering 285,000 residents in the 3-km radius. The
325 grey-colored circles (figure 4) localize the NAN deleted sirens, that will not be incorporated in the SAIP network, and
326 municipalities shall maintain or remove these sirens, or recover them on their behalf, with funding provided from their

11

327 own resources. In addition, the correlation coefficient (Spearman) is higher between the SAIP sirens and the
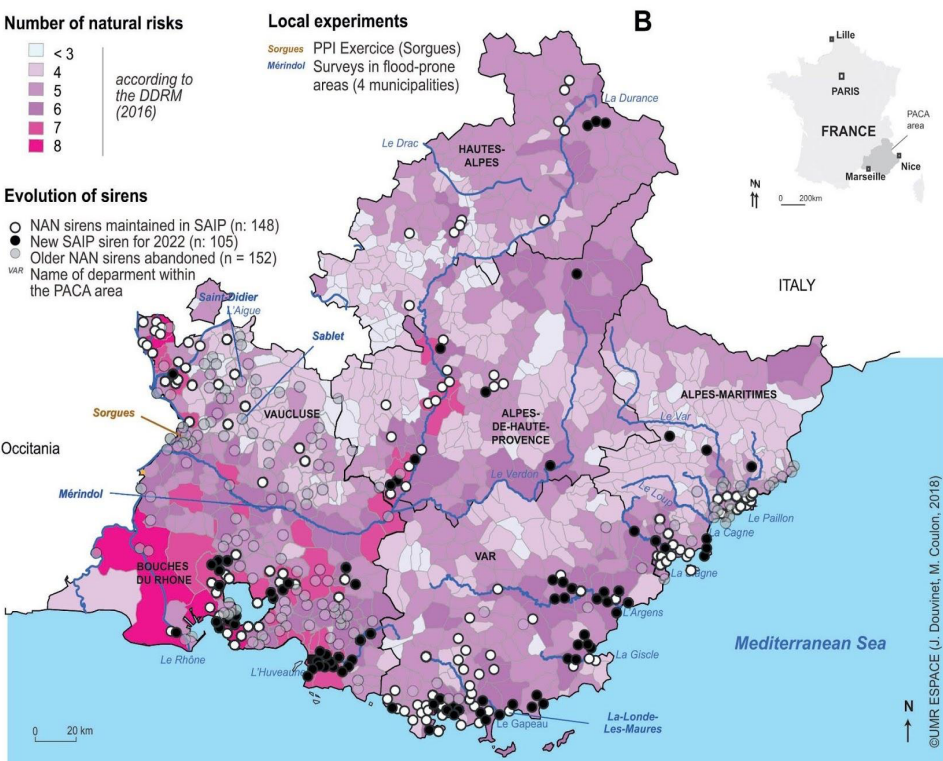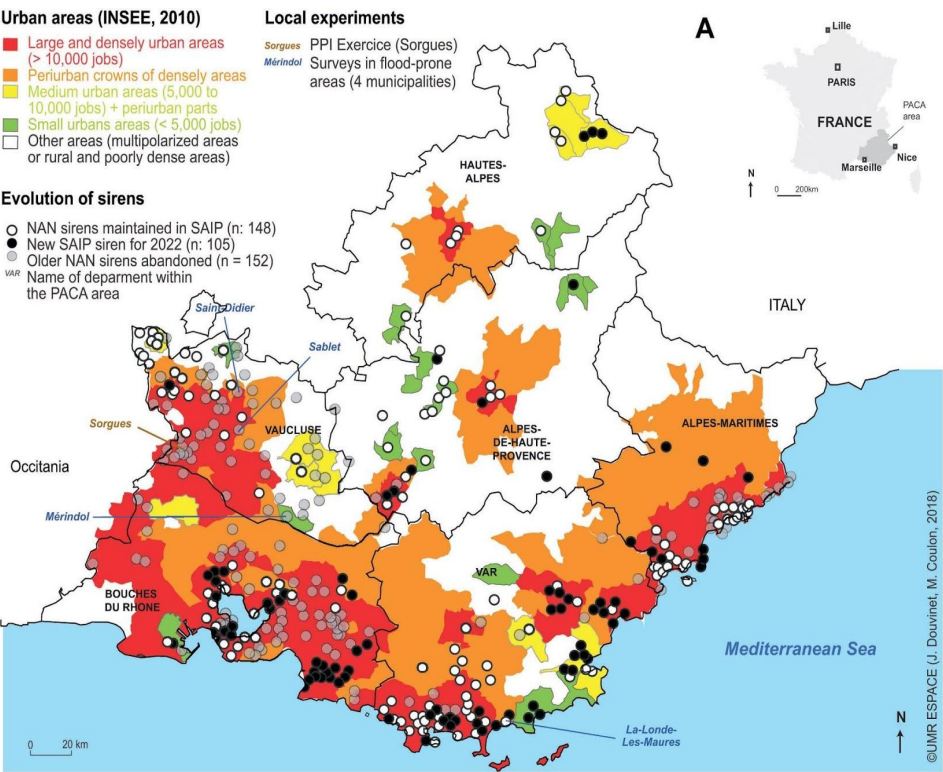328 population (rho=0.59) than between the NAN sirens and population (rho=0.46).

329

330 **Figure 4** Evolution between the NAN and SAIP networks in the PACA region (Provence-Alpes-Côte d'Azur), related

331 to **A)** the urban typology; **B)** the number of natural risks indicated by the French Ministry of Environment.

332 **Table 3** Overview on the rate of SAIP and NAN equipped municipalities, and populations living in equipped areas

333 by the 254 future SAIP sirens in the PACA region, in relation to different urban density areas (INSEE, 2014).

Urban typology (INSEE)	Municipalities			The SAIP siren coverage		Municipal population		
	Total in PACA region (n)	SAIP equipped (n)	SAIP equipped (%)	Total in PACA region (n)	Average number of siren per municipality	Total in PACA (in millions)	People covered (in millions)	People covered (%)
Large and densely urban areas *	220	71	32.3%	174	2.45	4.028	2.641	65.6%
Peri-urban crowns of densely areas **	296	22	7.4%	24	1.09	0.541	0.109	20.2%
Medium urban area + peri-urban parts ***	31	8	25.8%	17	2.13	0.109	0.067	61.7%
Small urban areas****	38	12	31.6%	20	1.67	0.122	0.075	62.2%
Rural areas*****	361	16	4.4%	19	1.19	0.220	0.033	15.2%
Total	**946**	**129**	**13.6%**	**254**	**1.97**	**5.021**	**2.927**	**58.3%**

334
335 *A group of municipalities, in a single block, consisting of an urban unit center with more than 10,000 jobs.*
336 *** Peri-urban municipalities in which at least 40% of the employed residents work in large and densely urban areas.*
337 **** Urban units with 5,000 to 10,000 jobs and rural urban areas in which at least 40% of the residents with a job work in urban*
338 *areas.*
339 ***** A group of municipalities, in a single block, consisting of urban units with 1,500 to 5,000 jobs, or rural areas where at least*
340 *40% of the residents work in urban areas.*
341 ****** Municipalities outside urban areas.*
342

3.1.3. Siren location is not related to the number of risks, past disasters or prevention plans

344 Studying the number of natural risks in equipped or unequipped municipalities in the PACA region (figure 4B)

345 indicates that number of risks or past disasters does not influence the location of sirens. The contrary could be expected

346 given that the 304 NAN sirens were located in priority within municipalities presenting 5 (103) or 6 (61) risks, and

347 that several SAIP sirens will cover a further number of people living in cities characterized by 7 natural risks (1.04

348 million people, compared to 0.43 with the NAN network; figure 5). New SAIP sirens will also exist in several cities

349 recently affected by flash floods, along the Argens River (+ 11 sirens; 25 victims the 15th, June 2010), and around

350 Cannes (affected by 2 flash floods; 20 victims, the 3rd, October 2015; 7 victims, the 23th, November, 2019) for

351 example. However, the increasing number of covered populations in municipalities presenting 7 risks (+ 0.59 million

352 people with SAIP) and 8 risks (+0.20 million people) is mainly due to the fact that new sirens will be planned in highly

353 populated areas. While 38 NAN sirens covered 0.43 million people, the future SAIP system will only exist in 18 cities,

354 including 15 cities with more than 20,000 inhabitants (figure 5). The covered population in municipalities where 5 or

355 6 risks exist decreases (1.43 million people with SAIP, against 1.98 with the NAN sirens), as well as the number of

356 equipped areas (82 in the SAIP network, against 164 with that of the NAN). And many municipalities with 5 (305-22

357 = 283), or 6 risks (320-33=287), are still unequipped. And the correlation coefficient between the number of SAIP

358 sirens and the number of risks (rho=0.32) remains low and is not really better than those obtained with NAN sirens
359 (rho=0.31).

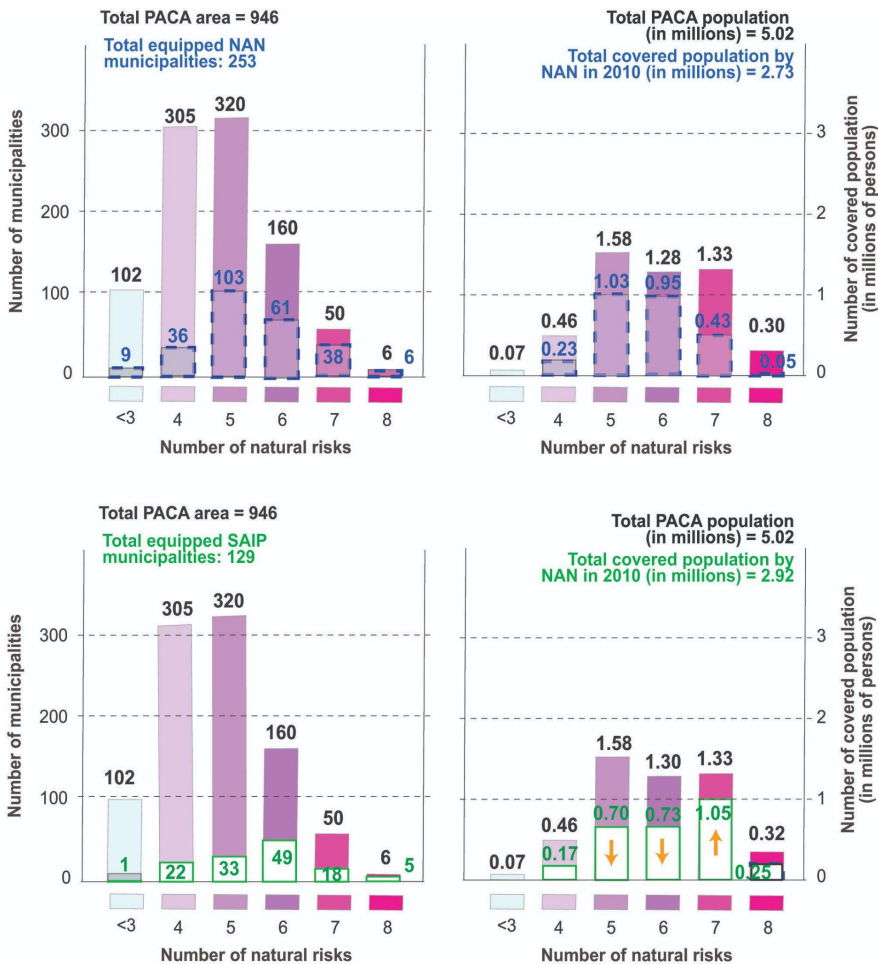**Figure 5** Covered municipalities and number of risks, for the NAN (A) and the SAIP (B) sirens, according to the DDRM (2016) in the PACA region

364   The weak correlation between the number of recent natural disasters (1983-2020) and location of sirens in the
365 PACA region may have negative consequences for risk management. Even if equipped areas have an average number
366 of natural disasters (10.3 over 37 years) higher than for those unequipped (5.12), no significant differences are
367 observed (figure 5). The correlation coefficients with the number of SAIP ((rho=0.32) and NAN (rho=0.29) sirens are
368 also limited due to the scattering of values. This trend is similar at national scale with the NAN sirens (rho=0.21) but
369 remains unknown for the future SAIP network. Moreover, a relevant correlation between the number of inhabitants
370 and the number of natural disasters exists (rho=0.67 in the PACA region and rho=0.78 in France), as well as a relation
371 between damage and the creation of Risk Prevention Plans (Vinet, 2012), or with the Municipal Response Plan (Pottier
372 et al., 2008). Thus, the statistical correlations between risk parameters are not related with the location of sirens. This

14

373 trend is reinforced by a recent study in the Vaucluse department, which showed that 100% of small basins (of less
374 than 5km^2) sensitive to flash floods were excluded in the 3-km radius of sirens (Douvinet *et al.,* 2020).
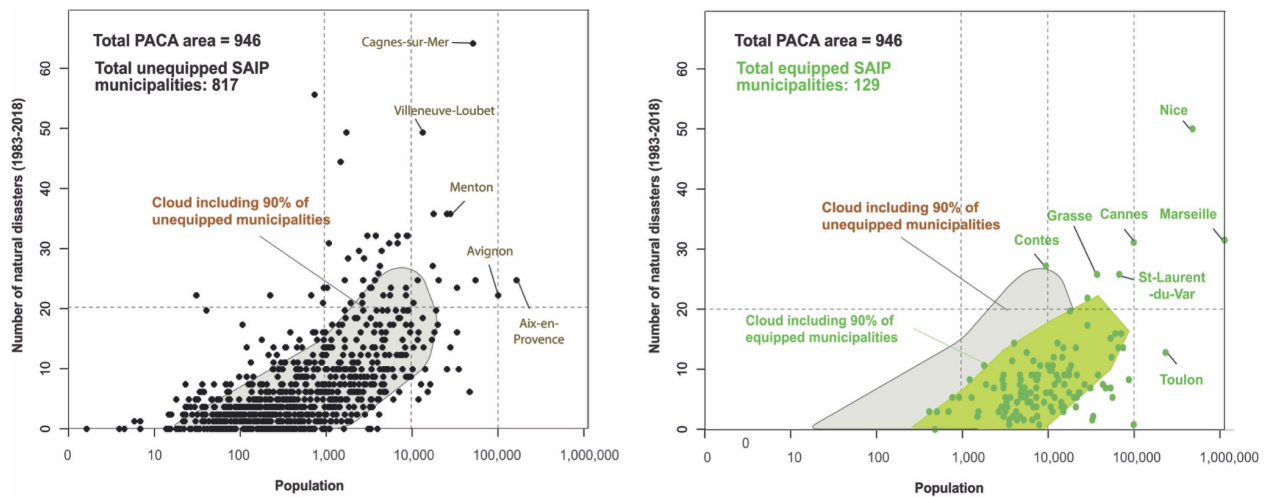375

377 **Figure 6** The number times that CatNat post-disaster funds have been granted in cities of the PACA region, equipped
378 (right) and unequipped (left) with SAIP sirens, ordered by the population log size

379

380 ### *3.1.4. Relocating sirens to optimize their efficiency?*

381   Regarding the spatial location of the sirens, we developed an alternative placement strategy for sirens to cover
382 the maximum population at a communal scale. With GIS tools, we created a regular grid in which each square has a
383 length and width of 1060m, i.e. it is circumscribed within a circle of an auditable radius of r=1,413m. We counted the
384 number of individuals in each square and selected the 254 most densely populated squares in the PACA region
385 (corresponding to the number of future SAIP sirens planned). With this method, 47.88% of the population would be
386 alerted in the South PACA region, 9.69% more than with the current location of the SAIP sirens. Another option
387 would be to have 1000 sirens distributed over highest density urban areas. In that case 74.53% of the population could
388 be alerted. However, this option would accentuate the location of the sirens in densely populated cities such as
389 Marseille (81 sirens), Nice (35 sirens), Toulon (19 sirens), Aix-en-Provence (10 sirens), Avignon (9 sirens), Cannes
390 (8 sirens) or Antibes (8 sirens) (figure 7). However, this option makes the siren placement exclusively urban, thereby
391 ignoring less densely populated areas that are also exposed to risks. So, authorities would have a more complicated
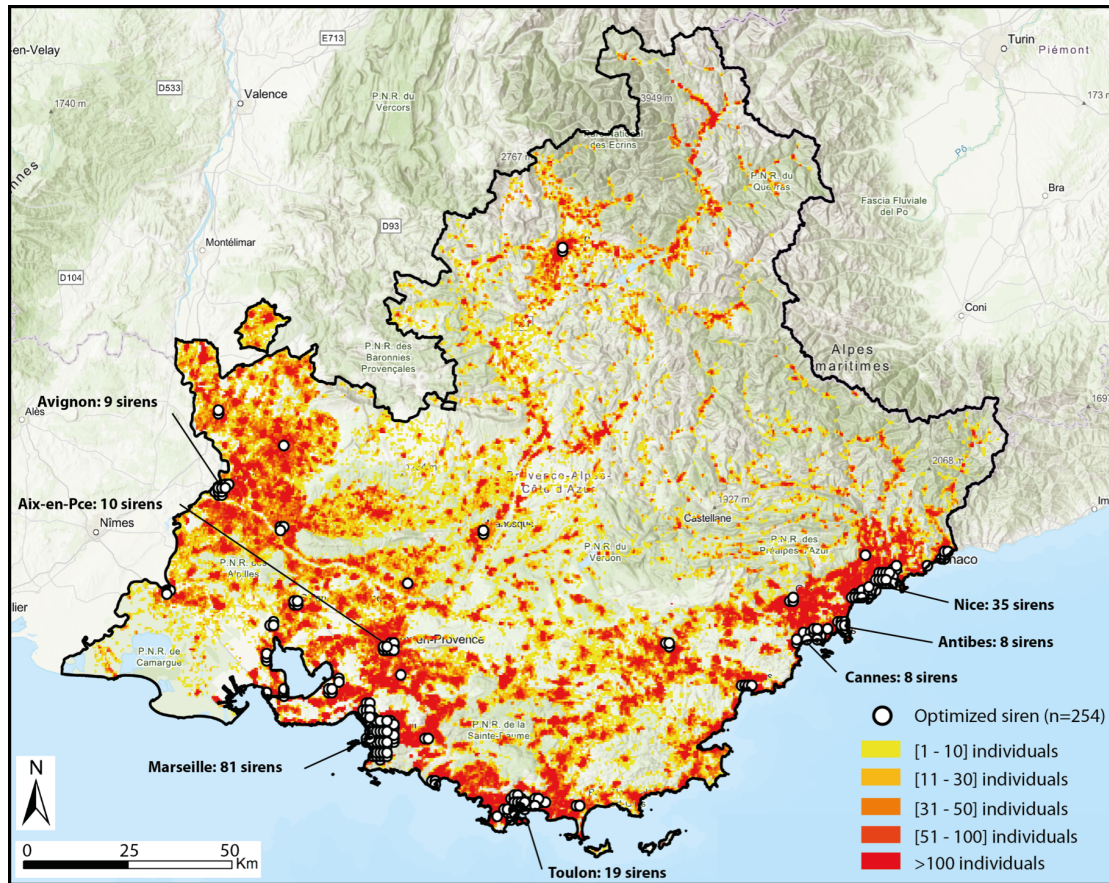392 choice to make.

Figure 7 Relocation of the sirens in the PACA region taking into account the most densely cities (the current location of the 254 SAIP sirens can be viewed before, figure 4). DEM layer (public data) was only reused ass background map.

3.1.5. Lower rates of coverage at finer scales

Estimating the number of people living in the 1.4-km optimized radius around sirens showed additional "holes in the racket" because coverage rates are lower than the first estimates. In the PACA region, the older NAN sirens covered 32.4 % of residents in the 1.4km radius (whereas 58.54% of the population lived in equipped cities), and this estimation increases to 38.2% with SAIP sirens (while 59.54% of the population is living in equipped cities). We calculated coverage values for 1-km (24.6% of residents), 2-km (40.5%), and 3-km (48.5%) buffers. Thus, the statistic 'number of people living in equipped cities' over-estimated the real siren coverage. In addition, more than 3.1 million inhabitants cannot be alerted by SAIP sirens in the PACA region, and the average coverage rate for the equipped municipalities is 58.1%. The first quartile is 29.8%, the third 83.8%, and only 2 municipalities have 100% of their population included in this 1.4km optimized radius (with respectively 428 and 5,766 inhabitants), out of the 129 equipped cities. Then, if we differently translate these figures, this means that a quarter of the cities equipped with SAIP sirens can alert less than 30% of the resident population. The strong spatial inequality is supported by the Gini index of the rates of individuals covered, equal to 0.87. Moreover, the Moran autocorrelation index is 0.22, which means that the number of individuals covered by sirens tends to be close between neighboring sites. This inequality

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becomes all the more significant when we classify the municipalities according to the type of urban area to which they belong. Only 6.9% of people living in communes outside urban areas can be alerted, whereas 46.8% of people living in small urban areas, with less than 50,000 inhabitants, can be alerted. The difference equals to 39.9%, and this is due to the greater sprawl of housing and the scale effect played by the size of the dispersed cities.

3.2.   Activating sirens: the political dilemma

3.2.1. The industrial accident in Lubrizol (2019): an iconic example

This accident occurred on September 26th, 2019, in the Lubrizol site (near Rouen, figure 1) it is the most recent event that has made several public reports in 2020 (Bonfanti-Dossat and Bonnefoy, 2020). But this first revealed the vision that the practitioners can have during the crisis. Earlier in the morning, at 2.40 a.m., a violent fire was reported on the site, and a crisis center was quickly put in place (at 3.30 am). The prefect of Seine-Maritime informed people of the situation on social networks (at 4.50 am) and through press releases (6.15 am and 6.45 am). But two sirens located less than 500 meters around the site were not activated until 7.45am, more than five hours after the accident began. As explained by the prefect, the delay resulted from: 1) fear of creating a panic reaction if the sirens had sounded during the middle of the night; and 2) fear of having to manage an anarchic evacuation when the issue was to avoid the slightest congestion on road network, to facilitate access for rescue and emergency services. Sirens were then activated to support containment instructions (to be sent out previously by press briefing). However, sirens were not intended to reveal the fire that had already been identified and communicated by the authorities. And such point of view is currently observed in the other operational reports analyzed. The siren's activation indicates to the population that the situation has been taken into account by the authorities but is not used as a means of alert (similar to their role during the Cannes flash flood in 2015). The 'fear of panic' was already put forward in discourses on the non-use of sirens (Vogel, 2017). However, researchers have discredited this 'myth' for many years (Sorensen, 2000), pointing out that in the face of danger, mutual aid and the search for proximity to familiar people and places predominate, rather than chaotic and unreasonable movements (Mawson, 2005).

3.2.2. An activation only justified by political decisions

A second problem, recurring in the reports and questionnaires (S1), is that actors involved in issuing sirens have had the same reference systems for decades (Courteaux, 2018). We could expect that the siren activation is influenced by the national context or crises that have occurred in the past, in the last months and also in the last years, which may contribute either to the transformation or the improvement of the national alerting system. But the siren activation is still vertical, "top-down" marked, and although a longitudinal approach is challenged, the pyramid approach remains predominant. During the reported flash floods, no sirens were activated, due to lack of anticipation (2003, 2008, 2010, 2015) or lack of electricity (2018, 2019), despite the existence of several sirens in areas impacted by the flash floods. No lessons were learned from the past. Moreover, the procedure itself is not 'apolitical': French government advocates for sirens to justify the funding allocated to them (Matveeva 2006), and they present them as a 'good tool (*We did*

445 *the best we could'*), while they were only used 3 times since the beginning of 2000's (during a fire in 2014; a flood in

446 2017; an industrial accident in 2019). Second, what might be termed a 'technological fetishism' for sirens led to the

447 abandonment in 2018 of the mobile application so-called SAIP, set up by the French Ministry of the Interior in 2016.

448 While similar mobile-phone applications have been successfully employed in other countries, its performance in

449 France was disappointing. For example, it was not activated during terrorist attacks in Nice in July 2016 nor in Saint-

450 Etienne-du-Rouvray in 2017, though it was activated for a false alert in the Louvre in Paris. Other technical devices

451 exist and are well suited to end users, for example 'kidnap alert' (inspired by the Amber Alert system set up in the

452 USA in 1996) or motorway warning systems that combine technical and social dimensions. The technical references

453 prevent any organizational change. Indeed, one may wonder about the efficiency of sirens in comparison to a system

454 that could send thousands of messages in a few seconds, if sirens are not adapted to the kinetics of the event or if they

455 are not understood by those who receive the alert, or if it takes hours for the authorities to make the decision to send

456 the alert. France has made a bold choice, but the resulting choice, based on control-and-hierarchical command, can be

457 questioned in terms of its real capacity to alert communities in good time.

458 *3.2.3. Where sirens exist, authorities also prefer not to use them*

459 In addition, in the sample S1, 7 of 11 authorities responding to our interview assumed that one of the objectives of

460 sirens is only to warn the greatest number of people in the area threatened by danger or risk, so that the population can

461 be aware of probable impacts. For them, sirens should provoke population to seek information in case of fires, floods

462 or bombing. Of the 11 authorities responding to our questions, seven highlighted the importance of prior experience

463 and feedback, to know corrective measures to be implemented, and to check coordination among the actors involved,

464 even if this means establishing synergies (by creating "gateways" for example). But 6 respondents observed that

465 lessons learned from past events have not been sufficiently shared. Other respondents said that tools should not be

466 differentiated according to hazards or the social conditions, highlighting that sirens would likely be better understood

467 by elderly individuals than social media, without evidence for whether this would actually be the case. Discussions

468 with these actors who had actually activated sirens in recent years highlight two contradictions in the current

469 procedure: 1) *"we activate the alarm to comply with the regulatory framework, knowing that the sirens will have a*

470 *limited range"*. In other words, this strategy is comfortable for authorities who "cover up" to avoid problems later on

471 (during post-event investigations in particular); 2) *"The difficulty is that it is necessary to alert locally with available*

472 *means, while benefiting from a robust architecture at the national level"*. Thus, the SAIP network is a positive

473 perceived solution, while sirens do not exist everywhere.

474 **3.3. The dichotomy between trust in sirens and reaction during siren alert**

475 *3.3.1. A blind confidence in sirens*

476 The second sample (S2), using an online questionnaire (2019), allowed us to evaluate the population's trust in

477 sirens in comparison with other dissemination tools, as Cell Broadcast or Location-Based SMS. Sirens remain the

478 most trusted tools for the 891 respondents (figure 8), whereas just after violent events, they declared do not understand

479 the usefulness of such tools. The siren scored the highest average (8.00/10) ahead of a CBC/LB-SMS solution

(7.80/10), the automatic telephone call system (7.78/10), door-to-door (7.17/10) and the smartphone mobile application (6.69/10). Scores are homogeneous as the Gini index IG equals to 0.15/1. In addition, social-territorial factors are not decisive in the notes given to the siren. There is no significant difference according to the age of participants (P=0.077), the urban area to which their residence belongs (P=0.794), or the individual's experience facing disasters (P=0.921). However, the siren is rated better by individuals belonging to a lower socio-professional category (SPC) than individuals belonging to a higher socio-professional category (P=0.031). Above all, compared to other means of alerting, the siren remains one of the significantly better accepted, undoubtedly attributable in part to monthly testing. Respondents did not know that only 18% of cities in France are equipped with sirens, that many NAN sirens are disappearing.
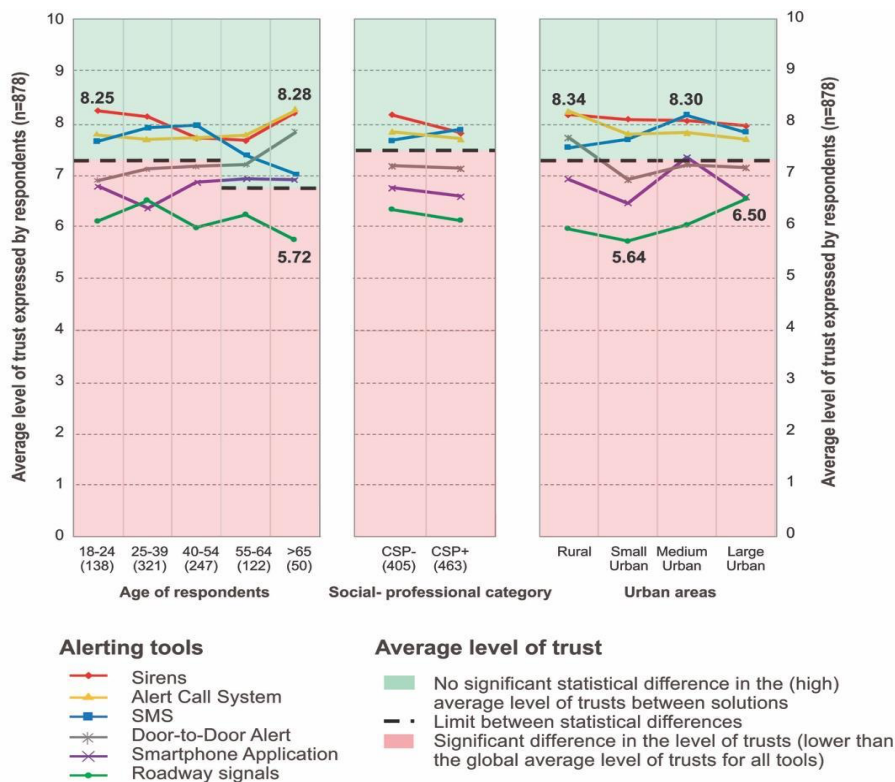
Figure 8 Average level of trust expressed by respondents for different means of communicating alerts.

3.3.2. Lack of reactions during real siren alert

The last sample (S3) conducted in Sorgues (see location in figure 4) also reveals the difficulty that people have in case of real siren alert. 72 persons (out of 280) declared that they would inform themselves in the situation of an alert, 75 reported that they would get inside building, 37 said they would call their relatives, and 40 do no change their activity. However, during the real activation of sirens, while they heard the sound, most (157) continued their activities at the time of the signal (figure 9). Only 23 attempted to enquire about why the alert had activated, 38 get informed, 16 panic, and 12 tried to escape without knowing why. These results reveal that behavior is clearly out of step with

499 declarations (Vinet, 2010; Weiss et al., 2011; Gsclard, 2017; Douvinet et al., 2020). People face difficulties in making
500 decisions in real time, like picking up their children from school or not, or driving (Creton-Cazanave, 2010; Ruin et
501 al., 2007). The question could be asked whether it is useful to add an anxiety signal at a time when individuals are
502 already stressed. Thus, assessing the utility of sirens in such cases requires a good knowledge of the nature and urgency
503 of the danger, which is not always predictable (as with terrorist attacks or industrial accidents), and these limitations
504 will persist with the future SAIP system.

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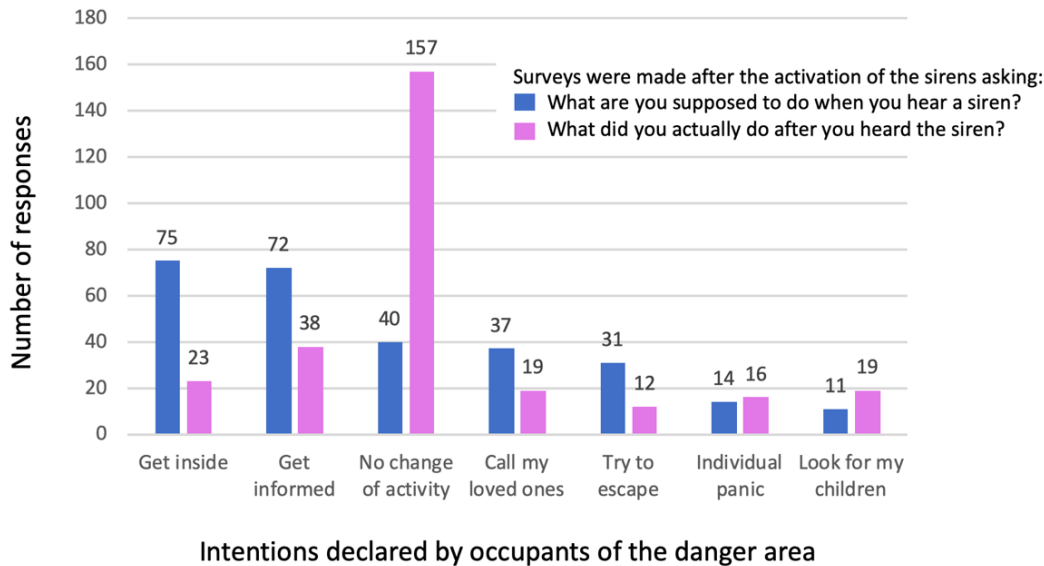
506
507 **Figure 9** Differences between the people's knowledge of safety measures (in blue) and their real behavior (pink) after
508 hearing sirens during an emergency exercise in Sorgues (Vaucluse).

4. Discussion and conclusions

510   The study of spatial, political and social aspects related to the siren network to alert the population in case of an
511 emergency shows several challenges that need to be addressed to increase their real efficiency. Results show that the
512 distribution of sirens in France is related to the population density, not to the number of hazards or past disasters that
513 have impacted a region. Furthermore, not all the population is covered by the sirens. In France only 7.4% of cities
514 were equipped with sirens from the old NAN (National Alert Network) system, and, in the PACA region in particular,
515 only 38.2% of residents are living in the 1.4km radius around sirens from the new SAIP (Population Alert and
516 Information System). Where sirens exist, they are rarely used, either due to the lack of reaction time during sudden
517 events or the reluctance of the authorities to activate them to avoid chaotic reactions from the population or liability
518 issues in case of a false alarm. Sirens have only been used 3 times since 2000 (and 6 times since 1954) in all France,
519 leading some to question the budgets allocated (more than 50 million euros were allocated for the SAIP in 2010).
520 Nonetheless, citizens, accustomed to hearing the sirens test on the first Wednesday of every month, express marginally

521 greater confidence in sirens as a tool to alert the population over other options such as smart-phone applications.
522 However, the lack of a specific message linked to the sound of the siren can create confusion and unpredictability in
523 the behavior of residents during an emergency, and our research demonstrates that in case of a real crisis, very few
524 people react when they hear it. In light of these limitations, we recommend changes (technical, organizational and
525 cognitive) in implementation of the new SAIP siren system, expected in June 2022 across France.

526 The sound of sirens should be complemented with a clear unified message so that members of the population
527 understand the expected behavior (Reed et al., 2010; Cvetković et al., 2019; Cain et al., 2021). The December 2018
528 Directive establishing the European Electronic Communications Code requires member states to establish a national
529 SMS alerting system by June 2022 (Vogel, 2017; Bopp et al., 2021). Countries such as Italy, Norway, Germany and
530 Romania are using the Common Alerting Protocol (CAP) to increase the alert effectiveness, as the protocol allows an
531 alert message to be consistently disseminated simultaneously over many warning systems to many applications, such
532 as cell phone broadcast (Bean et al., 2016). This can allow the integration of sirens with other tools. This path is
533 promising, but at the time of writing, it is unclear whether France will adopt the CAP.

534 However, for France to be able to use CAP, authorities in charge of activating the sirens' alert and the hazard
535 forecast community need to work together. An organizational change is then needed to make this happen. The current
536 services in charge of forecasting hazards do not alert people in France (whereas it is the case in Australia, Belgium or
537 the USA; Bopp et al., 2021). The delay of siren activation depends on the risks involved, but also on the detection
538 period for the hazards, the availability of tools, and the time before the first impacts on threatened people (Péroche,
539 2016). Schematically, earthquakes require automated systems since the alerting time is limited to a few seconds, or
540 even a few hundredths of a second, whereas tornadoes or flash floods occur in a few minutes or hours. When the latter
541 are forecast, various services can anticipate the event and it would be appropriate to activate the alert from the moment
542 the triggering thresholds are exceeded. This solution should give time for protective measures to be implemented. But
543 currently, the authorities prefer not to activate alerts, in part because they have misgivings about the likely behavior
544 of the alerted population, whereas with better population education and training in response, the sirens could have a
545 real utility.

546 It would also be logical to create a single platform to improve the coordination between different services with
547 their unique competencies, but without multiplying the number of services and of actors involved in issuing alerts,
548 operating differently and separately. At present, CENALT (National Tsunami Warning Centre) issues tsunami
549 forecasts; the CSEM (Euro-Mediterranean Seismological Center) monitors earthquakes; the SCHAPI (Central Service
550 of Hydrometeorology and Flood Forecasting) is responsible for flood warning and vigilance. Several emergency call
551 centers are increasingly shared, like those centralizing the 15, 17, and 18 calls within Greater Paris. Therefore, we
552 suggest going much further in this inter-service logic, and to promulgate the single 112 call number at the European
553 scale (currently being debated in the National Assembly).

554 Finally, citizens should be better informed about the different alert tools available and their expected behavior in
555 case of an emergency. Year-long population education, not only just before an emergency, is a critical last step to
556 increase the effectiveness of the current siren system in France. But populations are rarely trained nor involved during
557 safety and security exercises. To conclude, there are serious technical, organizational and cognitive problems related

558 to the efficiency of the current siren system in France. However, the implementation of the new SAIP system in 2022

559 has created a momentum to tackle these challenges and improve the efficiency of this alerting tool.

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Appendices

711 **Appendix A.** Questions included in the questionnaire done to authorities in charge of activating the sirens in 11 cities
712 of France.

713

Subject	Questions asked
Organizational objectives	What are the objectives of a Public Warning System? What are the expected results? Which time frame does it follow? Which steps must be taken upstream or downstream? What behavior is expected from the population, and from whom? Are these expectations clear (or understandable) during the alert?
Structure	Which organizations and players are involved? How does the approval process work? Who receives and analyses upward information? Who triggers the downward warning process? Who approves the broadcasting of the alert to the population?
Technology	Which tools are usually used? For which hazards are they most relevant? Did you use them? If yes, why and in which time frame? What tools would you need? Who is in charge of tool implementation (cost, investment)? Is it possible (or advisable) to use the same tools whatever the type of hazard?
Operational culture	How efficient are the available tools? What are the conditions for the appropriation of these tools by users? What factors lead to the decision of broadcasting a warning? When do you know it is the "right decision"? And the "right time"? Do these tools account for the diversity of users and communities?
The optimal warning system?	How could technical shortcomings be addressed? How could organizational shortcomings be addressed? What are the main threats / risks in the future? Does the current system seem optimal to you? Are there any obstacles? What are they?

714

715 **Appendix B.** Questions included in the online questionnaire done to 891 people to assess their trust on different alert
716 systems.

717

Subject	Questions asked
Previous disaster experience	Have you ever been affected by a phenomenon that put you in danger? If yes, which ones? Did you receive (or not) one alert? If yes, by what means were you alerted?
Opinion of the existing situation	Are you satisfied with the way you are alerted? If not, why and what kind of changes do you expect? Who would you like to be alerted by?
Qualitative estimation	Please rate the effectiveness of the following means of warning (1 = not at all effective; 10 = very effective) *Telephone call* *Illuminated signs* *Dedicated smartphone application* *Door-to-door* *Mail (on computer or smartphone)* *Geolocated SMS* *Megaphone* *Siren* *Interrupting message on phone (different from SMS)* *Church bell* Mobile Application

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719 **Appendix C.** Questions included in the face-to-face survey, asked to 280 people living in an industrial risk area during

720 an emergency management exercise in Sorgues.

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Subject	Questions asked
Situation	Did you live or work in Sorgues? Since how many years Do you know the industrial site CAPL? Do you know safety guidelines in case of an accident? Do you know we are located in the risky area?
Siren audibility	Did you hear the alarm this morning, at 9.00 am? Can you evaluate the sound (between 0 = no / 5: very good)? Where were you located at this moment?
Behavior during the alarm	In case of an industrial accident, what would you do? What did you do when you heard the siren? Were you aware of the exercise? If so, how were you made aware of it?

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