Adv. Sci. Res., 19, 51–71, 2022
https://doi.org/10.5194/asr-19-51-2022

Advances in Science & Research
Open Access Proceedings

21st EMS Annual Meeting – virtual: European Conference for Applied Meteorology and Climatology 2021

How to develop new digital knowledge transfer products for communicating strategies and new ways towards a carbon-neutral Germany

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Received: 15 February 2022 – Accepted: 13 May 2022 – Published: 20 June 2022

Abstract. Human-induced climate change is one of the most pressing challenges of our time. The Helmholtz Association is making essential research contributions to mitigate the causes and impacts of climate change and find ways to adapt. The "Net-Zero-2050" project, the Cluster I of the Helmholtz Climate Initiative, scientifically investigates and evaluates strategies and new ways to reduce, extract and permanently store carbon emissions. Two digital knowledge transfer products (DKTPs) were developed to present the complex research results comprehensively: (1) the "Net-Zero-2050 Web-Atlas" provides information on methods and technologies for CO_2 reduction and possible reduction paths; (2) the "Soil Carbon App" provides simulated soil carbon data to estimate climate protection potentials through different land management methods. Both formats intend to support users in making informed decisions and developing appropriate climate neutrality strategies.

During the two DKTPs development, common main challenges were identified regarding concepts and stakeholder involvement. Along with that, specific approaches to solving the tasks could be distilled for each product. In the still-evolving arena of digital knowledge transfer, no standard methods can be applied. At the same time, communication of climate research results to decision-makers is becoming more and more relevant. This paper extracts the challenges and gives approaches to facilitate a transfer of the gained experience to future similar projects.

1 Introduction

Human influence has warmed the atmosphere, ocean and land – this fact is unequivocal according to the Intergovernmental Panel on Climate Change (IPCC). Rapid and widespread changes in the atmosphere are already affecting many weather and climate extremes all over the world. Reaching net-zero CO_2 emissions[1], along with strong reductions in other greenhouse gas emissions, is required to limit human-induced global warming (IPCC, 2021). Multiple nations have already adopted or are in the process of adopting national strategies to reach net-zero CO_2 emissions by 2050 or earlier (Steuri and Jacob, 2020; UNFCCC-Documents, 2022). In Europe, the European Union's objective to be climate-neutral by 2050 is at the heart of the European Green Deal. On a country level, Germany has committed to achieving its climate neutrality target by 2045, although its overall climate targets, climate finance, and policies are still considered to be "insufficient" (Climate Action Tracker, 2022). Thus, substantial improvements are needed for the country to be consistent with the Paris Agreement's 1.5 °C global warming limit (Climate Action Tracker, 2022).

[1]"Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. Net zero CO_2 emissions are also referred to as carbon neutrality" (IPCC, 2018).

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1.1 Project framework

In the face of a lack of action to achieve climate goals and political stagnation, the Helmholtz Association launched the Net-Zero-2050 project on 1 July 2019. The Net-Zero-2050 aimed to address and map out the key issues, examine methods and ideas proposed, and move forward with promising technologies relevant to developing a national carbon neutrality strategy. Various approaches to reduce CO_2 emissions, to capture, store or convert CO_2 from point sources, and to remove CO_2 from the atmosphere via nature-based approaches were comprehensively assessed considering potential, economic and social feasibility, scalability and side effects, as well as possible vulnerabilities to climate change (About Net-Zero-2050, 2022). The Climate Service Center Germany (GERICS), which is a scientific organisational entity of Helmholtz-Zentrum Hereon, coordinated the Net-Zero-2050 and, thus, brings together the expertise of ten Helmholtz research centres across Germany.

The Net-Zero-2050 belongs to one of the three Clusters to the Helmholtz Climate Initiative (HI-CAM). This initiative aims to incentivise cross-cutting research on climate mitigation and adaptation at Helmholtz and beyond to support the development of coherent climate policy, as shown in Fig. 1. The HI-CAM bundles disciplinary expertise within the Helmholtz Association in an interdisciplinary setting to trigger innovation and provide up-to-date expert information based on scientific findings. Furthermore, the HI-CAM is breaking new grounds in terms of scientific methods and communication since it belongs to one of the largest scientific organisations in Germany, which is the Helmholtz Association, and sees itself responsible to "serve society and provide solutions to the central questions of our time" (Helmholtz – Association of German Research Centres, 2022). In this sense, the Net-Zero-2050 seeks active communication with stakeholders to transfer its interdisciplinary research findings to the society in a target-group oriented way. For this purpose, two Digital Knowledge Transfer Products (DKTPs) have been developed, namely an interactive web atlas and a web app (El Zohbi et al., 2021a). These two DKTPs aim to communicate scientific knowledge in an understandable way to society and specific stakeholder groups, to enable informed decisions and, thus, provide steps to move forward on the challenge of reaching carbon neutrality.

1.2 Development of two digital knowledge transfer products

In this report, the term knowledge transfer generally refers to an information flow of knowledge. In the context of the Net Zero 2050 project, knowledge transfer particularly means a flow of scientific knowledge on the topic of carbon neutrality from the research of ten Helmholtz Centres into the mainstream society. Digital knowledge transfer refers to the part

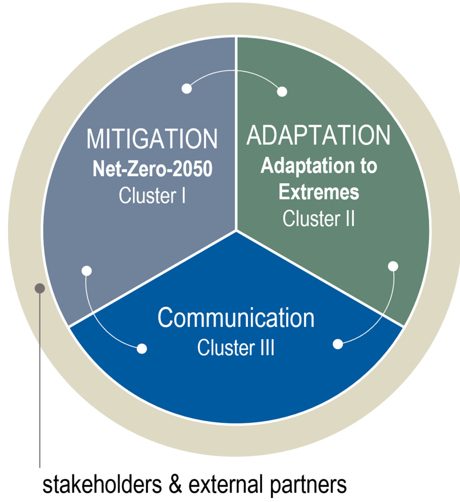

Figure 1. The three clusters of the Helmholtz Climate Initiative are closely collaborating. All of the three clusters seek active communication with stakeholders and external partners to transfer knowledge to non-scientific environments.

of this knowledge flow that contributes to the knowledge transfer with the help of digital tools. Accordingly, Digital Knowledge Transfer Products (DKTPs) are web-based, digital tools that contribute to knowledge transfer.

One of the DKTP tasks in Net-Zero-2050 was to create a web atlas. Therefore, an atlas development team, hosted at GERICS, and an external software development company designed and implemented the "Net-Zero-2050 Web-Atlas" to publish the project's results. The Net-Zero-2050 Web-Atlas was released in November 2021 and is available at https://atlas.netto-null.org/ (last access: 3 June 2022), as shown in Fig. 2. It serves as a showcase for the research findings of ten Helmholtz Centres that have contributed their expertise to Net-Zero-2050 and answers a central guiding question in a clear and comprehensible way: Which technical and nature-based options, as well as political decisions, can support Germany to become CO_2-neutral? Furthermore, the Net-Zero-2050 Web-Atlas globally visualises and compares the long-term national decarbonisation strategies (LT-LEDS) officially submitted to the UNFCCC. In this way, the Net-Zero-2050 project aims to promote the public and political debate on CO_2 neutrality at various levels. The targeted user groups for the web-atlas include the interested public, specialised audience, policymakers, and all kinds of experts at the federal, state, regional, and municipal levels.

The other DKTP, the "Soil Carbon App", provides scientific data and results from the project's land surface modelling, climate modelling, and agricultural science, as shown in Fig. 3. This newly developed app aims to offer a publicly available interface to simulation data and processed results and will be helpful for scientists, stakeholders outside science, and non-academic users. The target groups were defined at the beginning of the project: stakeholders in min-

Figure 2. Net-Zero-2050 Web-Atlas landing page. Source: Screenshot of https://atlas.netto-null.org/ (last access: 3 June 2022).

istries, administration, agriculture chambers or other entities, and farmers and other stakeholders from the agricultural sector. The app format should offer the user a certain degree of flexibility and interactivity in terms of functionality with the data provided. The interfaces for data processing, storage and transfer were to be developed and implemented through methods and tools generated within Net-Zero-2050. The app development required cooperation between the project scientists from the land surface and agriculture modelling, climate modelling, computational sciences and climate services. Thus, the development integrated different disciplines and institutions (i.e., Forschungszentrum Jülich and GERICS). A web development agency was engaged as an external partner to design and implement the app front-end.

In the product development, it was helpful to define interim-users to accompany and support the development process. The interim-users are generally the knowledge providers – i.e., the project partners – in the ongoing development process of a DKTP. The interim-users must be able to deal with the framework offered by the developers in the back-end. An interim-user-friendly environment facilitates the knowledge providers' publishing process of their contribution in the back-end of the respective digital format.

1.3 Challenges in the DKTP development process

Previous in-house experiences have shown that the development of DKTPs is multifaceted (Preuschmann et al., 2017; Bathiany and Rechid, 2021; Klimanavigator, 2022). DKTP development also comes with some pitfalls and the need for significant resources (Sun and Scott, 2005; Bessembinder et al., 2019). To learn from the experience gained and to be able to optimally use it in similar product development processes in the future, the identification of general approaches is desirable. Therefore, the two DKTP teams formulated the following question for product development: *What are transferable approaches that structure and support the development process of digital knowledge transfer products?* Analysing and reflecting the experience gained and lessons learned concerning the development process, this question led to identifying three main challenges that need to be addressed before and

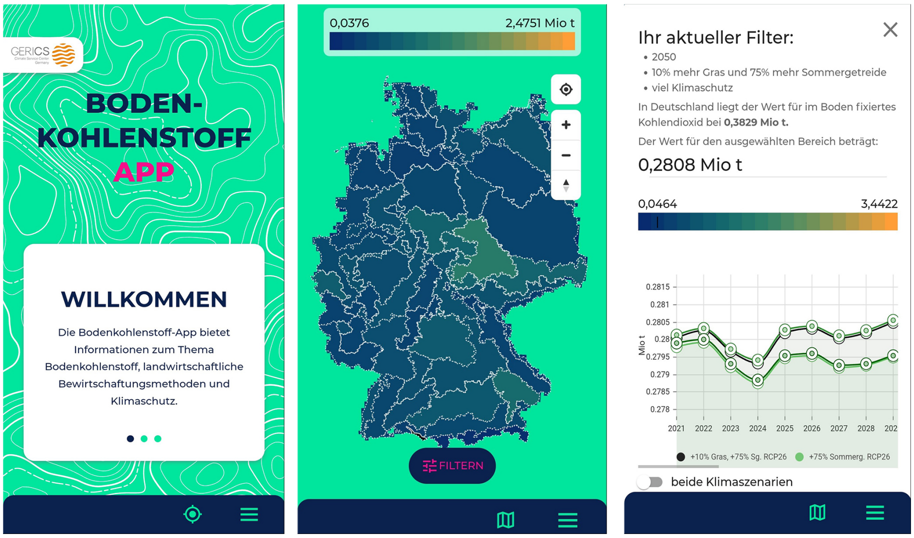

Figure 3. Three views from the application in its current state (from left to right: landing page, map of carbon variable covering Germany, time series displayed for one grid box). Source: Screenshots of developer view – current work status in application programming.

during the DKTP development processes. The challenges were reformulated into three key questions that significantly influence the product development process and support the structuring of similar processes in the future.

The first key question, "what to provide?", addresses the task of best matching the scientific content and users' needs. Different iterative procedures are necessary to determine the elements and content to be presented. Identifying what can be provided has two goals: (1) to find out from the project partners in their role as knowledge providers what can be communicated in the web product, and (2) to work out what should be conveyed by the identified displayable elements to benefit the user. Interdisciplinarity is a major challenge within the first key question. Further, the scientific results in the Net-Zero-2050 project are often based on large amounts of complex data. Thus, the developers have to address the aspects of multi-dimensionality and uncertainties as analytical and technical challenges. In particular, this means that the development team needs to determine what the DKTP shall provide in terms of data and visualisations and needs to define the technical requirements. The content identified is closely related to the design of the information structure, which is essential to the third key question, "how to guide?". However, the information structure design allows the development of homogenised structures along which the knowledge providers can orient themselves in the preparation of their content.

The second key question, "how to provide?", concerns how to present scientific content in a user-friendly way and make it usable to varying user groups. One challenge is that the educational background and professional orientation of potential end-users are usually very heterogeneous. A clear pre-definition of the potential end-users and, if possible, a categorisation of their interests is crucial here. However, the key question also includes developing measures for the user-friendly content preparation to be transported. "How to provide?" concerns the technical prerequisites and framework conditions that must be created for a product that is easy to use. Considerable additional challenges for the development teams arise when dynamic data and complex user interactions must be facilitated, which was especially the case for the Soil Carbon App.

The third and last key question "how to guide?" is determined by guiding users of different target groups through the communication formats. Having a well-designed information structure, which is also called information architecture, is therefore essential. The information architecture is necessary so that end-users can quickly understand and intuitively use the functionality of the DKTP. The goal is for users to enjoy the product and benefit from it for their purposes. Starting from a heterogeneous end-user group, the product developers' task is to meet the needs of the different user types as close as possible. The challenge for the developers is to anticipate the potential needs and the possible usage difficulties of the end-users. Ultimately, a clear user guidance helps the end-user to see where and how they can find the information in the form they need for their interests.

2 Methods

As pointed out in Sect. 1.3 Challenges in the DKTP development process, three key challenges were identified during the development of the DKTP. The methods used to find approaches and solutions for these key challenges will be explained in the following, describing the commonalities as well as respective specific approaches for the cases of the

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web-atlas and the app. Most of the methods addressed more than one of the three key questions simultaneously. As a result of the experience gained, recommendations for developing digital knowledge transfer products could be identified in Sect. 4. Conclusion.

2.1 Product and literature research

During the early stage of the process, a product and literature research were essential for both DKTPs. Finding existing web pages and apps with a similar aim, thematic background and underlying ideas provided information on building the planned format. Moreover, further literature research was conducted where necessary to develop a good understanding of the scientific content. Based on this understanding, the contents were distilled for delivery in the web applications.

The development process for the Net-Zero-2050 Web-Atlas started with product comparison research to address the two key questions “What to provide?” and “How to guide?”. For this reason, five knowledge transfer platforms were selected that offer online applications to present scientific content. These websites comprise web-atlas functions on related scientific topics, each using different knowledge transfer tools and features. An evaluation matrix was developed to compare the websites against three main criteria with twelve sub-criteria and 34 individual criteria. Five team-related inhouse reviewers completed the evaluation matrix for each product for the evaluation process. Subsequently, two supervisors synthesised the reviewers’ answers. The product research provisionally sounded out which solutions and implementations appealed to the reviewers as potential test endusers and which functions were perceived as less valuable. The results were summarised as a catalogue of requirements for the web-atlas, as shown in the Appendix A table.

In the case of the Soil Carbon App, product research was conducted by scanning the web and app stores using relevant keywords (such as “agricultural methods”, “soil carbon”, “land management”, “climate mitigation”, “climate”, “climate change”). Criteria and aspects were defined for this research and scanning existing digital formats to ensure that they are transparent, reproducible, and transferable. Criteria in this review included, for instance, details on the data provided (e.g., spatial and temporal resolution, point or gridded data) or the technical type of the applications. The research showed that no product was online or available in the app stores with a similar core design as the planned Net-Zero-2050 Soil Carbon App. Moreover, literature and web research were conducted for key findings, principles and methods in the field of web development, with a particular focus on concepts and app design (Resmini and Rosati, 2011; Information architecture of a Website, 2022). This research helped to build an understanding of conceptual and methodological approaches, related terms, and the various fields of expertise. The literature research for the Soil Carbon App delivered background knowledge on the scientific topics that are related to the app’s overall themes, which are agricultural methods, soil carbon, climate change and the linkages between them (Don et al., 2018; Riggers et al., 2021; Sanderman et al., 2017; Paustian et al., 2016). Furthermore, information on the land surface model that simulated the data was compiled for provision in the app (Lawrence et al., 2019; Andre et al., 2020).

2.2 Dialogues and expert interviews

Dialogues and workshops with both users and experts were essential methods in the DKTP development. Both development teams kept organising these exchange formats as the scientific methods and results developed or evolved during the project phase, e.g., in El Zohbi et al. (2021b). User dialogues were conducted to determine the scientific content of the communication format. In addition, previously published literature on user surveys (Heukrodt et al., 2019; Zahid et al., 2020; Steuri et al., 2020; Schuck-Zöller et al., 2017; SECTEUR – Copernicus, 2022), served as the basis for the end-user perspective. These published analyses led to assessing the users’ prior experience, their needs and expectations for web applications.

In the case of the Net-Zero-2050 Web-Atlas, the interim-users use a separate portal where they can upload their content. During the interim-user dialogues, the project partners were introduced by the development team to their role as knowledge providers. The interim-users were trained to meet the requirements of the end-users. They were also familiarised with the technical aspects and formatting options. Specific guidelines were developed for presenting research findings as described in Sect. 3.1.2 Net-Zero-2050 Web-Atlas: How to provide?. Meanwhile, the project experts called on the developers to ensure that formats accurately represent the underlying science.

In order to sharpen the data analysis and the contents, constant feedbacks through dialogues were necessary for the Soil Carbon App. This iterative process is similar to agile project management methods usually applied in software development processes. A constant and thorough exchange between the “science side”, those who work on the concepts, and the experts for large-scale data processing and provision ensured that the supply of simulation results in the app could work as fast and stable as possible. The app developers learned from the processes on the Soil Carbon App that data availability must already be ensured when planning a DKTP. DKTPs should either be based on existing or post-processed data that can almost certainly be guaranteed in the available timeframe. An exchange with a few selected stakeholders was facilitated to complement published knowledge regarding stakeholders’ needs, expectations, and preconditions.

In order to assess the technical possibilities for both DKTPs, web research and dialogues with developers of software and climate service products were conducted. In the atlas case, the main issue was the technical implementation of special effects or the required accessibility. In the case of the app, the main issue was the choice of technical format, as a native or web app.

2.3 Synthesis and integration work

A further method used to address the key challenges is the "synthesis of experience" from previous climate service product developments. The in-house climate service product developments at the Climate Service Center Germany (GERICS) and Helmholtz-Zentrum Hereon considered were the IMPACT2C web-atlas (IMPACT2C, 2022; Preuschmann et al., 2017), the Klimanavigator (Klimanavigator, 2022), the digital ADAPTER web platform (Bathiany and Rechid, 2021), the NAIAD E-GUIDE (NBS Solution Guide, 2022) and the 360° app (App Store, 2022). Lessons learned from previous development processes were considered where possible and appropriate. These experiences and process-related knowledge were analysed concerning applicability in the actual development process and was synthesised through correspondence, dialogues, and workshops.

At this point, the didactic reduction must be mentioned, which is called "pedagogical reduction" according to Lewin (2018) in Anglo-American educational theories. This method serves indirectly to derive the recommendations. The didactic reduction is a component of the recommendations and is implemented differently in the DKTPs. According to Preuschmann et al. (2017), didactic reduction is explicitly not a simplification of the content, instead it reduces the quantity of the content by presenting the essential aspects while omitting the irrelevant aspects. This process also involves a qualitative reduction of the content. The degree of qualitative reduction depends on the quality of the end-users, e.g., whether they are schoolchildren or a highly educated audience.

In the atlas case, the idea of didactic reduction gave rise to the need for structural questions to draw out only the essentials, as described in Sect. 3.1.2. In the case of the Soil Carbon App, the didactic reduction led to decisions regarding the data made available to users, for example, to the definition of aggregated data products pre-computed from the available daily data.

3 Results and discussion

The product comparison, literature and web research showed that the contributions to research on digital products for science had grown significantly in recent years (Future of Science Communication Conference, 2022; European Commission and Directorate-General for Research and Innovation, 2020). The research also revealed controversy about how new methods, such as storytelling, can be used in an academic context (Nachhaltigkeit erzählen, 2022; Sukalla, 2018; Dahlstrom, 2014). For example, Metag et al. (2016) showed that the perceptions of visual representations of climate change are rarely associated with feelings of meaningfulness or self-efficacy. In consequence, DKTPs with emotion-enhancing elements have the potential to promote user self-efficacy.

Furthermore, the research revealed that web products have taken on a special significance in terms of communication directed at political decision-makers. Today, political decision-makers increasingly use digital products: "Digitisation has numerous implications for modern democracies. These can no longer be classified as opportunities and risks. Instead, digital technologies are shaping political systems in numerous dimensions and can have both positive and negative effects, depending on the objective pursued – [translated from German by the authors]" (Ulbricht, 2021).

Overall, the research on DKTPs in Net-Zero-2050 clearly shows a growing market for new media such as social media and digital knowledge transfer products (Wilcox, 2012; Small, 2011; Scott, 2015). Digital knowledge transfer from research to society and politics has an informative benefit. Nowadays, digital formats for publicising and distributing findings from research projects in social media and new media platforms are a must-have (Wilcox, 2012; George and Dellasega, 2011). Although such formats have long since ceased to belong to the playful add-ons category, there is still no standard that meets the diverse requirements of such DKTPs (Williams et al., 2021; Filipenko et al., 2019).

The work on the two Net-Zero-2050 DKTPs was used to address this standardisation gap. Crucial common challenges among the two DKTPs were identified during the development process. However, the approaches to tackle them differ for the two products. The common challenges were described along with the three questions separately for the Net-Zero-2050 Web-Atlas and the Soil Carbon App.

Figure 4 shows the three identified challenges based on key questions supplemented by summarising questions.

3.1 Net-Zero-2050 Web-Atlas

The Net-Zero-2050 Web-Atlas (Netto-Null-2050 Web-Atlas, 2022), as a platform for digital knowledge transfer, acts as a showcase for the research contributions of ten Helmholtz Centres that have contributed their expertise to the Net Zero 2050 project. Technical framework conditions have a decisive impact on the concept and design of a DKTP. According to the project proposal for the web atlas, the primary technical framework was given and based on an existing DKTP. Therefore, the technical basis combines various open-source tools such as a web-GIS, a content management system, and a database (Preuschmann et al., 2017). Thus, the developers had to agree on new content under known technical conditions.

For this, however, the atlas development team was particularly confronted with the challenge that both the knowledge providers and the intended target group are heterogeneous,

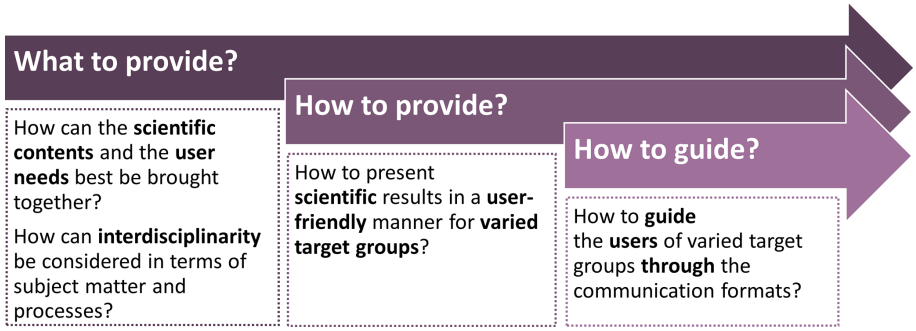

Figure 4. Summary of the DKTP development key questions.

especially in terms of subject matter. Therefore, multiple challenges were solved concerning the different user needs and providers' opportunities. This paper addresses how the development team responds to the challenges according to the three key questions during the product development.

3.1.1 Net-Zero-2050 Web-Atlas: What to provide?

Regarding the question of "what to provide?", the main challenge in the Net-Zero-2050 Web-Atlas development was to represent the diversity of the different topics from ten Helmholtz institutes. On the one hand, the challenge was identifying the project partners' diverse presentation options and formats and naming thematic and structural commonalities. On the other hand, the challenge was to find an easily accessible sorting system that allows a unique assignment of all contributions from the project partners.

For the Net-Zero-2050 Web-Atlas development, it was essential to making the contributions classifiable in a chapter structure. It became clear to the product developers that a technical target was necessary for the efficient classification of project contributions. Based on this assumption, the developers at first divided the Net-Zero-2050 Web-Atlas into four main chapters, whereby the knowledge providers distribute their contents into two chapters dedicated to the project results (Fig. 5). With the help of workshops with a group and individual discussions with the project partners as knowledge providers, a thematic pre-sorting of the contents was achieved. The entire community always checked whether the unambiguous allocation of the individual contributions could be maintained without a contribution having to bend thematically. During discussions, it became apparent, for example, that different thematic sub-chapters were needed within the two results chapters. This process was dynamic throughout and required multiple loops and readjustments of the pre-structure for individual cases and was strongly connected with the work of the "Netto-Null-2050 Wegweiser" within the project (Netto-Null-2050 Cluster I der Helmholtz-Klima-Initiative, 2022).

The resulting structure has a remarkable synergy effect on the end-user orientation within the "How to guide?" question. The developers assumed that the result from this structural process would also contribute to the orientation for the end-user in the final project. For this purpose, the development team made the unpublished product accessible to various test users. When asked about the orientation, our respondents perceived the developed structure as logical and helpful.

Further, based on the lessons learned from the previous DKTPs, the development team was prepared to discuss the representation of model uncertainties in this complex of topics. Technically, the representation of bandwidths and ensemble matches are possible (Preuschmann et al., 2017). However, the analysis of the transdisciplinary representation methods showed that such representation options and corresponding calculation concepts were not relevant within the Net-Zero-2050 Web-Atlas.

Several other aspects were extracted from the discussion processes. On the one hand, the discussions were successful if the knowledge providers knew about the technical requirements and had clear targets. The development of the information architecture resulted in the pre-structuring, Fig. 5, which supports orientation on a website for interim- and end-users. In order to do justice to the diverse project results and approaches, structural specifications must be defined that all intermediate users can uniformly apply throughout the development.

3.1.2 Net-Zero-2050 Web-Atlas: How to provide?

Inter- and transdisciplinarity were also a decisive factor in the Net-Zero-2050 Web-Atlas for the complex obstacle, "How to provide?". The heterogeneous data situation and the different methodological approaches of the project partners led to various representation options. In particular, only a few project partners had data that could be displayed on georeferenced maps.

In the product development process, the assumption was that in order to be able to provide a uniform-looking knowledge transfer product, a minimum consensus of the forms of presentation must be found. For this purpose, the technical possibilities for presenting scientific results in web

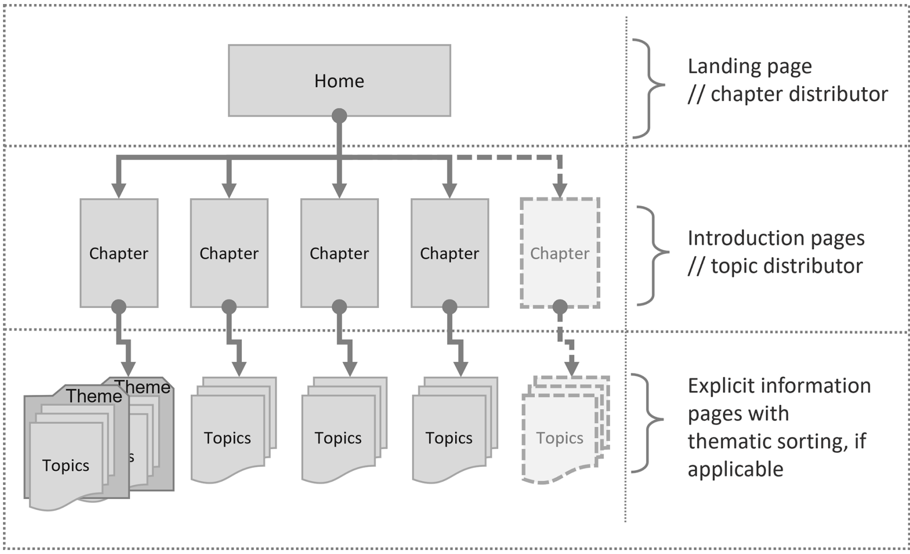

Figure 5. Technical target structure given to the project partners with the role of knowledge providers.

platforms were explored, e.g., by conducting product comparison research and interviewing experts in visualisation, knowledge transfer, and software development. At the same time, research was conducted on knowledge transfer techniques such as "storytelling" and addressing emotions (Pyczak, 2019; Sukalla, 2018; Doran et al., 2021; Martinez-Conde and Macknik, 2017; Moezzi et al., 2017; Benites-Lazaro et al., 2017; Brosch, 2021). In a co-creation process with the software developers and climate service product developers, feasible options were developed for the different presentation opportunities of the project partners. As a result, communication formats such as graphic stories or map representations were chosen, wherein the contributions could be presented in a user-friendly format. An additional presentation format was also developed to present and compare the long-term strategies for decarbonisation from a global perspective, i.e., the national "roadmaps" according to the UNFCCC. Figure 6 shows screenshots of the different implemented forms of presentation in the web-atlas.

Our experiences and surveys have shown that all project partners as knowledge providers could create picture stories and explain maps, if available. Thus, guiding structures were developed for the project partners in the role of interim-user. A modular guiding structure for picture stories and guiding questions for the map representations were developed; see Table 1. These guiding structures should support the interim-users in preparing their contributions in a user-friendly way. Such guiding questions support didactic reduction and help interim-users limit their texts to the essentials. On the other hand, the recurring structuring along the guiding questions helps the end-user to find out which information he or she needs. In addition, not shown here, a guiding structure was developed that enabled the interim-user to apply the method of storytelling in the manner of "defeat the beast" (Pyczak, 2019). These structures helped the providers simplify their subject areas to the essential, required aspects.

Nevertheless, even with the numerous instructions, including hints for text composition for non-specialist readers, the authors as interim-users had sufficient freedom to present results. However, the project partners in their role as interim-user particularly appreciated the support of journalistically trained staff within the Helmholtz Climate Initiative, who contributed to creating readable texts. Our project partners were thankful for the uniform text structure and format specifications, guaranteeing a homogenised appearance across all projects. Our test users perceived the uniform approach and presentation as pleasant. With the uniformity, an expectation was generated for the end-users, which the project partner as interim-user could comfortably meet by adhering to the specifications.

In summary, uniform text structures were specified to do justice to the diverse possibilities of expression and styles and support text composition.

3.1.3 Net-Zero-2050 Web-Atlas: How to guide?

The atlas development team dealt with the broad bandwidth of end-users expertise of the end-users in the question "How to guide?". Three focus groups were requested and required for the Net-Zero-2050 Web-Atlas within the project. The target groups of the Net-Zero-2050 Web-Atlas include the interested professional public, policymakers and experts at the federal, state, regional and municipal levels.

In order to assess the expectations of these end-user groups towards the DKTP, it was concluded from various in-process information that there are three basic commonalities of the target groups. For example, it appears that a topic insight is necessary for introducing the reader to the topic. Readers

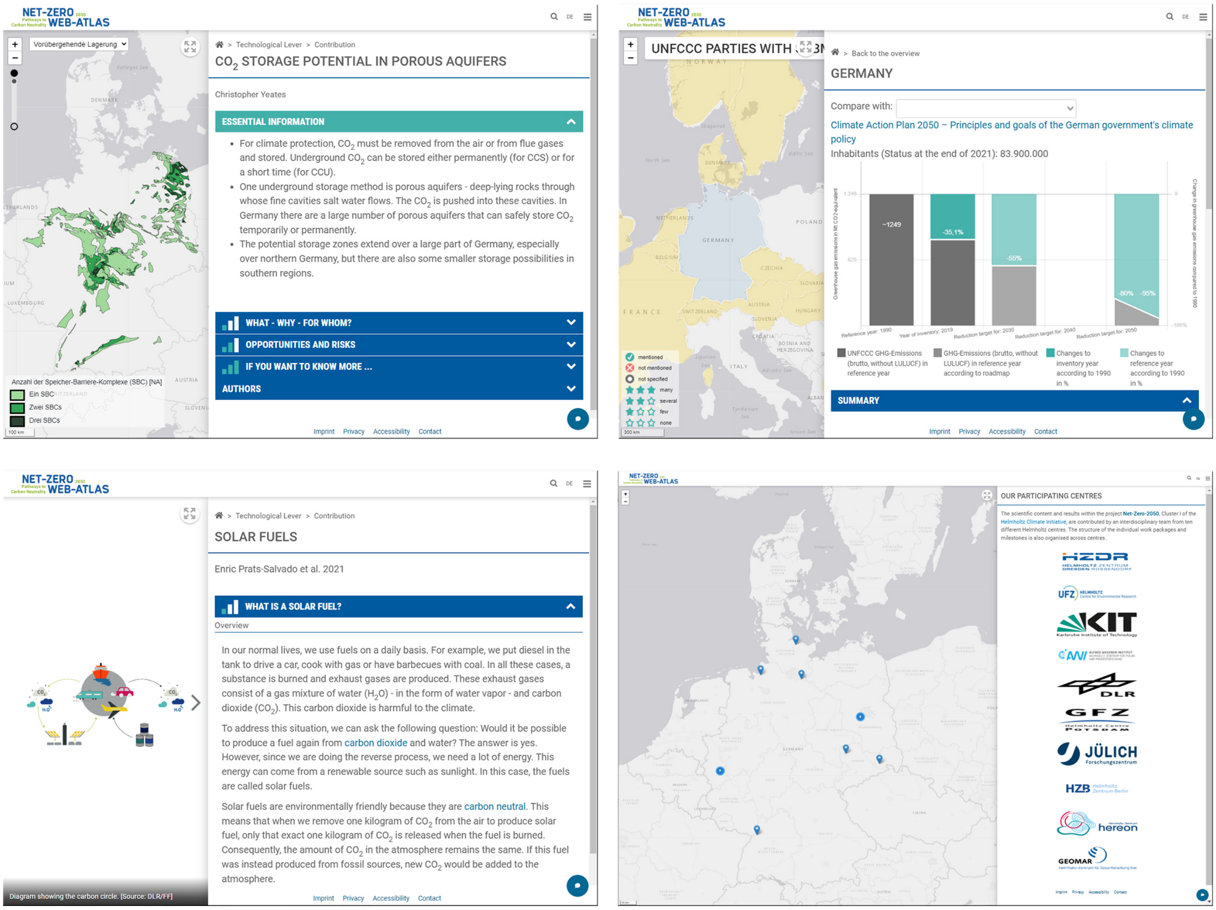

Figure 6. Screenshots of the Net-Zero-2050 Web-Atlas contributions: exemplary map contribution (upper left – Yeates, 2022); exemplary story contribution (lower left – Prats-Salvado and Monnerie, 2022); exemplary UNFCCC roadmap synthesis (upper right – UNFCCC-Roadmaps, 2022); our partner centres (lower right – Net-Zero-2050 Participating Centres, 2022).

who have a strong interest in making a difference are searching for instructions on actions. Other readers only need to deepen their knowledge. Therefore, the practical relevance, especially the deep dive into the topic, should be recognised as a selectable option to the atlas.

For the Net-Zero-2050 web atlas, it is assumed that if the expected users have different interests, clustering the interests with appropriate labelling will help the user to choose. The product comparison research (Preuschmann and Köhnke, 2020) and further expert surveys (diverse personal communications) with practitioners have confirmed the necessity and success of such choices. Therefore, the atlas developers implemented the level labels “Overview, Practice, Background”, which identify the level of information pictographically via a three-level bar system in addition to the explicit naming, see Fig. 7. As interim-users, the project partners received a statement defining what to look for at these levels. Our experience and research on the topic of labelling levels of interest have shown that the idea of “Overview, Practice, Background” levels is helpful. In the map contributions, these labels were predefined, whereas in the story-based contributions, the labels to the respective text section were individually assigned by the authors. However, it was still difficult for the project partners as knowledge providers to independently classify which information should be assigned to which level. Therefore, consistent implementation of these information levels requires powerful guidance and instructions to the project partners as interim-users to contribute to the web platform. While interest labelling helps with a general standardisation of the product, it leads to a restriction of the individuality of the authorships. A compromise is needed that offers a balance between standardisation and diversity.

In summary, to meet the needs of the diverse user community, potential clusters of interest were formed and marked accordingly.

3.2 Soil Carbon App

The Soil Carbon App aims to provide scientific data and results from the land surface modelling and agriculture science within Net-Zero-2050. In particular, the app conveys the po-

Table 1. Guiding Structures Free Story and Map contribution, given to the project partners for preparing the atlas contents.

Text scheme for Free Story contribution	Text scheme for Map contribution
Introduction *What?* – Catch up with the reader – briefly explain: what is shown in this graphic story?	*Most important messages for the readers in three bullet points* – For each bullet point, note the most important in brief.
Methods *How?* – Describe the approaches or methodology to carbon neutrality and place them in the larger Net-Zero-2050 context. *Results* *Why?* – Describe why the results have significance for society.	*What does the map show?* – Pick up the readers – briefly explain what is depicted on your maps. – If you show several cards on one topic, each card must be mentioned and explained in this text. *Why is this issue important for achieving the goal of* CO_2 *neutrality by 2050?* – Classify here the relevance of the topic to achieving the goal of carbon neutrality. Describe the significance of the results in the context of this goal and how they feed into society. *For whom are the results relevant?* – Explain here your topic, who can use this information and for what purpose.
Opportunities and risks *What are the opportunities and risks of the results for the decision-makers?* – If possible, outline opportunities and risks of the mentioned results of the contribution. The information should contribute to the understanding and derivation of action strategies and measures to achieve the CO_2 neutrality target.	*What are the opportunities and risks of the results for decision-makers?* – Outline opportunities and risks of the results of the contribution. The information is intended to contribute to the understanding and derivation of action strategies and measures to achieve the goal of CO_2 neutrality.
Conclusion and context CO_2 *neutrality target* *What consequence?* – Describe the results' significance in the context of Net-Zero-2050 and how or with which options for action they can be introduced into society.	*Note options for action for the decision-makers with the help of the contribution results.* – Give possible examples of courses of action that will help achieve the carbon neutrality goal.
If you want to know more *Further details on this topic (Voluntary)* – Background articles with unlimited words and links to articles or similar, written by the authors on the subject. *Further information around the topic (Mandatory)* – Short information on accompanying activities or other topics with further links	*If you want to know more* *Further details on this topic (Voluntary)* – Background articles with unlimited words and links to articles or similar, written by the authors on the subject. *Further information around the topic (Mandatory)* – Short information on accompanying activities or other topics with further links

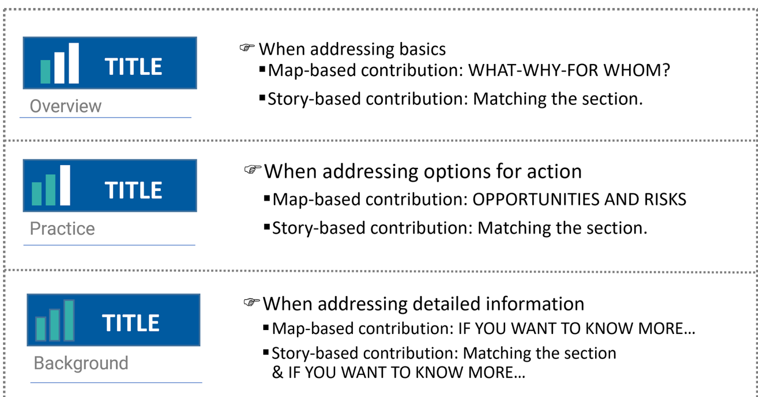

Figure 7. Interest-labelling including tasks for map- and story-based contributions, with tasks regarding the interest labels.

tential of different land management options for soil carbon storage under changing climate conditions. It was an explicit objective of the soil carbon app to explore the use of modern geodata infrastructure concepts, in particular data cubes and REST-API (Representational State Transfer Application Programming Interfaces), in this context. The challenges and approaches during the app's development process are set out below, taking the identified key questions into account.

3.2.1 Soil Carbon App: What to provide?

Answering the question "What to provide?" can be seen as bridging the gap between the supply and demand sides, which is explained in more detail in the following. To start with, where do challenges originate regarding the development of the Soil Carbon App?

One main challenge was that the data has a large volume, a specific format and multiple dimensions. The initial idea behind the Soil Carbon App was to provide simulated soil carbon data from a land surface model and regional climate model data used for driving the land surface model. The underlying data for the app had a substantial volume, and suitable methods for exploring the vast amount of data from many model simulations had to be developed. These methods aimed to enable diverse and flexible data analyses for various user applications, thus extracting information. At the same time, scientific expertise and guiding tools are usually necessary to use the original data in a meaningful way. To put this into context, numerous web portals provide fully processed data. Such data provision portals offer little interactivity and flexibility, and the benefit is limited to a pure download. In contrast, some portals offer customised data processing and visualisation simultaneously. The addition of such tools increases the flexibility of the web platform yet implies that respective technical and conceptual solutions need to be developed. Regarding users' capabilities, a higher degree of flexibility is more demanding. A balance needed to be found between these two aspects.

The second aspect, uncertainties, reflects that the scientific methods and the nature of the considered systems lead to a range of computed values instead of a single value of absolute precision for a given variable and question. In this case, several dimensions of uncertainty are combined in the experimental ensembles, making it more complex and difficult to understand. While this aspect is known and permanently discussed in the scientific communities, non-scientific users prefer results to be "precise" and "unambiguous", which is a challenge in science communication. This potential conflict should be addressed during the development process.

The development team addressed the technical and conceptual challenges through the following approaches. Through exchange and literature research among the project scientists, the scientific supply was evaluated using the following questions: What does the land surface model deliver with respect to agricultural methods and their influence on the soil carbon contents under changing climate conditions? How are the simulation data structured? Which questions could the model answer? What is the current knowledge in the published literature regarding the mentioned scientific topics?

A report published by the Johann Heinrich von Thünen-Institut (Heukrodt et al., 2019) delivered an overview of the target users' prior knowledge and expectations. What do farmers in Germany know about soil carbon management, agricultural methods and climate mitigation? What are their expectations towards potential tools for soil carbon management? Important results showed that there was already considerable knowledge amongst farmers on how agriculture can support soil carbon management, yet no widespread application of such methods was reported. Also, the climate mitigation aspect thus far was only anchored to a lesser degree in agricultural practises in Germany (Don et al., 2018). Potential users' expectations include, for example, that a product is easy to understand and that the methods offered are well explained (Heukrodt et al., 2019).

These scanning steps showed that it is necessary to curate the basis of the scientific background information and the original data. Therefore, concepts for a selection and definition of the app content were developed, which can be summarised as follows:

1. It was decided to offer a data-based part with interactive functions, plus one where users can browse text-based contents, such as used methods and data and scientific background information.

2. The data provided shall be pre-selected, and the development team shall predefine the analysis of the model simulation data. Thus, a data and data analysis portfolio need to be developed.

The idea was to offer users a pre-selected subset of aggregated data with pre-defined analysis features on the front-end, while the corresponding back-end should allow more proficient users to access the raw data and the aggregates in a completely unrestricted manner. This concept would allow the development of different and more complex analysis workflows and the combination of the soil carbon data with other data sources, thereby addressing the requirements of flexibility and interactivity.

User questions had to be developed to address the tasks of content selection and definition, especially for the development of the portfolio. These were anticipated questions that users might pose towards an application and thus helped identify what the app shall provide.

In-house experience from former product development processes and exchanges with experts revealed that non-scientific users often have relatively concrete questions, which they expect to be answered by a DKTP. To address this need, "user stories" were developed, and user questions were derived. The overarching question for the Soil Carbon App, as given by the Net-Zero-2050 project, can be put as follows: "How can agricultural methods support climate mitigation?". Through taking the perspective of the agricultural stakeholders while having the complex database in mind, this question was broken down into more detailed and directed questions (for instance, "If using soil carbon management methods, how much carbon could be stored in agricultural soils in the coming decades in our region?" "How does soil carbon storage depend on climatic conditions, and how could these change in future?" or "How much CO_2 could be stored in our region's soils when applying these agricultural methods?"). With these user questions, the portfolio of data analysis options was developed.

Exchange with partners from Johann Heinrich von Thünen-Institut and with potential stakeholders from the Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture) supplemented the database concepts, inspired by their extensive experiences and exchange with the target user groups. It was therefore decided that the comprehensive database, a strength of the Net-Zero-2050 project, should be used and both soil carbon and climate data, including future scenarios, should be made available in the web-app.

Furthermore, the above-mentioned concepts implied technical challenges: A processing of the comprehensive original data had to be conducted, and a provision of this processed data for further steps in a size and format that are digestible for an application and before the ultimate visualisation takes place. A construct of database and web service, the middleware, made this possible with special consideration of a flexible solution for the front-end side by ensuring direct access to the data and thus also individual processing by the user. The project proposal already envisaged the need for such a middleware, and its concrete design and realisation were decisive parts of the development process (see also Sect. 3.2.2., "How to provide?").

Concepts for uncertainties include the compilation of meta-information to users when interacting with the app's data and the deliverance of additional background information in the respective parts of the DKTP. It is necessary to decide on the amount of provided data to avoid overwhelming users. Concerning this, the visualisations should be carefully designed, help make uncertainties perceivable where necessary, and enable users to put a given result into context. This aspect also needs to be kept in mind for the question on "How to guide?". Due to limited resources, the underlying simulation data for the Soil Carbon App was based on one land surface model and one combination of global and regional climate model data. Thus, it was not necessary to transport an ensemble size in the app's data part. The unnecessary nomination of an ensemble size was communicated in the front-end along with the respective data filters and analyses.

The results of discussions, research, dialogues, and in-house experience led to a selection, pre-definition and structuring of what should be provided by the app, thus to a portfolio of data, data analysis and further information. The user questions were a helpful tool in this portfolio definition. Moreover, concepts for the provision must be developed to ensure the DKTP is appealing and highly usable.

3.2.2 Soil Carbon App: How to provide?

Addressing the question of "How to provide?" led to the challenge of presenting scientific results in a user-friendly manner to varied target groups.

Regarding the conceptual part of the development, the user questions were decisive for the solution for the mentioned challenge. Their development delivered the identification of different views on the topics, thus a sharpening of possible user expectations in terms of concrete needs for data analysis or for the provision of background information (see also Sect. 3.2.1 "What to provide?").

Regarding the solutions for the technical challenges developed for the app, several categories had to be considered, such as data processing, data storage, data transfer, and visualisation.

Strong expectations towards the app included high flexibility, constrained by scientifically defined boundaries, and a corresponding degree of interactivity, unlike many comparable web-based products. The data provided must be scientifically sound and meet high-quality standards. The technical frames ensure the concepts' realisation regarding the data portfolio in the DKTP. As explained, the original data come with a large volume and in specific formats, which hampers performant processing and thus visualisation in the app. These limitations especially matter when considering the requirement of interactivity.

The solution for flexible and interactive access to high-quality multidimensional data was the construction of a middleware, which includes a raster array database and a representational state transfer (REST) middleware web service. This component processes and transforms raw model output data towards a format and volume digestible by standard data transfer protocols and meets scientific quality standards. At the same time, it enables the app, based on the user's actual filtering, to access the data, conduct potentially necessary final processing steps, and visualise and display them.

Access to the data is independent of the front-end, which enables the necessary flexibility and is a particular strength of the technical component of the development. Also, the same data is always accessed, so that no problems can arise due to e.g., outdated copies. The conception and realisation of the Soil Carbon App's middleware as an innovative data infrastructure furthers new solutions from the computational sciences for the transfer of scientific data and results. The development and successful implementation of the middleware also ensures high-quality standards following the FAIR guiding principles (Wilkinson et al., 2016). Figure 8 schematically shows the components of the complete system regarding data creation by the land surface model and data flow through to the app's back-end.

Also, the team developed joint guides as a part of the solutions. The guides were based on extensive exchange among the involved project scientists from land-surface and regional-climate modelling, computational science and user-oriented conceptual development. They specify the processing, storage in the raster array database, and analyses and visualisations in the app front-end. These processing guides defined for the interim-users how to prepare the data for the variables to be shown and how to store it in the database. The processed data was then provided to the app front-end using the middleware web service. These guides were an important tool for a reliable flow of information between the different partners in the team, as a common technical language helps to avoid misunderstandings and ensuring the implementation of the concepts as intended.

Literature and internet research and dialogues with web development experts were needed to decide on the app's technical format. Important criteria for the decision were costs, transferability, maintenance, and the static nature of the data. The look and feel of the app were not of the highest priority. Additionally, today's technical frames also enable the use of a smart device's location function in web apps. It was decided that a web app should be realised instead of a native app.

To summarise, the question "How to provide?" was, to a large part, addressed by designing and implementing the middleware; its realisation in detail was oriented along with the mentioned findings regarding scientific supply and users' needs. In that sense, also the guidelines were developed that described and specified data processing in detail, again supported by the user questions (see Sect. 3.2.1). Exchange with experts, along with the research results, formed the basis for the decision regarding the app's technical format.

3.2.3 Soil Carbon App: How to guide?

The challenge of "how to guide?" can be formulated as follows "how to guide the users of varied target groups through the communication formats?"

Part of the solution is the information architecture of the app, thus the way the content is structured. It should be straightforward so that navigation is fast and easy, which helps users develop an intuitive way through the platform quickly (Information architecture of a Website, 2022; Resmini and Rosati, 2011).

Orientation on the platform has an important meaning for user satisfaction. The information architecture supports users' intuition with the format, if well designed. Apart from this implicit support, guidance can be given to the user explicitly, for instance, through a guided tour provided on the starting page.

Approaches for the app include a map provided on the starting page in the front-end, as an easy and appealing entrance and access to the data. Navigation is supplied, for example, through a menu with a flat hierarchy and meta-information for filter buttons, considering modern user experience principles. Also, the different forms of knowledge provision facilitate users to choose the level of information they prefer while using the app. These different forms of knowledge provision were supported by the two different areas of the app, the "data area" and the "background area". In the first one, users must apply filters on the data to produce their analysis and respective visualisations in maps or time series; in the second one, users can browse through background information provided through texts and links. The background information part enables users to learn about the most useful facts for meaningfully browsing through the data and understanding the results and might not be necessary for more experienced users. Apart from that, the app's background information on agricultural methods for soil carbon management is provided in a clear and homogeneous form to give an example for the supportive use of structures. A uniform outline facilitates the users to quickly extract the information on a particular agricultural method.

Apart from being crucial during the definition of the data and analysis portfolio, the previously mentioned user questions can also help develop a structure for the DKTP. Additionally, they may be included in the front-end to offer a learning tool for new users (thus offering an explicit guidance tool) or as an option just to follow a predefined analysis option.

To summarise, essential aspects identified for the challenge "How to guide?" are well-designed information architecture and good user guidance. These elements enable the users to quickly familiarise themselves with the app and successfully draw information from it.

3.3 Common points for discussion

In the following, additional aspects around the development of the two DKTPs are outlined.

In principle, it is desirable to thoroughly involve stakeholders in the development process to elaborate on their expectations, needs, and preconditions. In the case of Net-Zero-2050 DKTPs development, intensive stakeholder involvement was hardly realisable due to time constraints and the CoViD-19 pandemic situation. Regarding the needs of the target users, both developments had to rely on published knowledge.

Stakeholder involvement can be done through surveys, interviews and workshops. When planning a DKTP development, the associated resource needs should be considered. In this context, an analysis of the actual use of a DKTP could

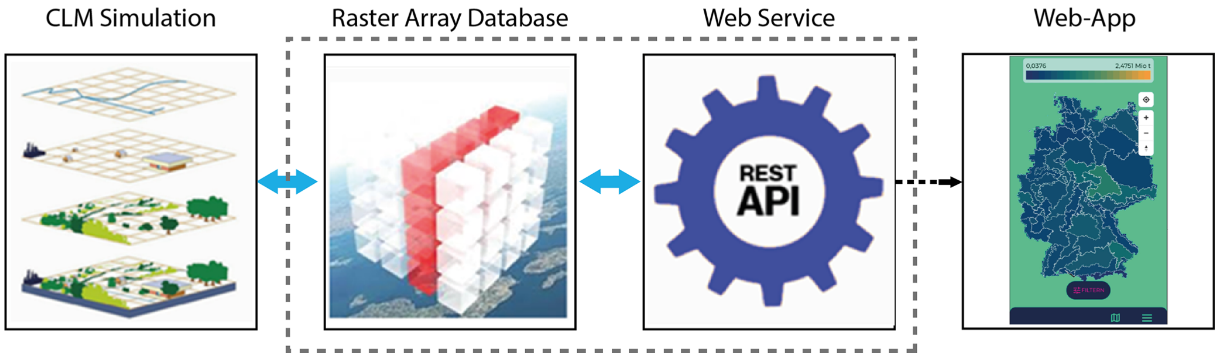

Figure 8. Schematic representation of the data flow components for the Soil Carbon App, from land surface model CLM (left) through the raster array data base and the web service towards the app's front-end (right) (graphics source: omnisci (land surface model scheme), rasdaman (Raster Array Database), DLR, mulesoft, buildfire).

explore the extent to which the developed product supports usability in the end-users' work context (Reveco Umaña, 2022). Further, when developing DKTPs, it is helpful to familiarise oneself with the background of communication theory, e.g., in (Digital Knowledge Transfer Project Leuphana, 2022; Liyanage et al., 2009). In particular, it is helpful to look more deeply into the interdependent user groups to prevent barriers within the knowledge transfer (Sun and Scott, 2005). Due to the time constraints of the Net-Zero-2050 project, barriers to knowledge flows within the different user groups could only be touched on the surface.

Another essential aspect concerns the imbalance between the knowledge of the developers and the end-users. The scientific knowledge providers can select and define possible content. The end-users can only choose from what is provided. This implies that the scientists are in a position of power to some extent. It seems advisable to take this aspect into account when developing a DKTP. In this sense, didactic reduction aims not to steer the end-user's gaze in a particular direction, therefore supporting the content's understanding. However, selection and reduction involve interpretive, subjective judgement on the part of the reducer (Lewin, 2018). This process carries the risk that the end-user may understand the reductions as censorship. For DKTPS, which function as virtual classrooms (FAO, 2021), it is necessary to dispel this suspicion by rendering the content in a scientifically sound and further transparent manner.

During a DKTP development process, it seems advisable to clearly define the roles of those involved. Depending on the task, team members can act simultaneously as concept and structure developers or content providers. In the app case, the aspect of uncertainties (see Sects. 3.2.1, 3.2.2) and their communication must be accessed in this dual role. Here, some developers are responsible for the actual presentation of the topic, while others must ensure that the corresponding technical solutions are implemented. In any case, a clear understanding of roles within a project promotes responsibilities. The dual understanding of roles also plays a role in managing information levels. For example, in the atlas, a "third-party" assignment of labels would be desirable. However, this would ultimately mean a much stronger control and regulation of the authors from the outside, which would mean a considerable amount of extra work in terms of time planning and human and financial resources planning. The framework conditions suggest that the team members classify their contributions from two perspectives. Thus, the authors must take on a double role, i.e., sender and receiver of the knowledge transfer. Team members should be aware of and sensitised to this dual role.

Another aspect worth considering is the project's interdisciplinary nature, which brought advantages and disadvantages to the development process. A clear advantage is the possibility of integrative cooperation, with the positive effect of mutual learning. The knowledge and experience gained can thus be more easily transferred to future projects. However, interdisciplinarity also risks that many processes require high iteration rates, which means a correspondingly high organisational and time effort.

4 Conclusions

Within the Net-Zero-2050 project, two digital knowledge transfer products (DKTPs), the "Net-Zero-2050 Web-Atlas" and the "Soil Carbon App", were developed. With the development of the two products, the opportunity arose to identify common challenges. The commonalities led to the question, "What are transferable approaches that structure and support the development process of digital knowledge transfer products?". In the refinement, three key questions were delineated, for which recommendations were then worked out. Thus, transferable approaches were found during product development that can support standardisation and future similar product development.

Various research has been carried out on the DKTP developments. One finding is that digitally available formats play

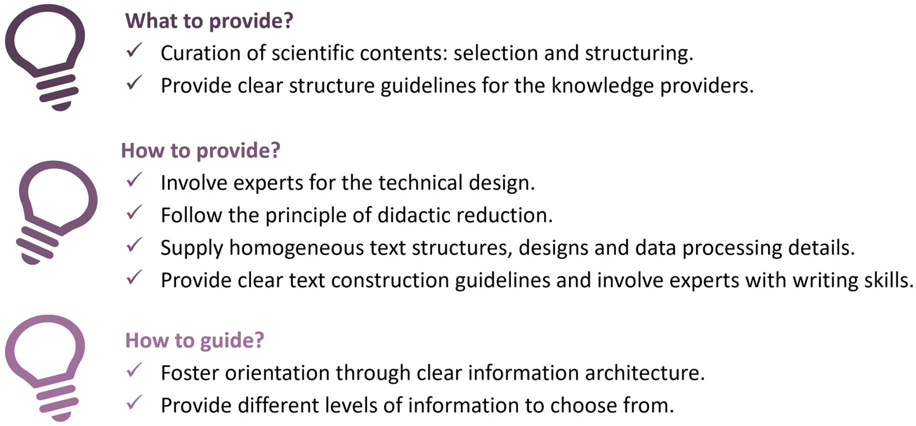

Figure 9. Short form of recommendations for developing DKTPs, categorised along with the key questions.

an increasing role in the transfer of scientific results to society.

While the challenges are common, it has been shown that each project specifically requires DKTP development adapted to the current project results and objectives.

Figure 9 shows a summary of the joint recommendations towards the three key questions.

Two recommendations were developed regarding the key question "what to provide?".

1. The curation of scientific contents: selection and structuring: In cooperation with the project partners, the development team selected the content that seemed useful to the target group from the diverse content and knowledge offered in the project. With the preselection, the scientific content was pre-structured in a user-specific way. Therefore, it is recommended to curate the scientific content, i.e., select and structure the content accordingly, and define the focus of the DKTPs.

2. Provide clear structure guidelines for the knowledge providers: To do justice to the different project results and approaches, structural guidelines were defined that could be applied to the contributions of all project partners. It is therefore advisable to provide the project partners with clear structural guidelines.

Four recommendations were developed regarding the key question "how to provide?".

1. Involve experts for the technical design: To meet the multidimensional data sets and content requirements, the project provided appropriate hardware and customised software for both DKTPs. Therefore, it is recommended to involve subject matter experts in technical design and IT implementation.

2. Follow the principle of didactic reduction: To do justice to the extensive and complex project results, guiding questions were developed that helped the project partners limit their research content to the essentials relevant for the users. Therefore, it is advisable to facilitate the project partners' didactic reduction of their content through text structure guidelines.

3. Supply homogeneous text structures, designs and data processing details: To do justice to the diverse and heterogeneous scientific result formats, uniform style options or even analysis procedures were identified and limited to these in the presentation of results. It is advisable to define uniform designs and text structures that nevertheless do justice to the diverse possibilities of expression

4. Provide clear text construction guidelines and involve experts with writing skills: For the implementation of the scientific results in the DKTPs, the project partners were given clear guidelines for the text design and journalistically trained experts were consulted. This resulted in scientific content that is suitable for every user and increased memorability through better comprehensibility. Therefore, it is advisable to give clear specifications for the text design and involve experts with knowledge of journalism.

Two recommendations were developed regarding the key question "how to guide?".

1. Foster orientation through clear information architecture: To categorise and sort the manifold contents, structures were developed in the project that serves as information architecture in the DKTPs. This pre-structuring enables the clear allocation of content and thus orientation on a website for intermediate and end-users in the final product. It is advisable to promote orientation through clear information architecture.

2. Provide different levels of information to choose from: To meet the needs of the diverse user community, the

DKTP developers have formed potential interest groups formed and labelled accordingly, such as “Overview”, “Practice”, and “Background”. Therefore, it is advisable to prepare and label the respective scientific information according to different information levels.

Critically reviewed, it is unclear whether generally valid recommendations can be developed from these commonalities identified for two products. During the product development in Net-Zero-2050, many desirable processes for product development could only be carried out in rudimentary form due to time constraints. Furthermore, the end-user groups and goals of the products were predefined. The extensive institutional experience, expertise, and resources that could be drawn on during product development is another enormous starting advantage in developing DKTPs in the service sense.

Nevertheless, these guiding questions, “What to provide?”, “How to provide?” and “How to guide?” along with the recommendations may pave the path for future successful DKTPs. These recommendations are particularly helpful in developing DKTP for knowledge transfer from large, inter-, and trans-disciplinary project groups to wide-ranging user groups.

Appendix A

Table A1. Catalogue of Requirements: Specific success criteria and the resulting recommendations from the evaluation Matrix developed for the Net-Zero-2050 Web-Atlas for product comparison of DKTP-Platforms, source: Net-Zero-2050 internal report.

Criteria		Recommendations
Content	Aim and coverage	– On the start page, it is useful to indicate the aim of the page concisely. – A description and naming of the target group help address the user. – Supporting user-tailored communication may be done by using the corresponding language style. – Integrating non-specialist users is more comfortable by avoiding technical terms and foreign words.
	Objectivity and relevance	– Emphasising neutrality and objectivity enhance the trustworthiness of the site. – The visibility of reputable partners on the first page increases the relevance of the content. – A recommendation on the use of information takes account of users' needs.
	Responsibility	– In order to increase trustworthiness, it is useful to provide links to the homepages of partner institutions, even if this means an increased long-term support effort. – An indication of how the site and individual contributions should be cited is beneficial for users.
	Carefulness and accuracy	– Good readability increases the attention capacity of the reader. The readability can be achieved by using a minimum of technical and foreign words and keeping sentence lengths short. Simple sentences of less than 20 words facilitate readability. – Information on scientific principles and methods should be given individually on all the respective pages. – It is useful to name the responsible authors and their affiliation with each contribution. It enhances the reputation but also enables a dialogue.
	Update level and maintenance	– It is beneficial for the user to know if and when the site is updated. – If there is a regular update, the frequency should be visible.
User experience	Accessibility	– It is convenient if the URL of the website contains the name of the website or has an apparent reference to the content of the page. – Smart search keywords, especially indirect search terms or variants and alternative terms mentioned in the text can increase the findability by search engines. – Users appreciate the design of the pages and sub-pages, which adapts perfectly to any output device. – In Europe, barrier-free access for public service websites is legally binding since 2016. The EU directive recommends that all providers of information and services understand the directive as principles and techniques to design websites and mobile applications to make them more accessible to users, particularly persons with disabilities (EU, 2016).
	First impression	– A straightforward structure helps to make a good impression. – It makes sense to have a minimum amount of text on the home page that invites the user to click further. – While familiar elements inspire confidence and instinctively cue the user, they can also be perceived as outdated and unfashionable. A creative mix of user-oriented standards with graphically individual preparation has a stimulating effect. – In particular, addressing users directly, such as "If you ..., then have a look here ..." implies user loyalty. – Graphic and discreetly animated elements have a dynamic effect and give the user the feeling of interaction, which contributes to user enjoyment. – A statement or explanatory page that anticipates questions about the goal of the page, the underlying project and the handling of the page provides direct access to the user's first needs.
	Structure and navigation	– Restricting the number of clicks to the information target to only three, if possible, facilitates navigation on a website. – Links or shortcuts to similar topics and overview pages are helpful. – Selecting topics via tiles with short explanations is very convenient. – Keyword searches and topic filters are welcome. – Hints on how to use the page and pointers to additional background information enable a quick understanding of the page. Attention: Overlays/tooltips need a barrier-friendly way of implementation.
	Design elements	– Colours are a matter of taste, but few high-contrast colours are beneficial. – Colours used for user guidance, need an additional combination with symbols for accessibility. – A legible font is a matter of course. A reference to font size adjustment may be useful if "Ctrl.+/−" is not intuitive. – An adaptive, responsive content orientation is compatible, especially for mobile devices. Responsiveness should also be possible for graphics and other visualisations, and it should be possible to deselect overlaying elements if necessary. – The text-image ratio should be balanced, and the generous use of white space is considered favourable.
	Multimedia elements, creativeness and originality	– The inclusion of various multimedia elements with interactive features facilitates understanding more challenging and complex information and enables exploratory learning. – Marked concise key messages help the reader to remember the content. – All elements should be enlargeable. – Animated graphics and diagrams have an interactive effect but must be controllable without barriers. – Including changing, representative images or illustrations is a visually appealing element. – The ability to personalise views can be beneficial.
Support and communication	User support	– A tutorial is a recommended tool to welcome first-time users. It would be advisable to embed the video on the website and have an audio commentary for videos. – It is helpful to include tooltips and page overlays, particularly in complex tools, to briefly explain individual parts of a web page. Tooltips and overlays must be accessible. – A glossary that opens as a pop-up window may be helpful to avoid the user switching to another window or external website.
	Dialogue and feedback	– A contact dialogue box or mail link is indispensable for a user connection. – If resources are available, an area where user feedback is transparent can be helpful to retain users but also to develop the site in a user-friendly way further.

Data availability. For the scientific data provided in the digital products themselves or in the scientific methods and models used to create those data, we refer to the website of the Net-Zero-2050 project https://netto-null.org/ (About Net-Zero-2050, 2022).

Author contributions. DJ initiated and supervised the Net-Zero-2050 Web-Atlas development. DJ, DR and MS initiated and supervised the Soil Carbon App development. BS managed and coordinated the Net-Zero-2050 project activity planning and execution. SP coordinated and managed the Net-Zero-2050 Web-Atlas development activity planning and execution. TB, DR coordinated and managed the Soil Carbon App development activity execution. SP, KG, BS and FK developed, formulated and implemented the conceptualisation and designs of the Net-Zero-2050 Web-Atlas. JEZ and FK performed and analysed project-related surveys to gain user-needs for the web-atlas structure. TB, DR, MS developed, formulated and implemented the conceptualisation and contents of the Soil Carbon App. MS and JS developed and implemented the app's middleware (database and web service). SP, TB, BS, KG and FK wrote the manuscript draft. JEZ, DR, DJ reviewed and edited the manuscript.

Competing interests. The contact author has declared that neither they nor their co-authors have any competing interests.

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Special issue statement. This article is part of the special issue "21st EMS Annual Meeting – virtual: European Conference for Applied Meteorology and Climatology 2021".

Acknowledgements. This paper has been produced in the Helmholtz Climate Initiative (HI-CAM) framework and is funded by the Helmholtz Association's Initiative and Networking Fund. Many thanks go to the Net-Zero-2050 and Cluster III teams and the many experts who contributed to the success of the two DKTPs with their input and experience. Particular thanks go to X-Net Services GmbH for co-developing and implementing the custom software of the Net-Zero-2050 Web-Atlas and to Kopfarbyte UG for the co-development and implementation of the Soil Carbon App. Thanks go to Christian Dold and Michael Herbst (Forschungszentrum Jülich) for their efforts regarding the land surface modelling, especially for the Soil Carbon App. Thanks are extended to Janna Gehrke for her very useful comments on the manuscript, and Armelle Reca Remedio for final edition.

Financial support. This research has been supported by the Helmholtz-Gemeinschaft (Klima-Initiative).

The article processing charges for this open-access publication were covered by the Helmholtz-Zentrum Hereon.

Review statement. This paper was edited by Gerald Fleming and reviewed by two anonymous referees.

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