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An Exploratory PPGIS for the Nuclear Waste Repository Siting Procedure in Germany – a Transdisciplinary Approach to Enable Meaningful Participation?

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Abstract

Germany's debate on nuclear energy is characterized by a potential for conflict. With the Repository Site Selection Act, a new strategy was adopted for a participatory search process for the best possible repository site for high-level radioactive waste in Germany. To gain insights into how a Public Participatory GIS application (PPGIS) can contribute to this strategy, a transdisciplinary approach was adopted. By involving a citizen group to take part in the research process, we co-designed and addressed three research questions regarding the role of the PPGIS, its usability and ability to enable dialogue. Key findings include the need for guidance on how to interpret the data provided. Although the potential of a PPGIS to support dialogue is recognized, the need for content moderation emerged as a significant challenge. The transdisciplinary approach was useful in capturing multiple viewpoints and providing new insights into how a PPGIS should be designed to maximize its usefulness.

Keywords:

nuclear waste, PPGIS, transdisciplinary, dialogue, bottom-up

1 Introduction

There are not many conflicts as long-running and divisive in Germany as the one around nuclear energy (Brunnengräber & Di Nucci, 2019). With the decision to phase out all remaining nuclear power plants (NPP) in Germany by the end of 2022, only three NPPs remain in operation. As the production of nuclear energy is no longer the focus of debate, attention is shifting to the management of highly radioactive waste (HLW). Brunnengräber (2019) describes HLW as an 'eternal burden' as it needs to be safely stored for approximately one million years (Schwenk-Ferrero, 2013). The political designation of a salt dome close to the rural village of Gorleben to bear all HLW from the former West Germany in 1979 sparked a conflict that lasted decades and resulted in the re-initiation of the entire siting process for an HLW repository. As the so-called decide-announce-defend strategy did not work in the case of nuclear waste management (Di Nucci et al., 2017), a new strategy was adopted: a participatory, science-based, transparent, self-questioning and learning procedure to find the best possible final repository site in Germany (StandAG, 2017). Currently, the Federal Company for Radioactive Waste Disposal (BGE) is in charge of conducting geological research on different kinds of host rock (crystalline, salt rock and claystone) that are regarded as capable of safely encapsulating and sealing HLW from the surrounding environment. In September 2020, a report was published which stated that 54% of German territory is potentially suitable for hosting an HLW repository. Those regions so identified are called sub-areas (BGE, 2020).

As the search for a repository site is a socio-technical challenge, Public Participatory GIS applications (PPGIS) can help bridge the gap between the complex scientific and societal parts of the challenge. To generate new insights into how a PPGIS can empower non-academic participants, a transdisciplinary approach was adopted, characterized by a flat hierarchy between researchers and non-academic partners (e.g. lay citizens). Non-academic partners are actively involved in the research process, as they co-design the study and co-produce knowledge (Hoffmann et al., 2017).

This paper elaborates on the need to connect HLW management, PPGIS and transdisciplinary research, and is structured as follows. The state of research regarding PPGIS for societal challenges is described, followed by a description of why and how a transdisciplinary approach was used in this study to design and address our research questions. These research questions were: *1) What role could a PPGIS application potentially play in the site selection process? 2) How can low-threshold usability be enabled against the background of the technically and geologically complex issue? 3) To what extent can dialogue be enabled by a PPGIS application?* After a presentation of the study's method, the results are presented and discussed.

2 State of research

PPGIS are characterized by their ability to enable lay people to voice their concerns and provide personal knowledge about matters in their own vicinity. This is in contrast to technocratic approaches, which usually focus on expert knowledge (Nummi, 2018). Schlossberg & Shuford (2005) emphasize that 'public' and 'participatory' aspects have to be taken seriously and should not function just as labels. Another defining aspect is the availability of, and access to, the PPGIS for all actors affected (Rzeszewski & Kotus, 2019).

PPGIS can reveal their full potential at the interface of societal and technological processes (Rzeszewski & Kotus, 2019). By recognizing non-experts, they integrate local knowledge to help address complex issues (Brown & Kyttä, 2018). Such knowledge would otherwise be difficult or impossible to obtain by a central operator or planner (Nummi, 2018). A key factor is enhancing personal capabilities and knowledge in making sense of spatial relations by providing relevant information in a comprehensible manner. Accessible information is important (Marti et al., 2019) but intertwined with suitable presentation and explanation. By taking local knowledge into account, PPGIS can contribute to procedural justice (Denwood et al., 2021). In this context, Prado et al. (2021) highlight that the equalizing effect between contributors favours just procedures. Procedural justice is highly dependent on the agenda and intention of decision-makers. Epistemic justice, especially hermeneutical justice (see Fricker, 2007), can be regarded as a prerequisite for making sense of spatially complex information. The availability of information in itself cannot be considered a gain if those in receipt of the information lack the ability or intention to make sense of it. Marti et al. (2019) describe how visual and textual enhancement can therefore improve hermeneutical capabilities.

Brown & Kyttä (2018) sketch out some key issues of PPGIS that are also applicable to nuclear waste management, such as stakeholder interaction, complexity of the topic, and wider applicability. For technical challenges, the flow of information is usually monodirectional (top-down), meaning that information about the progress of a specific project is directed from the operating side to the local population affected. PPGIS offer the unique possibility of low-threshold interaction with operating actors. Complexity can be broken down by a PPGIS and thus enable users to understand the spatial relation of data and why decisions were made in a certain way. Schlossberg & Shuford (2005) argue that a prerequisite for a PPGIS to succeed is simple communication about content, purpose and how to use the application. This simultaneously increases the application's credibility. If comunication is properly addressed, a PPGIS can enhance sustainable planning procedures while avoiding or minimizing conflicts (Rall et al., 2019).

As the willingness to participate via web tools is high (Rzeszewski & Kotus, 2019), participatory mapping is constantly intertwined with PPGIS. Participatory mapping refers to how humans interact via maps by contributing knowledge or ideas that are spatially fixed. This can be accomplished by adding a marker, line or polygon that can be described further by the addition of text (Brown & Kyttä, 2018). Material knowledge, but also societal (immaterial) matters, can be made visible and spatially explicit, such as a sense of place (Gottwald et al., 2021), which is valuable for the interaction of space and technology (Müller et al., 2020) and enables planners to gain a better understanding of socio-spatial relations (Huck et al., 2014).

Whereas conventional WebGIS applications enable users to assess their individual socio-spatial situation and gain additional information, e.g. regarding a seismic risk (Marti et al., 2019), PPGIS go beyond this informatory character. Gottwald et al. (2021) provide an example of how a PPGIS was used to improve the landscape design of a regional river landscape. Morse et al. (2020) show how a PPGIS was carried out to assess vulnerability to rising sea levels. And even when it comes to spatializing local values, as is done in cultural heritage planning, a PPGIS can contribute significantly (Nummi, 2018). On a national level, Walkobinger & Tauch (2018) present the case of infrastructure planning for a high-voltage power line from northern to southern Germany. They demonstrate how the mobilization and impact of local knowledge helped to optimize the course of the planned power line.

All these examples and studies have shown the wide-ranging potential of PPGIS approaches, but they have one thing in common: they analyse and conduct studies whose object can be spatially fixed above-ground. The case for nuclear waste is different. Only some facilities will be found on the surface, while most will be subterranean, in the deep geological underground. While people usually have sufficient knowledge about their own vicinity or region to meaningfully contribute, this cannot be presumed in the case of HLW management; new insights are needed into whether and how PPGIS can contribute in such complex cases. As there has been no transdisciplinary PPGIS study so far, other than for Huang & London (2016), there is a research gap that needs to be addressed.

A transdisciplinary approach was chosen in order to broaden out the perspective of researchers to include non-academic and other professional actors. Such approaches are well established in sustainability sciences (Brandt et al., 2013) but rather novel in geoinformatics research. Jahn et al. (2012, pp. 8–9) define transdisciplinarity as follows:

"*Transdisciplinarity is a critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress; integration is the cognitive operation of establishing a novel, hitherto non-existent connection between the distinct epistemic, social–organizational, and communicative entities that make up the given problem context.*"

Transdisciplinary approaches extend beyond citizen sciences approaches (Silvertown, 2009), as citizens do not merely support scientists in data collection but actively take part in the co-design of the research process and the co-production of the results (Lawrence et al., 2022).

We draw on the understanding of transdisciplinary research as presented by Pohl et al. (2017) and Hoffmann et al. (2017) and complement it by adding the standards for transdisciplinary research as formulated by Henze (2021). She describes dealing with complexity, contextualization, transparency, integration and reflexivity as major aspects of transdisciplinary research. As Pohl et al. (2017) state, transdisciplinary research aims to provide robust solutions for societally relevant challenges by linking scientific and societal processes. Hoffmann et al. (2017) emphasize the importance of the proper integration of knowledge into the research process. Transdisciplinary research is based on the meaningful and equal involvement of non-academic actors in the research process, i.e. in the design of the study (co-design) as well as in the generation of results and knowledge (co-production). The connection between transdisciplinary research and PPGIS can therefore help to bridge the gap between experts and the general public in complex decision-making processes (Dragicevic & Balram, 2006). GIS research needs to broaden its horizon to tackle increasingly complex societal as well as technical challenges and grow as a discipline (Kuhn, 2012).

3 Method

Our study design follows Pohl et al.'s (2017, p. 45) '10 steps approach' to determine how, when and why to involve which non-academic actors in the research process (indicated in section 4.1). The 10 steps correspond to the societal relevance of transdisciplinary research. We work with an accompanying citizen group (ACG), which consists of four male and two female members from different parts of Germany.

The study design is visualized in Figure 1. The procedure is as follows. The first workshop with two researchers and the ACG is carried out to determine the research questions (RQs) and the subjects on which the analysis of the PPGIS application will focus (co-design). We apply an adapted version of the 'Design Thinking' method (Pearce, 2020) to enable exchange between researchers and ACG without the barriers of roles. A silent discussion (exchange in written form only) generates topics for in-depth discussions in smaller groups before all insights are brought together in a final plenary discussion. In this final discussion, aspects for the RQs are agreed upon by all participants. The concrete formulation of the questions is carried out by the researchers and approved by the ACG.

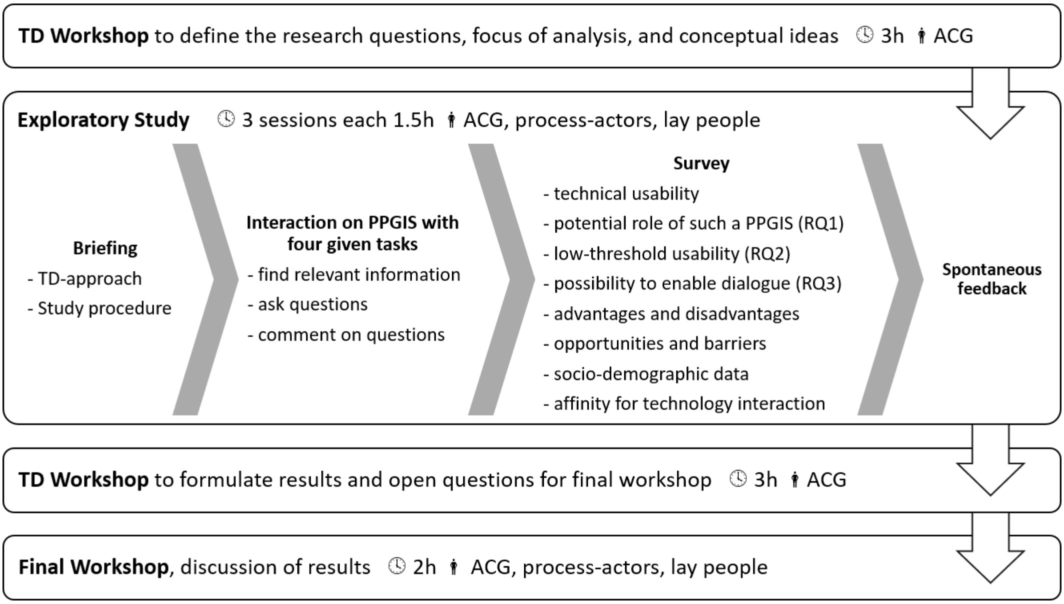

Figure 1: The study design

4 Results

The RQs, study design and methodological approach are all co-designed and therefore a result of the research process. Matters of the study design and methodology were derived from the content of the first transdisciplinary workshop and therefore originated from inputs formulated by the ACG together with researchers. Three RQs are formulated (step 1, cf. 10 steps (Pohl et al., 2017)):

RQ1. What role will a PPGIS potentially be able to play in the technical-geological siting procedure for a repository?

RQ2. To what extent does a PPGIS enable low-threshold use for a wide variety of population groups (e.g. age, gender, affinity for technology, language level)?

RQ3. To what extent can dialogue about the siting procedure for a repository be enabled by a PPGIS?

4.1 Co-Designed Methodological Results

The study is being conducted at the beginning of the participatory siting process for an HLW repository in Germany. Based on the RQs and impulses of the first workshop, an exploratory PPGIS application is set up (see Figure 2), comprising spatial data relevant to the siting process, as well as a forum for spatially situated questions and answers, as requested by the ACG. The challenge of comprehensible communication is framed against the background of the RQs; different platforms for dialogue are bundled into a single platform to enable comprehensible and transparent information exchange (step 2). The next step in the siting process is the massive reduction of above-ground sub-areas. Participants in the siting process have different types of knowledge to contribute to this process (step 3). The aim of our study is therefore to create target knowledge, especially how meaningful dialogue can be enabled in the future of the siting process (step 4). Various types of actor are involved in the course of the study. Whereas in the co-design of the study only researchers and the ACGare involved, the PPGIS is tested with additional actors, such as state actors, members of NGOs, municipal representatives, other researchers and laypeople. This is necessary for the exploratory study to be practically and societally relevant (step 5).

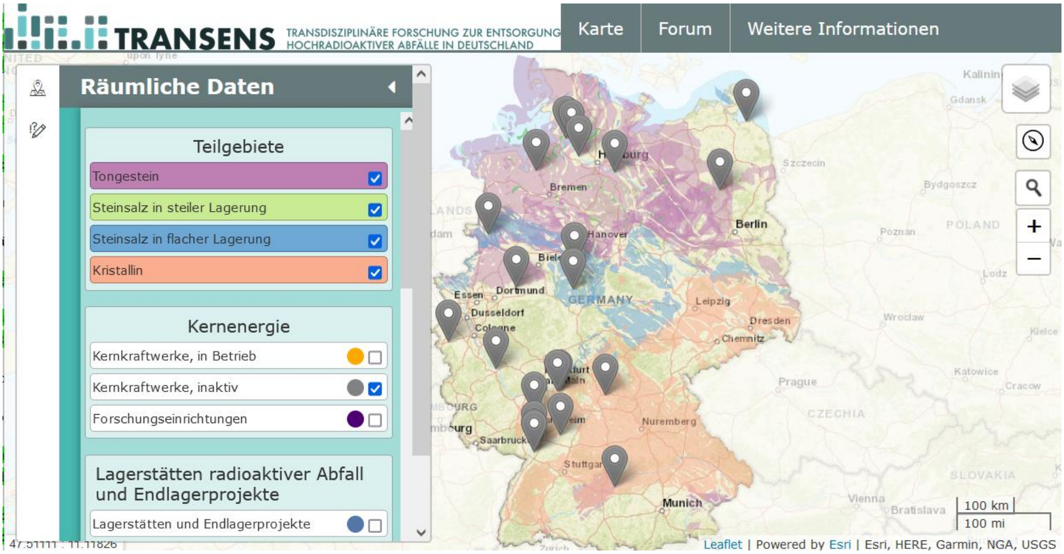

Figure 2: Screenshot of PPGIS in map view, with five layers displayed (sub-areas and inactive NPPs)

Although the approach requires research to be conducted without hierarchies between researchers and non-academic actors, some tasks need to be carried out by disciplinary specialists. The first workshop was necessary to determine which aspects should be included in the exploratory PPGIS. The application setup is carried out by the researchers, as specific knowledge is required for this step. The researchers log all comments and participate in discussions around the RQs as well as after the testing of the PPGIS application, thus creating a setting for meaningful exchanges (steps 6, 7, 9). We expect substantial and normative contributions from all participants concerning the necessity and conceptualization of the

PPGIS within the siting process (step 8). Through reflection on the study design and constant consultation with the ACG, the transdisciplinary approach has the potential to research societally relevant topics and generate knowledge concerning the RQs (step 10).

The PPGIS application contains spatial data about the sub-areas; sites of active and inactive nuclear power plants and research facilities; (interim) storage sites for low (LLW), intermediate (ILW), and highly radioactive waste (HLW), and other nuclear sites. It also includes spatial data on climatic variability, geology, demography and administration (see Figure 3). The inclusion of the mentioned data was suggested mainly by the ACG. For the implementation, the Leaflet library was used, and the layers were hosted via Esri. All the data in the PPGIS is derived from publicly accessible sources, such as federal agencies (e.g. Federal Institute for Geosciences and Natural Resources (BGR) and BGE), NGOs (e.g. Atommüllreport), or public data hubs.

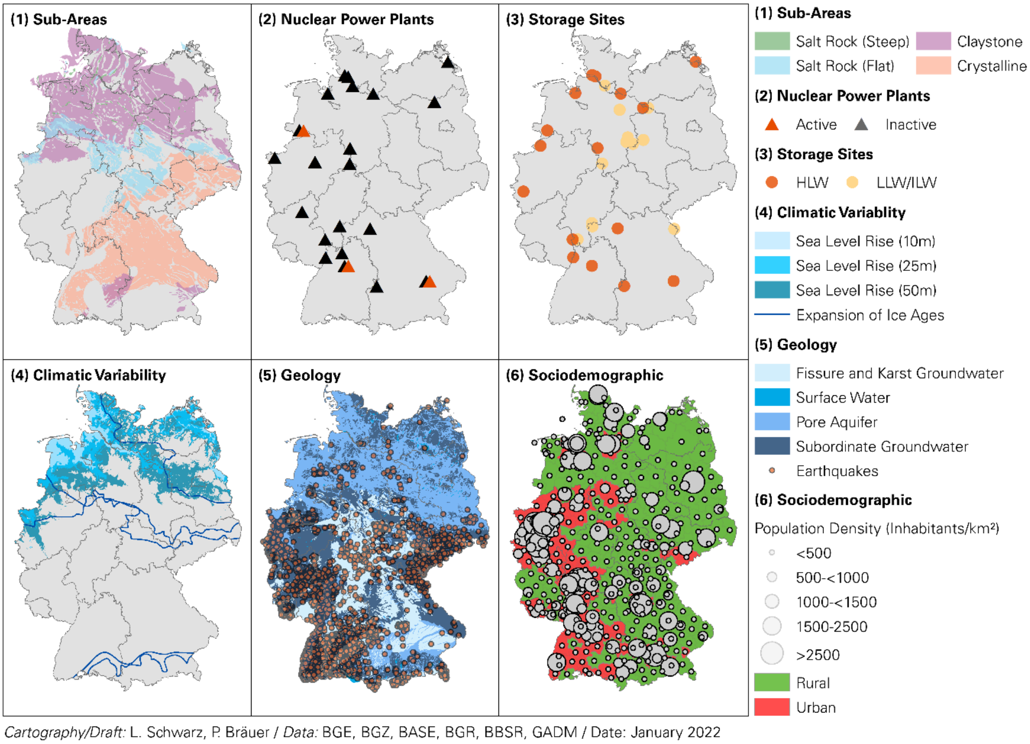

Figure 3: Selection of data displayed in the PPGIS (own figure)

In a second workshop, the PPGIS was tested by the ACG and the additional actors (gender: 21 male/19 female; age distribution: 5 people aged 18–25; 18 people aged 26–45; 11 aged 46–60; and 6 aged 60+). The study sample (*n=40*) was chosen to include participants who were actively or passively involved in the siting process, as well as ordinary citizens who were not directly involved. Data were collected on three dates in December 2021 (see Figure 1). Subjects were personally invited via e-mail and (except for the ACG) received no remuneration for their participation.

Subjects were briefed via an online conference tool and then received a link to the PPGIS. Within the application, participants were given four tasks concerning their ability to find relevant information, ask questions, and comment on others' questions. This stage was complemented by a survey and a free discussion. Figure 1 shows the themes on which questions were posed. All quantitative items were evaluated using a 5-point Likert scale (1=low, 2=fairly low, 3=neutral/medium, 4=fairly high, 5=high). To adequately address the RQs, descriptive, bivariate and cluster analyses were carried out. The cluster analysis was based on the affinity for technology interaction scale (ATI-S) (Wessel et al., 2019), as well as the subjects' knowledge about geology and nuclear waste repositories. A hierarchical approach was chosen, using the Ward method and the squared Euclidian distance as a proximity measurement (Backhaus et al., 2018). The open questions and insights from the free discussion were coded using MAXQDA and integrated to interpret the statistical data.

4.2 Results of the Exploratory Study

Most subjects had a medium understanding of repository questions (*mean=3.37, standard deviation=1.40)* – although this is fairly high compared to the general population – and less profound knowledge about geology *(Ø=2.61, SD=1.22).* To allow for a more detailed and in-depth analysis of those differences within the sample, we carried out a cluster analysis, detecting three clusters. Figure 4 shows how the three clusters are distinguishable by two canonical discriminant functions. The three clusters are the *Profound Subjects* (CLU1, *n=20*), the *Repository-Expert Subjects* (CLU2, *n=10*), and the *Subjects Without Stake* (CLU3, *n=10*). CLU1 is characterized by a high technical affinity (*Ø=4.00, SD=0.50*), a fairly high knowledge of nuclear waste repositories (*Ø=3.95, SD=0.85*), and a fairly high knowledge of geology (*Ø=3.53, SD=0.70*). CLU2 is distinguishable by a medium technical affinity (*Ø=2.88, SD=0.92*), high knowledge of nuclear waste repositories (*Ø=4.33, SD=0.71*), but fairly low knowledge of geology (*Ø=2.00, SD=1.00*). The last cluster (CLU3) has a medium technical affinity (*Ø=2.98, SD=1.03*) and low knowledge of nuclear waste repositories (*Ø=1.4, SD=0.52*) and geology (*Ø=1.4, SD=0.70*). As the characteristics of each cluster have implications for the perspectives of the participants within them, the differences will be discussed in the following sections. CLU1 and CLU2 are more similar to each other than CLU3, but still clearly distinguishable from each other.

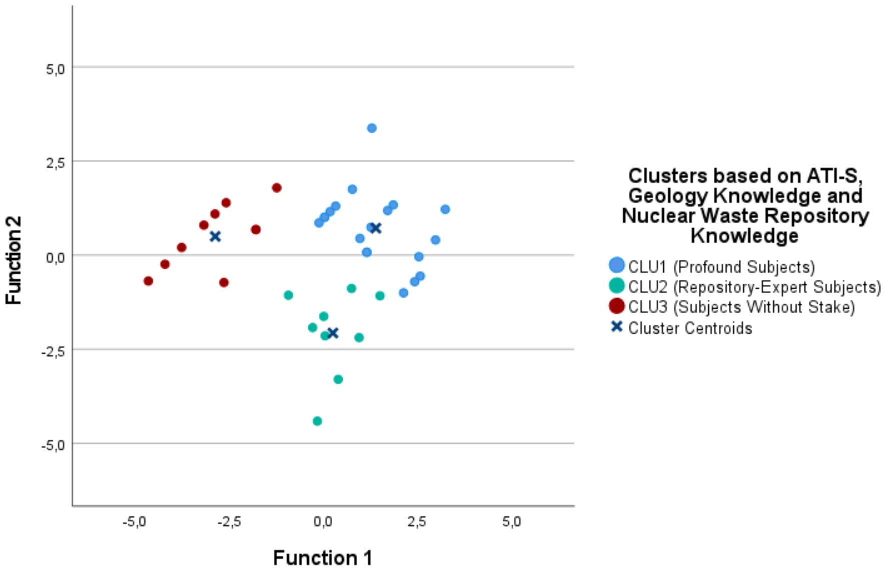

Figure 4: Canonical Discriminant Function between the three detected clusters

Most subjects (*n=30*) agreed that the application was not difficult to use (*Ø=1.98, SD=0.97*). 37 subjects stated that they would not need any technical assistance to use the application, with another 30 answering that they did not need to try out functions extensively before working with the application. Although subjects from all clusters imagined that other users would learn fairly quickly how to use the PPGIS, CLU3 would use the application the least often (*Ø=3.00, SD=1.00;* compared to CLU1/2 *Ø=3.88/3.70, SD=0.93/1.25*). Participants' responses led to the identification of a (general) improvement that could be made to the PPGIS application: to provide bundled spatial information that would allow overlap and comparison of data.

For the role of the PPGIS in the siting procedure (RQ1), 32 subjects agreed that it contained at least fairly relevant information. 31 subjects added that the data was at least fairly comprehensible (i.e. they were fairly neutral about the comprehensibility of the data itself (*Ø=3.46, SD=0.85*)). In addition, no clear tendency emerged as to whether participants thought that the application could enable a meaningful discussion, or whether it was suitable for the complexity of the siting procedure. Among all subjects, there is a moderate correlation between the comprehensibility of the application and its data on the one hand and its relevance (*a=0.452***) on the other; there is another moderate correlation between the suitability with regard to the complexity of the siting procedure and the relevance of information (*a=0.556***). All clusters agree to different extents that the information provided in the PPGIS is at least fairly relevant to the siting procedure (*Ø=3.89–4.05; SD=0.32–0.99*) and presented in a comprehensible manner (*Ø=3.89–4.15; SD=0.60–1.09*). In the open questions, subjects state that the application enables exchange between different kinds of actors (from the technical operator to the general population), can present information in a spatially meaningful manner, and offers the possibility to intersect different kinds of spatial data (e.g. sub-areas and the expansion of historic ice ages).

Some challenges and barriers to having a meaningful role in the siting procedure were identified. Subjects raised concerns that no real dialogue can be enabled by a virtual platform such as a PPGIS, which poses its own technical and thematic barriers. For the PPGIS to develop into a more meaningful platform, subjects in all clusters agreed that instructions for the interpretation of the data provided are needed – for example, what does the historic extent of ice ages mean for a potential nuclear waste repository, and how could a potential site be affected by this in the future? This specific thematic gap was identified by CLU3 subjects and supported by subjects from other clusters.

Concerning the low-threshold usability of the PPGIS (RQ2), the subjects were divided, especially regarding the language barrier, with a slightly negative assessment for CLU3. For CLU1 and CLU2, a very strong correlation between the application's complexity (suitable to the siting procedure) and the relevance of the information provided was observable (*a=0.848**; 0.823***). For CLU3, a very strong negative correlation between knowledge of geology and the need for moderation (*a=-0.818***) demonstrates that lay participants require the presentation of (definitive) facts within a PPGIS, as they are unable to interpret data and formulate opinions on their own. Although it is normally possible for a PPGIS to provide broad information to allow novices to enter the siting procedure, CLU3 identifies the absence of specific information without context or explanation as a barrier to low-threshold usability. A subject of CLU1 proposes 'target group-specific vocabulary and map design' to mitigate the unequal accessibility among participants that is due to their unequal technical and thematic knowledge.

On the question of whether dialogue can be facilitated via the PPGIS (RQ3), a positive tendency is noticeable for the possibility of thematically-focused discussions, but it is also recognized that the the platform needs moderation. Meaningful dialogue correlates with the possibility to ask questions (*a=0.597***), as well as with thematically-focused discussions (*a=0.567***). CLU2 especially is in favour of a (human) moderator deleting disruptive comments to enable precise and fact-based dialogue. CLU3 emphasizes that meaningful dialogue is about asking questions and receiving clarification. Regarding discussions, CLU1 and CLU3 have a more positive assessment than CLU2. Nonetheless, members of CLU1 believe that a professional discussion cannot be enabled, and that a PPGIS would mostly represents an additional application for dialogue. CLU2 concludes that no real dialogue can be achieved.

5 Discussion

The first results of the transdisciplinary approach for the conception of the PPGIS are generally positive, as evidenced by the perceived low-threshold usability of the application. Thus, our results are consistent with the work of Pohl et al. (2017), who also show that a transdisciplinary design can deliver low-threshold usability. The findings of Kuhn (2012) can also be confirmed: by taking a transdisciplinary approach, the GIS discipline can be developed further.

In line with Dragicevic and Balram (2006), our study provided a critical assessment of joining experts and laypeople with each other on a shared platform: experts could dismiss the PPGIS as irrelevant to them because of a lack of new information and consider it merely as a source of information; without further explanation, the data presented could be misunderstood, and thus a PPGIS would fail in enabling citizens (especially with regard to novice participants). This failure, in turn, could be used, for example, to mobilize protests on site, which would slow down the progress of the site selection process. Bridging the gap between experts and laypeople, therefore, needs to be critically examined in the continued course of the study.

All clusters see a potential for the PPGIS to be used by novices. At the same time, they formulate barriers to a meaningful and enriching dialogue for the siting procedure, especially the considerable and constant moderation that is required in the application. These concerns should be taken seriously, as this transdisciplinary study enables the transposition of conclusions from the exploratory setting to the real siting procedure. One aspect that cannot be properly assessed in the exploratory setting is to what extent local knowledge will be helpful. Just how the different stakeholders would assess a PPGIS as a source of local knowledge is one area for future theoretical discussion. However, data from practice is needed to assess the added value of such knowledge.

6 Conclusion

The transdisciplinary approach of co-designing the PPGIS and co-producing knowledge based on the application has proved insightful. Technical and thematic aspects regarding barriers have been identified, such as how a meaningful integration of non-specialists into the siting procedure can be achieved, from data acquisition to a forum for dialogue with interacting and contributing participants, moderation, data backup and documentation. The burden of moderation was pointed out constantly by participants, who stated that information can be outdated, and disrupting comments need to be deleted so that the dialogue within the application remains clear and focused. The question remains as to just what information can be contributed by public participation to the socio-technical and geological siting procedure. The PPGIS can work either as a dynamic map to show the progress of the siting procedure and to aid public understanding of the decision-making process, or as a platform for the contribution of (relatively) small-scale information. The findings so far are not clear about the language barrier and low-threshold usability. Further research should therefore look at how informatory texts and help guides could improve the PPGIS's ability to allow people meaningfully to contribute to the siting procedure (e.g. by increasing people's knowledge and capacities for interpretation).

The transdisciplinary approach described here helps in designing a PPGIS application that suits the requirements of non-academic users, and in identifying important criteria (such as moderation, role in the siting process, language, content) if the application is to be truly meaningful in the siting procedure for a final nuclear waste repository in Germany.

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References

Backhaus, K., Erichson, B., Plinke, W., & Weiber, R. (2018). *Multivariate Analysemethoden*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-56655-8

BGE. (2020). *Sub-areas Interim Report pursuant to Section 13 StandAG*. https://www.bge.de/fileadmin/user_upload/Standortsuche/Wesentliche_Unterlagen/Zwischenbericht_Teilgebiete/Zwischenbericht_Teilgebiete_-_Englische_Fassung_barrierefrei.pdf

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & Wehrden, H. von (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Brown, G., & Kyttä, M. (2018). Key issues and priorities in participatory mapping: Toward integration or increased specialization? *Applied Geography*, *95*, 1–8. https://doi.org/10.1016/j.apgeog.2018.04.002

Brunnengräber, A. (2019). *Ewigkeitslasten: Die "Endlagerung" radioaktiver Abfälle als soziales, politisches und wissenschaftliches Projekt* (2., aktualisierte und überarbeitete Aufl.). *Schriftenreihe / Bundeszentrale für Politische Bildung: Bd. 10361*. Bundeszentrale für politische Bildung.

Brunnengräber, A., & Di Nucci, M. R. (Eds.). (2019). *Conflicts, Participation and Acceptability in Nuclear Waste Governance*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-27107-7

Denwood, T., Huck, J. J., & Lindley, S. (2021). Effective PPGIS in spatial decision-making: Reflecting participant priorities by illustrating the implications of their choices. *Transactions in GIS*, Article tgis.12888. Advance online publication. https://doi.org/10.1111/tgis.12888

Di Nucci, M. R., Brunnengräber, A., & Isidoro Losada, A. M. (2017). From the "right to know" to the "right to object" and "decide". A comparative perspective on participation in siting procedures for high level radioactive waste repositories. *Progress in Nuclear Energy*, *100*, 316–325. https://doi.org/10.1016/j.pnucene.2017.07.005

Dragicevic, S., & Balram, S. (2006). Collaborative Geographic Information Systems and Science. In S. Balram & S. Dragicevic (Eds.), *Collaborative Geographic Information Systems* (pp. 341–350). IGI Global. https://doi.org/10.4018/978-1-59140-845-1.ch017

Fricker, M. (2007). *Epistemic Injustice*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198237907.001.0001

Gottwald, S., Brenner, J., Albert, C., & Janssen, R. (2021). Integrating sense of place into participatory landscape planning: merging mapping surveys and geodesign workshops. *Landscape Research*, *46*(8), 1041–1056. https://doi.org/10.1080/01426397.2021.1939288

Henze, J. (2021). Zur Wissenschaftlichkeit transdisziplinärer Forschung. *GAIA - Ecological Perspectives for Science and Society*, *30*(1), 35–43. https://doi.org/10.14512/gaia.30.1.8

Hoffmann, S., Pohl, C., & Hering, J. G. (2017). Methods and procedures of transdisciplinary knowledge integration: empirical insights from four thematic synthesis processes. *Ecology and Society*, *22*(1). https://doi.org/10.5751/ES-08955-220127

Huang, G., & London, J. K. (2016). Mapping in and out of "messes": An adaptive, participatory, and transdisciplinary approach to assessing cumulative environmental justice impacts. *Landscape and Urban Planning*, *154*, 57–67. https://doi.org/10.1016/j.landurbplan.2016.02.014

Huck, J. J., Whyatt, J. D., & Coulton, P. (2014). Spraycan: A PPGIS for capturing imprecise notions of place. *Applied Geography*, *55*, 229–237. https://doi.org/10.1016/j.apgeog.2014.09.007

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics*, *79*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Kuhn, W. (2012). Core concepts of spatial information for transdisciplinary research. *International Journal of Geographical Information Science*, *26*(12), 2267–2276. https://doi.org/10.1080/13658816.2012.722637

Lawrence, M. G., Williams, S., Nanz, P., & Renn, O. (2022). Characteristics, potentials, and challenges of transdisciplinary research. *One Earth*, *5*(1), 44–61. https://doi.org/10.1016/j.oneear.2021.12.010

Marti, M., Stauffacher, M., & Wiemer, S. (2019). Difficulties in explaining complex issues with maps: evaluating seismic hazard communication – the Swiss case. *Natural Hazards and Earth System Sciences*, *19*(12), 2677–2700. https://doi.org/10.5194/nhess-19-2677-2019

Morse, W. C., Cox, C., & Anderson, C. J. (2020). Using Public Participation Geographic Information Systems (PPGIS) to Identify Valued Landscapes Vulnerable to Sea Level Rise. *Sustainability*, *12*(17), 6711. https://doi.org/10.3390/su12176711

Müller, S., Backhaus, N., & Buchecker, M. (2020). Mapping meaningful places: A tool for participatory siting of wind turbines in Switzerland? *Energy Research & Social Science*, *69*, 101573. https://doi.org/10.1016/j.erss.2020.101573

Nummi, P. (2018). Crowdsourcing Local Knowledge with PPGIS and Social Media for Urban Planning to Reveal Intangible Cultural Heritage. *Urban Planning*, *3*(1), 100–115. https://doi.org/10.17645/up.v3i1.1266

Pearce, B. (2020). *Design Thinking*. https://doi.org/10.5281/zenodo.3717021

Pohl, C., Krütli, P., & Stauffacher, M. (2017). Ten Reflective Steps for Rendering Research Societally Relevant. *GAIA - Ecological Perspectives for Science and Society*, *26*(1), 43–51. https://doi.org/10.14512/gaia.26.1.10

Prado, C., Colectivo Salud y Justicia Ambiental, & Red de Ciudadanos para el Mejoramiento de las Comunidades (2021). Border Environmental Justice PPGIS: Community-Based Mapping and Public Participation in Eastern Tijuana, México. *International Journal of Environmental Research and Public Health*, *18*(3). https://doi.org/10.3390/ijerph18031349

Rall, E., Hansen, R., & Pauleit, S. (2019). The added value of public participation GIS (PPGIS) for urban green infrastructure planning. *Urban Forestry & Urban Greening*, *40*, 264–274. https://doi.org/10.1016/j.ufug.2018.06.016

Rzeszewski, M., & Kotus, J. (2019). Usability and usefulness of internet mapping platforms in participatory spatial planning. *Applied Geography*, *103*, 56–69. https://doi.org/10.1016/j.apgeog.2019.01.001

Schlossberg, M., & Shuford, E. (2005). Delineating "Public" and "Participation" in PPGIS. *URISA Journal;*, *16*(2), 15–26. https://www.urisa.org/clientuploads/directory/Documents/Journal/vol16no2.pdf

Schwenk-Ferrero, A. (2013). German Spent Nuclear Fuel Legacy: Characteristics and High-Level Waste Management Issues. *Science and Technology of Nuclear Installations*, *2013*, 1–11. https://doi.org/10.1155/2013/293792

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, *24*(9), 467–471. https://doi.org/10.1016/j.tree.2009.03.017

StandAG. (2017). *Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für hochradioaktive Abfälle: Standortauswahlgesetz - 1.Novelle.*

Walkobinger, W., & Tauch, A. (2018). Projekt SuedLink - ein Werkstattbericht. In J. Strobl, B. Zagel, G. Griesebner, & T. Blaschke (Eds.), *AGIT - Journal für Angewandte Geoinformatik: Vol. 4. AGIT - Journal für Angewandte Geoinformatik* (pp. 123–129). Wichmann.

Wessel, D., Attig, C., & Franke, T. (2019). ATI-S - An Ultra-Short Scale for Assessing Affinity for Technology Interaction in User Studies. In F. Alt, A. Bulling, & T. Döring (Eds.), *Proceedings of Mensch und Computer 2019* (pp. 147–154). ACM. https://doi.org/10.1145/3340764.3340766