Post-print version of the paper by Neset et al. in, Applied Geography 2016; Volum 74. s. 65-72 108 (2017) 27-46
http://dx.doi.org/ 10.1016/j.apgeog.2016.07.003

Climate change effects at your doorstep: geographic visualization to support Nordic homeowners in adapting to climate change

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Highlights

- VisAdapt aims to support Nordic homeowners´ climate change adaptation processes
- The research involved developers and users through a transdisciplinary approach.
- Downscaled information is a key element expected by users
- Assessment of interactivity and data varied both across countries and user experience
- VisAdapt made climate effects tangible and initiated discussions and reflections

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ABSTRACT

The complexity of climate information, particularly as related to climate scenarios, impacts, and action alternatives, poses significant challenges for science communication. This study presents a geographic visualization approach involving lay audiences to address these challenges. VisAdapt^{TM} is a web-based visualization tool designed to improve Nordic homeowners' understanding of climate change vulnerability and to support their adaptive actions. VisAdapt is structured to enable individual users to explore several climate change impact parameters, including temperature and precipitation, for their locations and to find information on specific adaptation measures for their house types and locations. The process of testing the tool included a focus group study with homeowners in Norway, Denmark, and Sweden to assess key challenges in geographic visualization, such as the level of interactivity and information. The paper concludes that geographic visualization tools can support homeowners' climate adaptation processes, but that certain features, such as downscaled climate information are a key element expected by users. Although the assessment of interactivity and data varied both across countries and user experience, a general conclusion is that a geographic visualization tool, like VisAdapt, can make climate change effects and adaptation alternatives tangible and initiate discussions and collaborative reflections.

Keywords: geographic visualization, climate change, Nordic climate adaptation, science communication

1. Introduction

The Nordic countries are facing several expected climate change and weather-related effects such as increased annual average precipitation and temperature, more frequent and intensified cloudbursts, an increased number of days with extreme high temperatures (i.e., heat waves), and potentially more days with strong winds (IPCC, 2013; Juhola et al., 2014). Anticipated impacts include increased variation in water runoff levels, higher humidity, increased coastal erosion and number of landslide events, as well as larger-scale sea level rise. All these impacts pose new challenges for society, not least for urban planning, the building and insurance sectors, and homeowners. To increase Nordic homeowners' capacity to cope with climate change and weather-related extreme events, a Nordic research collaboration has designed and developed a visualization-supported web tool. This paper presents the results of the tool development and evaluation process involving the designated end-user group—private homeowners. The paper analyses the overall results of the evaluation process based on three dimensions of the concept of the map-use cube (MacEachren, 1994; MacEachren et al., 2004), i.e., user profile, knowledge, and interactivity, to provide structured guidance for future tool development.

In recent decades, the Nordic countries have experienced severe damage and rising costs related to extreme weather events, such as flooding and storms. A subsequent increase in the number of compensation payments made to homeowners has been noted by the insurance industry, which is expecting a further rise in payments throughout the region in coming years (Danish Insurance Association, Finance Norway, Federation of Finnish Financial Services, & Insurance Sweden, 2013). The impacts of climate change and extreme weather events on private residential buildings have been addressed by an increasing number of scientific studies (e.g., de Wilde and Coley 2012; Lisø 2006; Nie et al. 2009). Anticipated risks in the region include various forms of leakage and flooding due to increased and intensified precipitation (Kvande & Lisø, 2009; ten Veldhuis, Clemens, & van Gelder, 2011), mould and rot due to increased humidity (Almås & Hygen, 2012; Nik, Sasic Kalagasidis, & Kjellström, 2012), and health risks due to intensified heat waves (Guan, 2012; Nikolowski, Goldberg, Zimm, & Naumann, 2013).

Against this background, we designed a web-based visualization tool, VisAdapt™, to meet the requirements of Nordic homeowners. The tool content includes some of the key climatic and weather-related impacts that might influence Nordic homes over the coming 40–60 years. In an effort to improve basic communication (Wibeck et al., 2013), the tool incorporates concrete measures for reducing these potential risks, linking them to the selected region and impacts.

Several online map-based tools focusing on climate vulnerability and adaptation are available, published by national or international agencies, research institutes, or private-sector organizations (Neset, Opach, Lion, Lilja, & Johansson, 2016). Initiatives like the ESRI climate resilience app challenge[1] have shown the great potential of map-based applications focusing on e.g. flood risk mapping, rainwater harvesting or urban heat waves. Multiple examples of such tools target the general public, but often without clear links to adaptation measures. Several tools have been established as part of more generic climate communication websites providing information on climate impacts and climate adaptation on separate parts of the site. A challenge addressed when designing the VisAdapt tool was how to integrate both climate information and adaptation measures into one comprehensive platform, while providing a certain level of human computer interaction (Card, Moran, & Newell, 1980) adapted to the intended audience. VisAdapt thereby seeks to take an additional step toward helping a specific target group—homeowners—to explore climate change risks and adaptation alternatives in their own regions and for their specific house types.

2. Geographic visualization

The development of the VisAdapt tool draws on the concept of geographic visualization or geovisualization (MacEachren & Kraak, 2001), which developed during the late twentieth century. Geovisualization integrates “approaches from visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis, and geographic information systems to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data” (MacEachren and Kraak 2001:3). Geospatial data are relevant to addressing numerous challenges, so we find geovisualization applications in many disciplines and adapted to various user groups: experts and specialists, users with moderate cartographic skills and experience, as well as lay users. Geovisualization solutions provide flexibility in data exploration ranging from sophisticated interactive multiple linked views (Andrienko & Andrienko, 1999; Roberts, 2005) used mostly by knowledgeable and experienced users (Andrienko & Andrienko, 2007) to simple tools such as interactive weather forecast maps that can be used by everyone. In interactive geovisualization tools, geospatial data exploration is often facilitated by the integration of map and data displays that support information acquisition and extraction as well as knowledge construction (MacEachren et al., 2004). Key elements of geovisualization tools are graphical data representation as well as an interactive user interface (Bishop, Pettit, Sheth, & Sharma, 2013), which together help communicate complex multidimensional issues (MacEachren et al., 2004). The rethinking of mapping that has taken place during recent years (Dodge & Perkins, 2009; Kitchin & Dodge, 2007) bears great relevance on the conceptualization of geographic visualization, expanding the perspective of mapping far beyond data representation, and emphasizing that ‘maps are practice – they are always mappings; spatial practices

[1] http://www.esri.com/software/landing_pages/climate-app

enacted to solve relational problems' (Kitchin & Dodge, 2007), which points towards the importance of considering the user interaction and contextualization of maps. This paper explores the multiple dimensions of a map based tool, relating to the transition from traditional cartography to geovisualization as discussed by MacEachren and Kraak (2001) in relation to the three dimensions of the map-use cube (MacEachren, 1994). As illustrated in Fig. 1, the communication of predefined messages (i.e., presenting the known) has expanded to encompass the possibility of acquiring new knowledge (i.e., knowledge acquisition/exploration), significantly increasing the level of interaction. The development of interactive geovisualization tools has similarly gone along with a shift in audience from a public (lay/broad) audience toward a more private (expert) audience. Applying this framework to describe and evaluate VisAdapt allows for more generic guidance for future tool development.

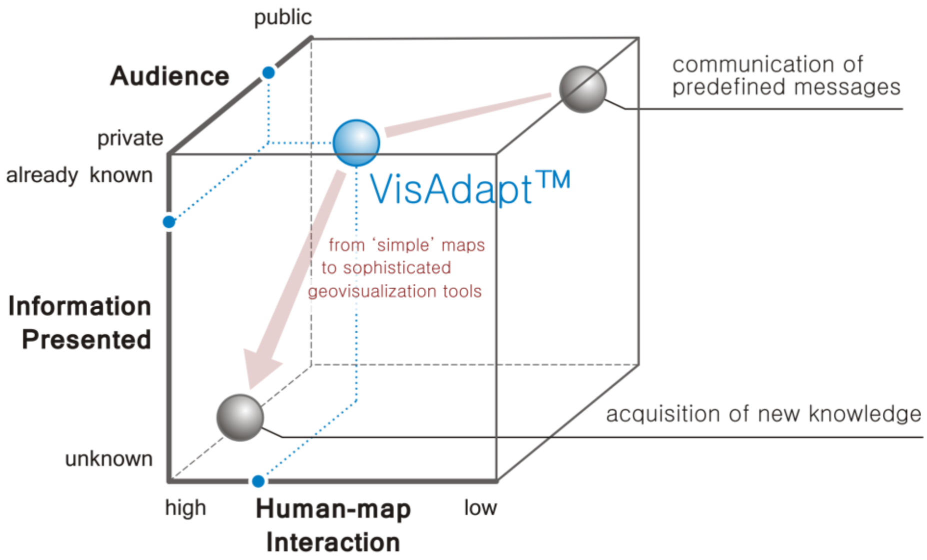

Fig. 1. The role of a geovisualization tool changes depending on its target audience's level of expertise, level of interactivity (human-map interaction), as well as its data content (whether it shows already known or unknown information).

Referring to the map-use cube shown in Fig. 1, we developed the VisAdapt tool for a lay audience (i.e., the public), and argue that it represents already known knowledge and features a relatively high level of interactivity (MacEachren, 1994; MacEachren et al., 2004). Evaluation efforts focused on the specific end-user group, on assessing whether the level of interactivity was adequate for this end-user group and for the purpose of the tool, and on the extent to which the included information was considered relevant and comprehensible. The design and development of VisAdapt draws on basic principles of geographic visualization and additional elements of information visualization.

Usability evaluation has become a common approach to study the benefits of map based interactive displays (Nivala, Brewster, & Sarjakoski, 2008) . We however apply the map-use cube as an analytical lens through which we evaluate end-user reflections regarding the form, interactivity, and the knowledge structure of the VisAdapt tool. We did this through focus group interviews with participants from the target audience of Nordic homeowners. As such, this paper reports findings relating to how these potential users of VisAdapt perceive the tool in relation to the three dimensions of the map-use cube. This allows for reflexive evaluation of both the design and development process to guide the future development of interactive visualization-supported tools in the field of climate science and related areas.

3. The VisAdapt tool

VisAdapt applies elements of geographic and information visualization in order to help individuals increase their capacity to adapt to climate variability and change by facilitating the exploration of expected climate and weather-related effects in the Nordic region. Users can select specific locations or regions to obtain specific information about potential climate impacts and adaptation measures. This enables the assessment of local vulnerability and reflection on possible adaptation options. VisAdapt was developed mainly for private homeowners, to be used in a personal setting on a personal computer, tablet or smart phone, but has the potential to function as a decision-support and information tool for insurance professionals, land-use planners, and property managers as well as facilitating knowledge exploration for students and teachers.

The design process started with the requirement identification phase in which relevant climatic parameters were reviewed, and downscaled data being acquired for this purpose. Other risk-related data comprising flood-risk maps, sea level rise maps, and exposure indices were selected as well as adaptation measures from multiple sources in the Nordic countries. A geographical visualization approach, which constituted a continuous evaluation process, was used to design the tool and plan evaluation sessions with stakeholders and end users. This continuous evaluation accompanied the development process.

3.1 Analysis of climate and risk related data

Global warming is anticipated to lead to increased annual mean temperatures, especially at higher latitudes. For the Nordic countries this means the increased occurrence of heat waves, higher annual precipitation, and more frequent cloudbursts (Glaas, Neset, Kjellström, & Almås, 2015)—important climate parameters selected for inclusion in the VisAdapt tool.

The Rossby Centre of the Swedish Meteorological and Hydrological Institute provided us with regional downscaled ensemble data for representative concentration pathways 8.5 and 4.5 (i.e., the highest and a moderate scenario). The present version of VisAdapt, however, incorporates RCP 8.5 to avoid too many selection options for the user. Data were derived from netCDF format for daily values for the 1961–1990 base period up to the 2051–2070 scenario years. The end of this period was selected to be sufficiently far in the future to indicate trends in the selected parameters, though close enough in time to be relevant to homeowners' current renovation needs.

Flood-risk maps, one of the most common tools encountered in climate adaptation planning and management, were integrated as far as they were publicly available. The availability of flood risk maps varies between the Nordic countries. While only a 100-year flooding map layer was available for Sweden, the Danish, Finnish, and Norwegian national authorities provide a larger variety of flood risk maps, a selection of which were integrated into the tool. Danish and Finnish authorities also provide risk maps for sea level rise.

3.2 Analysis of adaptation measures

The compilation of adaptation measures in the tool is based on an assessment of information available from a large number of public and private actors and networks in Sweden, Denmark, and Norway, presented on their homepages or in reports. The criteria used when gathering this information was that it should specifically target individual homeowners, and that it should relate to the climate and weather risks outlined for the region (Glaas, Neset, et al., 2015). The information sources include the following:

- national adaptation web portals of the three countries,
- national government authorities in relevant areas, e.g. environmental protection, building and housing, climate and energy, coastal protection, water resources, and civil contingency,
- the three largest municipalities in the three countries, which all have developed management

systems for climate change adaptation, and
- the three largest insurance companies and their national organizations in each of the three countries.

Measures were systematically compiled and sorted in accordance with anticipated climate change or weather-related risks for residential buildings in the Nordic countries. In order to do this in a scientifically sound way, a literature review of climate change and weather risks for residential buildings was performed, which provided an extensive list of risks for various house parts (roof, façade, foundation, garden and location) and components/materials (Glaas 2014). The house components/materials, i.e. roofing felt or tiles/tin roof, were held general enough to be sufficient for all found climate/weather risks. The lists of climate/weather risks were then sorted under the specific climate variables outlined in the VisAdapt tool. Risks not relevant for the Nordic region were deleted. Last, the collected measures were sorted under related climate/weather risk in the list. This compilation allowed a direct linkage between the measures and the climate scenarios and anticipated risks in the region, as well as with the possible choices in the house builder function (see Fig. 2).

3.3 The visual interface

VisAdapt is a web-based tool with coordinated multiple views. It was developed based on open-source APIs such as AngularJS, OpenLayers3, D3, and Bootstrap, using a single web page application design (Johansson et al. forthcoming). The map component was developed using OpenLayers3, which enables the functionality to display map tiles and layers on an HTML canvas. The interactive gauges are implemented using the D3 API. The interface is structured in a three-step exploration process and designed to guide non-expert users in locating their house and exploring data and measures for this location.

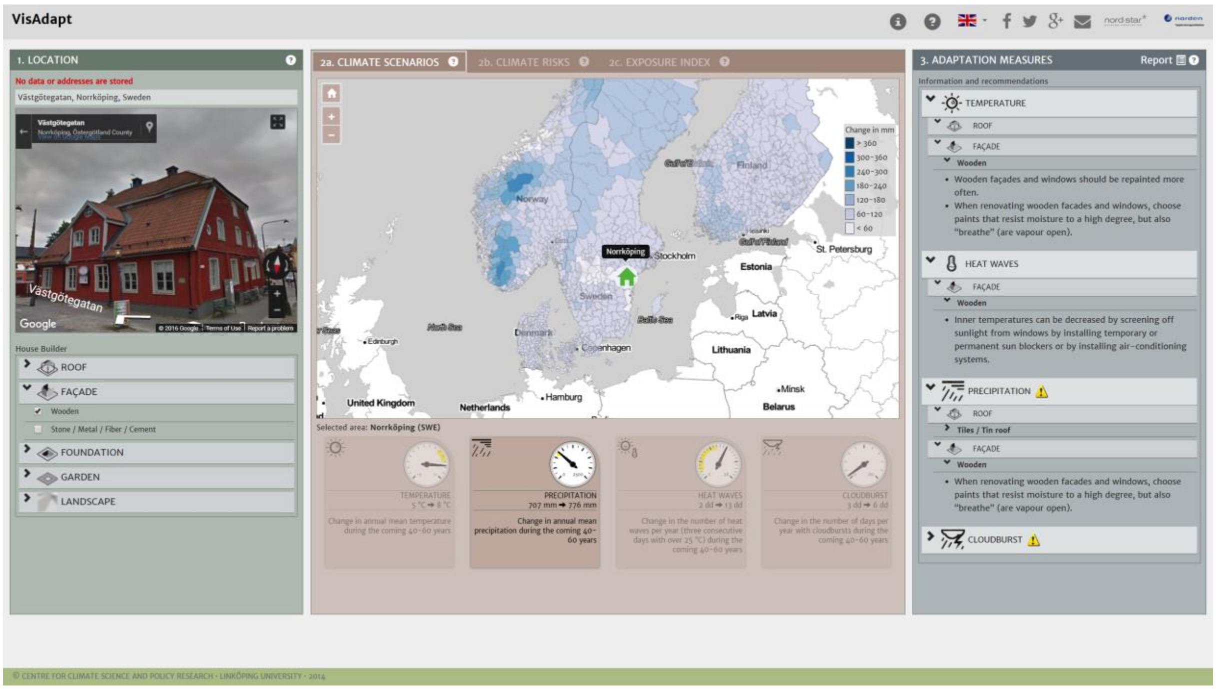

Fig. 2. The VisAdapt visual interface.

In step one, the user inserts his/her address and selects specific features of the house, such as roof type and garden topography. In step two, the user is enabled to select climate parameters, risk maps, or exposure indices. Climate parameters include change in annual average temperature, change in number of heat waves, change in annual precipitation, and change in annual number of cloudbursts. The risk map tab provides a selection of available risk maps for areas covered by 20-, 50-, or 100-year floods or sea level rise. The exposure maps, currently available only for Norway, provide municipal indices for exposure to storms, landslides, and flooding (Opach & Rød, 2013; Rød, Opach, & Neset, 2015). In the third step, adaptation measures are presented. These are of particular relevance to the climate or risk parameter selected in step two for the specific region and house type.

Experimental evaluations, both individually and in groups with house owners or experts, continuously informed the tool development. We present and analyze the main results of the comprehensive focus group evaluations in Sweden, Norway, and Denmark in the following section.

4. Focus group evaluation with end-users

To ensure that the tool was perceived as relevant to homeowners, and to gather continuous feedback during the design and development process, we conducted multiple stakeholder workshops with experts from the insurance industry, a pilot study based on the first prototype, as well as seven focus group interviews with end users. The former feedback, i.e. workshops with insurance experts and the pilot study with homeowners, resulted in lists of improvements which were systematically incorporated in the design of the tool. The workshops with insurance experts were held two times per year during the three year design process, while the pilot study was held once after the first prototype had been developed (Johansson et al forthcoming). The latter focus group material is analyzed in this study since this material was collected after the final design of the tool and served the purpose of evaluating the tool from a user perspective.

VisAdapt was developed as a means of communication with Nordic homeowners as the main intended user group. Defining communication as a constitutive practice, where users or audiences are seen as active participants in interpreting and assigning meaning to, for example, visual content, highlights audience interpretations as particularly relevant aspects of an evaluation process (Ballantyne, 2016; Craig, 1999). In this perspective, communication is not conceptualized as a matter of transmitting information to an audience, nor is the focus on outcomes or effects in terms of measuring behavior or attitude change. Rather, communication – and the evaluation of specific efforts – is seen as a process that focuses on how audiences interpret message content. Hence, specific questions tied to the evaluation of VisAdapt addressed qualitative aspects of communicative effects of the tool, which was examined through the use of focus group interviews.

Acknowledging that people in different cultural and social contexts interpret things differently, and following that creators and users of VisAdapt likely interpret and assess the relevance and applicability of the tool in different ways, we applied a focus group methodology to gain insights into how targeted users actually perceive the tool. Focus group interviews are defined as "a research technique that collects data through group interaction on a topic determined by the researcher" (Morgan, 1997, p.6). The interactive and social nature of focus group interviews encourages participants to verbalize their perspectives and allows for their views to develop in the social context of the focus group context, making the method appropriate to study how people's perceptions, knowledge, and ideas are shared and evolve in a social setting (Krueger, 1998; Marková, 2007; Wibeck, Dahlgren, & Oberg, 2007). Accordingly, as applied in the evaluation of VisAdapt, the methodology focused on gaining insights into potential end users' perceptions and interpretations of the tool's contents and interactive features in a social setting to study, for instance, the perceived relevance of the tool from the users' perspectives. Focus group interviews were considered the best method for analyzing end-user perceptions and understanding of the tool since it allowed us to analyze in-depth how homeowners made sense of and understood specific contents by allowing us to record both participants tests of the tool, as well as the follow-up discussion where the tool were discussed. Such in-depth analysis would not have been possible by using quantitative methods such as questionnaires.

Studies of climate change communication emphasize the importance of considering contextual factors and audiences' interpretive frames of climate change when planning and evaluating communication efforts, as these shape people's interpretations (Ballantyne, Wibeck, & Neset, 2016; Wibeck et al., 2013). To accomplish this, we divided the focus group interviews into three phases. First, we engaged the participants in a general discussion of climate change focusing on risk perceptions and perceived adaptive capacity. This served to create an understanding of the participants' general perceptions of climate change and of associated risks and adaptive capacity. Second, we divided the participants in small groups (two to three people) and gave them the opportunity to explore the VisAdapt tool. Third, after these test sessions, the discussion returned to the focus group format, in which we encouraged the participants to discuss their experiences and views of VisAdapt. This last session provided insights into participants' perceptions and interpretations of VisAdapt's content, visual representations, and interactive features.

Since Nordic homeowners are the target users of VisAdapt, we held the focus group interviews in three Nordic countries, i.e., in the cities of Aarhus (Denmark), Trondheim (Norway), and Norrköping (Sweden), to ensure a distribution in perceptions of climate change exposure. The focus group participants represented a variety of homeowners in relation to rural/urban location, age, occupation, and gender. Table 1 lists some facts about the seven focus groups. We used the first interview as a pilot study to test and adjust the three-phase structure of the interview design.

Table 1. Distribution of focus group interviews.

No.	Group size	Place	Date
1	3 (pilot study)	Aarhus, Denmark	20 June 2013
2	6	Norrköping, Sweden	17 June 2014
3	5	Norrköping, Sweden	18 June 2014
4	5	Trondheim, Norway	3 Nov. 2014
5	8	Trondheim, Norway	4 Nov. 2014
6	6	Aarhus, Denmark	6 Nov. 2014
7	5	Aarhus, Denmark	7 Nov. 2014

5. Results: assessing VisAdapt with end users

For the purpose of data analysis, we conducted a thematic content analysis (Halkier, 2012; Wibeck et al., 2007) in which the interview transcripts were systematically categorized, coded, and analyzed in accordance with the three dimensions of the map-use cube: audience, knowledge, and interactivity (MacEachren, 1994). Applying these three dimensions of the map use cube as analytical perspectives allowed us to create a structured analysis that generates several generic insights that will advance future tool development. The qualitative data obtained from the seven focus group interviews provided insight in the joint reasoning of the participants. As such, individual comments are featured to exemplify analytical points, but the overall thematic analysis revealed generic features related to the three analytical dimensions, rather than quantifiable results.

5.1 Audience

Two key issues for the design of a geographic visualization tool of any kind are, first, the specification of the information to be conveyed and, second, the specification of the intended audience, which might range anywhere from uninitiated lay users to expert users. However, a lay audience might be somewhat initiated and well aware of various types of data, as was the case with some of the focus group participants. While participants were selected to match the criteria of being homeowners from various age groups with homes located both in the countryside and in more urban areas, their professional or experiential background had in several cases provided them with significant previous knowledge relevant to either using the VisAdapt tool (through previous IT experience) or to understanding and interpreting the data provided. The challenge of how to achieve the right level of information in the tool for both uninitiated and initiated users was captured in several focus group discussions. One segment of participants (especially in one of the Norwegian focus groups) suggested, for example, increasing the amount of selectable data or increasing the interactivity and flexibility so that it would be possible to add other types of data to match the needs of a well-informed audience. Several participants in this segment claimed that the tool did not reveal much new information to them individually, but that it would make a valuable contribution to the general public. Participants that brought forward such perspectives had in several cases professions in which they were used to manage geospatial data, which would not be the case for an average user. Even though the assessment of the tool differed both across countries and between users, it was described more as a tool for ‘everyone’ than for experts, placing it closer to the ‘public’ corner of the map use cube (fig1).

Discussions in both Swedish focus groups also concerned how to approach a broad user group. However, as opposed to the above, these participants instead emphasized the great complexity and amount of data integrated into the tool. They even suggested reducing the complexity of the information included and instead adding optional links to more detailed information. In particular, some participants described the map featuring climate scenario data and risks as overwhelming. Reflections concerning “ordinary users” and their time constraints were among the arguments articulated in the second step; it was claimed that featuring both geospatial data and “compasses,” i.e., information on data changes, was too time consuming and could lead to stagnation in learning to use the tool for uninitiated users. In particular, several participants expressed difficulties understanding what specific changes in climate parameters might actually lead to. This appeared as a general challenge where many participants expressed that they did not have sufficient previous knowledge of the current climate to be able to understand how much difference e.g. a four degree change in annual average temperature actually would be. These results revealed that the standard way of presenting climate scenarios through choropleth maps is far from straight forward for triggering reflection on climate impacts. In order to spur further reflection on impacts, the relation between climate scenarios and impacts thus appears as a key feature to develop further in future climate change related tools.

Participants nevertheless identified the possibility of personally exploring climate impacts and measures as a positive feature, and claimed that VisAdapt enables users to create their own unique analysis, to select data or information relevant to their own localities and house types. However, a frequently raised issue was the need to create a clear connection between the individual user’s own house and the presented data. This applied in particular to the climate data rather than to the third step with measures, where the link to the user’s house was considered more explicit but could arguably be developed further. Critical comments on the measures concerned their general nature: the measures were compiled for the entire Nordic region, and hence did not differ so much between the selected locations. Users argued that they should have access to different measures proposed by their local and regional authorities, to capture local and national practices and policies.

An additional issue raised, which appeared important with respect to the user profile, was the terminology used in the tool. As some of the climate and risk parameters were described in subject-related technical language, several questions about their meaning were raised in both the test sessions and the ensuing discussions. Similarly, terminology that described practical measures for adapting a house to climate change effects was considered to be too technical or expert oriented by one participant.

Moreover, several users argued that the tool's accessibility was highly dependent on user age and computer literacy. Most participants argued that the tool was designed in a lucid and pedagogical way; however, after the short test sessions, some participants described that the individual entry level to the tool, including the ease of navigation, varied within groups. As this study was not experimental and lacks a structured analysis of user profiles, this observation is not supported by further empirical data.

5.2 Knowledge

The knowledge dimension of geographic visualization tools is guided by the basic distinction between knowledge categorized as unknown or known, as such tools allow both the creation of new knowledge by exploring and combining data (revealing unknown knowledge) and the mere viewing of static data (observing known knowledge). Although the possibility of exploring data through posing and testing hypotheses with the help of the interface modules is limited in VisAdapt, the participants commented on a number of issues related to the creation of new knowledge, such as increasing the level of detail and facilitating the integration of local knowledge.

The level of detail, referring to both the geographical and data resolution, was an issue frequently raised in most focus groups. Several participants, particularly in the Norwegian focus groups, said that the information provided in the tool is not detailed enough, and that more local knowledge and data should be incorporated. Accordingly, VisAdapt should provide higher accuracy so that "for other places in the country you should receive other measures" (participant in the Norwegian focus group, author's translation). This desire for local and specific measures appeared to be guided by the first module of the tool, in which users are asked to type in their own address, generating a "street view" image of their house as well as the task "build your own house" (see Fig. 2). Even though the street view function appears relevant for creating a localized perspective of the climate change issue, it also risks creating demands for information, which would be impossible to include in a tool with such a broad scope. For example, several participants argued that municipal specific guidelines and local building regulations should be included, which would not be possible to keep updated for a region including more than a thousand municipalities.

Regarding the climatic parameters, some groups questioned the relevance of using changes in *average* annual temperature and precipitation, as they were seen as too general. As one participant in the Trondheim focus group put it, "We have four seasons in Norway." However, while the communicative relevance of annual average temperature change is a debated issue in this as in previous studies, annual average precipitation appeared in our study to be a key quantitative measure that serves as a frame of reference for many lay users in their home areas. For example, several participants were aware of the current annual average precipitation in their area, making anticipated precipitation changes easy to discuss.

Another frequent theme raised by participants was that of the data. Several participants explained that the data did not "scare" them (see also Glaas, Gammelgaard Ballantyne, et al., 2015). The relatively "low" risk assessment of climate change effect in the presented data created a sense of low urgency. As participants in the Trondheim focus group expressed it, the average data presented are not sufficiently interesting or scary to evoke a reaction. It was suggested that presenting the "peaks," i.e., extreme values, might constitute more relevant information with greater potential to attract attention as exemplified in the quotes below:.

> This is based on average expected increase. Would it have been more appropriate if the "peaks" had been shown? So what happens at the extreme peaks? Because it is there that, in many ways, it is interesting to the homeowner, because the house has to withstand these peaks. Suddenly we have 1000 mm per day or something. What will the area look like then, and what will happen with the ravines? (participant in the Norwegian Focus Group, author's translation)

> Well, I think that the changes are so small, and I don't think it matters to me whether we get four or six days with cloudbursts. (participant in the Danish Focus Group, author's translation)

To make the tool more useful, participants requested data on sea level rise, links to concrete actions, and how to approach some of the suggested changes, as well as more detailed maps in terms of time spans. In particular, some participants claimed that the adaptation measures (step three; Fig. 2), which received significant attention during the test sessions, appeared oversimplified and over-generalized. Some of the suggested measures were considered generic and not necessarily connected to climate change, such as cleaning one's stormwater drains.

> It's too simple. They are too generic—that you have to paint your house when the paint peels off, to ensure that the gutter is not too tight. … You probably don't have to connect these to climate change either, because these are things you have to do anyway. (participant in the Norwegian Focus Group, author's translation)

> But I think that the measures suggested by the program … well, for me there was nothing new in relation to how to maintain your house by cleaning gutters and making sure that drainage is okay and removing snow near the house, because all of those things we do anyway. (participant in the Danish Focus Group, author's translation)

Furthermore, the number of items/signifiers that can be selected to design the specific house type was considered too limited by some participants. For example, only two types of roof can be selected. Some participants mentioned that the tool should consider the year of construction of the selected house as an additional important factor that would influence the type of measures presented.

Nevertheless, several participants considered the overall level of detail too great for lay users, illustrating the difficulty of striking a balance between level of detail and information overload in interactive tools for lay audiences. Several participants commented on the "right level" of information in terms of both quantity and detail. Several other participants said that the tool provided the appropriate level of detail in terms of quantity, but also that most of the information was not surprising in itself. Some participants referred to VisAdapt as "a tool to make you more conscious" of both climate change risks and adaptation options. The fact that the information VisAdapt presents is collected in one comprehensive tool might make it easier to remember, reflect on, and refer to in various situations. However, end users might already be aware of the presented information. Particularly in the Norwegian focus groups, participants explained that they were already familiar with, for example, local downscaled data about flood and landslide risks, which are made available through the national spatial data infrastructure. With reference to the map use cube, VisAdapt consequently situates towards the already known corner. Data availability, however, varies significantly between the Nordic countries, Swedish data, in contrast to Norwegian and Danish data, remaining rather inaccessible for the general public. As one Swedish participant put it, "just collecting everything in one place is excellent" (participant in the Swedish focus group, author's translation).

5.3 Interactivity

Compared with other issues, the interactive features of VisAdapt were discussed to a lesser extent in the assessments. Throughout the focus group discussions, participants most frequently referred to what they regarded as improper functionalities or offered suggestions for improving them, similar to how they reacted to the information content issue. During the assessment period, VisAdapt still had some technical flaws that required attention. Comments on interaction with VisAdapt therefore often concerned functionalities that did not fully work rather than the experience of interacting with the tool.

Some general observations concerned smooth navigation between the sections and parameters, zoom and pan functions for exploring multiple geographic areas, and the exploration of multiple parameters, particularly for the risk categories. A particularly smooth interaction frequently mentioned as increasing user's interest, was the insertion of one's address and selection of house features. The three-step structure of the tool guided participants to follow the tool's logic, although the second step was described as more intensive in terms of the time needed to explore and understand the content as well as the difficulties in navigating with the pan and zoom functions. The third step, which was less complex but provided more text to read and discuss, often led users to return to the second step and revisit information about a parameter that attracted their interest or arose in discussion, spurred by the list of adaptation measures. Visual attributes were predominantly discussed when interpreting the maps in step two. Color scales in the legend were related to data on one's own location and gave a rapid overview of other comparable regions and places.

The possibility of selecting different parameters was appreciated; however, several participants mentioned the potential benefits of alternative options, such as allowing the selection of other time periods and providing more of a "checklist" in the third step dealing with adaptation measures. Participants also requested the ability to generate a printed summary report on one's house. The tool itself, however, was frequently described as a useful "dashboard" that enables a quick overview and raises awareness. Some of the interactive features of the tool seemed not to have their intended effects, however; for example, users appeared in principle unaware of the sorting of priorities in the adaptation measure panel. Nevertheless, in sum the end users assessment situates VisAdapt towards the high interactivity corner of the map use cube.

6. Conclusions

While many web-based tools for science communication exist in the field of climate change and climate adaptation, at the time of its development, the design of VisAdapt was unique in its combination of information on climate change and risk parameters with concrete measures for specific house types. Although several visualization tools have been developed for various purposes over the last few years, we found no other tools of similar design. The design and development of the VisAdapt tool has been an iterative process starting from early experimental studies that indicated the need for a clear structure to guide users. The continuous stakeholder evaluations and focus group studies with end-users discussed here contributed to the optimization of the tool as well as to deeper insight into the level and type of information and the interactivity for the intended audience. This study focused on end users' reflections on VisAdapt, and sought to draw conclusions as to how tools in this segment could be further developed to attain higher functionality and reach an even larger group of users. Applying the dimensions of the map-use cube as an analytical lens allowed us to generate a number of generic insights that might support future tool development in this field.

A main finding of this study was that users expected more local and "personal" answers to their queries. This expectation was apparently induced by the first step of tool usage, when users were asked to enter their addresses and select settings for their houses. The more localized information referred, for example, to the change in precipitation for the specific location of a user's house, which was not regarded as "very local" because the same data applied to a larger area. The idea that climate change effects could differ significantly between areas within a city region was evident, as was the disappointment that differences caused by topography (particularly relevant in the Trondheim case) were not captured in the data. While this issue is difficult to address with the currently available downscaled climate model results, doing so would appear important in order to advance communication of the generic features of climate information and to convey that climate scenarios are more about "trends" than exact numbers of degrees.

A truism within geovisualization is that a high degree of user interaction is recognized as paramount for visualization tools to lead to new knowledge (MacEachren & Ganter, 1990). Our results, however, suggest that although interaction is relatively high and the tool facilitates exploration of large and complex datasets, it does not necessarily lead to the discovery of new knowledge if the content being shown is too aggregated and too general. With reference to the map use cube (figure 1), we therefore realize where the VisAdapt tool is today and where it should be in order to function optimal for knowledge discoveries.

The challenge remains that data represented in a tool such as VisAdapt are interpreted as predictive rather than as constitutive of many scenarios with inherent uncertainties (cf. Lorenzoni and Hulme 2009). This problem is linked to the nature of mapped representations. People are generally less skeptical toward maps than toward written or oral forms of expression (Monmonier, 1995), making maps more likely to be accepted without deeper reflection. Reflections regarding tool interactivity and user profiles diverged between groups, to some extent depending on the individual participants' country, background, and experience. During the workshops, we could observe that VisAdapt—despite its occasional bugs and lack of textual clarity at the time of the test sessions—functioned as a starting point for discussion and collaborative reflection even when participants disagreed about the information presented, for example, as in the case of specific adaptation measures.

Most participants could navigate easily through the tool, and the step-by-step structure provided a simple way to gauge progress in tool exploration. Nevertheless, participants appeared to move freely back and forth in the tool, exploring new parameters, testing other settings, and exploring other geographic areas for comparative reasons.

Despite all the features and functionalities that could be improved to satisfy the requests and needs of the Nordic end users, participants agreed that the VisAdapt tool represents a useful approach to collecting more specific information about adapting their homes to climate change. A general reflection from all focus groups was that a tool that collects and visualizes "all" relevant information is valuable to homeowners. In terms of both time and coverage, many participants described the tool as an efficient way of making climate information accessible and concrete to this group of end users.

Acknowledgements

This paper is a deliverable of the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR), which is funded by the Norden Top-level Research Initiative sub-programme "Effect studies and adaptation to climate change".

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