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Connecting Sound to Data: Sonification Workshop Methods With Expert and Non-Expert Participants

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Sonification and sonic interaction design aim to create meaningful displays and digital interactions using data and information from the most disparate fields (astronomy, finance, health, and security, for example) as the basis of the design. To date, there are no standards and conventions on how to meaningfully link data to sound; therefore, designers develop these connections on a case-by-case basis. Participatory workshops that target end users and domain experts are a way for sound designers to find meaningful connections between data and sounds at the start of the design process so that final outcomes are more likely to be effective and accepted by users. In this paper, the authors present and discuss the participatory workshop methods they have developed within the *Sound for Energy* project. In particular, they will highlight the aspects that can be easily transferable to other target domains. With this, the authors contribute to the effort of making sonification and sonic interaction design a more viable and accepted alternative to traditional, usually visual, displays.

0 INTRODUCTION

Sound is an incredibly powerful channel of communication in everyday life. By listening to everyday sounds around them, people understand what is happening in their environment and make decisions accordingly. The fields of auditory displays, sonification, and sonic interaction design have developed greatly in the last 30 years providing effective new digital sounds that people can use in their lives to process their environment. However, so far, researchers have not been able to establish standards and conventions to link sound to data in an agnostic manner (i.e., without having some knowledge of the data domain) in the same way that the field of visualization has.

Microsoft Excel's graphs and diagrams are an example of this. The conventions are known by all (e.g., positive numbers are displayed on top or on the right; negative numbers are displayed down or on the left; unless otherwise indicated, the zero is where the axes cross; etc.). This is because they are taught at school everywhere in the world. Consequently, the visualizations created with these standardized templates are meaningful for most people and across many different types of data, independently of their original domain.

The same is not true for sonification. This is partially due to the fact that the auditory display field is much younger than visualization and many aspects still need investigation but also that the lack of a generalized sound education from an early age [Carla Scaletti's keynote lecture for International Conference on Auditory Displays (ICAD) 2017 describes this issue very clearly[1]], something that could help develop general conventions.

Sound is also a fundamentally different design material to visuals: it is highly dependent on context and personal and subjective experiences of it. While there is a solid foundation of research on auditory perception in the context of sonification as well as effective sonification techniques upon which to base new designs [1], researchers have argued that a common basic terminology and constructs similar to those existing in visualization (e.g., what are the auditory equivalents of visual channels such as shape, color, or scale?) are yet to be fully established [2]. Additionally, research [3] has shown that, to develop further, the field of sonification needs to address a number of challenges including, among others, users' individual differences in audition abilities and the bias toward musical or reduced listening that is often expected from users. Musical or reduced listening refers to the ability to attend to perceptual attributes such as pitch or loudness [4]) as opposed to listening attending to the cause of the sound (everyday or causal listening), which is what is normally done in everyday life.

To create more meaningful connections between data and sonifications (if not causal, perhaps metaphorical [5]),

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[1] http://tinyurl.com/4b4puhmx.

researchers need to explore with users the potential connections between sound and the target domain, be it astronomy, finance, or health, to name a few. In this context, the adoption of a design thinking approach is useful. This involves a divergent phase in which to explore the design problem with stakeholders (end users and domain experts), before converging on a specific design brief and developing a solution. During the exploratory phase, sound designers and stakeholders, through participatory methods, take time to identify what can be the meaningful connections between sound and the data domain of interest so that a design brief and final design can be developed on the basis of a common ground.

In the *Sound for Energy*[2] project, which aims to explore the relationship between sonic interactions, sonification, and energy consumption in the home environment, the authors have developed methods for participatory workshops that can be transferable to other domains. In this paper, they will report on two workshops with end users and one workshop (divided in two parts) with sustainability and sonification experts. The authors will reflect on the connections and differences between the workshops and how they can be used in sonification workshops targeting other domains.

1 BACKGROUND

1.1 Using Sound to Display Information

Visualizations are used in most fields to display information and make it accessible to experts and end users. From early in life, people learn the name and colors of shapes, how to compare them, and how to distribute them in space in a conventional way (for example using a Cartesian coordinate system). Visualizations are not universally accessible, however, and they are not always the best way to display information. In the field of energy efficiency, for example, consumption and production data are often invisible to users [6], and smart meters are the primary means to provide this information. However, visual displays often result in short-term gains in efficiency [7], followed by the tools being forgotten or even abandoned [8]. Researchers [9] have found that design decisions are often shaped through the lens of a small group of perceived data experts, famously referred to as "Resource Men," and therefore, the design is not as inclusive as it should be to address the diversity of people in households.

Similar problems in other domains can be found. For example, in the field of astronomy, the need for developing auditory or multi-modal displays of astronomical data has become more and more urgent to tackle the issue of accessibility for visually impaired scientists and provide multiple dimensions for displaying large datasets for public engagement, research, or education [10].

Sound offers a range of advantages in terms of display of data and as a method of feedback and control. In particular, sound is omnidirectional, can be used as a method for touchless control, and can contain a complex set of information in a short amount of time [1]. However, there are challenges when using sound as a design material.

People who are not experts in sound often find it difficult to describe sounds and accurately articulate their thoughts and feelings about them. Overall, a commonly used and understood vocabulary for sound is lacking [11]. Therefore, when designing with sound, creators must take into account the complex relationship people have with it. In addition to this, often sonification or sonic interaction designers do not have enough knowledge of the target domain (the domain from which the data is coming from) to make informed decisions about what aspects should be highlighted and in what way. Utilizing and developing participatory design methods can be helpful in this respect. They can facilitate interactions and communication between designers and domain experts, as well as bring together designers and end users, who might not be experts in either sound or the data domain, to meet and discuss needs and requirements.

1.2 Design Approaches

Participatory Design (PD) aims to include end users as full participants in design activities [12]. PD began as part of the Scandinavian workplace democracy movement [13], motivated by a belief in bringing the value of democracy to civic, educational, and commercial settings. More generally, PD aims to support the "many voiced nature of design" [14]. Bringing together different expertise, needs, and perspectives is no trivial task. Researchers [15] have argued that the risk of "participatory washing"—where efforts are mischaracterized under the banner of participation—need to be countered. One way to tackle this is through the creation and establishment of "hybrid" spaces for mutual learning and reciprocal validation of diverse perspectives [16], so that people's differences (in their relationship to the design task, life stage, physical and cognitive condition, etc.) can contribute effectively to the design activities, rather than being perceived as difficulties.

Muller and Druin [16] summarize successful participatory practices that involve two-way discussions where designers can effectively "learn something that they didn't know they needed to know." Participatory spaces can be considered along a continuum varying from *abstract*, where the end user needs to enter the designer/researcher world to participate, to *concrete*, where the designer/researcher enters the world of the end user to participate [17]. Between these extremes, spaces can be found that provide a *hybrid* experience. This hybridity can be influenced by a number of factors including the place where the activity happens, nature of the activity (workshops can be fruitful spaces for egalitarian exchanges of ideas and knowledge), modalities used to communicate between people (stories vs. dramatizations, for example), and types of constructions that result from the activity (low-tech or high-tech prototypes vs. reflections and descriptions, for example) [17].

These aspects also need to be modulated in relation to *who* is participating in the activity. In this paper, for example, the authors are considering both activities between

[2]https://soundforenergy.net.

experts (in sound and energy) and non-expert end users, as well as workshops that bring together sound experts and domain experts. These two situations might require different hybrid spaces (with different constructions, workshops, and communication modalities) in order to ensure that participants feel able to contribute effectively.

1.3 Workshop Methods in Sonic Interaction Design and Sonification

Design approaches, and in particular PD approaches, entered the field of auditory displays in the late 90s. Barrass [18] was the first to introduce the concept of Task and Data analysis (Tada!), which was followed by research on design patterns [19, 20]. Since then, several examples of PD approaches to sonic interaction design and sonification have emerged.

In 2009, the Sonenvir [21] 3-day workshop brought together sonification experts, programmers, and scientists to work on a variety of datasets coming from the energy field, climate and social sciences, and more. At the start, a number of short lectures served to inform the domain scientists about sonification history, methodology, and psychoacoustics in an attempt to create a common language. Then, in interdisciplinary teams, the participants ideated sonifications of the data provided using existing sonification tools. In each team, the domain expert introduced the dataset given. Then, participants brainstormed sonification ideas, attempted to code them, and created small demos to show and discuss. The evaluation of the workshop showed that participants were positive about the results overall and that they learned a lot about sonification. However, more time could have allowed for more in-depth results, and more pre-workshop preparation could have helped with the efficiency of the workshop.

In 2015, Goudarzi and colleagues [22] developed a workshop in which participants from sound and science worked on pre-defined and exploratory tasks to sonify climate data. As with the previous case, the main issue faced by the participants was the time pressure as programmers and sound experts were not able to develop all the ideas thoroughly. One particularly positive aspect of this hands-on and multidisciplinary workshop was that it helped reduce the domain scientists' initial skepticism toward sonification.

In 2021 and 2022, the Audible Universe [23] workshops (AU and AU2) made a similar attempt to bring together astronomers, sound designers, experts in sound perception, and digital tool developers (from the field of astronomy rather than the field of sonification) to provide a platform for developing sonification ideas and exchanging knowledge. Three aspects could be considered novel in these workshops: the in-depth focus on one target domain (astronomy), use of design and evaluation tools to support the hands-on sessions, and focus on sound design evaluation and ideation.

During AU2, in interdisciplinary teams, participants ideated new sonification solutions using a design tool called The Data Sonification Canvas [24]. This proved to be very helpful in focusing the minds on specific aspects of the design (use case, sonification approach, etc.), though it also highlighted the lack of a shared vocabulary as some terms (especially those referring to listening modes [25]: *causal*—listening to identify the source of a sound; *reduced*—listening to attend to the characteristics of the sound; and *semantic*—listening to interpret a code such as a language) were not easily understood by non–sound experts. The following day, the groups attempted to draft an evaluation study for their sonification ideas.

In regard to participatory workshops with non-expert end users, Droumeva and Wakkary [26] ran two participatory workshops to support design decisions in the making of the audio display for an ambient intelligent game platform. The main concern was the design of a compelling environment based on user engagement, movements in physical space, immersion, and narrative or game progression. Both workshops were set in a black box environment with controlled light and sound displays delivered via the "Wizard of Oz" technique, which is one that simulates the functionality of a technological system without actually building a prototype. Through this method, participants were able to tap into their creativity and evocative individual memory and suggest changes to the environment and interaction rules, despite not being experts in sound.

Franinovic and colleagues [27] used a number of techniques to sketch sonic interaction designs for new digital products. In this case, the approach was based on *learning through experience*, in the spirit of Basic Design, an approach that originates with the Bauhaus school. Methods originated from a range of disciplines, including industrial design, ethnographic inquiry, and theater, and included ear-cleansing exercises, soundwalks, and bodystorming as well as lo-fi prototyping and role playing. The choice of these methods connects well with Svanaes and Seland's [28] work on participatory workshops, which has found that role playing and using bricolage to create lo-fi prototypes are highly accessible methods for non-users to ideate since they relate to the human experience of "play" and "practical intelligence" in tool making. Once again, time constraints and the lack of a common language were highlighted as the main challenges in these workshops, bringing the authors to conclude that providing a glossary and reducing the use of expert vocabulary could be helpful.

In the next sections, the authors will: (1) summarize their two workshops with non-expert users and highlight the main lessons learned; (2) describe in detail a participatory event combining two workshops: one with experts in ICT and sustainability and one with sonification experts; and finally, (3) discuss and reflect on the key takeaways from these workshops that can be transferable to other domains. They will then conclude.

2 PARTICIPATORY WORKSHOPS WITH NON-EXPERT END USERS

In their project, the authors ran two workshops with non-expert end users. These are thoroughly described in [29, 30]; therefore, only aspects relevant to this paper will be summarized here.

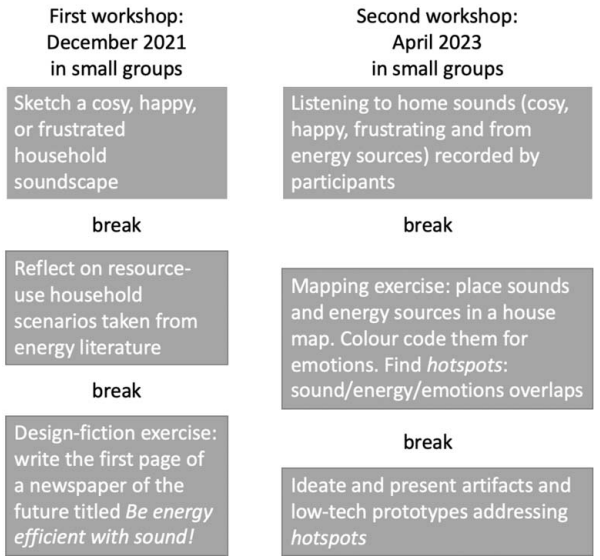

Fig. 1. Structure of workshops with non-expert users.

The overall research question for both workshops was: *what are the connections between the way we experience sounds in the home and the way we experience energy consumption in the home that can be leveraged to develop meaningful, informative, and engaging sonic interaction designs?* While the first workshop focused on finding the connections between sound and energy, the second used the insights from the first workshop to go further and empower participants to ideate and even prototype new sonic interaction designs. Fig. 1 shows the very similar structures of the two workshops, each lasting 3 h.

Participation was facilitated by the creation of a hybrid space [16] with the following characteristics:

- **Spaces and Places:** The activities took place in a university classroom, a familiar space for all participants. The workshops included novel procedures unfamiliar to participants (e.g., sketching soundscapes with everyday-sounding objects; writing the front page of a near-future newspaper for the Design Fiction exercise [31]; mapping on house-plan sounds, energy sources, and the emotions connected to them, etc.). This engaged participants in discussions and negotiations in order to reach a synthesis of their diverse voices.
- **Narrative Structures:** Participants engaged with stories in a number of ways. They were asked to analyze short scenarios, summarize their reflections in short presentations, titles, subtitles and select pictures for near-future newspapers' articles, and dramatize behaviors with their ideated prototypes. These techniques triggered conversations, articulating diverse views, and increased empathy toward future users.
- **Constructions:** Small constructions were made in the first workshop (for example, sketches of household soundscapes or sketches of the first page of a newspaper), while in the second, participants engaged in ideating and developing descriptive artifacts or low-tech prototypes. This allowed them to use visual and auditory ways of sensing, knowing, remembering, and expressing to articulate new ideas; include subjective experiences; and ground discussions in concrete artifacts.

Overall, through this participatory approach, participants were able to formulate connections between areas that only a few hours earlier seemed completely disparate. In particular, the workshop organizers realized that by foregrounding reflections about sound, and invoking personal experiences and feelings about both sound and energy, a bridge, related to how they emotionally respond to various situations in the home environment, emerged. Through this, participants were able to indirectly connect the different fields. The authors explicitly leaned on this key lesson in their second workshop *Sound of the Future Home*, and participants were able to produce original design ideas in a very short time. This confirmed that moving the attention to how something "makes you or should make you feel," rather than on technical detail or a specific terminology, may allow non-experts to quickly ideate concepts that can then be further developed by designers.

3 WORKSHOPS WITH EXPERT PARTICIPANTS

During their project, the authors had the opportunity to run two connected workshops at two consecutive conferences. The first workshop took place during the ICT for Sustainability Conference (ICT4S) in Rennes on June 9, 2023. The second took place at the ICAD in Norrköping, Sweden, on June 29, 2023. These workshops, although separate in time, place, and audiences, were conceived to be two parts of one participatory event. The rationale was that sustainability experts would first reflect on the energy-related datasets and ideate potential designs for novel interventions, and then, sonification experts would use some of the results of the first workshop (not the sound ideas that were redeveloped from scratch, but the more general aspects of the interventions developed at ICT4S, such as use case, target audience, etc.) and develop these interventions, and particularly the sound aspects, further.

In this case, the participation of two different expert communities was facilitated by developing a sort of "virtual hybrid space" (see Fig. 2). The workshops' organizers would travel to meet the experts in their place of work, they would introduce new concepts where necessary (e.g., they introduced sonification concepts to sustainability experts) and relay the outcomes of the first workshop to the next (e.g., they introduced the interventions conceived by sustainability experts to the sonification experts). While bringing together two distinct groups of experts in the same physical place might be preferable, it is often logistically and economically difficult. The authors' approach could be considered an effective alternative that combines the advantages of a *concrete* approach, i.e., participants are at ease because the organizers travel to their space, with the advantages of *hybridity*, i.e., external voices and points of view are brought to the activities by the workshops' organizers.

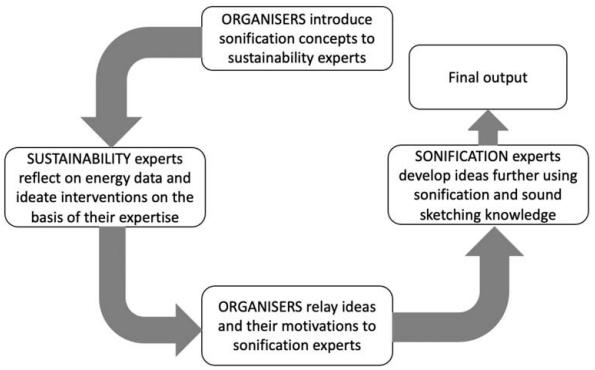

Fig. 2. Connecting the ICT4S and ICAD workshops.

Table 1. The structure of the ICT4S and ICAD workshops.

ICT4S	ICAD
Description about everyday experiences with sound	
Introduction to sonification and sonic interaction design	Introduction to the energy datasets
Discussion about energy datasets	
Introduction to Sonification Canvas	Introduction to design briefs from ICT4S
Description of design task	
Ideation and sketching	
Group presentations, discussion, sonification canvas update	
Conclusion	

It must be noted that this was possible because the organizers included experts active in both communities. This facilitated relaying information and ideas clearly.

It terms of other participatory aspects, both workshops included hands-on group activities and discussions. Several types of narrative structures were used: from recalling stories to dramatization. Finally, both workshops included the collaborative construction of artifacts and low-tech prototypes with sound.

3.1 ICT4S and ICAD Workshops' Structure

Both workshops lasted about 4.5 h and were structured very similarly (see Table 1). The initial discussion on sound experiences served both as an ice breaker and a way for people to think about their attitudes and feelings toward sound in their everyday life. From their previous workshops, the authors learned that discussing feeling and emotions toward sound and the scenarios conjured up by the data domain could facilitate communication and counteract the lack of a common vocabulary.

For the ICT4S audience, the fields of sonification and sonic interaction design were introduced with illustrative examples. For the ICAD audience, the two energy datasets to be used in the workshop were introduced in some depth. Next, both audiences spent some time discussing the energy datasets focusing on their meaning and implications for sustainability and what the audience considered to be the most important aspects to portray with sound. After that, the Sonification Canvas [24] was described to the ICT4S audience in detail. Since the ICAD audience was already familiar with the Sonification Canvas, this time slot was used to introduce the design briefs developed by the ICT4S workshop instead.

The final stages were the same for both workshops. The authors described the design task and divided the audience in two groups ready to ideate and sketch new sonic interaction designs; then, the groups presented their ideas to all, followed by a general discussion and the opportunity to revisit the Canvas in light of the feedback received.

3.2 Participants

Thirteen (ten male and three female; average age: 35) people participated to the ICT4S workshop. Six sound experts participated to the ICAD workshop (four male and two female; average age: 42). All participants read the project information sheet and signed a consent form.

3.3 The Energy Datasets

The first dataset showed the *Per Capita Energy Usage* of seven countries (Sweden, France, Brazil, the United States, China, India, and South Africa). These countries were selected to include those in which the conferences took place and countries representative of the *Global South* and *Global North*. The data spanned from 1960 to 2023.[3] The second dataset showed the *Energy Mix* (range and percentage of energy sources) over the same 48 h in April 2023 of three countries: Sweden,[4] France,[5] and the United States.[6] These two datasets were proposed because of their different perspectives and temporal scales. While the first dataset might spark discussions about ways to compare, in time, different countries in relation to sustainability, the second relates to the home environment and to how people might decide to manage their day-to-day habits while being aware of where their energy comes from.

3.4 Design Tool: The Data Sonification Canvas

The Data Sonification Canvas[7] [24] allows designers to explore a design problem and its characteristics. It encourages reflections on the Use Case (the context, goals, and users), Sonification Approach (analytical or narrative), Listening Experience (causal, reduced, and semantic), and data-to-sound Mapping Choices (sounds, behaviors, functions, and multi-modality). Such explorations are helpful for guiding the ideation process and converging on a design brief that can then be sketched and prototyped.

This tool was used by the first author at the AU2 workshop [23]. The tool worked well as a way to structure a design; however, people unfamiliar with sound concepts

[3]http://tinyurl.com/bdh2kk4e.
[4]http://tinyurl.com/8ajjjpyb.
[5]http://tinyurl.com/3mm46xzn.
[6]https://tinyurl.com/mek7wjut.
[7]http://tinyurl.com/4nz42ybf.

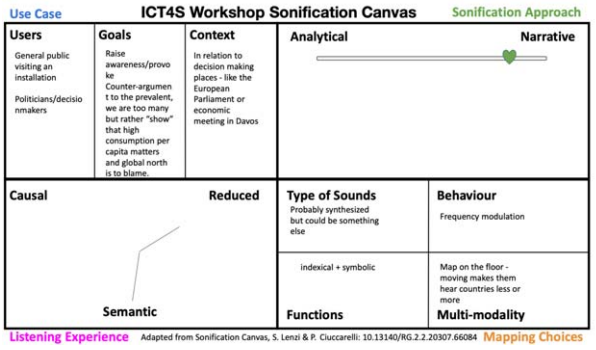

Fig. 3. ICT4S Per Capita Group Canvas.

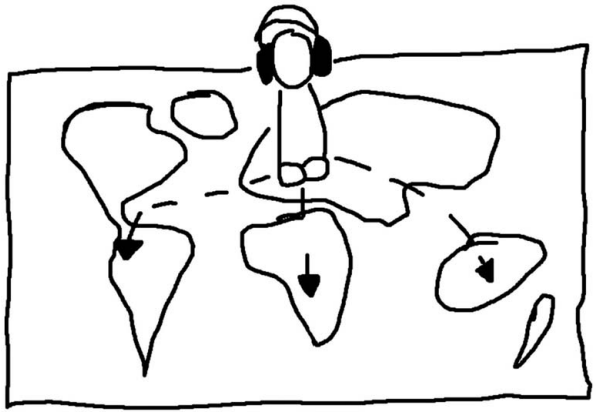

Fig. 4. Per Capita Sketch (digitally retraced) by ICT4S PC Group.

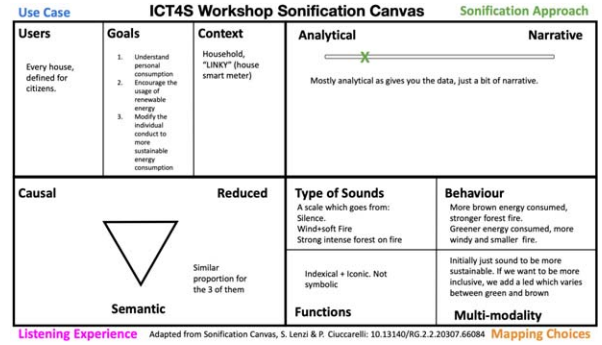

Fig. 5. ICT4S Energy Mix Group Canvas.

found it quite difficult to understand some of the language and concepts used in the canvas (for example, the terms describing the listening experience). To avoid this issue, a modified version of the sonification canvas was created for the ICT4S workshop (see for example Fig. 3).

The main modifications consisted of providing simpler explanations of the Listening Experience section and avoiding, by taking away the dividing lines present in this section, the graphical implication that these listening modes are mutually exclusive. In the accompanying notes, the authors provided more examples for the more difficult terms. Finally, the numbering was taken away so as to not imply an order when reflecting on the design characteristics. For the ICAD workshop, the original version of the Sonification Canvas (e.g., see Fig. 9) was used because participants were fully familiar with the terminology. Note that the Canvas Figs. 3, 5, 8, and 9 are included here only to provide an

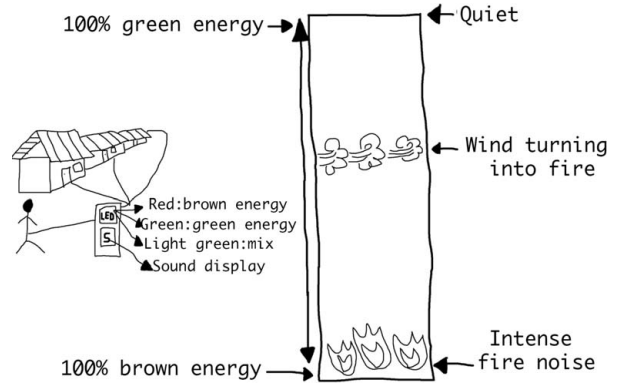

Fig. 6. Energy Mix Sketch (digitally retraced) by ICT4S EM Group.

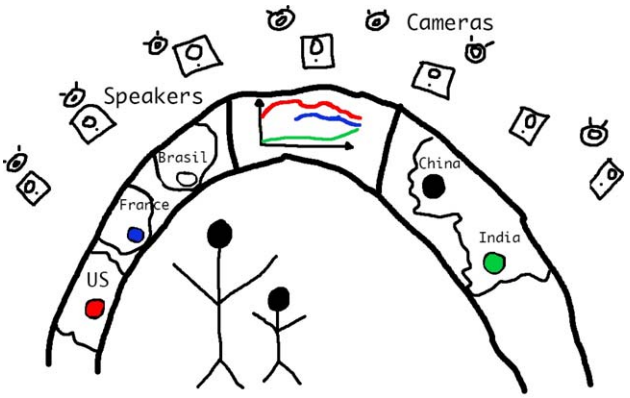

Fig. 7. Per Capita Usage Sketch (digitally retraced) by ICAD PC Group.

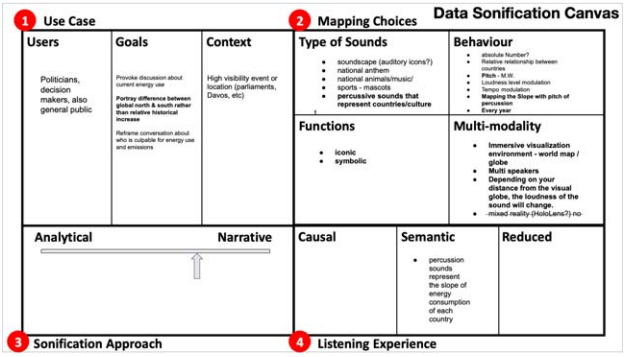

Fig. 8. ICAD Per Capita Group Canvas.

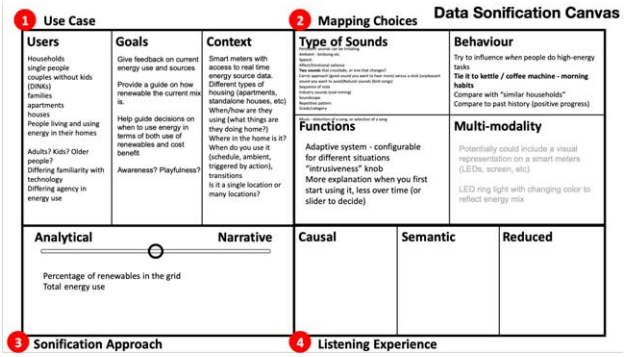

Fig. 9. ICAD Energy Mix Group Canvas.

impression of the level of detail in these documents; they are not intended to be fully readable.

4 RESULTS: ICT4S AND ICAD WORKSHOPS

The workshops were video and audio recorded, transcribed with Otter.ai, then corrected manually. The sections below summarize the workshop discussions, and, where appropriate, verbatim quotes are reported.

4.1 ICT4S: Reflections on Sound

At the start of the workshop, the authors asked participants to describe the first sounds they heard that day. This was used both as an ice breaker and a means to make the participants think about sound and their everyday experience with it. People discussed how sound and music can elicit memories, affect mood, help focus on a task, and mask unwanted noises. As people reported very different preferences in sound (some liked natural sounds, while others only music or silence), the importance of individual sound preferences was highlighted as a potential design characteristic to be considered. One participant mentioned the link between sustainability and audio technology and stated that they were trying to stop listening to streaming music for sustainability reasons. The group discussed how some sounds can be frustrating (e.g., drilling, car claxon, and leaf blowers), while others can be useful even if at times annoying (e.g., fire alarms, oven timer, and the audio description on public transport).

4.2 ICT4S: Reflections on the Datasets

The ICT4S participants found the *Per Capita Usage* dataset particularly interesting because it shows that the countries of the Global North have the highest per capita usage. This was considered in some way surprising, because often countries of the Global South are portrayed as the main culprits in terms of usage. While participants agreed that the arguments in this area are complex and cannot be settled on the basis of one dataset, they thought that this dataset could make people reflect on the complexities of the more common argument. In regards to the *Energy Mix* datasets, the audience thought that adding sonification to this data, which is often displayed graphically on a smart meter or app, could increase accessibility and allow users to make decisions on how and when to use energy at home.

4.3 ICT4S Workshop: Reflections on Sonification Examples

Concrete examples of sonifications and sonic interaction designs were played to the participants (*Iraq Body Count*,[8] *The Sound of a Falling Currency*,[9] and *Sound From the Milky Way*[10]). This clarified what a sonification is and sparked the imagination of participants. The first example showed a metaphorical sonification where the sounds chosen have a direct link to the information given (e.g., number of people killed in the war are sonified with clicks that remind of gun shots); the second was more narrative (e.g., the sonification of the falling currency is accompanied by quotes from politicians forming a narrative); the third was a more abstract sonification that uses astronomy data to create a music that reflects the data but is not linked in any other way to astronomy. Finally, the authors showed some sonic interaction design examples from the *Sound for Energy* project that can be seen in the website.[2]

Overall, these examples, and their different approaches, were very easily understood and appreciated. People were particularly taken by the emotional effectiveness of the "Iraq body count" example and listened to it several times. Participants thought that the currency and Brexit-related example communicated many aspects of the problem in a very short amount of time. The example from astronomy was considered very pleasing and reflective of the beauty of the universe. The sonic interaction design examples were discussed less due to some technical issues during playback, but they were nonetheless a source of inspiration during the design task.

4.4 ICT4S: Design Sessions

Two groups were formed: one working on the *Per Capita Usage* (PC) dataset and one working on the *Energy Mix* (EM). The **PC Group** imagined a sound installation with spatialized audio. A person would hear different sounds for different countries and these sounds would come from different directions. The data would be mapped to loudness so that the Global North would sound loud and noisy, because the data values are higher. This was perceived to be a good metaphor of the higher per capita usage of the Global North. One participant highlighted the potential for "suspense" that exists with sound: "In a graph you do not have any suspense, unless you plot a graph little by little. What is striking with sound is that you do not know what to expect, what is coming next."

The main goal of the sonification would be to compare countries, not the temporal evolution of the data; therefore, the installation could use real-time data (changing very slowly), and the interaction and comparison could take place by walking around the installation. It was suggested that a world map could be printed on the floor so that when a person steps on a country, its sonification is foregrounded in the spatialized mix. The group discussed what the sonification sound signal should be. Speech, national anthems, and music typical of a country were discussed as options (as well as characterizing some countries as spoilt, e.g., loud children, and others as subdued, e.g., whispering), but this also opened up reflections about the dangers of stereotyping. Additionally, the group thought a sustainable level of energy usage per capita could be established, and sound could then be filtered when surpassing this threshold.

When discussing the Use Case section of the Canvas, the group decided that this installation should address politicians and decision makers, perhaps be shown at venues

[8] http://tinyurl.com/mtpdvx8k.
[9] http://tinyurl.com/aat488xf.
[10] https://youtu.be/3N9RnmwIWbA.

such as the World Economic Forum or the European Union parliament. One participant thought that this data reminded her of the IPAT equation [Impact = Population + Affluence (consumption per person) + Technology (impact per unit of consumption)], and she stated: "People think that technology is going to solve it. People think that the production is the problem. But really affluence is the problem." This point of view became the main message for the sonification. The aim of this group was to *affect* the target audience and make them reflect.

In the Canvas, the sonification was considered to be somewhere between *analytical* (objectively reflect the data values) and *narrative* (help tell a story) with the overall aim of telling the story of the data in a different way and affecting decision-making.

This group used a lot of spontaneous vocal sketching to communicate their sound ideas. During sketching, the group moved away from country-related sounds and converged on a more abstract idea: a pitch modulation for each country with different pitch ranges characterizing different countries. The frequency of the modulation would be mapped to the data: a higher frequency would be connected to a higher Per Capita Usage data point. The group thought that foregrounding the country a person steps on while walking around the installation would make listeners *curious*. Hearing all countries in this way would also give the idea of chaos, something the group found fitting with the general message. This final idea (the pitch modulation idea) was presented to the rest of the participants (see Fig. 4). The group commented that the Canvas helped them stop and reflect on their ideas; however, some sections were difficult to fill in.

The **EM Group** decided to concentrate on the data of one country, France, because they were familiar with this country's energy and smart meter systems. In regards to the target audience, the group first considered whether companies would be interested in such an application. They discussed the concept of "Guarantees of Origin" where companies show the quantity of energy produced from renewable sources to the end customer. Since companies often buy renewable energy from other countries, the sonification could include the country of origin. But in the end, they decided that household users should be the target audience of the sonification design.

The application should help the user to become more aware of what kind of energy is used when and consequently help them decide when to use high-consumption appliances. Ideally, two variables should be sonified: percentage of renewables (without separation between sources) and peak of usage. The organizers did not provide data for this second variable, but the group thought that this could be an important addition to avoid stressing the energy network, and, since it is related to the cost of energy, it would potentially allow the user to be more cost effective.

Initial sound ideas were birds for renewables and noise for non-renewables. This sparked a discussion about how pleasant the sound should be and whether it should be playing all the time. The conclusion was that sounds should not be annoying; otherwise, people would turn them off. Since the user would not have control over the sounds, because they do not have control over the energy mix, all the sounds would need to be *usable* and *acceptable* because they would impact the overall household soundscape. Therefore, for this group, achieving silence would be the goal of the application, i.e., if the behavior is sustainable, the app should not make sound. Additionally, since producing sound requires energy, to equate silence to sustainable behavior was considered to be very meaningful.

By the end of the design session, the group settled on the following sonification. When energy is in use and the energy mix is made of 100% renewable energy, there is no sound. When energy is in use and the energy mix is not made of 100% renewable energy, the sound will vary depending on the *brownness* of an energy. The more CO_2-intensive the energy mix is, the more intense the sound is. If the energy mix is still fairly *green* (including nuclear) then there would be a gentle wind sound. The more CO_2-intensive the energy mix becomes, the sound gradually would turn into a more intense wind, and it would be connected with a forest burning sound. While the initial wind sound and initial fire sounds could be quite pleasant and cozy, but still clearly perceivable, the forest burning sound should provide an association to issues of climate change and a sense of alarm (see Fig. 6).

The group also decided that the system should provide visual feedback through LEDs in order to be more inclusive. Finally, the group described potential extensions to the system: "To create an aggregated indicator of 1) renewable energy percentage within the energy mix and 2) the intensity of usage of energy in the national grid. In this case the sound would not represent the energy mix, but indicate when it is best to use electricity within the household (better for the planet and the national grid)." This group used sound samples found on YouTube to communicate sound ideas. They decided that the overall sonification should be quite *analytical* rather than *narrative*.

4.5 Design Briefs Developed at ICT4S for the ICAD Workshop

From the workshop with sustainability experts (at ICT4S), two design briefs were derived to be used by the sonification experts of the ICAD workshop. Brief 1 (see Table 2) aimed to create a sonification of the Per Capita Energy Use dataset. Brief 2 (see Table 3) aimed to create a sonification of the Energy Mix dataset.

4.6 ICAD: Reflections on Sound

Similarly to the ICT4S workshop, participants were asked to reflect on the first sounds they heard that day. Attention turned to the sounds of alarm clocks, birds, or traffic from the window. This prompted reflections on whether a sound is more acceptable if it can be *controlled* (e.g., turned on or off) or not. Opinions differed. One participant realized that he missed many everyday sounds by concentrating on the sound of a lorry passing near the window, a sound he could not control. He explained that there are many everyday sounds that still provide people with information but

Table 2. Brief 1: Per Capita Usage.

Feature	Description
Users	Politicians, decision makers, and general public.
Context	High-visibility event or location (parliaments, World Economic Forum, etc.).
Goals	Provoke discussion about current energy use. Portray difference between the Global North and Global South rather than relative historical increase. Reframe conversation about who is culpable for energy use and emissions.
Sonification	Mix of narrative and analytical approach, listening to raw data but separating out by country to illustrate differences. Not interested in identifying single data points, rather perceiving overall differences.
Multimodality	Physical installation, visual map on floor. Speakers or headphones, head or body tracking.
Extensions	Be able to compare current per capita emissions to defined sustainable levels.

Table 3. Brief 2: Energy Mix.

Feature	Description
Users	Households (families, single people, couples, etc.).
Context	Smart meters with access to real-time energy source data. Different types of housing (apartments, standalone houses, etc.).
Goals	Give feedback on current energy use and sources. Provide a guide on how renewable the current mix is. Help guide decisions on when to use energy in terms of both use of renewables and cost benefit.
Sonification	Mainly illustrative of data. Data is collapsed into a current percentage of *green* energy vs. *brown*; 0% is entirely non-renewable, 100% is entirely renewable. This scale is sonified.
Multimodality	Potentially could include a visual representation on a smart meters (LEDs, screen, etc.).
Extensions	Also somehow illustrate peak usage, to encourage usage at off-peak times as a method for saving money.

work almost subconsciously. In that sense, he thought that sound could have the potential to *manipulate*.

The discussions turned toward reflecting on issues of care, of sound as something that can be external to or produced by people as well as something that connects people to the world. One person stated: "This is something that could be instrumental also for informing sustainability. We use sound as something to connect, it helps us think of ourselves as part of the world rather than separate from it." One participant also discussed sound in relation to the concept of *responsibility* and *guilt* (one could be ashamed of the sounds they produce) and in relation to *culture* (smashing a beer glass could provoke cheers in one country and disapproving silence in another).

4.7 ICAD: Reflections on the Data

When reflecting on the dataset, one person with a background as an energy journalist in the United States mentioned how little people know about energy consumption. Electricity is often taken for granted, and therefore, it is important to make people more aware of where it comes from. The *Energy Mix* dataset was considered helpful in this regard. Then the group discussed the *Per Capita Usage* dataset. They mentioned the limitations of the dataset since it does not show what the energy is used for, where it comes from, etc. The group wondered what the general goal of displaying this dataset would be and who the target audience could be.

4.8 ICAD: Design Session

At the start of the session, the ICAD participants were divided into two groups (PC and EM) and provided with the design briefs developed during the ICT4S workshop. The ICAD's **PC Group** focused on comparing the values of different countries. They imagined projecting a map in a large visualization wall, or in VR. They thought of using sounds from national music or animals typical of the country in focus; however, they quickly realized that these options could created cacophony and be very confusing. Interestingly, this was something the ICT4S PC Group liked about this concept because it would reflect the "messiness" of usage; however, the sonification experts were less enthusiastic about it. Similarly to the ICT4S group, the sonification approach should be somewhere between *narrative* and *analytical* with the aim of affecting politicians, but also the general public, and make them reflect. The group decided that sonifying the slope of the data, i.e., whether the trend is upward or downward, might be more useful than sonifying the single data point.

However, the group still found it difficult to define a clear message for the display. This perhaps was because they were less convinced (comparing to the ICT4S group) about the importance of this dataset as a way to make a point about differences in usage between the Global North and Global South. They discussed adding additional information (e.g., which country signed the Paris Agreement or the percentage of energy used for manufacturing or other industries). Toward the end of the session, the group sketched the installation on paper and the sound using the software package Logic. They decided to use different percussive sounds (typical of the different countries) to sonify the trends of the data. The group envisaged a large interactive visualization wall with a number of speakers and motion capture cameras lined along the wall (see Fig. 7) to track

viewers. The user would be able to call up and focus on the graphs of one country, listening to its sonification in the foreground, while other countries' sonifications would play in the background.

The ICAD's **EM Group** worked with the *Energy Mix* brief (see Table 3) and discussed whether the brief would call for a more *analytical* or *narrative* sonification. Participants had different ideas, with one person stating that even if the sonification is analytical, "people will start telling stories with it." But another participant wondered whether the designers should impose a story or message or none at all. This led the group to discuss whether a narrative could be created by sonifying the summary of the previous day's consumption, not just the real-time data. The group discussed the difference between sonifying data to let people discover patterns or help them make better decisions. One person wondered if producing a form of *nudging* could be somewhat patronizing. The group discussed the motivations people might have for using such a design (reduce costs, improve sustainable behaviors, etc.), as well as the age of the potential users, and whether their design could address children as well as adults.

The discussion then moved toward different objects that could be augmented to provide the sonification (perhaps an alarm clock or a smart door) and where in the house they should be (in a room or distributed in multiple places). Overall, they agreed that homes are very personal spaces and such a system should most likely be adaptive. Finally, the group decided to focus on creating a design for a well-off couple because this might be the kind of demographic who can, more easily than others, take individual responsibility for unsustainable behavior, and might be more inclined to activate the local politicians when necessary. The sonification would be connected to a typical morning routine (e.g., boiling the kettle to make tea).

The group discussed several sounds (e.g., birds, mining sounds, wind, or music) as well as using speech to humanize the sonification or to produce short sounds and make them quite "vocal-esque." They imagined developing an "emoticon" sound provoking negative emotions if the energy is very *brown*, while creating more positive emotions when the energy is more *green*.

This brought the group to discuss the benefits and challenges of using such a reward system (i.e., linking a negative sound to negative behavior and vice-versa), reaching the conclusion that negative sounds could be counterproductive since they might create a resistance in the user. Overall the group agreed that the sonification should not be difficult to learn. To sketch the sonification, the group used a mix of synthesized sounds, produced with an online software, and recorded vocal sketching. The procedure of using the kettle was segmented into separate actions (filling it with water, putting it on the base, etc.). Different segments were seen as different meaningful opportunities for sonification. Both the energy consumption of the previous day and the current, real-time data would be sonified. The sound duration would be mapped to the percentage of *brown* vs. *green* energy in the previous day. For example, if the *brown* energy was 30% and the overall sonification lasts 6 s, the *brown* sound would last for 2 s and the *green* sound for 4 s.

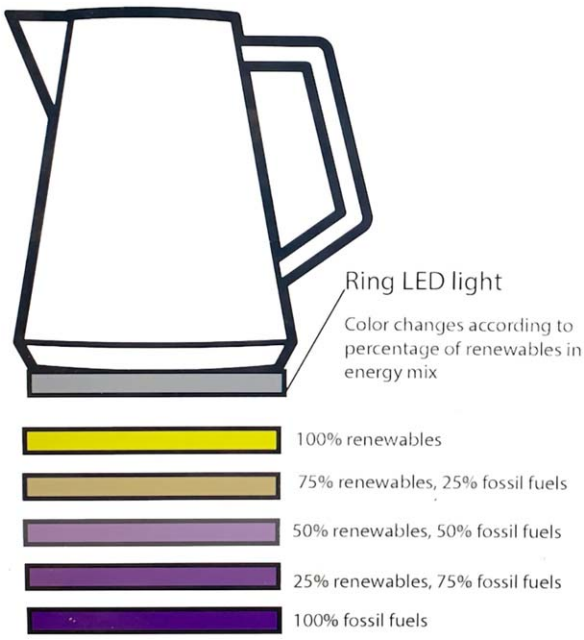

Fig. 10. Sketch of kettle LED lights (original).

Short abstract sounds would mark the passing of 6 h, helping the user interpret the sonification. The *brown* energy sound should come first, and the *green* second in order to finish the sonification of the previous day in a positive way. Finally, they "dramatized" the morning scene for the presentation. The scene was described as follows: "It is 7am on a Wednesday morning. Thomas wakes up. He stumbles from his bedroom into the kitchen and he desperately needs a cup of coffee. So he goes over to his electric tea kettle. He picks it up. He goes over he fills it with water. And then he sets it back on the base [sonification of current energy mix]. So much fossil energy!" Here, the user can decide whether to boil the kettle or not on the basis of the energy mix, which would also be visualized through LEDs (see Fig. 10). If the user proceeds to boil the water, then they will also hear the sonification of the previous 24-h energy mix.

5 DISCUSSION

As mentioned in the SEC. 1, participatory design methods have started to be used in the domain of sonification and sonic interaction design relatively recently. These areas of research present a unique fundamental challenge: the need to find connections between sound and the target data domain, which could potentially be anything. Among the many stakeholders who might be interested in participating in the design of a sonification, two groups are usually important: data-domain experts, who may want to use sonification or sonic interaction design to mine their data in novel ways, and end users, who could have little expert knowledge about sound (its perceptual characteristics, how to attend to them when listening, its technical vocabulary,

etc.) or the data domain (but might be using something related to the target domain on a day-to-day basis). It is then important to devise effective ways to bring these groups together in a workshop setting in order to develop meaningful design ideas that could be accepted more easily, because they have been co-ideated by the target audience, when fully developed.

The workshops presented here—two with end users and one that is the combination of two workshops with different domain experts—learn from previous similar endeavors and highlight methods that can be transferable to similar efforts in connecting sound to other data domains (astronomy, health, etc.). These methods relate to: (1) how to create an effective hybrid space (even at a distance) where domain experts and sound experts can participate equally; (2) the importance of using common tools and workshop structures; (3) the use of narratives and constructions and the role of emotions as a way to overcome the lack of a common vocabulary when designing with sound.

5.1 Hybrid Space

The authors have shown two effective ways to create a hybrid space where participants feel empowered to discuss quite unfamiliar concepts and develop new, original ideas in a short amount of time. In the first two workshops with end users, the authors brought participants into a common and familiar physical space. The workshops' tasks (described in depth in [29, 30]) facilitated the discussion and presentation of different points of view. In the workshop with expert users, a virtual hybrid space was created using the organizers as the main bridge between the two participating communities.

When bringing together people from different domains is not feasible, it has been shown that it is possible to conduct a two-part workshop first with the data domain experts and later with the sound experts. Data domain experts can be instructed about sonification concepts and techniques quite rapidly, and they are then able to develop domain-related design briefs that can be passed on to sonification experts for more in-depth sound ideation and prototyping. Domain experts will usually have an understanding of the data that is different, or differently motivated, than what sonification experts might understand. In this case, it is important that the organizers effectively communicate these differences because they are the bridge between the various perspectives at play. It is, therefore, useful to have expertise from both communities within the organization group.

5.2 Common Tools and Structures

In these workshops, the authors have seen that employing common workshop structures (particularly when workshops are separate but connected), durations, materials, and tools help to create the feeling that all participants (non-experts, domain experts, sound people, etc.) are treated equally, that one expertise is not valued over the other, and that everybody is contributing equally to the same overall goal. In this case, the Data Sonification Canvas has proven to be a flexible communication tool, both for ideating a design and delineating a brief to be passed on. However, the workshops have confirmed that this tool needs to be adapted for people who are not experts in sound. The authors have created an adapted version that helped their tasks, but more work would be required to simplify the terminology and improve the guiding questions. On this point, one participant from the ICT4S workshop commented: "We are not sound people and then there are too many things in the canvas. On our level it might be better to do a scenario. It was a way to transfer our sketch in a requirements for next step. But it was difficult for us."

5.3 Narratives

Narrative structures and dramatizations have been used in various ways in these workshops. When non-expert users might find it difficult to ideate and prototype an actual design, using design fictions for the near future can be an easier way to indirectly refer to their initial, perhaps embryonic, idea. The design fiction exercise used in this case allowed participants to comment on their idea (i.e., write what a journalist would write) rather than directly describe a concept. This can be of real value in communicating ideas when a common vocabulary and terminology is lacking. Other types of narratives that have worked well are dramatizations and presentations of ideas using constructions or sound sketches.

5.4 Constructions

Both expert and non-expert users were found to be able to sketch a sonification idea (vocally or with simple sounding objects) or create a lo-tech prototype. These skills are found in children's play and, therefore, might be common to expert and non-expert users. The level of the results, however, vary as would be expected, with the sonification experts being able to sketch a much more complete scenario and more complex sounds (often created quickly with complex technology) in a very short amount of time.

5.5 Emotions

The authors have found that emotions and feelings can be used as a connecting bridge between sound and data. Experiencing sound often affects the listeners. Therefore, rather than asking people to directly talk about sound, something really difficult to do, the authors asked participants to imagine situations in which they felt particular ways. Once a scenario is conjured up, it is easier to imagine what sounds could be in it. If the participants of the workshops are users of something related to the data studied, then it is likely that they will also have feelings about these experiences. So emotions and feelings become the common language that can be used to talk about these two disparate design materials (sound and data).

The *Sound for the Future Home Workshop* has shown that if it is possible to connect (spatially or temporally) sound scenes in which feelings are strong with similarly strong situations involving the domain data, then a design opportunity is created because one might be able to temper those

feelings or enhance them by manipulating the sounds or data situation in complementary ways. In the ICAD workshop, a discussion relating to positive and negative reinforcement through sound, and how sound has the potential to provoke a sense of guilt (e.g., people can feel ashamed by the sounds they are producing), as well as responsibility emerged. This highlighted the need for sonification displays to be personalized in order to work effectively across different people.

Overall, the methods used allowed participants in all workshops to touch upon and reflect on key sonification design issues such as individual preferences, stereotyping, rewarding through sound, annoyance vs. pleasantness, issues of care, nudging and steering behavior with sound, issue of control, and more. All workshops effectively elicited in-depth reflections about sound, its contextual and contingent nature, and about energy consumption and sustainability (the data domain in this case), becoming fruitful moments for learning and the exchange of ideas.

6 CONCLUSION

The authors have described a series of short participatory sonification workshops with both experts and non-experts in which it was possible to produce a number of original design ideas very rapidly. The methods, structures, and tools used in the workshops are not dependent on the data domain under study, and they can easily be replicated in other data domains. Overall, this work contributes to further develop the field of participatory design methods for sonification and sonic interaction design.

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