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Wind energy and noise: Forecasting the future sounds of wind energy projects and facilitating Dutch community participation

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ABSTRACT

This paper presents a case of a digital device – a noise app – employed by a wind farm operator as a response to growing noise annoyance by residents living next to their wind farm in the Netherlands. This noise app communicates predicted sound levels to the residents and monitors their noise annoyance. We analyse the noise app as a digital framing device that governs concerns around wind turbine sound through three processes: *capturing*, *channelling* and *managing*. We show how in the process of *capturing*, the app uses a particular definition of 'the public' and construes 'noise' as a matter of concern. We use the term *channelling* to highlight who is involved in the interpretation of the data about annoyance, and how certain conclusions come to be seen as legitimate. Finally, we discuss how in the process of *managing*, specific kinds of solutions are proposed that fit with this problem definition. The framing process of the noise app also leads to unforeseen effects in the form of *overflows*. Particularly, we see that concerned residents develop an expectation to be more actively involved in decision-making around the wind farm, and that residents resort to alternative forms and channels for expressing existing and new concerns. We conclude by reflecting on the broader energy justice implications of digital framing and overflowing in terms of recognition justice, procedural justice, and distributional justice.

1. Introduction

Wind energy takes up an increasing share in the energy system, but wind energy projects often meet local resistance. For residents living nearby a wind project, noise annoyance is one of the main negative and long-term impacts [1–3]. Concerns about noise may lead to opposition [4], often already during the planning process of projects [5]. For governments and professional actors involved in wind energy projects, tackling concerns linked to noise annoyance can therefore help to increase local acceptance of wind energy projects [6]. A challenge for these actors is how to manage noise annoyance in such a way that the concerns of local communities are recognised, that local communities experience their participation in processes as fair, and that the 'solutions' to noise annoyance are experienced as 'just' outcomes.

To define how much noise is 'acceptable' for communities living near wind turbines, national (and sometimes state or local) governments have established legal limits for wind turbine noise [7]. An assumption underlying these limits is that the higher the level of sound in decibels, the more annoyance is reported by local communities (so called 'dose-response' rationale) [3]. However, while noise exposure matters, the perception of wind turbine noise may also differ per person [8]. According to a study by Haac et al. [2], noise annoyance is strongly correlated to "subjective factors of wind turbine appearance and self-reported noise sensitivity" (p. 1124) rather than objective factors like wind turbine sound level. On top of that, wind turbine sound has been shown to be perceived as 'noisier' than other kinds of sound [9], and the presence of tonal sounds can be experienced as very annoying by some people [10]. In general, concerns about wind turbine noise are often a subject of controversy, linked to disagreements within society around what and whose definitions, concerns, and knowledge should be recognised [11,12]. In acknowledgement of the various concerns over wind turbine noise, and how they may differ among stakeholders, noise regulations may not be sufficient for tackling and preventing noise concerns.

To better manage noise annoyance, actors in the wind energy sector have started to experiment with participatory tools to communicate with residents about wind turbine sound (e.g. [13]). In this paper, we analyse a case of a so-called 'noise app' that can be installed on mobile phones. The noise app is deployed by a wind farm operator to manage wind turbine noise produced by a Dutch wind project. It communicates a

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sound forecast to the local community and enables residents to provide feedback on the level of noise annoyance they experience. The app thus enables real-time monitoring of perceived noise annoyance, which could provide the wind farm operator with a dynamic and contextual understanding of how residents experience wind turbine noise.

Our aim is to examine how the use of this digital device affects how, by whom and in what way concerns about wind turbine noise are governed. We use the term governance to refer to how different actors - experts as well as lay people - steer decisions about how and by whom wind turbine noise should be defined, and how and by whom noise annoyance should be measured and tackled. To understand the role of the app in the governance of noise concerns, we conceptualise the noise app as a 'framing' device [14] that stabilises concerns by constructing a 'frame' around a specific problem (here wind turbine noise). We argue that the framing that arises from the noise app takes place through three processes: *capturing*, *channelling*, and *managing* concerns around noise. Through these processes, some (aspects of) noise concerns become part of the frame, while others are excluded. Excluded aspects become 'overflows', understood here as unforeseen (positive or negative) effects or 'externalities' [15]. An example of a negative externality would be the emergence of new conflicts around the use of the noise app, while a positive externality would be unexpected benefits for local stakeholders. With this focus, we aim to reflect on the justice implications of using digital devices to govern concerns including, but also beyond, wind turbine noise. In doing so, we distinguish between recognition, procedural and distributional justice [16]. More specifically, we focus on 1) recognition justice in terms of the perceived fairness of how the noise app includes and excludes concerned residents as the 'public' of the noise app; 2) procedural justice in terms of the perceived fairness of how and when residents can voice concerns about noise and participate in wind project operational management; and 3) distributive justice with respect to the perceived fairness of how the noise app redistributes the costs associated with wind turbine noise annoyance.

The paper is structured as follows: In section two, we explain how the theoretical lens of framing and overflowing can be used to examine the role of digital devices in governing (noise) concerns. In section three, we introduce the empirical case of the noise app and describe our methodology. Next, we examine the noise app by analysing the three processes of *capturing*, *channelling*, and *managing*, and the overflows that occur in this framing process. We conclude by reflecting on the justice implications of the noise app and describe conditions under which such digital devices can improve public engagement in understanding and managing noise concerns. Finally, we propose an agenda for future research.

2. Digital devices, framing and overflowing

To analyse the noise app as a framing device, we draw on Michel Callon's [15] understanding of framing and overflowing. Framing is both cognitive and physical in nature [15 p. 249], establishing "a boundary [a frame against the outside world] within which interactions – the significance and content of which are self-evident to the protagonists – take place more or less independently of their surrounding context" (Goffman, 1971 in [15 p. 249]). Framings help to stabilise networks around matters of concern as they qualify which definitions and evidence count and which actors can legitimately participate [17]. Overflows are the unforeseen effects of all those things that could not be contained within the frame, as framing always involve inclusion and exclusion processes [15]. In the context of energy projects, Pesch et al. [18] have argued that with any energy project, framings will be contested and lead to overflows. As they argue, "overflowing is not a negative side-effect of energy projects, or […] evolves from bad management. Overflowing is inherent to decision-making on energy projects. Energy projects and systems involve a wide range of uncertainties that are not only technological, but also social and normative and that play out on different geographical, jurisdictional and temporal levels, as such increasing complexity and creating tensions" (p. 832). In addition, a study on energy controversies by Cuppen [19] shows that if the dominant framing solidifies a particular definition of an issue at stake, alternative interpretations might be marginalised and become overflows.

To the best of our knowledge, no framework has been developed yet for how digital devices in energy projects act as framing devices, and how this produces overflows. Because the use of digital devices shapes how problems are understood and governed [20], it is necessary to develop an analytically more precise understanding of the framing process. Doing so will in turn help to reveal the potential justice implications of framings and overflowing [16,18]. We conceptualise framing as an active process that involves decisions about how to translate a matter of concern into the digital realm, including which data to collect, how to analyse this (digital) data, and the type of solutions designed to address the problem at stake. We therefore dissect framing into three processes: (1) *capturing*, (2) *channelling* and (3) *managing*.

First, framing through digital devices includes *capturing* - an active process of setting boundaries around which aspects of socio-material reality to translate into digital data, and delimiting which actors can legitimately participate in this data collection. Specifically when concerns are translated into (digital) data, the choices about parameters for which data is generated, and how it is digitised often tend to be black-boxed [21]. Processes of capturing in the case of digital devices may thus allocate decision-making power in the hands of those who decide about what is being digitalised in the first place [22,23].

Second, digital devices act as framing devices through *channelling*, which we define as the active process of setting boundaries around how and by whom data is analysed, interpreted, and concluded upon. This process of setting boundaries may align with the interests of some actors more than with those of others. In the context of digital devices, scholars have shown how private actors increasingly own and manage digitalised data. As such, they steer the channelling processes and assign specific roles to other actors and stakeholders [20,22,24].

Third, we distinguish *managing* as an active process of creating data-driven interventions and solutions, and of allocating roles and responsibilities for interventions to specific actors. A key characteristic of this process of managing is the design of solutions that are based on a continuous flow of (real-time) digital data [25]. Such data-driven management therefore increasingly takes the form of real-time or anticipatory decision-making (as in smart grids, smart traffic management) [26–28]. Together, these three processes constitute the framing process of digital devices. The overflows that may occur are the unforeseen effects of things that cannot be contained in this frame.

3. Methods

In 2021, a noise app was implemented at a wind project in the Netherlands. There had been a long-standing conflict over the planning and implementation of this wind energy project and during the operational phase, many residents complained about wind turbine noise. The noise monitoring app was commissioned by and developed by a major consultancy firm in the Netherlands. The aim was to provide noise predictions to residents and collect their feedback on perceived noise annoyance. We (the authors) decided to investigate this case after finding online information about it, and had no stake in the wind farm project nor in the development of the app. To set up a study of this noise app, we contacted the noise app developer and the wind farm operator, as well as local networks and associations to ask if they were willing to participate. In this paper, we do not mention the names of individuals (nor their association) in order to assure that the statements are not directly attributed to specific individuals.

To gain in-depth understanding of the noise app as a framing device, we used a mix of qualitative research methods. We began with analysing documented information about how this app was designed, implemented and used. The key written resources included a webpage of the wind energy project, the app user interface, and additional secondary material including a podcast and a documentary. Next, the first author visited the area for observations and informal conversations, and identified relevant respondents for interviews, which was done via purposeful and snow-ball sampling (following [29]).

The first author of this paper conducted 25 interviews with stakeholders, including 10 residents of four villages located next to the wind project, one expert involved in the development of the noise monitoring app, two wind farm operators, three noise- and one digitalisation expert, one local journalist and seven representatives of various interest groups. The sampling strategy for respondents differed per stakeholder group. The experts (all the professional actors) were contacted directly by the first author with an interview invitation. To interview residents concerned about noise, the first author contacted a community representative who reached out to the concerned residents and asked if there were any who wanted to participate in this study. A few residents offered to participate and also suggested other residents. This sample of concerned residents was complimented with residents in the wind project area that the first author met randomly when visiting the area. This means that the focus in sampling was mainly on understanding the perceptions of concerned residents rather than those who are not annoyed by wind farm noise. Consequently, this leads to a limitation, since we were not able to account for how the residents who are not annoyed by wind turbine noise perceive the noise app and how they prefer the problem of noise annoyance to be tackled. We used semi-structured interviews with residents and professionals to at understand how the app was used to engage residents in the governance of noise concerns, and to also leave space for aspects that the respondents considered important.

The interviews were transcribed, or alternatively summarised in written form (if they were not recorded or - if recorded – included repetitive or irrelevant issues for the present study). Afterwards, interviews were coded inductively in the Atlas.ti software through open coding. As a next step, these open codes were grouped into themes and categories based on concepts from our theoretical framework [30], that is, the detected processes of capturing, channelling, and managing in framing and overflowing. The complete list of codes and themes can be found in Appendix A. This analysis was accompanied by simultaneous reflection on whether the information was relevant or if there was some information missing [31]. This analytical approach enabled internal validation of the data [32].

4. Empirical results: how a digital device captures, channels and manages noise annoyance

4.1. Capturing noise as a matter of concern

The noise app offers a novel approach to understanding residents' concerns about wind turbine noise. The app provides noise predictions and allows residents to rate how annoyed they are by the actual noise of the wind farm in their surroundings. In the Netherlands, the legal norm is 47 decibel Lden (a yearly average during the day, evening and night) and 41 decibel Lnight (average sound level during all nights of a given year). These noise limits determine how a wind farm is operated to control noise produced by wind turbines. As long as the wind turbines do not exceed these yearly norms, the noise is considered to be 'normal'. However, by implementing the noise app, the wind farm operator acknowledged that there was a possibility that wind turbine sounds can be annoying even when these norms are not exceeded. The wind farm operator explained that with the noise app, they went beyond what is expected from them based on the noise regulations: "*We did not implement the app because we had to, but because we wanted the best way for the local people.*"

The noise app provides sound forecasts tailored to individual addresses in the area. Based on variables such as local weather and background traffic noise, the app provides a 48-hour sound forecast. According to a noise expert involved in the development of the app, providing wind turbine sound forecasts may increase acceptance for the given wind project:

> *We try to show people what is really happening, because we see a lot of distrust (…) usually when people can hear the wind turbine better, they think the wind turbines are making more noise. But that's not always the case. Sometimes it's the atmosphere that causes that the noise can propagate more easily. So, they hear more noise, but the wind turbine itself makes the same noise. With the app we can now provide that insight, you'll also get insights into energy production. So, people understand also the benefit of the wind turbines. And if we give more insight, create more understanding, the social acceptance will grow.*
>
> (App developer)

The noise app provides a sound forecast expressed in A-weighted decibels (dB(A)) (i.e., which weights the sound as heard by the 'average' human ear). In addition to viewing these forecasts, residents can submit information about perceived annoyance on a 7-point scale of sound levels. Each level is represented by a bar. The bars range from dark green to red, starting with dark green indicating sound levels lower than 30 dB (A) and ending with red, which indicates sound levels between 46 and 48 dB(A). The residents can submit the feedback about noise annoyance in real-time by clicking on one of the seven bars, as well as through a written message. The wind farm operator and app developer contended that the noise app thereby provides a dynamic understanding of how residents' perceptions of wind turbine noise vary on different moments and may change over time.

As the noise app was developed to better understand the peculiarities of noise annoyance at the local level, the wind farm operator needed to define the geographical area for which they wanted to provide predictions and collect feedback. They chose to limit the area to 2 km around the wind project. One noise expert providing advice on wind farm operation found such spatial demarcation logical, explaining that "from a practical point of view, there should be a limit to where you assess effects" (Expert on wind turbine noise). Through collecting feedback from these local residents, the aim was to find out why and when wind turbine sounds are annoying (and hence when sound becomes constituted as 'noise'). The noise app would also help to understand complaints about low frequency noise, including a specific low frequency tone that respondents referred to as the 'hum'. According to a local noise expert, this low frequency tonal sound should not be occurring at all, as it is a sign that the wind turbine was not working properly. By enabling residents to provide feedback whenever they wanted, the idea was that the app would also help to get more insights into this 'hum'.

4.2. Channelling noise concerns by interpreting the feedback

In the next phase of the framing process, channelling, boundaries are set around who can analyse and access the data about noise annoyance. To enable analysis of the data, data handling protocols and agreements had to be developed. The consultancy firm that developed the app became responsible for running the data analysis by coupling the data on perceived annoyance with data such as respondents' location, wind direction, background sounds and sound forecasts. App users need to accept privacy policy, stating that the feedback data are processed and stored by the consultancy firm and the results are shared with wind farm operator, residents and other stakeholder. This privacy policy also stated that the feedback could not be traced back to individual users and would not be shared in raw form with others. In practice, this meant that the app developer regularly communicated the results in the form of (graphical and anonymised) reports and charts to the wind farm operator who in turn discusses the results with representatives of the local community. For some residents, however, using the app had generated the expectation that they would be involved in the interpretation of the data, and they expressed a desire to have more access to the data.

The results of the analysis were presented to various stakeholders, but in different ways. For the wind operator, a dashboard was developed that allowed them to monitor the sound levels and the feedback on annoyance in real time:

"*[to communicate the results] we developed a dashboard for the wind farm operator, so that they can see the feedback from residents in real time. The dashboard presents results of automatic analysis. So, we give the wind farm operator insights into how the feedback from the residents relates to the distance of the wind farm, to the orientation of the wind farm, to the wind speed and direction and to the power production of the wind turbines.*"

(App Developer)

For the local residents, general insights were presented verbally in meetings with a few community representatives. The wind farm operator stressed that their intention was not to be secretive about the results; on the contrary, they explained they wanted to be open and to create a dialogue with the residents. At the same time, they considered a dashboard with restricted access the 'safe' option that would prevent misinterpretation of the results by the local community. This approach to data analysis, ownership and accessibility underscored the continuation of pre-existing conflict, negative sentiments towards collaboration and mutual lack of trust between some residents and professional actors involved in wind farm operation.

4.3. Managing concerns by findings solutions

How are these results about noise annoyance translated into wind farm operation and management strategies? The results from the data analysis showed that wind turbine noise, including the hum tone, was most annoying at night. On this basis, the wind farm operator decided to slow down rotation of the turbines during particular nights when weather conditions were expected to create high noise annoyance. Reducing the rotation at some nights was a voluntary initiative of the wind farm operator. In doing so, they went beyond the legislation-based approach that prescribes action only when the noise limits are exceeded. A while after this new management strategy had been implemented, the wind farm operator noticed a decrease in the amount of feedback submitted through the app. This led them to conclude that people were less annoyed by the sound of wind turbines. Interestingly, the wind farm operator said that at that point, they could identify those people who always complain:

"*When we started off in, say, January, and then you see until April, we didn't pull the power back, then you see a lot of complaints, then we pulled the power back at night. And then you see you see that the complaints were getting down. And now you see only complaints from people who are complaining always. So, they can't accept that the wind turbines are there. So, I think it's about five people or something. So, you know, you can't satisfy everybody.*"

(Wind farm operator)

The operator concluded there is a need to accept that some people will always remain annoyed, regardless of interventions taken.

In this step of managing, responsibility for the problem of noise and for the solution was allocated to the wind farm operator and wind turbine manufacturer. According to the wind farm operator, the hum was a problem in the software of the wind turbines, and the wind turbine manufacturer in response updated this software. While decreasing the noise through a software update was one type of solution, another type was 'managing annoyance'. The wind farm operator viewed the app as a management solution on its own because they could use it to be a 'good' neighbour to the local community:

"*When people are complaining, it's not okay, so together with a producer of wind turbines, we try to reduce all nuisance there is. That's why the app is so good, because you can continuously measure if people are satisfied or not.*"

(Wind farm operator)

For the app designer, the app was a tool for management of noise concerns because it engages residents on the issue of wind turbine noise and enables expectation management. Furthermore, while the wind turbine operator was satisfied with the amount of feedback they received through the app, they also noticed that some app users did not report any annoyance at all, and that there were people living within the geographical range of the app who had never installed the app. This group of residents was recognised by the wind farm operator as a 'silent majority' whose experience of noise annoyance was not captured but would be a valuable addition in understanding the problem.

4.4. Overflows: that which isn't captured, channelled and managed

Above, we have shown how the noise app produces a particular framing of noise-related concerns in the way those are captured, channelled and managed. In doing so, this framing is inevitably accompanied by overflowing in the sense that unforeseen effects occur.

4.4.1. Overflows in capturing

As residents started to make use of the app, it became clear that the app's definition of noise on a scale of different sound levels expressed in decibels (dB(A)) sometimes mismatched with their subjective experience of noise. In general, residents were most annoyed by the presence of the low frequency tone that we referred to above as the 'hum'. A common remark that residents made was that it was difficult to locate the source of the hum, which appeared to be omnipresent and stable. One respondent described the hum as "a heavy, industrial sound. As if you stand in a room with heavy machinery" (Resident [7]) and another said it sounded "as if there was a truck stationing next to your house, with a running engine" (Resident [10]). Because the rating scheme with the seven bars did not explicitly include the hum tone as a category, some app users were concerned that this specific experience was not recognised. A local noise expert explained that the assumption foregrounded in the noise app is that annoyance grows with the level of dB (A), but that this might not hold in case of the hum. This is because, he explained, at this specific wind farm, wind turbines produce most hum at lower wind speeds. While higher wind speeds make the turbine blades rotate faster, sound generated by the movement of blades is likely to be experienced as less annoying than the hum tone. Ultimately, this ambiguity around if and how the hum was included in the noise app became a subject of concern on its own.

Some residents asserted that the noise app did not take into account the inconveniences around providing feedback at night. That is, the app encouraged people to provide real-time feedback about annoyance, but many respondents found the wind turbine noise most annoying at night, when they are not willing to use the app:

"*When I got it [the app], I checked it and it was written that you have to indicate when exactly you are annoyed by the noise. For me it is almost always at night. You don't think I will use this app at night?! (…) I sent an email, in which I said: this is a one-time message, in which I indicate that I suffer day and night and that I am not prepared to send feedback that I am annoyed every night. This bright screen would be one more disruption to my night rest.*"

(Resident [2])

Moreover, while the noise app captured noise annoyance as a concern, it did not recognise people's concerns about the impact of noise annoyance on health and well-being. We found that health impacts in particular worried the local community, and this also became a subject of controversy. To come up with evidence for health impacts, a group of residents established a noise group who consulted and hired their own noise experts to undertake noise measurements and to provide alternative evidence about the negative impacts of wind turbine noise on health. The noise experts that we interviewed, however, generally agreed that scientific evidence for the residents' concerns was lacking. One expert mentioned that concerns about wind turbine noise might be an expression of opposition by people who are fundamentally against wind energy:

> "*They are almost professional opponents of wind energy, they come up with all kinds of publications about how devastating their low frequency sound is. Because that's where they found something they can use in the opposition.*"
>
> (Expert on wind turbine noise #1)

A final example of overflows is connected to the spatial demarcation of the area in which the app could be used. Only residents living within 2 km distance of the wind farm were able to submit their feedback via the app, which means that potential complaints from outside this area were not captured. Several residents asserted that this meant the noise app failed to include everyone who could be affected by noise. Some people found other channels for submitting their complaints, for example per email or phone directly to one of the wind farm operators or to the municipality. Most commonly used and trusted by the residents was the email address of the local association of residents, which received complaints from both people within and beyond the 2 km radius. According to one respondent, this provided proof that the impact of wind turbine sound was found far beyond the area that was recognised with the app. Hence, overflows linked to the active process of capturing by the noise app were found to occur because of the reliance on expert-based definitions and strict spatial demarcations, both of which were contested by alternative knowledge claims made by residents.

4.4.2. Overflows in channelling

The noise app channels the data analysis in such a way that conclusions about annoyance are drawn by one actor group in particular: the noise experts. As a result, the residents felt left out of this process. A representative of the local community explained this as follows:

> "*I am also wondering, how can I get some insights about the data that is gathered by the app, why don't they share the data? We do have people in the community who could interpret the data. I also do this for my work. I also wonder what they think about the data that they receive.*"
>
> (Community Leader)

While the results of the analysis of app data were regularly shared with the wind farm operator and wind turbine manufacturer, some residents also wanted to be informed:

> "*It would be great if they could make a report in which they would describe what the status quo is around noise, how many complaints were submitted and what they have done with them […] For example, if they send a flyer around the village twice a year with information about the app and its results, this will give us a much better feeling.*"
>
> (Resident [7])

Based on the analysis of data patterns over time, the wind farm operator concluded that noise annoyance had decreased. Some residents, however, came to a different conclusion: the decrease in feedback about noise annoyance meant that residents were simply tired of complaining and stopped providing feedback. While the wind turbine operator understood the data gathering and analysis as a long-term activity that would gradually increase their insights into noise annoyance, the residents expected a solution and actions in the short-term:

> "*Some people are willing to use the app, but they want to know when the problem will be fixed. The app gathers data and so there is an expectation for a solution. But it takes so long, and this worries me.*"
>
> (Resident [7])

Overflows in relation to channelling thus include new concerns by residents over the lack of possibilities to be involved in drawing conclusions based on app data. For the residents, this feeds into pre-existing worries over how the wind farm operator approaches the problem of noise annoyance and seeks to solve it.

4.4.3. Overflows in management

When it came to the management solutions that followed from the noise app data analysis, the opinions of residents about who should be involved in designing and implementing these responses were split. Some residents were unhappy about the fact that the wind farm operator was taking decisions about wind farm operation on their own and stated that they as residents should be involved as well. This also led to a new concern about the noise app, namely that it was implemented to legitimize choices of the wind farm operator and was aimed at keeping the wind farm operational. A local journalist said that: "it is also a bit difficult to entrust this app in the hands of wind farm owner because it is in their interest to show that the noise problem is small" (Local Journalist). On the other hand, there were also residents who saw the wind farm operator as a 'problem owner' and thus they expected that a solution would also need to come from them.

A few local residents were concerned that the wind farm operator expected the residents to use the noise app as a tool that would help them to better live with the noise. In general, people had various coping strategies to deal with wind turbine noise, such as sleeping in a different room or house or even moving away. In practice, the role of the noise app in such adaptation practices was rather small as many residents relied on their prior experiences of when and how much noise could be expected under different weather conditions rather than on the sound forecast communicated by the app. Overall, the operator's emphasis on long-term monitoring with the help of the app was rather unsatisfying for the residents who wanted to have a clear timeline for when the problem of noise annoyance would come to an end.

Another matter of contestation was how the feedback gathered through the noise app would translate into specific operational decisions. While the wind farm operator decided to slow down the rotation of the blades at night, the representatives of local communities proposed different strategies. Some people wanted to have the wind farm completely switched off at night. Other people contended that in the absence of any evidence that (low frequency) noise is unharmful to health, a precautionary approach should be taken in which exposure to wind turbine sounds would be minimised. Such more fundamentally different ideas about noise as a matter of concern directly affected ideas about what is safe, possible, or desirable in wind farm management. Overflows in management were thus found to consist of residents holding alternative visions for wind farm operation that included a much more active and co-managing role for residents. Table 1 summarises our findings of framing-overflowing dynamics in the capturing, channelling and managing of noise concerns.

5. Discussion

While the existing literature on framing and overflows in energy projects often discusses how framings are constructed by social actors (e.g. [18,33]), our paper focuses on how digital devices mediate this process (also following Callon's [15] focus on the role of technologies and other non-human actors). We argue that looking at framing through the three processes of capturing, channelling and managing enables us to understand how digital devices frame issues and create overflows. While the processes are analytically distinct, they need to be understood as entangled because they impact each other. *Capturing* will shape the process of *channelling* by defining what kind of concerns are relevant to analyse, and thereby whose expertise is deemed relevant for data interpretation. In turn, the outcome of the analysis in the channelling process will be acted upon in the *managing* phase, providing governance solutions tailored to the framed problems. In combination, the three

Table 1
Summary of framing-overflowing in relation to capturing, channelling and managing.

	Framing	Overflowing
Capturing	Defining sound levels through dB(A) metric Residents receive predicted sound levels for their location	Mismatch with experiential definition of wind turbine noise; residents focus on the 'hum' and on the impacts of wind turbine noise on health
	Noise concerns captured by gathering real-time feedback on the perceived sound levels; a feedback scale that assumes that the higher the perceived sounds levels, the more annoyance is experienced.	People's concerns about noise impact on health not captured, producing annoyance and uncertainty Some residents do not want to use app during night-time
	Spatial demarcation (2 km radius)	Email list that gathers complaints from area beyond 2 km
Channelling	Protocols for using data provided by the residents (privacy statement) and proprietary data agreement with wind turbine manufacturer	The local community felt they received too little information about the results and expected that the data would be shared
	Closing down and objectifying the process of analysis (automatic analysis and interpretation by wind farm operator and app developer)	Sparks 'citizen science' – noise group formed to research the impacts of wind turbine noise, commissioning own noise measurements, and consulting alternative noise experts
	Continuous, interactive process of analysis: the more data from the residents gathered in the future, the better understanding of noise annoyance	Residents expecting more immediate solution and a time-bounded strategy
	Possibility to see the results of feedback provided by the residents in real-time: how many complaints there are	It is not known why people provide or stop providing feedback
Management	Solutions are sought together with wind turbine manufacturer	Closes down the possibility for the residents to propose alternative ideas e.g. to stop wind farm operation at night
	The noise app enacts noise governance as an ongoing process that requires continuous feedback	Generates expectations about the creation of a timeline in which the problem will be solved
	App as a tool for informing and managing expectations	Leads to contestation of the information that is communicated by the app and how it should be used to manage expectations

processes - *capturing*, *channelling*, and *managing* - thereby construct both the 'problem' and its 'solution', and at the same time produce 'overflows'.

Analysing the noise app from the perspective of framing and overflowing brings to the fore the justice implications of using digital devices for public engagement in the governance of (noise) concerns. Using [16] three tenets of energy justice, we can evaluate the *recognition, procedural, and distributional justice* of the noise app. Recognition justice is about who is ignored or misrecognised, procedural justice asks the question about fair processes and participation in decision-making, and distributive justice considers how and where the costs and benefits are distributed [16].

First, the use of the app has implications for who is *recognised* as bearing the burdens of wind energy projects, and whose concerns are considered legitimate. In line with Felt and Fochler [34], we argue that experts who design tools and processes of participation affect whose voice and stake is recognised. By introducing the app, the wind farm operator and developer recognise that residents can experience noise annoyance even when the noise limits are not exceeded. At the same time, specific groups and individuals that are unable or unwilling to use digital devices are not recognised. In addition, the noise app can only capture feedback about noise annoyance within a 2 km area around the wind farm. It thereby fails to acknowledge experiences of noise annoyance beyond this restricted area. In the channelling phase, the app allows to categorise residents according to their user-behaviour with labels such as 'people who always complain', 'the silent majority' or 'serious app users'. While the term 'the silent majority' is more commonly used by policymakers and researchers to refer to people who do not report any annoyance to wind turbine sound [2], the other two terms are new and specific to the noise app. Referring to specific groups as 'people who always complain' is an example of misrecognition of the concerns of these people, categorising these people as unwilling to collaborate with the wind farm operator and app developer.

Second, the noise app affects procedural justice through changing how and when residents can provide input to and participate in decision-making about wind turbine noise. The app in general fosters participation of local communities in wind energy projects because it creates a new channel for information exchange between the wind farm operator and local residents. By voluntarily disclosing information about the negative impacts of wind turbines (that is, providing sound forecasts), the operator can be said to improve procedural justice in the operation of wind farms. Ultimately, however, we argue that this digital device organises participation around a scientific and expert-based definition of noise, rather than opens up alternative ways for residents to express their own interpretations of 'the problem' at stake. Moreover, the app does not provide space for residents to voice a more diverse set of concerns such as impacts on health, which is then manifested in overflows. While the residents had an active role in providing feedback via the app, they did not get an active role in the analysis of the data or in proposing solutions. A lack of participation in the management decisions tends to lead to more opposition and to make residents search for new ways to adopt or resist these decisions. For instance, the introduction of sensor-based obstruction lights in Denmark has caused residents to find strategies to adapt to the technology-based solutions rather than to collaboratively develop solutions [35]. At the same time, the app – deployed as a management solution – assigns the public with the responsibility to provide feedback in order for the operator and developer to listen to the public's concerns. The noise app did help the developer to go beyond what is legally required from them based on the Dutch noise limits, and thus was an attempt to overcome structural injustices [36]. Yet, in practice, the implementation of the noise app generated new concerns about fairness and engagement in the process of data interpretation and operational decisions.

Third, in terms of distributive justice, the implementation and use of the noise app diminished the local burdens associated with wind energy projects to some extent, as the operator adjusted its operation in response to annoyance. Traditionally in governance of noise concerns, intervention is only expected and enforced if noise limits are exceeded in a given area [7]. Meanwhile, the digital device created expectations among its users for more responsive operation of wind turbines. Some residents hoped that wind turbines would be switched off entirely when high levels of noise annoyance are reported, for example at night, or called for a precautionary approach. The specific siting of wind energy projects by definition makes the distribution of burdens of wind energy projects unequal, disproportionally affecting people who live in the surroundings. Our case shows that adaptive operation of wind turbines can contribute to a sense of justice, but that the use of the app could also lead to new distributional justice claims from local communities.

How can digital devices for public engagement be used to create more just processes and outcomes in the governance of burdens of the low-carbon energy transition? We argue that by not pre-defining the solutions, and opening up to alternative views of the local community on the issue at stake there is a better chance for increasing the different kinds of justice [16] in the future. When local communities choose to continue resisting both wind energy projects as well as the solutions offered to address their concerns (such as the noise app), it is important to examine the role of framing processes in shaping the problem definition, and thereby also the types of solutions that can be envisioned. Thus, framing may lie at the root of many of today's controversies over renewable energy developments. More research into these underlying reasons for opposition is needed to better govern the energy transition in a 'just' way and to deal with situations of conflict (see also [37,38]).

One of the ways to deal with ubiquitous overflowing is to acknowledge its existence and to discuss it openly with local communities. Doing so, we argue, can create an open and fair space for the governance of concerns and for developing and facilitating alternative forms of engaging residents. As argued in research on citizen science projects [39], the end-product and goal of digital tools such as the noise app should not be the making of a dataset, but rather the very 'process' of collecting data and engaging citizens. In the case of the noise app, this could include engaging small groups of residents in discussions– about noise annoyance and acceptable solutions to this problem in various phases, from the development of the app to the interpretation of monitoring data. Following Ferrero et al. [40], a role play – in which the roles of different residents, app developer and wind farm operator are enacted by residents – could help to reveal the tensions and understand various positions. This may help to increase empathy among different stakeholders and as such help to improve decision-making in case of complex problems. In this way, digital devices can be used to improve participation in decision-making about wind energy projects by providing a starting point to gather and discuss different experiences and understandings of both problems and solutions.

6. Conclusions

This paper analysed how a noise app was used to manage noise annoyance experienced by residents living next to a wind farm. We approached the noise app as a digital framing device that shapes the governance of noise concerns through three framing processes - *capturing*, *channelling*, and *managing*. Through these processes, concerns are translated into the 'digital domain' in which digital data are used to demarcate and define 'the problem' and to 'solve' it. Boundaries are set around the definition of the problem, the solution and around the roles and responsibilities of different actors such as noise experts, the app developer, wind energy actors, and residents. Because digital framing devices affect which and whose matters of concern or knowledge are being recognised as relevant, or which are dismissed, their use in energy projects has important justice implications. Building on this study, future research could focus on how the quantification of issues may perform a particular valuation of what counts as legitimate concerns. For example, does the use of digital devices (and their workings through algorithms) prioritise easily quantifiable over less easily quantifiable concerns? If so, how can digital devices better recognise concerns that are complex and include lay-people knowledge?

Our paper also showed that this active process of *capturing*, *channelling* and *managing* inevitably leads to overflowing, in the sense that unintended side effects occur. Decision-makers need to be aware that overflows are inevitable, and that from a perspective of justice, it is important to recognise what kind of concerns are overflowing. Future research could look into the ways in which overflowing, and in particular alternative forms of engagement such as citizen science, could be used to inform or even reform spatial planning procedures and environmental legislation around wind turbine noise.

Finally, we suggest two areas for future research and policy around the use of digital devices in wind energy projects. First, as prior research [41] has shown that acceptance tends to be linked to perceptions of how and whether operational turbines produce financial benefits to the community (e.g. lower energy bills, funds for local development, co-ownership), future research could examine how residents respond to information about power production in addition to the information about sound levels. Second, we suggest exploring ways in which digital devices such as apps could further open up opportunities for local communities around energy projects to voice concerns and to be involved. This could include transdisciplinary research or practices of co-design that support societal actors in posing research or design questions linked to their matters of concern. Further, such research should invite the concerned public to actively participate in decisions about how and where such digital devices are implemented. Wind farm operators who implement these devices could explore or experiment with how such devices can facilitate alternative ways for citizens to engage with their concerns and participate in decision-making, thus doing digitally-enabled governance *otherwise*.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Helena Solman reports financial support was provided by the European Union's Horizon 2020 - Research and Innovation Framework Programme [grant numbers 763990, 2018].

Data availability

The data that has been used is confidential.

Appendix A. Analysis: themes, sub-themes and codes

Groups (of respondents):
1. Noise and digitalisation experts
2. Residents
3. Representatives of stakeholder groups/local community
4. Government officials
5. Wind farm operator and app designer
6. Media

Theme: Knowledge, expertise and uncertainty related to WT noise
- Code: 'Official' Expertise on noise
- Code: Noise measurements
- Code: Knowledge claims related to noise and LFN
- Code: Citizen science of noise (also overflowing)

Theme: Management of WT noise and digitalisation
- Code: Definition of digitalisation
- Code: Digital technologies and centralised vs distributed modes of governance
- Code: Governments and digitalisation
- Code: Data ownership (also overflowing)
- Code: Data quality (also overflowing)
- Code: Cyber security (also overflowing)
- Code: Private companies and digitalisation

Theme: virtual engagement through the app
- Sub-theme: Data
  - Code: Noise annoyance data gathered by the app
  - Code: Data shared by the app (noise predictions, weather, wind, who controls the kind of info that is shared)
- Sub-theme: Networked actors
  - Code: The role of Dorpsraad and other interest groups
  - Code: Relationship towards WT manufacturer
  - Code: Sub-theme: Digital technologies
  - Code: Opinion about the noise app
  - Code: Considerations about the app as a tool for participation
  - Code: Decision-making based on data output
  - Code: Experts
  - Code: Prior experience of participation
  - Code: How people use the app

Theme: overflows/controversies
- Sub-theme: Noise as a matter of concern
  - Code: Definition of noise (legal)

Code: Concern about the impacts of low-frequency sound (mainly health)
Code: Experience of low-frequency sound
Code: hum/'brom' tone
Code: Noise by blades
Code: 'lasten, niet de lusten'
Code: Adapting/living with noise in everyday life
Code: Spatio-temporal context
Code: Wind turbine technology/design (importance or management of)
Code: Prior expectations for noise
Sub-theme: Demarcations and decision-making
Code: 2 km distance
Code: Legislative context
Code: Communication about noise
Code: Finding solution and taking responsibility for noise
Code: Fairness of solutions
Code: Socio-economic context
Code: Connected concerns
Code: Stakeholder networks

Description of codes

Themes: Knowledge, expertise and uncertainty related to noise
Code: 'official' expertise on noise: this includes the scientific knowledge on noise, the statements brought by RIVM, noise consultancy and official noise data/noise measurements
Code: Noise measurements: mentions about all kinds of noise measurements that have taken place at the wind farm or on residents' properties, or in the wind farm area.
Code: Knowledge claims related to noise and LFN: information gathered or used by opposition groups or residents related to wind turbine noise, including LFN and its impacts on health
Code: Citizen science of noise: all the action taken by the residents to prove (measure) LFN and outline its impacts on health (often experienced as a pressure to provide evidence for their matters of concern related to noise); trust in noise measurements
Theme: Management of WT noise and digitalisation
Code: Definition of digitalisation: how different actors discuss the trend of digitalisation in wind energy and in their everyday life
Code: Digital technologies and centralised vs distributed modes of governance: ideas about how digital devices and technologies allow to distribute the decision-making power form centralised to distributed forms of decision-making
Code: Governments and digitalisation mentions of how governments try to keep up on the increasing use of digital tools in governance of (wind) energy infrastructures
Code: Data ownership: mentions about who owns the app data, wind turbine data, noise data etc.
Code: Data quality: opinions around the quality of data that is being digitalised
Code: Cyber security: concerns about the cybersecurity in online domain
Code: Private companies and digitalisation: ideas about the role of private actors in (wind) energy when implementing digital tools for assets management, citizen participation etc.
Theme: Virtual engagement with the app
Sub-theme: Data
Code: Data included by the app: explanation about what kind of information the noise app includes and how it is shared with residents.
Code: Data excluded by the app/limitations: mentions of what kind of information was not possible to include, what were the limitations
Code: Experts motivation: motivation for why wind farm operator and app designer developed the noise app and included certain functions in it
Code: Noise annoyance data gathered by the app: this includes the kind of feedback that people provide about noise and how the wind farm operator and app designer perceive it
Code: Data shared by the app: perceptions of people on the usefulness of noise predictions, weather; residents' understanding of who controls the kind of information that is shared
Sub-theme: Networked actors (this includes residents, experts, media, developer, manufacturer)
Code: The role of Dorpsraad and other interest groups (how they are mediating, communicating concerns, the role as an alternative point for residents' complaints)
Code: relationship towards WT manufacturer mentions related to the process of communication or a lack thereof and possibilities for engagement with WT
Sub-theme: Digital technologies
Code: Opinion about the noise app: different opinions about the noise app, ideas about how trust matters for the overall opinion about the noise app, how the opinion changed over time (e.g. if people 'gave up' on it over time or change their mind based on the user experience)
Code: Drawing conclusions from app data: how results about what is annoying about wind turbine noise and under what conditions are drawn based on the app
Theme: overflows/controversies
Sub-theme: Noise as a matter of concern
Code: Definitions of noise: ways in which different respondents explain what wind turbine noise means and what kinds of noise exist and are annoying
Code: Concern about the impacts of low-frequency sound: this includes mainly health-related concerns for humans such as brain damage, stress, hearing problems, heart disease, but also impacts on animals (cows, wildlife)
Code: Experience of low-frequency sound: this includes stories of people bodily experiences of LFS: people experience it as a sort of vibration, amplified by their house, people explain it as long sound waves that can travel through the ground for long distances, some people make a distinction between LFS and 'brom' tone, others do not.
Code: 'brom' tone: the ways in which residents experience it
Code: Noise by blades: how respondents characterise it and compare to other kinds of WT noise
Code: 'lasten, niet de lusten': this code represents the negative sentiment towards noise as an externality- that residents hear wind turbine operate but do not receive any benefits form them developers/landowners do- this gives the wind turbine sound a negative association
Code: Adapting/living with noise in everyday life this code includes collection of information about how residents adopt to the presence of WTN/LFN/brom tone and deal with noise annoyance. For the people who are very annoyed this includes changes to lifestyle such as new patters of recreation and relaxation (both inside and outside home), changes to the bedtime routine and sleep time, altered perceptions of comfort and safety at home.
Code: *Spatio-temporal context:* this includes information about the effect of landscape and vegetation on perceived noise annoyance and when during day/night it is experienced. For example, vegetation is very important in shielding them form noise or that the 'brom tone' is most annoying at night, and why (no other environmental noises that would mask the 'brom' tone and sound of blades)
Code: *Wind turbine technology/design:* residents own ideas about how design/selection of wind turbines or how the

design could be improved, concerns about malfunctioning turbine or about a wrong choice in the WT model
Code: *management of wind farms/smart operation:* this includes the information that residents shared about their expectations for what noise modes will be implemented, how wind farm will operate, the promises that were made about the noise levels
Sub-theme: Demarcations and decision-making.
Code: *2 km distance:* how people make sense of the 2 km demarcation for the app- ideas about whether noise can be heard outside of 2 km but, presence of LFS or the hum tone
Code: *Legislative context:* opinions the current Dutch legislation for noise - especially the contestations of the rule that the noise limits are based on a yearly average rather than an absolute daily maximum and the fact that there is no legislation for LFS/tonality
Code: *Communication about noise* opinions about the process of receiving information, searching for information about the noise app, and potential misinformation about the noise
Code: *Finding solution and taking responsibility for noise:* perceptions about of collective/individuals' ideas about who should be responsible for providing data about noise annoyance, to solve the issue or to adapt to and how to manage the wind farm
Code: *Fairness of solutions:* perceptions about the fairness of proposed solutions, also in relation to financial compensation
Code: *Socio-economic context;* ideas about how the issue of noise relates to other wind energy projects in the Netherlands and to the trends in governance of wind energy developments (how the needs of local communities are accounted for/not)
Code: *Connected concerns:* this includes shadow flicker (minor concern), obstruction lights (major concern).

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