

Article

Smart Sirens—Civil Protection in Rural Areas

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Abstract: Germany carried out a nationwide “Alert Day” in 2020 to test its civil alarm systems. The test revealed some problems. Heterogeneous development structures and topography can be limiting factors for sound propagation. In consequence, sirens could be heard inadequately, depending on their location. Furthermore, the reason of warning remains unknown to the public. In terms of civil protection, warnings with the code of behavior by general available media is desired. Smart sirens can transmit additional spoken information and be installed on already-existing streetlights. In this study, we analyze how smart sirens could lead to an improved civil protection. Exemplarily, a detailed analysis is made for a different structured rural area, Dansenberg in Germany, whereas the influence of local conditions on the sound propagation is considered. We analyzed with the software CadnaA—a software for calculation, assessment and prediction of environmental sound—how the location and number of smart sirens can be optimized in order to produce a full coverage of the study area. We modeled the coverage in different scenarios and compared four scenarios: (a) current situation with two E57 type sirens; (b) replacing the existing sirens with two high-performance sirens; (c) one high-performance siren at the more central point; and (d) optimized network of smart sirens of the type Telegrafia Bono. The aim was to achieve a full coverage with a minimum of warning sirens. We could show that the current situation with two E57 type sirens fails to reach out to the whole population whereas the optimized network of smart sirens results in a better coverage. Therefore, a reconsideration of the existing warning system of civil protection with smart sirens could result in a better coverage and improved information of warning.



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1. Introduction

“In some cases, you realize not before that something exists when it does not work or is extremely needed. The latter is applied for civil protection” [1]. The emergency warning system of civil protection in Germany and other European countries has improved over the last years but is still not in a perfect condition [2–4].

The topic of civil protection obtained public awareness in September 2020 in Germany due to the nationwide “Alert Day”. This “Alert Day” identified general problems and pending issues, e.g., how can the general public be properly informed and warned in case of risks or hazards? It became apparent that warning apps can fail in cases of an emergency [5]. Moreover, they are also not generally available for the whole public.

Sirens working with compressed air can still be found in several German municipalities, but their coverage is far from adequate—although a general accessibility is given. Sirens working with compressed air have a crucial weak spot, i.e., acoustic coverage. Building density and other obstacles modify sound waves, so that, in dependence of the vicinity, the siren cannot be heard or heard only inadequately.

Furthermore, the reason of warning remains unknown to the public, and this can be especially relevant in many cases (e.g., serious fires with emission of hazardous substances or threats such as flooding after heavy rainfall). In these situations, a warning through

general accessible devices with information about behavior in terms of civil protection would be desirable. Warning apps could be supportive, but a complete coverage cannot be achieved as not all people have a direct access to a smartphone.

Smart sirens could be an assistance for such risk situations. Streetlights or bus stations could be equipped with smart sirens and thus provide a general accessibility. An early warning of the population with recommended actions would be possible. A more detailed consideration of the urban development is needed to optimize the distribution of the devices within the urban area.

The first basic idea of the paper is about the current status of civil protection systems in rural areas in Germany. Are the existing warning systems capable of warning the whole population in a case of an emergency? Warning apps failed in Germany this year in an extreme flooding of the “Ahrtal” as the radio network of the mobile providers failed due to a power blackout. Approximately 180 people died in this flood [6]. Rural areas might need special attention as they are often left behind. This study intends to show that in Germany efforts need to be made in order to be able to warn its whole population, including rural areas, in cases of emergency. Only being loud at one central point does not mean reaching out to everyone. This leads to the question of how a warning system can be installed in dependence of different factors such as topography and development structure in order to reach out to everyone and additionally taking immission standards into account.

1.1. Sirens as Warning Devices

In general, sirens are devices that produce a loud sound to warn against risks by a so-called wake-up effect. The sound is very loud, but information is rather low, as no quantitative information can be transmitted. Furthermore, there are no standard siren tones.

In Germany, the siren type E57 is used in many cases. This mechanical siren type consists of an electric motor that rotates and generates an airstream, which penetrates the surrounding housing with slits thus producing the warning sound.

The difference between an electronic–mechanic siren type and the siren working with compressed air is clearly visible because of the distinctive horns of the first mentioned one. In addition, their sound is not comparable, because the sound is generated by a synthesizer, amplified and then emitted by the horn loudspeaker.

Smart sirens are small, compact devices with optional additional features and can be a combination of a traditional siren with a loudspeaker. The wake-up effect of smart sirens does not differ from normal sirens, but there is a significant difference because additional information can be transmitted. For example, smart sirens can emit a voice message besides the alarm tone. Thus, smart sirens could not only warn the public against danger but also add information about the danger itself and recommendations of action [7]. Whilst conventional sirens are often mounted on rooftops or poles, smart sirens can be installed on streetlights for example [8].

1.2. Problems with the Usage of Sirens in a Rural Context

In recent years, siren technology has developed decently. Some devices can now emit voice messages or live announcements besides the warning sound. The wake-up effect of the siren is upgraded by further information. In this way, where otherwise only a loud signal could be heard, a short-term and specific warning can now be given. It is also possible to communicate preventive measures. Considering more frequent extreme weather events such as heat waves or heavy rainfall, smart sirens can improve civil protection in the rural area.

The aim of this study is to evaluate how smart sirens can contribute efficiently civil protection and to optimize the coverage in a rural area with inhomogeneous structures such as the current housing and topography. The optimization of the distribution of the devices is taking into account the development structure, the propagation of sound, the quality of warning, the occurrence of extreme events and networking with other warning devices [9].

Human settlement areas are characterized by development, which is important for the usage and intensity of it [10] (p. 138). However, the structural situation poses an enormous challenge for the application of sirens. Buildings are obstacles for sound propagation, because if sound waves hit a facade or another part of the building, the propagation is disturbed by absorption or reflection. In fact, the acoustic shadow can be reached by sound waves but with lower sound energy [11] (p. 260).

Until the siren signals reaches the immission point, it is attenuated by sound absorption, reflection and diffraction, and it is questionable if the warning signal is still perceptible at an appropriate volume. In the case of a central emission point such as a central siren, sound propagation is tricky within a development.

Sirens are acoustic warning devices, and thus, the volume level is another problem. The sound level must be between 65 db (A) and 118 db (A), and in addition, the warning signal must be clearly differentiable from other sound sources [12] (p. 148), [13]. There is also a difference between the siren's A-weighted sound pressure level and the A-weighted sound pressure level of other noises must be at least A-weighted 15 db [13,14]. Sirens have to be loud enough to be heard despite background noise. It is possible that sirens are perceived as too loud or as an unwanted sound, and in some cases, citizens might not accept sirens in their nearby vicinity in spite of their protective effect.

A suitability analysis for a certain siren A at a predefined position B is only feasible in reality with great effort as a real-world model should be used. For non-municipal stakeholders, this is hard to realize. Hence, in such cases, other methods can be used such as a special computer software for modelling acoustical parameters and sound propagation settlement areas. Therewith, the basic knowledge about sound propagation can be applied in a complex digital model to estimate how siren A behaves at location b.

2. Materials and Methods

The software "CadnaA" (Computer Aided Noise Abatement) was used to model sound propagation in the rural investigation area. CadnaA is a state-of-the-art software for calculation, presentation, assessment and prediction of environmental sound. The aim of the study is to analyze different sirens in different rural and urban areas, respectively. Focus was placed on how the smart sirens can be integrated in the local system of civil protection.

CadnaA offers an enormous amount of possibilities such as noise forecasts and noise analyses. For this purpose, for example buildings, noise sources and protection measures can be taken into account in addition to influencing factors such as sound attenuation by reflection and absorption. The software is raster-based, and buildings with their height and a digital elevation model can be integrated in the model. Thus, the question of the analysis was if a specific siren can be heard loud enough but not too loud at a specific location. The recommended values of DIN EN ISO 7731 are used as references. The challenge of the computation is to distinguish between "too loud" and "too quiet" in the area under investigation. CadnaA automatically allocated frequencies of sirens by a value of 500 Hz according to [15] and represented it as point source. Sirens mounted on rooftop are in general 1 m above the roof itself.

For smart sirens mounted on streetlights (height between 3 and 5.5 m above ground level (a.g.l.)), a general height of 4 m a.g.l. is assumed. Residential buildings are assigned with a height of 12 m, public buildings with a height of 20 m and outbuildings (>40 m²) with a height of 3.5 m. After modelling the acoustic values for the sirens, the disturbing noises have to be considered as well.

Thereby, it is possible to check if the siren is too loud or too quiet. The evaluation is completed with normal sirens. Thus, it is only shown how the sirens' sound waves propagate in the environment. For smart sirens, a rural network is additionally modelled, evaluated and established. In order to achieve it, the amount and position of sirens are changed in every modelling step and optimized until the network is working well.

Not all siren types are suitable as a smart siren because some high sound levels are too loud in parts of the area. This means that a person who is in close vicinity, when the siren

is emitting a warning signal, must not be harmed. This can be adjusted by changing the height of the siren, so that the prescriptive sound power level of 118 dB (A) is not exceeded. In addition, the sirens should have the option to be independent from power grid. Because of these requirements, the model "Telegrafia Bono" (sound power level 138.5 dB (A)) was used for the analysis. For a comparison, two traditional sirens were chosen. Because of the high amount of still-used electro-mechanical sirens, the siren E57 (sound power level 141.5 dB (A)) as well as the newer type the electronic high-performance version "Hörmann ECN 3000D" (sound power level 163.5 dB (A)) were selected.

Study Area

The study was conducted in Dansenberg, which is a rural structured part of Kaiserslautern (Rhineland-Palatinate, Germany). The district of Dansenberg is located 6 km southwest of the city of Kaiserslautern, and its settlement area is about 88 ha. There was a high population growth since the incorporation of the village Dansenberg into the city of Kaiserslautern in the year 1969. The site ranges over the so-called mountain Dansenberg and its surroundings are characterized by dense forest areas. The area of Dansenberg is also characterized by a predominant distinct relief.

In contrast to the urban area of Kaiserslautern, the rural site of Dansenberg is characterized by loose development. Almost the whole housing development area is dominated by detached and semi-detached houses, but in the center, apartment buildings and buildings with mixed usage can be found as well. The sports hall, located in the northwest, is the highest point a.s.l., whereas the village entrance in the western and southern areas of Dansenberg have a rather low altitude.

A siren of the type E57 is mounted on the town house which is located in the center (see Figure 1). Another siren, also type E57, is mounted on the sports hall. The rural development of Dansenberg is different to a dense urban development, and thus, other general conditions for a siren-based warning system must be considered. This particularly includes the effects of the relief and the loose development, which do not necessarily generate an amplified warning signal such as in an urban street canyon in a dense development.

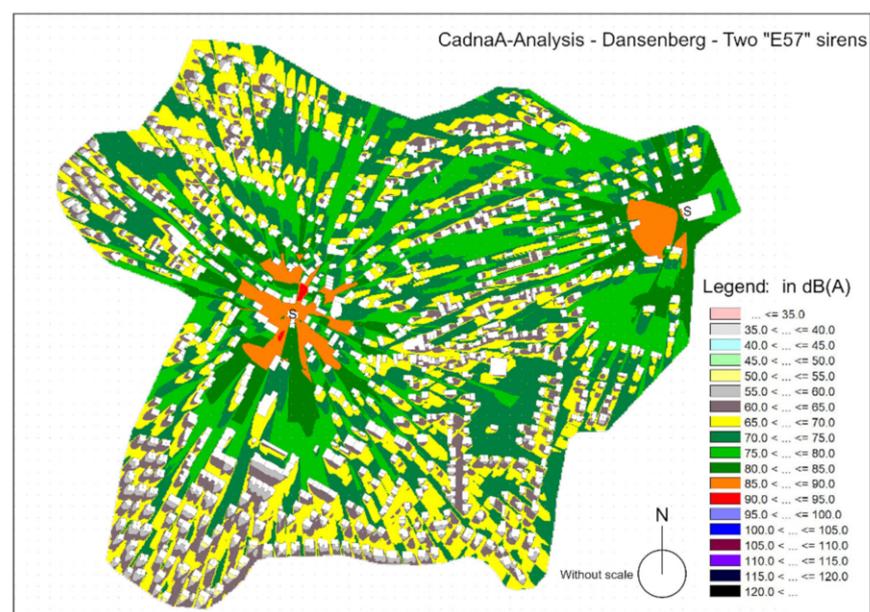


Figure 1. Spatial sound analysis for Dansenberg (Germany) using two E57 sirens. Two sirens (S) are mounted on the town house in the center and the sports hall in the northwest as well. Sound level in dB (A) is given in different colors that show an uneven sound level within the investigation area.

3. Results

In Dansenberg, the structure of the development varies substantially over the entire settlement area, in density or rather loosening. Thus, the measurements for background noise levels were conducted by the Sound Level Meter. The highest background measurement level in Dansenberg was 56.8 dB (A), resulting in a minimum requirement of the warning signal of 71.8 dB (A). This value was measured west of the center. The lowest background measurements level of 41.7 dB (A) was detected in the northeast resulting in a minimum requirement of 65 dB (A). However, depending on the topography, the effects of sound propagation might differ. As, in Dansenberg, two sirens can be operated (town house and sports hall), firstly both positions were incorporated in the models. When using the high-performance siren ECN 3000D, in addition, a one-siren option was also considered.

The town house and the sports hall are 15 m a.g.l. and are thus represented in the models with a height of 16 m a.g.l. Surprisingly, when operating the sirens E57 at both locations, the coverage is not sufficient (see Figure 1). There are grey acoustic shadow areas distributed over the whole settlement area, in most cases caused by the shielding of buildings. One option would be to equip these inadequate covered areas with smart sirens in order to support the existing sirens.

As the high-performance siren is louder than its electromechanical counterpart, the operation at one and at both locations is investigated, respectively. The operation height is again 16 m a.g.l. Both were mounted, such as the real existing sirens, on the roof of the sports hall and town house or in the second case only on the town house (because of its central position). Considering the results of the CadnaA analysis with two high-performance sirens (see Figure 2), it is apparent that the noise is generally high, and the values have three digits in many areas. This means that all areas of Dansenberg are adequately covered by the wake-up-effect. However, it must be noted that the warning signal would be higher than required and might harm people. In the periphery, the lowest sound levels (75 dB (A) to 80 dB (A)) are modelled.

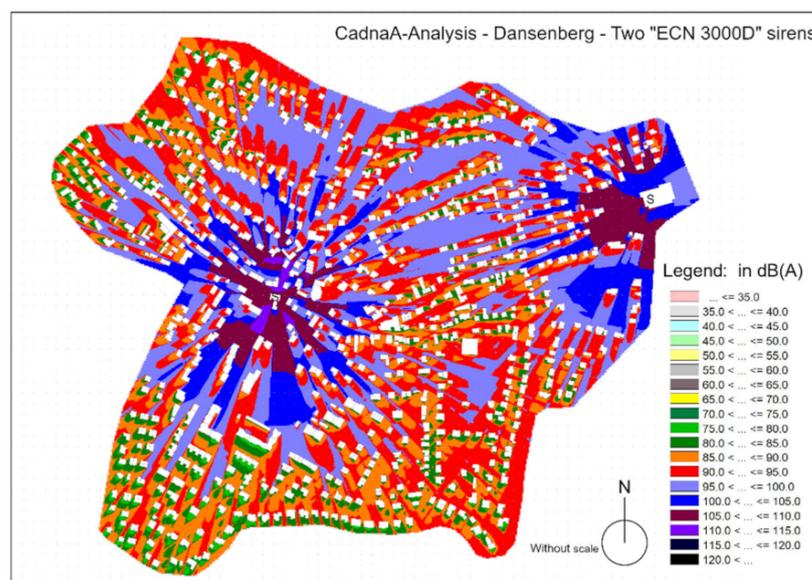


Figure 2. Spatial sound analysis for Dansenberg (Germany) using two high-performance Hörmann ECN 3000D sirens. Two sirens (S) are mounted on the town house in the center and the sports hall in the northwest as well. Sound level in dB (A) is given in different colors that show a high coverage within the investigation area.

In addition, the option of only one high-performance siren was analyzed to control if it would be capable to cover the whole settlement adequately. The modelling results reveal (see Figure 3) that the sound levels are not below the requirement level of 65 dB (A) at any

point of Dansenberg. In addition, all individual measured values calculated are adhered to the measurements. Thus, it can be stated that in the case of a technical update Dansenberg could principally be equipped with one high-performance siren mounted on the town house. Nevertheless, just as with the siren E57, it only would remain a wake-up effect.

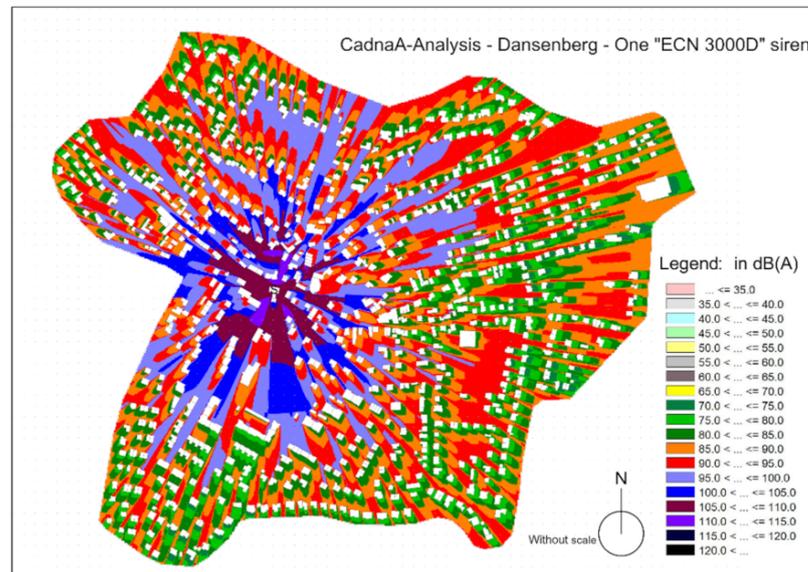


Figure 3. Spatial sound analysis for Dansenberg (Germany) using one high-performance Hörmann ECN 3000D sirens. The siren (S) is mounted on the town house in the center. Sound level in dB (A) is given in different colors that show a good coverage within the investigation area.

Finally, a smart siren network is set up for Dansenberg using the siren Telegrafia Bono. Initially, 20 sirens were planned for the whole area of 88 ha. The general minimum sound level of 65 dB (A) and the specific minimum requirements due to the determining background sound measurements are all met (see Figure 4). The smart siren network could potentially realize and enhance the warning infrastructure in a quantitative as well as in a qualitative way (spoken messages) within the whole settlement area of Dansenberg.

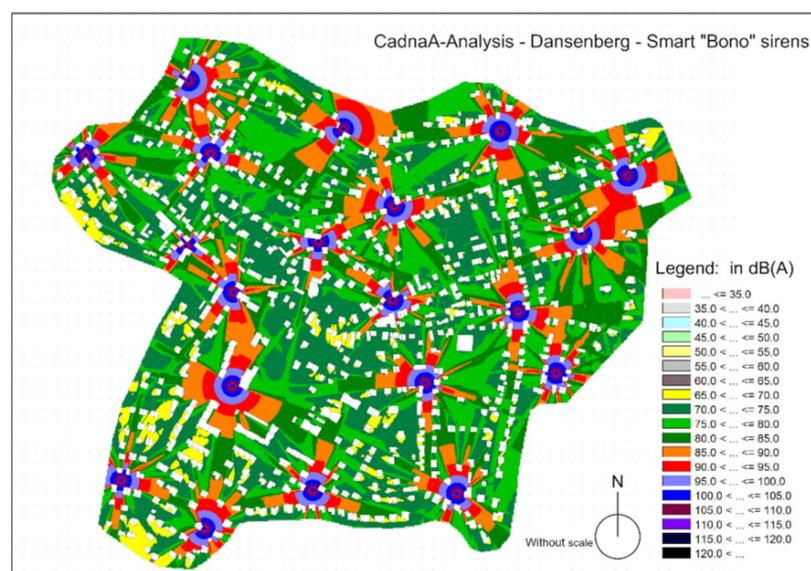


Figure 4. Spatial sound analysis for Dansenberg (Germany) using a network of smart sirens with the model Telegrafia Bono. The sirens are distributed all over the settlement area. Sound level in dB (A) is given in different colors that show a good coverage within the investigation area.

The modelling of a network in a rural area such as Dansenberg is more challenging in comparison to an urban area. It is noteworthy that in Dansenberg a comparable number of sirens is necessary considering siren analysis within urban areas such as [9] or [16]. Nevertheless, the sound propagation is more difficult to predict due to the less ordered and punctiform development and the more elevated topography.

4. Discussion

This study intends to point out that a warning system has to be diverse, which means to have multiple systems to warn the population such as a warning app [17] but also a siren network that reaches everyone, as not all people, especially the elderly that live in rural areas do not use smartphones and the smartphone network can break down in cases of emergency due to a power breakdown.

The example of the rural location Dansenberg indicates that the current double usage of the siren model E57 is not adequate in order to cover the whole settlement area. Rural areas are characterized by special development structures and topography for modelling sound propagation by the software CadnaA. This results in different location-based requirements in planning but also the sound-technical modelling for the desired siren network. In rural areas, it is partially possible, in spite of a larger area, to set up a smart siren network with the same number of sirens in comparison to densely build up urban areas. High-performance sirens show their functionality at rural locations as well as for urban ones, but they also offer their lack of spoken messages. In general, a siren network can be set up more easily in a rural vicinity as in an urban area on the one hand due to the loose development and lower environmental noise, but considering the topography could hinder the installation of such a network on the other hand. Designing a smart siren network, taking a conservation of resources into account, there are areas at rural locations such as Dansenberg that can hardly be covered.

In a similar study about the effectiveness of the French siren network, the authors recommend a relocating of the sirens to optimize their efficiency and complementing the sound of sirens with a clear and unified message [3], which agrees with our results.

The discussion about the German warning system in civil protection is dominated by technical and financial aspects. An aspect that has been considered rarely so far is the social aspect in civil protection [18] (p. 131). The noise of a warning system reaches out to the larger part of the population, but this does not imply an understanding or consideration of the warning. In a worst-case scenario, this could lead to false behavior or disregard of the warning. This might result in a gap in the warning process that could be closed by smart sirens by giving appropriate information. The population as the receiver of the warning is mostly interpreted as an uniform group. The dispatcher of the warning relies on the correct perception of the warning information, but many people might not be able to notice a special warning signal correctly and to act accordingly [19,20]. In case of an emergency, the misinformed part of the population would lose precious time before acting appropriately. This situation could be improved by smart sirens that give spoken information about the warning situation and how to behave.

Besides warning systems, there are other important factors in the case of an emergency such as the influence of several policy competencies, e.g., to activate sirens [21] or the general knowledge of the people about warning tones and their appropriate behavior [22]. In our study, we only look at the communication of authorities to citizens by sirens.

We chose the analyzing tool CadnaA, because it is capable of taking all requirements into account, such as changing environment and development, to give information about sound propagation, for the purpose of optimization of the location of different sources in order to provide a full coverage of a given area and not to overlap the signal, thus resulting in a best minimum solution. Of course, there might exist other software that can deliver similar results.

This case study focuses on the warning system of civil protection in Germany and especially in Dansenberg. Nevertheless, the analysis of the existing sound propagation of

sirens and thus coverage of areas that can be warned can be applied in other countries as well. The optimization of the location of several (smart) sirens in dependence of topography and development structure could be applied to other countries as well. The situation or status of civil protection in other countries differs from the situation in Germany [23] and should be considered for sure. In addition, the financial factor could be a limiting factor for the application of the results to other countries as well.

A crucial factor, especially for policy makers, is the financial factor. With the example of the siren E57, the cost effectiveness of smart sirens can be shown. The initial costs for material and installation of a new E57 siren can be attributed to approximately 5000 €, and the cost of repairing can reach ~2100 € [24]. On the other side, the initial costs of one smart siren such as the one used in our study are about 100 €, resulting in lower costs for a smart siren network ($100 \text{ €} \times 20 = 2000 \text{ €}$) with a full coverage of the study area. Bearing in mind, the two standard E57 sirens are necessary, and these smart sirens can operate with solar energy being self-sustaining and are able to transmit additional information additional spoken information, for example, about what to do. Of course, a renewal of the whole warning system of civil protection in Germany would mean a big financial and organizational effort, but when a siren needs to be repaired or replaced due to malfunction, one should consider a smart siren network. A case study from France showed that there is a monetary benefit of improved early flood warnings in Europe and the capital investment will pay off [25].

5. Conclusions

This study intends to point out that a warning system in Germany has to be diverse in order to reach out to everyone. A siren network should be part of a good warning system in Germany. We analyzed the siren warning system for one rural scenario in Kaiserslautern, Germany, i.e., Dansenberg. In a previous study, we focused on the urban area of Kaiserslautern. Exemplarily, we could show that the existing warning systems in Kaiserslautern are not adequate to warn the whole population as the sound cannot be heard at all places. Therefore, it is necessary to think about improving or renewing the warning system network. With our presented smart siren network, it is possible to model the location where to install a minimum number of smart sirens in order to reach out to a larger part of the population. In addition, smart sirens can operate with solar energy being self-sustaining, and additional information can be transmitted and the immission standards can be achieved as well. For future studies, the results should be generalized for other several urban and rural areas in Germany and in addition for foreign countries. Of course, other parameters such as social factors have to be considered in the warning process as well. Additionally, in future studies, it should be analyzed how spoken warning messages of smart sirens must be presented or how the population could be sensibilized for the warning process in order to obtain the best result in the case of an emergency.

A crucial factor is the financial one, but we could show that a smart siren network would have financial benefits, if an old siren needs to be repaired or replaced due to mal-function. The financial factor is not only a limiting factor for Germany, but maybe even more for other countries, but in the end, this effort might save many lives.

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