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Abstract:
Making research results accessible and transforming them to usable information for policy and decision making through a web-based tool is a complex challenge. Research projects are generally not designed to meet the information needs of specific stakeholder groups. Furthermore, tools developed in these projects are usually intended to disseminate research data on a wide scale, not to provide answers to specific questions of these stakeholders. User-centered design techniques can guide the development process of such tools, to enhance their usefulness and thus the applicability of the research outcomes for the intended audience. We applied techniques for user requirements analysis of the Impacts Explorer tool in the AgMIP research project, which models the impacts of climate change on agricultural systems with a focus on farmers' income and food security. The objective of the Impacts Explorer is to support users in different continents, with different requirements and levels of knowledge, in developing adaptation plans in agricultural management.
This paper discusses the approach we followed for the user requirements analysis and evaluates the effectiveness of the techniques and lessons learnt. We conclude with recommendations for implementing this approach in the development of similar tools.

***Keywords**:* user-centered design; policy tool; requirements analysis; boundary work.

1 INTRODUCTION

The importance of scientific advice in planning and policy-making for climate change adaptation is widely acknowledged. In order to make sustainable decisions, governmental institutions, NGO's and private organisations require thorough understanding of the future impact of climate change on their sector, problems that may occur, and possible solutions to these problems. Many international research projects claim to support policy development and decision making on climate change adaptations using model-driven approaches that reflect complex real-world dependencies between for instance environmental, social, and economical factors. However, scientific results are often not used effectively in adaptation planning and environmental decision making (Kirchhof et al, 2013; Ruppert et al, 2015). The results often do not match stakeholder information needs or are not easily accessible.

The attempt to span the divide that frequently exists between science and non-science disciplines and sectors, by translating scientific knowledge into something tangible and useful for decision makers formulating new policies, is known as ''Boundary work'' (Chaudhury et al., 2013). The main principles that underpin successful boundary work are credibility (is the information valid, accurate and tested); salience (is the information provided perceived as relevant); and legitimacy of the information generating process (was the process inclusive, and unbiased). Advancements in information and communication technologies (ICT) and availability of internet world wide offer opportunities for meeting these three demands by bringing research results closer to stakeholders and increasing transparency and acceptance levels. Policy-making increasingly depends on ICT support, driven by developments such as open data, computational methods for processing data, opinion mining, simulation, visualisation of rich data sets, social media, and participatory tools (Janssen et al., 2015). However, the vast amounts of data that become available through these developments also generate new problems in managing the overabundance of the data; at the same time problems of uncertainty in

models and future scenarios continue to exist, complicating decision making. To fully take advantage of the opportunities ICT developments offer, and deal with the complexity of information and information overload, visualisation tools are developed that help users to better understand data, that provide a more meaningful view in context, and that allow discovery of new patterns.

Information visualisation is defined as "the use of computer-supported interactive, visual representations of abstract data to amplify cognition" (Card et al. 1999). Information visualisation allows to intuitively access results of complex models, even for nonexperts. Visualisations are regarded as one of the categories of ICT tools that support policy-making processes by increasing its efficiency, bringing it closer to all relevant actors, and enhancing its transparency and acceptance levels (Kamateri et al., 2015). In the last decade many visualisation and geovisualisation tools have been developed in various domains to present statistical data. They allow users some kind of interactivity like exploring, querying, filtering and combining data, which supports data selection for specific questions and interpretation of the outcomes through a user-friendly interface. To ensure the tools meet the information needs of users in planning, policy-making and decision making processes, their development should follow a user-centered design methodology that focuses on users and their requirements (instead of a data driven approach). In the next sections we describe the activities conducted to determine user requirements of a tool for policy-making and planning in agricultural adaptation, the AgMIP Impacts Explorer, in which a visualisation tool, the Data Exploration Tool, is embedded.

2 THE AGMIP IMPACTS EXPLORER

The Agricultural Model Intercomparison and Improvement Project (AgMIP) aims to deliver information for adaptation planning by stakeholders in the agricultural sector. The goals of AgMIP are to improve the characterisation of world food security due to climate change and to enhance adaptation capacity in both developing and developed countries (Rosenzweig et al, 2013). Crop model outputs are aggregated as inputs to regional and global economic models to determine regional vulnerabilities, changes in comparative advantage, price effects, and potential adaptation strategies in the agricultural sector. The project develops Representative Agricultural Pathways (RAPs), economic and social development narratives that include agricultural technology trends, prices and costs of production trends, and agriculture and conservation policy. RAPs enable testing of climate change adaptations in the context of other global trends. The work is undertaken with regional research teams in Africa and South Asia, who collaborate with regional experts in agronomy, economics, and climate, to build a basis for applied simulations addressing key climate-related questions.

A key objective of AgMIP is to enhance the uptake of the knowledge generated in the project by stakeholders for policy development and policy implementation. One of the instruments for dissemination of the project outcomes to the intended audience is a web-based tool, the Impacts Explorer. The tool is being designed to assist policy makers, planners and other interested professionals in their exploration of data and results to inform decisions, and to help researchers better understand how to describe their findings for experts in other professions.

The Impacts Explorer presents results of the modeling conducted in the regional studies. To enhance their credibility, salience and legitimacy and make them useful and applicable for planning purposes, they are refined and enriched in an iterative process with local stakeholders. The resulting descriptions, or *key messages*, explain the expected effects of changes in temperature and precipitation on crops and livestock, economic effects like smallholder farmer income, and possible successful adaptation strategies. The key messages are presented in the Impacts Explorer with relevant background information, and explanation of scientific issues such as uncertainty in modeling. In the Impacts Explorer an interactive visualisation module (the Data Exploration Tool) gives access to results of complex computational models in a user-friendly interface..

The design and development process of the Impacts Explorer tool faces a number of specific issues and challenges:

1. The research is in progress, so the outcomes of the project are not yet established, and content of the tool is being delivered and refined continuously;
2. The project includes seven regions in Sub-Sahara Africa and South Asia with large cultural, socio-economic and governmental differences, affecting stakeholder requirements;

3. The project timeline determines the regional and global meetings where stakeholders are met and can be consulted.

This paper discusses the techniques in designing the Impacts Explorer, their effectiveness, features of the design of the tool itself, and lessons learnt during the process.

3 USER REQUIREMENTS ANALYSIS FOR THE IMPACTS EXPLORER

The user-centered design process outlines the phases throughout a design and development life-cycle while focusing on gaining a deep understanding of who will be using the product (http://www.usability.gov/what-and-why/user-centered-design.html). The design of an application is based on the explicit understanding of users, their tasks, and their environments; is driven and refined by user-centered evaluation; and addresses the whole user experience. The process is iterative and involves users throughout the design and development cycles. It starts with specifying the context of use, so identifying the people who will use the product, what they will use it for, and under what conditions they will use it. Secondly, requirements are specified; after which design solutions are created to answer these requirements. The designs are evaluated with users (Benyon, 2010).

For the Impacts Explorer we distinguish stakeholders and actual users or end users. Stakeholders are seen as a broad group of individuals and organisations that have an interest in the project research and its outcomes. They are involved in the project through a range of stakeholder engagement processes, for example to refine the key messages and to advance the uptake of the results in agricultural adaptation. We define users as those individuals who will actually use the tool, or in the words of one of our stakeholders, “the persons holding the mouse”. For application development, this distinction is important because the interface must support the users of the tool in their activities (for instance searching information, comparing results, etc.), and designers must take into account their computer experience and the context of use. It was however difficult to explain the difference to stakeholders and researchers outside the development team during the requirements analysis process, and the distinction was not maintained entirely in the requirements process.

3.1 Approach and methods

The requirements definition process had to take into account the physical distance between the research teams and the limited opportunities to meet face to face. Online communication was complicated by bandwidth problems and time differences between the regions involved. Meetings with the research teams and stakeholders to define stakeholder and user groups and establish their information needs were organised during AgMIP workshops in 2014, 2015 and 2016. In these meetings, stakeholders were interviewed individually or they participated in small scale sessions led by the Impacts Explorer development team. After the meetings follow up contact was maintained mostly through mail.
The steps in our process included:

1. Stakeholder mapping and prioritisation. Stakeholders were involved in the AgMIP project from a very early stage. The researchers in the African and Asian regional teams maintain extensive networks of practitioners in their countries and have understanding of local policy processes. To identify all groups of stakeholders with high interest in the AgMIP results and the Impacts Explorer, we mainly used research teams’ knowledge of their stakeholders, and literature in the field on similar projects. In workshop sessions we identified important stakeholders and mapped them on a so-called Influence-Interest matrix (Bourne & Weaver, 2010). The use of these two “dimensions” (low-high influence, low-high interest) helps to specify who will be affected or benefit most and who will be key players in or promoters of a project or application. This in turn allows to focus the stakeholder oriented activities and (in the case of application development) to proceed to user identification.

2. User identification. In the workshops and in several online sessions the stakeholders and project researchers were invited to identify typical users for the Impacts Explorer and to discuss their ideas with each other. In this step, also the information need of the specified users was determined.

3. PACT analysis. PACT is a framework for discussing and scoping the design situation. It concerns the People who will use or be affected by the application; the Activities that the system will support (related to functionality); the Context that the system will be used in (and how this will affect the

design); and the Technologies that can be used and are available to support the activities (Benyon, 2010). In the review of Activities, extra attention went to the data and information need of the users, because presenting the AgMIP research outcomes will be the main objective of the Impacts Explorer. A PACT analysis was first conducted with seven stakeholders in a workshop in Zimbabwe to evaluate the physical, organisational, and cultural context that would affect the user demands and the use of the tool. For the other regions the analysis will be conducted in a later development phase, and results will be used to adjust the Impacts Explorer prototype.

4. Persona- scenario construction. Personas are widely used in application design (Pruitt and Grudin, 2003). Personas help to guide design decisions and support communication in the development process. They are fictional characters that are representative of typical, desired, user groups. The description includes their function, education, computer skills, domain knowledge, goals and daily work tasks. When a number of Personas (primary users) is established, together with users *scenarios* are created that describe how the Persona will use the application to attain a certain goal. This goal may be for instance to prepare an advice for a farmers' organisation on adaptation measures, or to find answers to specific questions for a policy brief. The scenario includes a description of the actions of a user, the response of the application, and the results; as well as the context, such as location, time, and the collaboration with other people. Scenarios help to imagine how the application will be used, and how contextual factors may influence this use. The construction of Personas and scenarios for the Impacts Explorer started in 2014. They will be refined during the development process and will be used to test and evaluate the application.

5. Requirements definition. All user-centered activities, especially the PACT analysis and the Persona scenarios, lead to requirements for the Impacts Explorer. The scenarios reveal what functionalities the Personas need to achieve their goals, how they expect to interact with the interface, and what they expect regarding the content, both the information itself and the presentation. From these descriptions, designers can derive user requirements and to some extent technical and data requirements for the application. The requirements are prioritised and form the basis for the design solution.

During these steps, we noticed that the participants found it hard to create a mental model of the tool to be developed. To facilitate the discussion and prevent miscommunication we presented prototypes of the Impacts Explorer to the participants, starting with a very rough outline and gradually showing content contributed by the regional research teams and the main functionality of the tool.

3.2 Results

1. Stakeholder mapping and prioritisation and 2. User identification.
The workshops resulted in the identification of a broad range of possible *stakeholders* of the information presented by the Impacts Explorer; most mentioned were policy-makers at regional or national levels, but also researchers and educational institutes, farmers' organisations, and industry. Stakeholders who were considered to have high interest and influence include government agricultural ministries (policy planners and extension program developers), development organisations, donors, and NGOs. Although the ambition of the regional research teams is to reach decision makers working on district up to global levels, the emphasis lies on national level policy and decision making.

The most important *users* for the Impacts Explorer are the so-called technocrats: professionals with a relevant academic background, working for government; either focused on preparing policy plans or advising farmers or farmers' organisations. The discussions led to secondary user types (also important, but not target users): a development worker, a practitioner at a NGO having a relevant academic background; a commercial farmer; and an individual with expertise in farmers' organisations/associations.
Other users mentioned were for instance agricultural officers at financial institutions (banks or insurance companies); consultants working at climate change boards; and researchers.

3. PACT analysis
In the PACT analysis workshop the Zimbabwe stakeholders considered the type of activities for which the users would likely turn to an instrument like the Impacts Explorer. They determined two main categories:

- focusing on policy: collecting information on adaptation strategies and options, in the context of preparing policy plans and vulnerability assessments. For instance: describing a current situation, determining risks, comparing adaptation options;
- focusing on advising farmers: collecting relevant information on adaptation options and current climate trends for raising awareness and pathways for change; the objective is presenting these to other audiences, such as extension workers or farmer organisations.

Main observations regarding the decision making context were that:

- the developments of commercialisation of farming and increased concern with a changing climate lead to a strong network of the different stakeholders, and an interest in receiving information on the impacts of climate change;
- there is an intricate network of stakeholders which develops over time. Each stakeholder group is in itself highly heterogeneous, but there is usually a technical layer providing advice and support;
- trust and quality of the information are important criteria for the use of information;
- the importance of specific stakeholder groups differs between regions.

The significance of researching and respecting local circumstances can be illustrated by an example from a meeting in South India with district administrators and policy implementers. A hydrological engineer put forward that any recommendation for adaptations in farming practices based on climatic predictions would only be accepted locally if it conformed to the predictions of the Panchang. The Panchang is a classical Hindu astrological almanac that is published yearly and is used for making astrological calculations and predicting rainfall (Sivaprakasam & Kanakasabai, 2006). Agricultural professionals in Tamil Nadu have high trust in the predictions and use them for planning farming activities. This issue was supported by other participants in the meeting and led to a more general discussion on the acceptance and use of research results by policy makers. It emphasises the importance of creating trust in the information provided by the Impacts Explorer, and of close collaboration with local stakeholders to understand obstacles and opportunities to achieve this.

Regarding the technological context, the stakeholders remarked that for Zimbabwe, internet in the cities is reliable and reasonably fast, however power cuts are a problem. Outside the main cities internet access is less reliable and farmers generally rely on their cell phones for information.

4. Persona-scenarios

Based on the results from steps 1-3, two primary Personas are defined. The first is a policy officer at national level, involved in preparing policy plans for agricultural adaptation. The Persona is constructed with input from stakeholders from African countries; in addition, a version for one of the Asian countries involved will be constructed. The second is a principal agronomist at a national ministry of agriculture, advising agricultural extension personnel on many aspects of agricultural production. This Persona often works at provincial offices. His main activities with the Impacts Explorer are collecting information on adaptation strategies and options in the context of preparing policy plans, and searching for relevant information to determine future risks and compare adaptation options. The scenarios created for this second Persona provide a detailed description of work on specific issues, the steps he takes to collect the required information, also using other online sources, how he expects the information to be presented, and how he integrates the information for a report.

Both these primary Personas have expert knowledge on some aspects of agricultural adaptation, however not on all domains. A secondary Persona will represent a user with an interest in practical implications of climate change and adaptation, and a general, so not expert, knowledge of research in this domain.

5. *Requirements definition*

The outcomes of the requirement activities, and especially the PACT analysis and Persona scenarios, led to a list of requirements that will be adapted and refined in the next phases of development. A large number of requirements concern the data made available in the Impacts Explorer, for instance resolution, the time period they cover, uncertainty and trustworthiness; this however belongs to the tasks of the research teams and is outside the scope of the development team. Many requirements relate to the use and presentation of the data and concern for instance options to explore data, combine them (also with data sets from other sources), visually compare, and download data.

Besides the data, the Impacts Explorer will present the key messages on adaptation highlighting the main conclusions from regional case studies. These messages contain text, photos and graphs for quantitative information, in a format common for all regional studies.

Some of the user requirements concern the desire to give feedback on the data and the key messages, and to read other users' comments on the content of the Impacts Explorer. Technical requirements concern the bandwidth available in the user countries and the platform of the tool: the tool should be accessible in a "light" version and have a responsive design to meet the increasing use of mobile devices. However, based on the Persona description we expect that in the near future most users with specific information needs will access the Impacts Explorer on a personal computer, which for now determines the design of the website and the Data Exploration Tool. Another challenge will be to offer the information in different languages, which would enhance the uptake by users not proficient in English. Both issues will be addressed during the testing phases.

3.3 Design Solutions

An important high-level requirement concerns the accessibility of the project outcomes for users with different knowledge levels. A general design principle for the development of the Impacts Explorer is therefore to present the content in three "layers" progressing from simple to more complex:

1. Layer 1. Overview of the main outcomes of the project and main messages of the regional studies; concise text, easy to understand infographics; some background information;
2. Layer 2. More in-depth explanations of the regional studies; related background information;
3. Layer 3. The interactive Data Exploration Tool, to evaluate the underlying datasets.

Layer 1 meets the needs of an audience with a general interest and directs users with a specific interest to other parts in the IE; pages are for instance the landing (home) page, background information, and the summary pages of the regional studies;
Layer 2 presents information relevant to individuals with specific interests in a region, crops, economic effects, etc.; and leads to the interactive Data Exploration Tool. Examples are for instance the detailed pages on the regional outcomes, methodology of the project;
Layer 3 allows users with more in-depth knowledge to further explore the data with the interactive Data Exploration Tool. Layers 2 and 3 answer the needs of the primary Personas (Fig.1). The design will allow experts to access the more complex and specialist information directly as well.

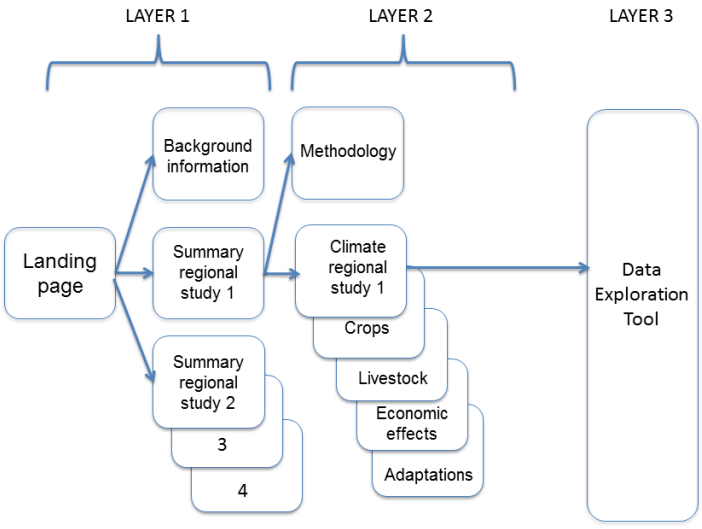

Figure 1. The three layers in the design of the Impacts Explorer.

The Data Exploration Tool gives access to the model outputs and economic evaluations on which the key messages of the regional studies are based. It is an interactive tool or information dashboard that allows users to select, filter and visualise data in a structured manner. Several indicators from different categories (climate, crop, livestock and economic) can be compared to give an overview of how climate change, agricultural developments and adaptation affect the production and welfare.

Information dashboards are often confusing to users who are not familiar with the data and therefore do not understand the results of their actions in selecting and displaying data. To reduce this problem, the Impacts Explorer provides a transition from the regional study pages to the Data Exploration Tool. The regional study pages show static graphs on for instance crop yields and or economic effects in a specific climate scenario. When the user clicks on this graph, the Data Exploration Tool opens, presenting the same data, so the same region, commodity, and other selections that apply. From this state, the user may select other regions or commodities (Fig.2). By starting from a static chart image in context of a regional study and from there directly initializing the Data Exploration Tool in the same state, the user is offered a known situation and starting point for further analysis.

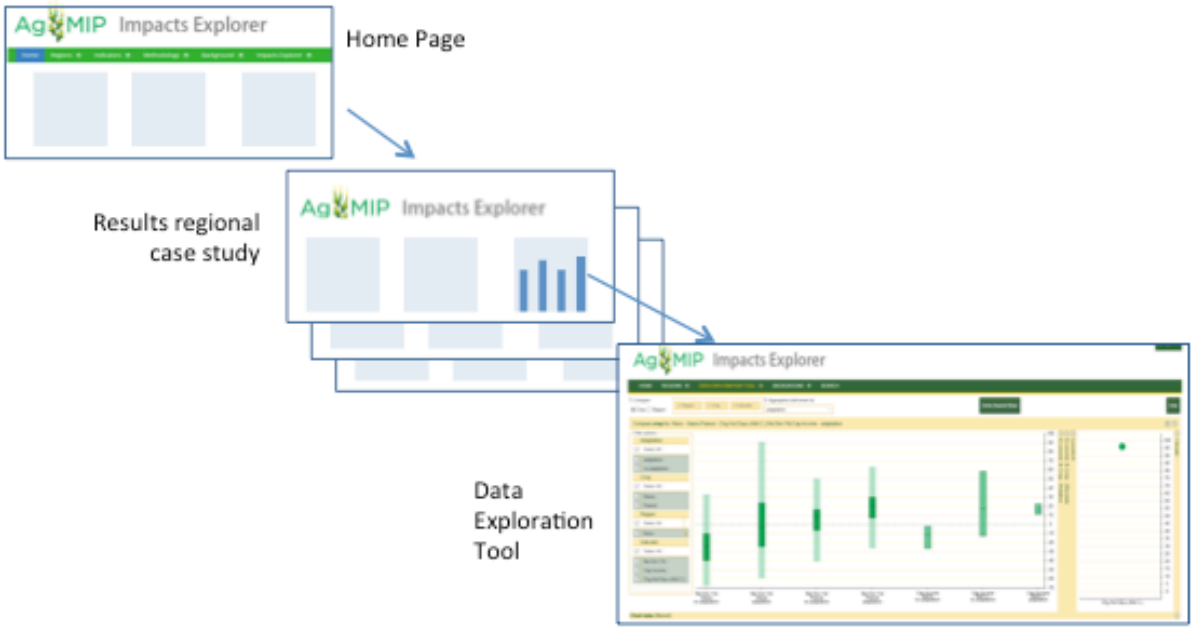

Figure 2. The transition from a graph to the Data Exploration Tool (http://agmip-ie.alterra.wur.nl).

3.4 User evaluation and testing

The first Impacts Explorer prototype was evaluated by research teams and stakeholders in February 2016. The improved prototype will be tested with representative users with a Think-aloud protocol and evaluated using the Persona-scenarios. This procedure will be repeated before the final version of the tool is launched in 2017. A stakeholder panel is established to give feedback on the Impacts Explorer prototypes and to advise on enhancing the impact of the tool in policy-making context.

4 CONCLUSIONS AND RECOMMENDATIONS

Designing a tool in a large scale international project like AgMIP requires understanding of regional and national needs in different countries and continents, of the decision making process, cultural differences and language issues. During the requirements analysis and design process of the Impacts Explorer we observed a number of benefits and difficulties of the approach and techniques we applied. Our general conclusion is that the approach has led to a robust design of the Impacts Explorer that will support the principles of Boundary Work introduced earlier in this paper, namely credibility, salience and legitimacy. The process itself has led to better understanding within the research teams of information needs of the stakeholders of the AgMIP project and has provided extra opportunities to engage stakeholders. The difficulties were mainly related to planning and conducting the activities:

- ICT tool development is taking place during the research, when outcomes are not yet available, which complicates the design and testing of the tool during the project;
- ICT tools have to bridge huge gaps between research and policy/implementation: modelling outcomes must be transformed into predicted effects and scenarios, and these again into adaptation strategies and local implementations to make sense to users;

- Although our approach consists of a number of sequential steps, in reality the activities are not conducted strictly in this order: in a large international project the involvement of stakeholders may be difficult to organise. As a result the design may require adjustments more often than planned.

In many research projects budget is allocated for technical development of an ICT tool, not for investigating the intended users and expected use and impact of the tool. “Users” of research outcomes are therefore often not well defined, and their information needs not understood. ICT tools must be tailored to the needs of a defined user groups, or usability factors (usefulness, effectiveness, satisfaction, etc.) cannot be taken into account in the design, nor tested during development.

The user-centered design techniques we applied in the requirements analysis and design process help to address these issues by continuously focusing on the expected product and its users. The techniques do not require technical or domain knowledge and can therefore be conducted in projects with stakeholders and users of different backgrounds. However, it is essential to include these steps in the project planning from the start and recognise that creating understanding of the importance of these activities and conducting them in an international research project requires time and effort from many project participants.

The AgMIP Impacts Explorer demo : http://agmip-ie.alterra.wur.nl

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