The development of decision support tools for climate and environmental action (a mini handbook)

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Summary

Decision support tools are popular outputs from academic projects aiming for societal and policy impact in the fields of climate and environmental research. A considerable number of these tools have been made, and there are numerous reviews and lists of existing tools, as well as some papers evaluating these tools. However, there is a lack of evidence that these tools reach those they are intended for, work well or are used to make policy decisions; as such there is a danger that they can be perceived as greenwashing. Surprisingly there is little advice on how to make a good decision support tool. The purpose of this review is to reduce the 'unknown unknowns' for people wanting to develop and build this kind of tool. We provide an overview of different types of decision support tools with relevant climate/environmental examples for each. We then cover the key considerations for designing and building better tools, from a developer's perspective. Our hope is that this supports more effective decision support tools to be made, and eases the process for those who are new to this area. All referenced resources are open access, and archived links have been provided where relevant and possible.

Introduction

Decision support tools are usually aimed at the gap between what researchers can provide and what decision-makers need, and are intended to help people come to faster or better decisions [1]. These tools typically analyse and organise large amounts of data/information, then structure and present it such that it is easier for people to understand, or to provide specific answers for people's questions. They are not always about the simplification of data, they can also be to help people see the richness, details and complexity within datasets.

These types of tools are often made by university and research institutes, government departments/agencies/institutions, and sometimes by non-profit initiatives or commercial businesses. The work involved is typically funded through research or innovation grants. Such tools have clear benefits when developed for specific situations (e.g. emerging infectious disease surveillance [2] or sustainable farming [3]) and this approach has attracted widespread interest up to intergovernmental level policy organisations [4, 5]. The Intergovernmental Panel on Climate Change (IPCC) note their use for a wide range of applications and particularly the benefits for Integrated Assessment Models (IAMs, representing the biophysical, social and economic systems and the feedbacks between them [6]). At a time where we urgently need evidence-based action on climate and environmental issues, decision support tools offer a tempting solution, and a considerable number are made, often as part of an academic project promising policy or societal 'impact'. However, many of these tools don't end up reaching those they are intended for, and indeed many don't work well from the off-set. A considerable number also don't get beyond the prototype stage, as they are made for a project deliverable without planning for their legacy, which requires ongoing development and maintenance. The purpose of this review is to reduce the 'unknown unknowns' for people wanting to develop and build this kind of tool, with the aim that better (and perhaps fewer) tools are produced.

For those looking for a comprehensive review of what decision making tools are and how they are beneficial for climate action, this has already been done excellently [1]. There are also numerous reviews of climate/environmental decision making tools that have been built, often covering specific topics/contexts (e.g. urban heat stress [7], city planning [8], or for specific countries [9], and a there are a large number of online lists of decision making tools [e.g. 8, 10, 11, 12, 13]. However, when tested, many of the tools reviewed or linked on these online lists didn't work at all or were prohibitively slow to run - which highlights some of the development issues that we will cover later in this review. The earliest list of decision support tools we found was from 1999, demonstrating that these types of tools have been prolifically produced for decades [14].

Published literature includes differing concepts of decision making tools, including tools that are computer-based (which we cover in this review), formalised decision making techniques/frameworks for people working together to come to decisions as a group [e.g. 15, 16], and analytical methods for assessing available options (like Cost-Benefit Analysis, Cost-Effectiveness Analysis, Multi-Criteria Analysis or Analytic Hierarchy Process [17]). Unsurprisingly we have also started to see projects that hope to use Artificial Intelligence

(AI) to automate climate decision making [18] - an approach fraught with its own particular ethical and quality issues. AI and machine learning techniques historically have been shown to model biases and questionable subjective decisions by obscuring poor quality datasets and presenting them as objective information [19]. Far from providing a magic bullet for removing the labour of interpreting complex data sets, much care and extra work is required to ensure that their benefits can be realised [20]. Of course sometimes more than one of these 'tool' type approaches are also combined into a single output, for example Cost-Benefit Analysis performed within a computer-based tool [21], and many tools exist that can be used for climate/environmental decision making but were not specifically designed for this purpose (for example widely used generic systems for collective decision making like Loomio). Setting aside the traditional understanding of the role of policymaker, a flourishing area exists building decision making software used for the collective organisation needed for climate protest [22]. In the case of Extinction Rebellion, this incorporates both the use of a variety of existing open source software such as MatterMost, Discourse and NextCloud as well as bespoke platforms for decision making and visualisation for understanding the organisation as a whole [23]. These collectively provide the digital extension of XR's "Self Organising System", which is itself based on a management theory known as "holacracy" developed in 2007 by Brian Robertson, an American software engineer [24].

Because of the varying definitions of 'decision support tools' it is important that we clearly state our scope. For the purposes of this review, we are using the term 'decision support tool' to broadly include anything computer-based that can help people make decisions specifically on climate and environmental issues, supporting people to analyse problems, identify and compare options, make decisions, and/or evaluate outcomes of decisions. Even within this definition, drawing the line for what type of 'tools' to include/exclude is not straightforward, for example any data visualisation to do with climate change could count, even if it is not interactive and not actively guiding people towards a decision, as people could make decisions based on the information portrayed (e.g. [25]; many people have written on climate visualisation e.g. [26]). Because of this tricky delineation, we begin with an overview of different types of computer-based decision support tools, with climate/environment-based examples for each. We believe this will act as a useful set of case studies for what could be possible for anyone setting out to design/build their own tool. We then lay out considerations for building a climate/environmental decision support tool, which we hope will provide others with a solid foundation from which to design and develop their own.

Different types of computer-based decision support tools

This list of tool types is designed to show different methods of data presentation. We have only included tool types where we could find examples that are related to climate and the environment, and that could conceivably be used to base a decision on. Some are debatable in terms of whether they constitute a 'tool', however this division is largely subjective, so they have been included to allow readers to draw their own lines. We have loosely split them into tool types that do or do not require the building of new custom software. The ones that may require custom work are divided into those that are either primarily text/number or image based. Within these loose categories we have ordered the tool types roughly by 'interactivity'. Interactivity usually simply means not showing all the data at once, and giving the user filters (in the form of geographical selections, dropdown menu options, sliders, or tick boxes for example) to only see the data they want - however it is a vague term and even scrolling or clicking a link within a PDF can be considered interaction. It is clear that the vast majority of the English-language documented tools come from Europe and North America, as such we are missing knowledge and information on the approaches taken in the rest of the world - this must be kept in mind.

1. Tool types that do not require custom software or visualisation methods

Online PDF files: These are essentially fact sheets, but are often referred to by their makers as tools so have been included for completeness. A recent example (2022) comes from city and heat packs developed by the MET Office [27]. Data has been analysed for specific locations, and presented as text and images with a view to informing decision makers.

Information websites: These are sites that have been made to provide information and/or data in the form of text or visualisations, but that have no interaction built in beyond clicking on links/tabs (as is also possible within a PDF). In a sense, they are simply a PDF in a 'live' format. Examples include The European Climate Adaptation Platform Climate-ADAPT [28]. Despite the technical simplicity of this approach, Hewitson et al. (2017) evaluated 42 climate information websites and drew the overall conclusion that they all '*grossly overestimate the ease of use*' [29].

Spreadsheets: Many simple tools are spreadsheets designed to work within existing proprietary software like Excel (some may also work with open software like LibreOffice Calc, but few are designed with this in mind so some functionality may be lost). These were popular in the early 2010s but the approach still persists. There are a few types of spreadsheet 'tool'. Some are intended simply to guide a users' process/thinking by encouraging them to fill out information (e.g. the UKCIP's 'Wizard' [30] and 'LCLIP: Local Climate Impacts Profile' [31] - note that the links are extremely slow loading), others are essentially databases of information (e.g. the UK Adaptation Inventory, which allows some basic search/export functions [32]). The spreadsheet tool approach offers straightforward possibilities to include automated calculations to summarise user-inputted data, for example in lifecycle analysis tools (e.g. FootprintCalc [33]).

2. Tool types that may require custom software or visualisation methods

2.1. Text/number based tools

Non-interactive text based information visualisations: These are perhaps the simplest form of portraying data in a dynamic way but without interactivity, an example is the Carbon Clock by Bloomberg, which is a live feed of current CO2 emissions [34]

Interactive text based information, without narrative: This type of tool is very similar to an information website, but the interactivity is slightly more complicated. It is still delivering only text-based information, but the user has more options to select from to filter what they see. This can make the volume of information less overwhelming for a user, but the selection options can overcomplicate the usability if they are not very carefully considered. An example is the Climate (Co)benefits Portal, which also shares some similarities with the spreadsheet tools [35]

Interactive text based information, with narrative: This format is most common in media outlets (English language examples are found most often from NY Times, Bloomberg and the Guardian) and involves a narrative article about a topic, interspersed with selectable options to filter the information, and sometimes also interactive data visualisations. The user is guided through the topic but also has the chance to explore elements of it in more detail [e.g. 36, 37]. A great, open source starting point for building this type of tool is Nutshell [38]. These tools often include some combination of interactive maps and graphs (see categories below), but the core thread is narrative text.

Calculators: This type of tool requires inputs from the user and then delivers a calculated answer, however they have been developed beyond a simple spreadsheet, usually to have an easier user interface. The most common example is perhaps carbon footprint calculators, which usually take the form of a questionnaire with selectable options, where the answers are analysed numerically behind the scenes (e.g. the WWF's Footprint Calculator for individuals [39]). Others require numerical inputs, which can require specialist knowledge prior to use (e.g. the Carbon Trust's SME Carbon Footprint Calculator for businesses [40]).

2.2. Image based tools

Non-interactive data visualisations: There are a considerable number of examples of climate data visualisations, for example those listed by the Climate Lab Book [41] and work from Information is Beautiful [42]. Typically they are aimed at informing people, rather than specifically supporting decision making, but this category is included for completeness. Data sonifications are also closely aligned to this category, as representations of data through sound rather than images, which could be particularly beneficial to people with visual impairments [43, 44, 45].

Interactive graphs: These tools usually involve some selection options to filter data that is then shown on a graph, and the graph itself may have some interactive elements like allowing the user to hover over data points to see additional information pop up. The barriers for building simple forms of this type of tool have been lowered, for example by the use of Shiny from RStudio [46]. Often there has been little attempt to take the data presentation away from normal academic standards, and/or the language used is complex. This can be a particular problem for users if specialist knowledge is needed to decide which options to select or to interpret the outputs. Additionally the use of graphs can form barriers in their own right as they are not widely understood/used [47]. Examples include the CropNet Demonstrator which shows graphs of crop yield projections [48]. Other examples combine the use of graph-based climate and flood projection data with maps with layered data (see Interactive Maps section below), like the Climate Explorer [49] and Climate Risk Indicators

[50]. Some tools try to use graphs in novel ways, for example the IPCC's Interactive Atlas Regional Synthesis which essentially puts graphs into hexagon formats, organised into an approximate map shape, with perhaps somewhat confusing results [51].

Interactive maps: Tools of this sort are very common, likely because GIS expertise is reasonably widespread within university and government departments. Essentially these types of tool are base maps showing a geographical area, with layers of data over the map which can be turned on or off so that they are seen or hidden. They are useful for contextualising data geographically. Examples include the Keep Bristol Cool Mapping Tool (ArcGIS based. Warning - this is very slow loading [52]), the NOAAView Data Exploration Tool [53] and the IPCC's Interactive Atlas Regional Information [54]. Some allow the selection of a specific location as opposed to showing the data for the whole geographical range of the data, for example the Climate Matching Tool [55], however the technical approach for building these is broadly similar. The interaction within these tools is usually limited to making selections from a range of options to view/hide different types of data. A common constraint with this type of tool is an inability to view multiple layers at the same time, although some do try to provide this functionality (e.g. Erosion Hazards in River Catchments [56]). These tools are often slow to load due to the volume of data, however this is a problem that can be solved by a skilled developer and thoughtful design.

Landscape visualisations: These are a specific type of data visualisation where (usually future) landscapes are constructed, often in 3D, to give a feel for what might happen to an area (e.g. with climate induced sea level rise) or what might be possible (e.g. by greening and adding active transport infrastructure to cities). The visualisations can take the form of static images, videos, or explorable 3D spaces (e.g. on a web page or using virtual or augmented reality). This approach comes from the architecture and design fields, and can be particularly helpful for enabling people to more clearly envisage/imagine change, which can make decision making easier [57, 58].

Other interactive systems: Data presentation in the form of maps and graphs is by far the most common in the decision support tools we have come across, probably because these methods are the most familiar and accessible for researchers. More ambitious approaches will likely need the involvement of designers and developers who can bring more divergent ideas and skills. An example is the My2050 Calculator which allows users to tweak sliders for various climate mitigation strategies to see how to reach net zero, along with an animation to give a hint of what this might look like in a city - this particular example has some similarities to landscape visualisation [59]. Another example, the Local Climate Adaptation Tool, uses a combination of narrative text and icon-based summaries for quick data overviews, with opportunities to explore the data in more detail both through the use of standard graphs for climate projections, but also using an interactive network that shows how climate impacts are connected and how uncertainty appears within a complex system [60].

This list of tool types is of course not exhaustive. More interesting possibilities exist that offer greater opportunities for understanding systems and for decision making, including understanding the implications of decisions themselves. Playable/explorable explanations are an underused approach that work extremely well for understanding complex systems like climate impacts. Nicky Case is one of the forerunners of this approach, and their Loopy tool is particularly well suited to climate and environmental systems thinking, as well as being open source and editable within the browser, meaning that the barriers to getting started are very low [61]. For some time, people have been working on interesting new ways of interacting with and exploring data, with collaboration and collective decision making at the core of their approach (for example, see the work of Bret Victor [62]), and we see great promise in approaches like DynamicLand [63]. Generic collaborative working tools like Miro and Etherpads allow people to build resources together without having to meet, and we can imagine intriguing scope for equivalent approaches for building peer-contributed tools and resources for climate/environmental purposes.

Considerations for building a decision support tool

For a decision support tool to work well it needs to attract attention, let the user examine/explore the data, help them form understanding/opinions, then encourage them to act. In other words the tool takes a user from insight, to actionable knowledge, to practical involvement (paraphrasing [64]). This section covers some of the main practicalities involved in designing and building a good decision support tool, to help those who are just starting out.

Platform decisions: Almost all of the decision support tools we looked at were browser based. This makes the tools widely accessible, and means that they should be able to be used on various device types (laptops, tablets, phones), operating systems (e.g. Mac, Linux, Windows), and browsers (e.g. Firefox, Brave, Chrome, Safari etc.). However, in reality making a system that works well across devices, operating systems and browsers requires development experience, partly because some features may work on one operating system/browser but not another, and partly because layouts need to be optimised to work on different screen aspect ratios (e.g the layout on a small portrait phone needs to be quite different to a large landscape desktop screen). Sometimes these systems can be developed as a phone app, in which case again the device type/operating system is a consideration (i.e. iPhone vs. Android). Phone apps are only really beneficial when the system needs to be used in a particular outdoor setting, like at a field site or on a research vessel, which is unlikely to be necessary for this type of tool and indeed we didn't find any tools made only for phone use. We came across a small number of tools which were made as software downloads for installation (a hurdle which will significantly reduce user numbers), however most of these were very outdated (e.g the Crop Sequence Calculator - 'a user-friendly program that runs directly from a CD-ROM' [65]). If the processing in a tool is particularly intensive, it may run faster as a downloaded app than in a browser, however this is becoming increasingly uncommon.

Open source: Free and Open Source Software (FOSS) allows anyone to access, use, copy or modify the software in any way, and allows people to view and voluntarily improve the software [66]. The 'free' in FOSS refers to 'freedom', not to financial cost, although this type of software also usually comes at no financial cost. This approach to software development is particularly well suited to research and policy areas because it allows users to interrogate the code and check that the system is working as it is said to be working. This helps to build trust, and also allows the software to be collectively improved as mistakes can be picked up by having more people able to look at the code. It also enables others to build on the work and adapt it for their own purposes, which maximises the reach of a piece of work, and makes good use of public funding. A commonly used licence is the GNU General Public License [67] however there are also specific derivative licences that may be appropriate for climate and environmental purposes such as the Common Good Public License [68]. Open source is considered best practice by the UK Government [69]. The opposite approach is 'proprietary' software, where the code is not made accessible.

Availability/cost: Open source and availability/cost are linked issues, but should not be conflated. Open source software can still be charged for (although others could replicate it and make it free), and proprietary software can be made free (although people won't be able to access the code to understand or build on it). In the process of writing this we came across several examples of climate decision tools which were being charged for, either as a one-off fee or a subscription, and sometimes with a simple free version and the full version accessed by paying a fee. These come both from public funded organisations (e.g. the MET Office's Decider, offering 'quick and comprehensive advice to forecasting teams or traders to ensure that decision makers working in weather-sensitive trades are fully informed' [70]) and from commercial organisations (e.g. S&P Global Climanomics [71]). However most climate/environmental decision support tools are provided to users at no costs, which will undoubtedly maximise the number of users, and is arguably the only ethical option given the urgency of climate action, the need for action to take place globally (not only in wealthy countries/institutions that can afford to pay for software and data access), and the fact that the development of many of these tools (and the data within them) were paid for by the taxpayer. In some countries, research institutions are coming under increasing marketisation pressure, meaning that charging for 'products' and creating profit generating 'spinouts' is increasingly encouraged, despite being at odds with the social purposes and often charitable status of universities. On a similar note, we found some tools requiring users to sign up and log in to use them, even if they were free (e.g. the Adapt2Clima tool [72]). This is rarely necessary for this type of tool as no personal data is usually stored, and requiring log-ins will significantly reduce user numbers. However it could be necessary if, for example, a user needed to enter confidential data and be able to return to that data in future.

Defining users: It is good practice to design tools with/for a very well defined audience. For example this could mean people in specific job roles, like decision makers (e.g. elected councillors), support staff (e.g. civil servants), or technical staff (e.g. data analysts), or it could mean people in specific geographical areas or facing specific issues (like people living in areas that flood, or farmers who need to understand changes to growing conditions). Usually the more specific, the better. Once a user group has been defined, it becomes possible to understand what other tools exist and why they are not adequate for their needs, as well as considerations like the expected language/terminology and what level of prior knowledge and technical expertise can be assumed. Most funders and public engagement specialists will put great emphasis on specifying the audience and involving them before planning any work, and will note that 'public' can not be considered a defined group as everyone is a member of the public. Starting with a tightly defined audience makes it more likely that a new tool will be used, as it will be made for specific people with problems that need solving.

Co-design: Co-design goes beyond consultation, and means working with the user group (and any other relevant parties) from the start of project conceptualisation through to the completion of the project, in a meaningful way. For climate and environmental tools, this could mean government representatives, civil servants, activists, or specific geographical or social communities for example. By definition co-designers play a role in the design of the tool, and decision making, not just in testing the tool. Co-designers must get something out of the process, and their input must be considered at least equally to others in the development group. This ensures that the end result is consistently sense-checked, so it ends up both usable and genuinely useful for its intended users. One major benefit of co-design is that it makes it much easier to pitch the tool's level (particularly with respect to data literacy), avoiding jargon while still providing all the necessary data and information detail. The choice of the data presented is also something that can benefit from co-design, avoiding the following issue highlighted by Raman and Pearce [73]:
'Climate science has produced extensive volumes of knowledge, but it is not self-evident which sources should be selected to frame participation events or how knowledge should be connected to climate futures. Such decisions are fraught and value-laden and increasingly made in a decentralized information environment whose patterns and structures are still opaque.'. There is a helpful quick online tool called 'But is it Co-Design' which may be useful for understanding this topic in more depth [74]. Paying co-designers is best-practice, as their time is as valuable as anyone else's on the team; this helps to avoid excluding those who couldn't afford the time to contribute voluntarily, and helps avoid situations where their time is used inefficiently or disrespectfully on projects where others (e.g. academics) are salaried. It is worth noting that professional facilitators can be hired who bring expertise in leading co-design projects.

User testing: User testing is a skill in its own right, combining social science approaches around avoiding leading questions, with experience seeing how people use and interact with tools. For example if one person misses a feature one time, it is not necessarily meaningful enough to act on, however if many people miss the feature, or the person who misses it has a visual impairment for example, it is worth acting on. When done well, user testing should primarily pick up places where people either become confused/misunderstand something, or where something doesn't work (for example software bugs). No tool should be released without having been tested by a naive group of people (who have never used any version of the tool before) belonging to the user group. It is not good enough to test systems, for example, on colleagues within a university (unless they are the intended users). Ideally, user testing should be performed early and often, not only once prior to release.

Project management: Software projects need managing carefully, in particular to ensure version control of the code - usually this is done through Git [75]. Various platforms/services are available which implement Git, for example GitHub (see ethics section) and GitLab. A good developer will undoubtedly use one of these, and these systems have the added benefit of including built in project management tools like issue tracking where anyone on a team can see outstanding 'to-do' and 'done' lists, time estimates, and who's doing what. Most experienced developers will use agile practices for development to some degree, which advocates for frequent iterative software updates and testing (rather than one big release at the end of a project), as well as a focus on simplicity ('the art of maximising the amount of work not done') [76]. The most pervasive and problematic software management issues are 'mission creep' where the scope of a project is poorly established [77] (kept in check by 'scope management' professionals in some organisations), and 'bikeshedding' where trivial issues are given disproportionate weight [78]. Understanding these basics will be crucial for anyone wanting to build a decision making tool with a professional developer.

Robust data: It is of utmost importance that the data a tool is based on must be collected in a rigorous way. It is crucial to work with the relevant experts, for example no climate decision making tool should be made without the involvement of climate scientists from the start. Remarkably, it is still not uncommon for crucial climate data to not be publicly available, as either it is either not uploaded on any open repository, uploaded but paywalled or only available in very inaccessible specialist formats. This is despite the openness of science being one of the most fundamental recommendations and learnings post-Climategate, as the reticence to share data played a significant role in the reputational damage to climate science [73]. As such an extremely valuable role of such tools can be to simply allow people free access to previously inaccessible data. The research methods behind any data collection must be transparent, rigorous and reproducible, following best practice (like the use of systematic reviews, meta-analysis, pre-registration etc.), and the data itself should be freely accessible. Both the methods and data should be published open access for example on repositories like Zenodo, and linked within any tool that is built so that users can download, scrutinise, and potentially re-use the data if they wish. If the tool then filters or combines data in a new way to make specific suggestions, these methods must also be made openly documented, as this provides users with clear criteria for why they are being shown particular information. If the methods used within the tool can not be interrogated in this way, then it can be considered to be a black box [79] and users' trust may rightly be eroded. A related issue for consideration with climate tools is the choice of future scenario to show likely future outcomes, balancing the pathways that we are closest to under existing policies, with the fact that policy planning for worst case scenarios can be prudent.

Design: Design skills are key, and it is worth noting that interaction design, communication design, user experience (UX), data visualisation, graphic design, and branding are all relevant specialisms in their own right. It can be tempting to underplay the importance of design, however it underpins whether people notice and are attracted to a new tool in the first place, find it appealing enough to use, how easy they find it to use, and how they perceive the information within the tool. Design and communication of climate and environmental topics bring very specific issues, as noted by Windhager et al.: '*The communicators of "inconvenient" ecological topics...face not only general challenges such as attention deficit, information fatigue, and competing disinformation, but also advanced forms of resistance: From psychologically constituted defense against mitigation demands to politically organized defense industries of special interests*' [64]. Risk and uncertainty need to be communicated in a responsible manner, because a tool could shape people's decisions in a very serious way; one further concerning aspect is that people can leave with the wrong information if the tool is poorly designed. A key recommendation from Raman and Pearce is that openness to the uncertainty of climate data is essential for trust and enabling climate action [73], and The Russell Review warned of the '*widespread misconception that science produces unequivocal and absolutely precise answers*' [80]

By definition, climate and environmental issues are complex and stressful due to their existential nature. Contrary to typical scientific approaches, showing the ambiguity and humanity of data can make it more accessible and better trusted, and guiding people's explorations in a non-overwhelming way helps them to explore multiple different possibilities. It has been shown that using sketchy styles of showing data improves engagement and creates more positive attitudes [81] and some of the top data visualisation experts adopt this style (e.g. Pulitzer Prize winner Mona Chalabi, Stefanie Posavec, and Nicky Case). Showing data in ways that are confusing or complex can alienate people, and there is an art to condensing a story, sequencing, and holding attention where it's needed, without making the user work too hard (e.g. see the work of Mona Chalabi for inspiration [82]).

There are some fantastic tips available for data visualisation, including common pitfalls [83, 84], however nothing will compare with working with a professional. Data visualisation skills help to maximise cognitive effects and cognitive efficiency, and help people to make emotional, cognitive and behavioural connections from complex data [64]. Thoughtful layering of information allows people to see a clear story at a glance, but explore and scrutinise the data in the depth that they need and want. Interactivity also makes this easier to achieve. How quickly users can get an answer they were looking for can also be improved through design, reducing 'bounce', where people go to a resource then quickly leave, usually because they either don't find it appealing or don't see what they are hoping to see as fast as they need to see it. For example, The Guardian news site counts a bounce as 10 seconds or less, so users need to see what they are hoping to find within about 10 seconds or they will go elsewhere [85]. It is worth noting that a user's search for information does not necessarily equate with what the actual information is that they need, so some design/copywriting skill can be needed to bridge this gap [29]. With good design long supplemental user-guides or walk-throughs should not be necessary.

Accessibility*:* The accessibility of tools for a wide range of users can be built in from the start. At a basic level, image descriptions for photos and subtitles for videos should be standard. Numerous tools are available to help improve visual accessibility, for example colour analysis to make sure that a chosen palette works for people who are colour blind [86], and contrast checkers [87] can help with basic design choices. Making a tool work for those using a screen reader will reduce exclusion - this can be a tricky design task for map based data, requiring a competent developer (plenty of advice exists [88, 89, 90, 91]. Developers could consider options for narrated audio for charts (e.g. approx 7:10 minutes in: [82]) and data sonification. The UK Government design standards are also a helpful starting point [92], and accessibility can be checked for existing websites using online tools [93].

Speed: Climate and environmental tools may involve a considerable amount of data, which can cause problems with how fast they work. Many of the tools we looked at were extremely slow to load, and this is one of the most notable differences between professional and amateur development. If a tool is slow then people are less likely to use it, and it is another reason for people to 'bounce' after visiting a site. Speed is an important consideration for accessibility globally, as not everyone has fast and reliable internet connections, so a badly built tool can be exclusionary. Loading speed may also be a climate issue in its own right, as online websites/tools themselves have carbon emissions, and some are more intensive than others (many very basic website checkers exist e.g. [94], but it is also possible to check the developer tools tab within a browser to see what takes time to load, or to use Google's Lighthouse in a Chrome browser's development tools). Moreover, speed of use is a demonstration of respect for a user's time.

Privacy: It is common for people to want information on who is using something they've made and how they are using it, and indeed this can be critical for evaluating a tool and reporting to funders, however this can come at a cost to the privacy of the user. Best practice is to avoid the use of cookies and trackers, and to avoid collecting any personal data unless it is absolutely necessary [95]. Legislation like the General Data Protection Regulation (GDPR) in the EU/EEA may also provide helpful guidelines for how user data must be treated under law, and note that in some countries it is illegal to ask for personal data like ethnicity. Cookies/trackers require consent (in the EU), for example the pop-ups you regularly see on the internet when you enter a site, and these are very likely to reduce the number of people who decide to use your tool. A straightforward way to get useful information while respecting people's rights to privacy is to build a short survey to ask questions about who they are and how they are using your tool; a link to this survey can then be added to the tool as an opt-in consensual way of gathering information. Alternatively users could have the option to provide their email address and consent to contact, and they could then be emailed directly for feedback. Even so, care must be taken to retain their privacy if you collect any personally identifiable data, for example by encrypting the data collected.

Ethical considerations: For tools made for climate and environmental purposes, there are ethical considerations for the technology itself. For example developers can choose to use server providers running on 100% renewable energy [96], existing websites can be checked for whether they run on renewable energy [97], and many developers have chosen to move away from hosting their code on GitHub due to human rights issues [98]. Those wishing to delve into issues around longevity, efficiency, and environmental sustainability of software (and other technology) could consider exploring established movements like Appropriate Technology [99] and Permacomputing [100]. It is also worth considering whether a code of conduct may be relevant to your tool, either for the development process (e.g. how co-designers are included), and/or for how it is used (e.g. to brace against abuse). As Sheppard et al. said '*We need stronger professional standards or an adapted code of ethics if we are to use visualisation to convey effectively and vividly the science of climate change, acknowledging the uncertainties and maintaining professional credibility*' [57].

Maintenance of software and hardware: Software and hardware needs to be maintained if it is to have longevity. Many of the tools that we looked at never went beyond the prototype stage, or had stopped working, and this lack of longevity is particularly common when tools are developed as part of a research project with a fixed length of funding, as maintenance beyond the length of the project is usually not considered or even possible to cost into funding applications [101]. There are basic considerations like paying for a URL (usually these are bought for between 1 and 10 years rather than permanently, it is wise to decide on one early and stick to it to make the tool more easily searchable/findable by users), and for server space (often rented by month or by year, although sometimes bought outright, or institutional server space may be available). As devices and operating systems change over time, software can stop working and need updating, and so the length of time that a tool needs to work must be considered. The device type that a tool is designed for can also have an impact, for example with phones, Apple devices tend to change faster than Android, which means software becomes obsolete faster.

Maintenance of data: Another aspect of maintenance is keeping data up to date in a fast moving research area, for example tool designers/developers need to consider how to include changes in model predictions, and in the case of climate change, how to address issues like tipping points being reached. If the data is not kept up to date and the user is not aware of changes in the science, they may make decisions based on out of date information, and issues like maladaptation to climate change become likely (defined as '*actions taken that reduce the options or ability of decision-makers now or in the future to manage the impacts of climate change*' [102]. One related consideration is to archive any links used in a tool, which provides a snapshot of a website in time, rather than use the original link which may change over the years [103].

Evaluation: Evaluation of decision support tools is essential, otherwise it is impossible to know whether any decision-making has actually been supported, and we will collectively continue to spend time and resources building systems we have little evidence of being beneficial. Some tools are described and published in journals together with a level of evaluation [e.g. 104]. However, one study of decision support systems for natural hazard risk reduction evaluated 77 systems that were designed for generic use, and found that only 28 were used beyond the single case study in the paper that originally described the tool, and only 11 were used in more than 4 locations [105]. While tempting, simplistic evaluation approaches like relying on basic metrics like visitor numbers to a website can be misleading, for example because 'bounces' may be registered as valid visits, and many hits may be web crawlers [106]. Instead, evaluation should focus on who is actually using the tool (is it who the tool was aimed at?), what aspects they find useful or not (is it well designed, is the data what they need?), and how they end up using the tool (are any decisions made, do they keep coming back or do they only use it once?). For helpful pointers on common issues to look out for, Hewitson et al. reviewed 42 climate information websites (CIW) and found consistent issues with assumptions about the users' familiarity with terminology and their technical skill level, complex navigation '*testing the user's patience and raising frustration*', a lack of clarity of what was being displayed, multiple and often confusing choices, and different avenues through the tools leading to different outcomes; they conclude that '*in many cases, the level of effort required by the users is in contrast with the expectation that the CIW will simply deliver information*' [29]. There are various tips for evaluating affective engagement (how emotionally connected or invested someone is to what they are learning about from a tool or visualisation) [e.g. 107, 108], however evaluation is a field in its own right, and expert evaluators can be hired to support projects. Evaluation can be done not only on the outcome of a project, but also on the development process itself [e.g. 109]. Once a tool has been launched, it can be helpful to follow test cases of how people use it, then make that information openly available for others so they can see how the tool might be useful for them too.

Discussion and Future Directions

It is clear from our research for this review that a large number of climate and environmental decision support tools exist, many of which no longer work, and many of which were likely never used beyond their initial pilot case study. We urge readers to think carefully about planning to build such tools, and to consider the advice provided in order to make these tools as well made and long-lasting as possible. Despite exciting innovations in the fields of data visualisation and communication, this doesn't often find its way into support-tool building. It is perhaps an area where a hurry to come up with any potential solution or research 'impact' is at odds with the experimentation needed in order to lead to significant advances. The improved design of such tools should perhaps be considered a fascinating and potentially fruitful research field in its own right. Our main advice is to not try to do everything within an academic setting - instead collaborate with people who are skilled experts in the areas needed, particularly in data visualisation, software development, user testing and evaluation.

Hewitson et al. succinctly outlined four concerns for climate information websites which are also relevant to decision support tools: '*(1) the ethics of information provision in a context of real-world consequences; (2) interfaces that present barriers to achieving robust solutions; (3) weak capacity of both users and providers to identify information of value from the multi-model and multi-method data; and (4) inclusion of data that infer skill*' [29]. With full awareness of these issues, working together with a skilled team and led by the users, it should be possible to develop considerably more advanced and thoughtful tools.

There is a very real possibility for maladaptive decisions to be made on the basis of such tools, and because of these potentially serious real-world consequences, great care needs to be taken at all stages. Once packaged into a neat decision support tool, there is a danger that users will overinterpret the robustness of the data, or misinterpret the information and data provided. Clear, honest caveats and guidance are needed to counter this, together with defensibility and transparency of both the data and methods, as well as the humility to make the limitations known within the design. Uncertainty in particular is a very real part of scientific data that must not be shied away from, and needs to be carefully presented so that users are not misled into thinking that the data is more convincing than it might be. As Hewitson et al. state, '*the act of providing information into an environment of adaptation investment and action carries serious responsibilities*' [29].

While this review has listed plenty of drawbacks, and all the different skill sets required in the production of good decision support tools, we can see policy and government direction globally provides scant evidence that more conventional methods such as written reports and graph figures are providing ways to successfully navigate the complexity of the situation we face in climate change. Eye tracking studies have shown low levels of graph reading literacy in society can lead to confused and inaccurate understanding of scientific information [47]. These kinds of studies underline the need to be continually on the lookout for new developments in visualisation and graphical user interface design, comparatively young fields in relation to the long history of standard line graphs and bar charts. It might be the case that there is much more we can do in this area. There are clear, and currently largely missed, opportunities for such systems to bridge between existing datasets, particularly relating inequality and vulnerability data to climate and environmental data.

Ultimately if it is possible to design tools that allow people to explore data and processes themselves before, or without telling them answers or providing pre-packaged interpretations, this will likely lead to better outcomes, as shown in Inquiry Based Science Instruction [110, 111]. We believe it is prudent to employ proven educational techniques in software decision making tools to remove didactic interpretations, or more accurately to use interactivity to allow people to access simplified interpretations but also to deeply explore and play with the full complexities of the data. This approach allows people to explore not only *what* is known but *how* it is known. These 'explorable' approaches are technically difficult to build, but could provide more humane and successful methods for navigating complexity in critical and urgent issues like climate and environmental breakdown.

If a tool is well designed, despite being focused for a specific user group, others will be able to access and explore it - this provides opportunities, for example, for activists and broader communities to experience the same data as their policy makers, making society better equipped to hold policy makers to account, and to more effectively reason together. We believe that the improved design of decision support tools could contribute to forging '*a public culture comfortable with epistemic diversity and ambiguity, able to reason together critically in the public good*' [73].

Further reading and watching

Because many of us read reviews in order to find more fundamental readings for understanding a new topic, we would like to point to the four papers we think are most important to read more on the topic of decision support tools for climate and environmental applications. As with all references cited in this review, these are all available open access:

- Hewitson et al. - Climate information websites:an evolving landscape.
- Palutikof et al. - Decision support platforms for climate change adaptation: an overview and introduction.
- Windhager et al. - On Inconvenient Images: Exploring the design space of engaging climate change visualizations for public audiences.
- Raman and Pearce - Learning the lessons of Climategate: A cosmopolitan moment in the public life of climate science.

To provide deeper context, we also point readers towards three excellent online talks by data visualisation/explanation experts:

- Nicky Case - Seeing Whole Systems.
- Georgia Lupi - Information Designer.
- Mona Chalabi - Sequence, Sequence... Surprise! Designing Data for Maximum Impact.

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