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Report on the co-design workshops in FANFAR to create a flood forecast and alert system for West Africa

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Editor	-
Brief Description	We describe the co-design process to create a co-adapted, integrated and sustainable FANFAR flood forecast and alert system in West Africa. It is based on a structured Multi-Criteria Decision Analysis (MCDA) framework that guides the participants of four co-design workshops and the FANFAR consortium through problem structuring phases, including stakeholder analysis, agreeing on objectives and options (FANFAR system configurations), eliciting expert predictions and stakeholder preferences and assessing the performance of system options based on these input data. We also introduce interactions with participants in and between the co-design workshops (e.g. rainy season surveys) concerning their experiences with floods in West Africa and with using the FANFAR flood forecast and alert system. This includes feedback on the FANFAR technical system components from hands-on practical sessions in the FANFAR co-design workshops. In this report, we focus strongly on the methods, and also present preliminary results.
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Executive Summary

FANFAR enhances the capacity of West African institutions to forecast, alert for and manage floods. The overall objective of FANFAR is to reinforce the cooperation between West African and European hydrological modellers, field observers, data managers, operative forecast analysts, emergency managers, developers of information and communication technologies (ICT), satellite experts and decision analysts in order to provide a co-designed, co-developed, integrated and co-operated hydrological forecasting and alert pilot system for West Africa.

This report describes the co-design process, based on co-design workshops to create a co-adapted, integrated and sustainable FANFAR flood forecast and alert system in West Africa. Over the course of the FANFAR project, four of such workshops are organised. The co-design process is based on a structured Multi-Criteria Decision Analysis (MCDA) framework that guides the workshop participants and the FANFAR consortium through problem structuring, data collection and analysis phases.

The first phases included a stakeholder analysis, which was prepared by the FANFAR team and completed during the first workshop in a group assignment with participants from the 17 countries in West Africa. During the next phase, participants developed and prioritised a set of objectives (workshop 1), that was consolidated into 10 top objectives during workshop 2. This was achieved using a mix of three types of brainstorming techniques. Furthermore, a set of 11 system options (FANFAR system configurations) were developed during sessions in workshop 1. In between workshops 1 and 2, expert predictions were made regarding the performance of the system options on each objective. In workshop 2, stakeholder preferences were elicited regarding the fulfilment of the objectives. Stakeholder preferences were continuously measured using surveys in the consecutive workshops.

The FANFAR system is continuously further developed by the consortium between workshops to match the elicited preferences of the participants. During the workshops, technical system components are tested with participants in hands-on practical sessions. Systematic feedback collected during these sessions then feeds back into the further development of the system between the workshops, in order to improve FANFAR iteratively. Additionally, we introduced interactions with participants to elicit their experiences with flooding in their domain, as well as their usage of the FANFAR system. These experiences are gathered using surveys that are taken both during the workshops as well as between the co-design workshops (e.g. 2019 and 2020 rainy season surveys).

Overall, involvement and commitment from our West African participants has been very positive. Their input significantly improved the evolution of the FANFAR system. Results of the co-development process indicated that accuracy of information and clarity of flood risk information are top priorities. Using this information, the MCDA identified a number of FANFAR system options that perform well across participants' various preferences. Although usage of the FANFAR system among participants is not yet at 100%, all participants have a strong intention to use it in the near future.

In this report, we focus strongly on the methods of the co-design process and present some preliminary results. Our innovative co-design process facilitated the development of a flood forecast and alert system that is truly built with and for its prospective West African users.

1 Introduction

Flooding is a rapidly growing concern in West Africa, projected to increase with climate change. There is a great need for reliable access to operational flood forecasts and alerts adapted to regional conditions and operated by capable West African institutions. The general aim of the FANFAR project is to reinforce the cooperation between West African and European hydrologists, information and communication technology (ICT) experts, decision analysts and end-users to provide a co-designed, co-adapted, integrated and co-operated streamflow forecast and alert pilot system for West Africa.

For such an ambitious aim of close collaboration and partnership, an essential step is to include relevant stakeholders and end-users in the project, and to co-design the flood forecast and alert system together with them. In such an understanding, the development of the ICT system is thus not only a technical task, but also requires adapting to user needs. During the ICT development, various decisions have to be made. Decision topics are, for instance, data sources that feed into the ICT system, representation of the output information such as alert levels, output products, distribution channels or economic constraints. The development of the FANFAR flood forecast and alert system relies on an iterative co-design process that is specified in Work Package 2 of the FANFAR project. Decision analysts from the Department of Environmental Social Sciences at Eawag, the Swiss Federal Institute of Aquatic Science and Technology[1] lead the co-design process. It relies on four one-week workshops that are carried out in West Africa.

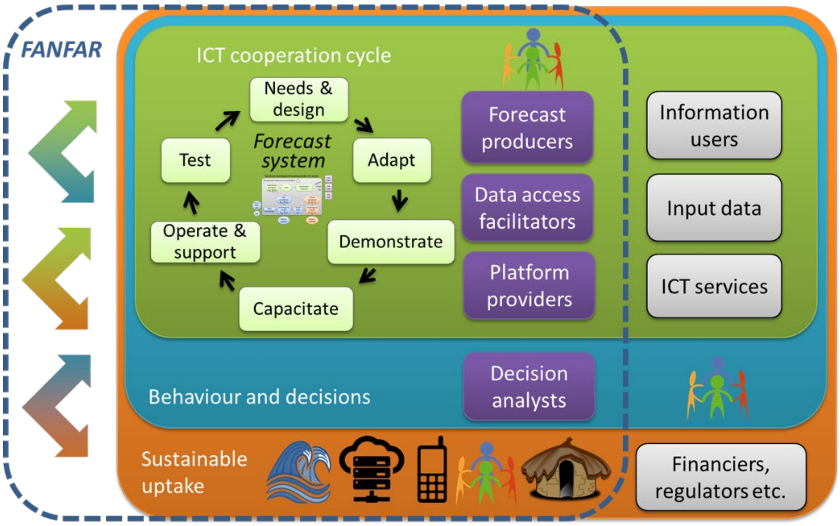

Figure 1: The FANFAR co-development process. Top left: the ICT cooperation cycle, which is based on co-development in four co-design workshops in West Africa. Figure: J. Andersson.

Co-designing the system is an iterative process with several development cycles: define specific need → develop functionality → test and provide feedback → revise functionality, etc. (Figure 1). Specifically, important stakeholders and users of flood forecasts and alerts are invited to the co-design workshops. These participants closely interact with the FANFAR consortium during the workshops, and they use, test, discuss and challenge the FANFAR flood forecast and alert system. They are asked to provide structured feedback to the system developers and to make suggestions regarding various other important aspects concerning an integrated, well-functioning and sustainable flood forecast and alert

[1] www.eawag.ch and https://www.eawag.ch/en/department/ess/main-focus/decision-analysis-da/

system for West Africa. In between the co-design workshops, the FANFAR system is adapted to meet the requests and feedback of participants, wherever possible. Additionally, some direct interactions with West African users and the FANFAR consortium also take place in between workshops, e.g. during the 2019 and 2020 rainy seasons.

This report summarizes the main co-design activities conducted during and between the first three FANFAR co-design workshops that have taken place thus far, carried out in 2018, 2019 and 2020. The fourth and final co-design workshop is planned for autumn 2020. This report gives an overview of the types of interactions, the methods used, and preliminary results. We focus strongly on the methods in this report, as interactions are on-going and results are still missing or need more thorough analyses (e.g. uncertainty and sensitivity analyses for the Multi-Criteria Decision Analysis, MCDA).

1.1 Objectives of the co-design process

The objectives of Work Package 2 (WP2), "User needs, tests and behavioural responses" are to lead, prioritize and refine the technological adaptations of the FANFAR flood forecast and alert system, based on the needs, preferences and objectives of key stakeholders and users of the forecast system (termed "users" below). This co-design process is based on a social science analysis framework that uses Multi-Criteria Decision Analysis (MCDA). MCDA is a structured, stepwise process (section 1.3) we applied to ensure that the developed flood forecast and alert system and its services indeed meet the needs of users.

WP2 is broken down into three tasks. Task 1 specifically focuses on the co-design process. Task 2, *"Test forecasting and alert system in practical local flood management, and technical validation"* led by the Nigeria Hydrological Services Agency (NIHSA)[2] and task 3 "*Explore technology adoption by analysing the behavioural responses to the introduction of new technologies to facilitate the sustainable uptake of the system in the region*" (led by Eawag) are not part of this report.

Task 1 is designed to meet following objectives:

- identify key users;
- establish a co-design committee of key West African organizations (co-developers, end-users);
- define priorities and receive feedback on systems with different functionalities; and
- evaluate the overall performance of updated systems, based on technical performance and user preferences.

1.2 Overview of co-design workshops in West Africa

To date, we have carried out three co-design workshops in West Africa. These workshops are described in three publicly available reports. Below, we shortly summarize their main aims.

1.2.1 Co-design workshop 1, Niamey, Niger, 17.–20. September 2018

Participants:

- 47 participants from 21 countries, including the consortium members from Europe.

[2] http://nihsa.gov.ng/

- Representatives from hydrological service agencies and emergency management agencies on the regional and national level from 17 countries in West Africa.

Download report: https://fanfar.eu/resources/[3]

Aims:

The overall aim of this first workshop was to initiate the co-design process of the flood forecast and alert system in West Africa (Figure 2). Targeted activities were performed to achieve following specific aims:

- **Baseline information:** to receive information from each country representative concerning the currently used flood forecast and alert systems, the distribution channels and their wishes and expectations for a well-functioning, improved system (power point presentations);
- **Stakeholder analysis:** to identify key stakeholders to be involved in the continued co-development of the FANFAR system;
- **MCDA:** to identify which objectives are important to the participants for developing an operational flood forecast and alert system (i.e. what the system should achieve) and to identify options (i.e. how the FANFAR system should be configured to meet the objectives);
- **Technical feedback:** to understand the matching between expectations and the current development status of the FANFAR prototype systems for the flood forecast production (Hydrology-TEP) and interactive visualization portal (IVP).

Figure 2: Impressions from FANFAR co-design workshop 1 in Niamey, Niger (Sept. 2018). After a plenary discussion, participants decide on which objectives they consider as most important for developing a flood forecast and alert system for West Africa. Photo: Emilie Breviere.

1.2.2 Co-design workshop 2, Accra, Ghana, 09.–12. April 2019

Participants:

- 48 participants from 21 countries, including the consortium members from Europe.
- Representatives from hydrological service agencies and emergency management agencies on the regional and national level from 17 countries in West Africa.

Download report: https://fanfar.eu/resources/[4]

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[3] https://fanfar.eu/wp-content/uploads/sites/4/2019/04/190404_FANFAR_ExecReport_WS1_WP2_EN.pdf

[4] https://fanfar.eu/wp-content/uploads/sites/4/2019/06/FANFAR_ExecReport_WS2_En.pdf

Aims:

The overall aim was to further co-design the flood forecast and alert system in West Africa. Targeted activities were performed to achieve following specific aims:

- **MCDA**: consolidate list of objectives that participants had previously acknowledged as important for developing an operational flood forecast and alert system (i.e. what the system should achieve) and to elicit preferences regarding the achievement of these objectives;
- **Technical feedback:** to understand the matching between expectations and current development status of the FANFAR prototype systems for flood forecast production, the Hydrology-TEP (H-TEP) and interactive visualization portal (IVP), and integrated support systems;
- **Experience survey:** to gain feedback on user's experiences so far and prepare testing the FANFAR flood forecast and alert system in the 2019 rainy season;
- **Flood risk representation:** to better understand how the output from the IVP is understood by emergency managers and to propose suitable visualizations of the flood risks.

1.2.3 Co-design workshop 3, Abuja, Nigeria 10.–14. February 2020

Participants:

- 58 participants including the consortium members from Europe, and two representatives from the World Meteorological Organisation (WMO), who are FANFAR advisory board members.
- Representatives from hydrological service agencies and emergency management agencies on the regional and national level from 16 countries in West Africa.

Download report: https://fanfar.eu/resources/[5]

Aims:

The overall aim was to further consolidate and expand the co-design process of the FANFAR flood forecast and alert system and to review and learn from user experiences gained during the 2019 rainy season. Targeted activities were performed to achieve following specific aims:

- **Experience 2019 rainy season:** to learn about the severity of floods during the 2019 rainy season in different West African countries and regions (power point presentations from every country and regional organizations) and to share and discuss the user experiences and accuracy of FANFAR forecasts over the past rainy season;
- **Technical feedback:** to report progress on system components and build capacity on the updated FANFAR flood forecast system components by carrying out practical sessions where participants actually used the FANFAR system, and to continuously improve the FANFAR flood forecasting system using structured feedback;
- **MCDA:** to assess the user preferences and stability of the importance that participants previously assigned to the objectives for developing the operational flood forecast and alert system;
- **Flood risk communication and response strategies:** to refine the communication content and format of information generated by the FANFAR forecast system as well as to inform distribution channels and response strategies;

[5] https://fanfar.eu/wp-content/uploads/sites/4/2020/03/2003024_FANFAR_ExecReport_v3.1.pdf

- **Experience survey:** to gain feedback on users' experiences so far and prepare testing the FANFAR flood forecast and alert system in the 2020 rainy season;
- **Sustainability**: to start structured discussions within the FANFAR consortium to advance toward long-term sustainability of the FANFAR system (not part of this report).

1.3 Problem Structuring and Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) is an umbrella term for a set of methodologies to support complex decisions (Eisenführ, Weber, & Langer, 2010; Gregory, Failing, et al., 2012; Keeney, 1982). At the core of Multi-Attribute Value Theory (MAVT), is the understanding that rational decisions should include what is of fundamental importance to decision makers or stakeholders (Keeney, 1996). Decisions should thus be guided by the objectives that one wishes to achieve. However, in any complex decision, trade-offs have to be made because not all objectives can be fully achieved. In FANFAR, to compare different decision options (i.e. configurations of the ICT system) and to select the most suitable one, a MAVT-model is used. The model draws on hard facts and expert predictions (e.g. the accuracy of the forecasts and estimated costs for system development) as well as the subjective preferences of users. An MCDA is carried out in steps, which reduces the complexity of the decision by splitting it into manageable parts and increases its transparency (Figure 3). Disentangling the facts from values can be very helpful, especially if stakeholders have conflicting interests (Gregory, Failing, et al., 2012; Keeney, 1982).

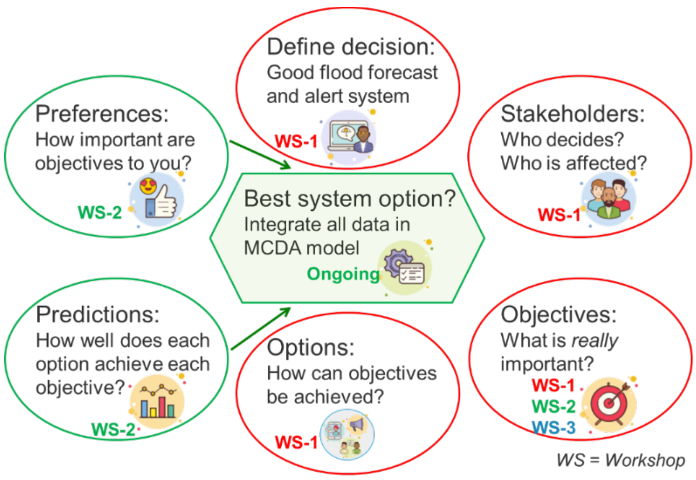

Figure 3: The steps of Multi-Criteria Decision Analysis (MCDA) as carried out in FANFAR project. Start of the process is defining the decision (top), then identifying and selecting stakeholders and system users (top right), etc. (clockwise). In the final step (centre), the predictions and expert estimates (bottom left) and subjective user preferences (top left) are integrated into a mathematical model to define best options (i.e. FANFAR system configurations). Figure: J. Lienert.

In FANFAR, the stepwise MCDA framework supports us in developing the ICT system in such a way that it best fulfils what is of fundamental importance to stakeholders: the objectives. In any MCDA, the first steps can be summarized under problem structuring, where different "Problem Structuring Methods" (PSMs) are used. The combination of PSMs with MCDA is very common, and has been successfully used in many applications (reviewed by Marttunen, Lienert, & Belton, 2017). A detailed overview on the problem structuring steps in an application to wastewater infrastructure planning is given in (J. Lienert, Scholten, Egger, & Maurer, 2015).

In FANFAR, we started the problem structuring with a detailed stakeholder analysis (Grimble & Wellard, 1997; Judit Lienert, Schnetzer, & Ingold, 2013; Reed et al., 2009). The aim was to better understand the interested parties by asking who makes important decisions and has decision-making power, and who would be affected by a decision. In FANFAR, the aim was to identify and select those participants who should be involved in the project, i.e. whom to include in the co-design committee and in co-design activities. We carried out a thorough stakeholder analysis during the first FANFAR workshop in Niamey, Niger (16.–20.09.2018). The selection of the first workshop participants was based on existing knowledge in FANFAR, and a preliminary stakeholder analysis carried out during the FANFAR kick-off-meeting with the FANFAR consortium members in Norrköping, Sweden (17.–19.01.2018).

Also at the beginning of an MCDA process is the identification of objectives (Figure 3). Identifying objectives and evaluating their importance is an essential task in any decision-making process; also within the FANFAR project. The objectives are those factors that need to be considered when comparing different FANFAR ICT system configurations (options) with each other. Indicators called “attributes” allow us to estimate how well each system option achieves each objective. We started identifying objectives at the FANFAR kick-off meeting in Norrköping (Jan. 2018), and continued with different problem structuring methods (brainstorming) during workshop 1 in Niamey (Sept. 2018), where the West African workshop participants identified an initial set of fundamental objectives. These were discussed and updated at an internal meeting between Eawag and SMHI in Switzerland (Dec. 2018), and discussed and consolidated in the co-design workshop 2 in Accra, Ghana (Apr. 2019).

Furthermore, we generated ICT system configurations (FANFAR system options; Figure 3) at the first co-design workshop together with the West African stakeholders (Niamey, Sept. 2018). Different options fulfil the objectives to different degrees. We used two problem structuring methods: a strategy generation table and the brainwriting-635 method. Thus generated options were post-processed by the FANFAR consortium.

In the next step of MCDA, the predictions were made (Figure 3). Predictions reflect how well each FANFAR system configuration could achieve each objective. Predictions can be based on literature, scientific modelling or expert estimates. We interviewed experts from the FANFAR consortium to predict how well an option achieves each objective. We included the experts’ uncertainty in these predictions. This uncertainty can then be propagated to the MCDA results with Monte Carlo simulation.

In parallel, personal preferences are elicited from decision-makers or stakeholders. Such preference information concerns, for instance, which objectives are most important to consider when deciding about best FANFAR system options. In most complex decisions, trade-offs need to be made between achievement of objectives, because not all can be fully achieved. Preference elicitation methods therefore focus on the trade-offs that a stakeholder is willing to make. Elicitation questions include e.g. how much “forecast precision” a stakeholder would be willing to give up to better achieve another objective, e.g. “low development costs”. According to the philosophy of Multi-Attribute Value Theory, every person has the right to have his or her own opinion and own preferences. There is no right or wrong answer to such questions. Rather, the aim of the MCDA process is to identify those FANFAR ICT system options that best meet all users’ preferences – or in other words, we try to find consensus solutions in the case of diverging preferences.

The MCDA model then combines the expert predictions with the subjective stakeholder preferences (Figure 3) to generate an overview of the performance of the options, given the stakeholders’ preferences. This result is given as a neutral value between 0 (none of the objectives achieved at all) and 1 (all objectives fully achieved). Additionally, a ranking of the options from best to worst was made.

1.4 Behavioural changes and sustainable uptake

During all three FANFAR co-design workshops we elicited the importance of the objectives from each individual stakeholder with a shorter survey. Each workshop participant ranked each FANFAR objective according to importance, and classified it in different importance categories. The survey respondents could also list additional (new) objectives if they wished. This additional preference information allows us to analyse whether preferences changed over the entire duration of the co-design process. Together with other information, e.g. personal demographic data, having experienced floods or effects of our methods, this will allow us to better understand preference changes, which we will analyse together with other behavioural aspects. This in turn might allow us to identify factors that influence a sustainable uptake of the FANFAR forecast and alert system. These data are not presented in this report; they are ongoing and part of Deliverable D2.5, “Report on behavioural changes and sustainable uptake”.

1.5 Experiences with flood events, forecast & alert systems, technical feedback

The FANFAR co-design process entails feedback from the participants on the flood forecast and alert systems they had been using at the start of the FANFAR project – and also during the FANFAR project in those cases, where they were still using other systems from 2018–2020.

To assess a baseline of the currently used systems in West Africa, we sent a set of questions to all participants of the first FANFAR co-design workshop in Niamey (Sept. 2018). These questions guided each participant’s introductory oral presentation at the start of the workshop. The feedback from these presentations is very rich and helps us to better align the FANFAR projects’ co-adaptation process to the needs and expectations in the West African countries.

Furthermore, we were interested to receive information on the participants’ experience with flood events during the FANFAR project. We collected this information with a questionnaire filled in by each individual participant in co-design workshops 2 and 3 (“experience survey”). This questionnaire also included some demographic data for the behavioural analyses (not presented in this report; see section 1.4) and questions on the users’ experience using the FANFAR ICT system (Figure 4).

Figure 4: Presenting the users’ experiences with the FANFAR system from workshop 2 (Accra, April 2019) in a plenary session at workshop 3 (Abuja, February 2020). Photo: J. Lienert.

A main interest within FANFAR was to understand whether the West African stakeholders were actually using the FANFAR system and how well it performed. To this end, we are carrying out two “rainy season surveys”, one in the 2019 rainy season between workshops 2 (Apr. 2019) and 3 (Feb. 2020), and an ongoing one during the 2020 rainy season. Furthermore, we asked the participants of the co-design workshop 3 in Abuja (Feb. 2020) to present their experiences with using the FANFAR system and on flood events in their country at the beginning of the workshop. They prepared their presentations using a template that we sent to them beforehand.

Finally, in all three co-design workshops, we collected technical feedback on the FANFAR forecast and alert system. Hands-on exercises and trainings were carried out during workshop 1 (Niamey, Sept. 2018), workshop 2 (Accra, Apr. 2019) and workshop 3 (Abuja, Feb. 2020). These introduced the workshop participants to the initial FANFAR pilot system in workshop 1 and allowed them to experiment with it. Thereafter, the pilot system was updated, based on the users' experiences and feedback, and again used and tested in workshop 2, then updated, and again used and tested in workshop 3 (see ICT cooperation cycle in Figure 1). During these practical sessions, we distributed a simple questionnaire to collect feedback from each participant on how well the FANFAR pilot system components worked, and in which way they could be improved. This feedback is analysed after each workshop by Eawag and sent to the ICT developers as input for further improvement of the FANFAR systems for both the flood forecast production (Hydrology-TEP) and the interactive visualization portal (IVP).

2 Methods

2.1 Multi-criteria decision analysis (MCDA)

2.1.1 Problem structuring: stakeholder analysis

An in-depth stakeholder analysis was carried out during the first co-design workshop in Niamey (Sept. 2018) to identify the key stakeholders to be involved in the FANFAR co-design process. The selection of the workshop participants was based on existing knowledge in FANFAR, and a preliminary stakeholder analysis carried out during the FANFAR kick-off-meeting, 17.-19.01.2018 in Norrköping, Sweden. In the workshop in Niamey, a systematic questionnaire survey was completed by 18 groups, with a total of 31 workshop participants.

First, we presented the aim of the stakeholder analysis, an overview of the method and the type of results to be expected. The PowerPoint presentation also included detailed instructions, especially for the more difficult parts such as the classification into categories with numbers. The workshop participants were then given the opportunity to ask questions. We clarified that any personal data would be anonymized and treated confidentially (the participants had given written informed consent regarding our confidentiality procedures at the beginning of the workshop). We then asked the workshop participants to fill out the questionnaire in small groups, consisting of representatives from the same country. Most groups consisted of two people, some of three, and few people filled in the questionnaire on their own.

The questionnaire had been prepared in both languages of the workshop, i.e. in French and English. Filling in the questionnaire took about 2.5 hours, with a break in between. Some participants finished the questionnaire relatively fast; others would have required more time. The two experts from Eawag continuously passed by the groups to answer questions and to check if everything was well understood.

The workshop participants were kindly asked to fill in two tables, one to identify and better understand the key West African organizations involved in the production and operation of the flood forecasts and early warning systems. The second table contained the same set of questions, but for the downstream stakeholders that might use flood forecasts and early warnings (i.e. "Who might play a role because they use information from such systems in society?"). In each table, they were asked to complete eight tasks. For instance, we asked to list of key West African organizations involved in the production and operation or use of flood forecast and early warning systems. We also asked them to list downstream organizations or stakeholders. We wanted to know the main interests of all organizations and stakeholders, why they might use the FANFAR flood forecast and alert system and which distribution channels seem most appropriate. Finally, we used a 10-point Likert scale, asking the participants to rate the importance of considering each listed stakeholder or organization in the FANFAR co-design process, the presumed influence of each stakeholder in the implementation of the FANFAR system and how strongly each stakeholder or organization would be affected by the system (if it works well or not so well).

2.1.2 Problem structuring: generating objectives

To develop the objectives, a careful, step-wise procedure was carried out, starting with the FANFAR kick-off meeting in Sweden (Jan. 2018), and being continued in the co-design workshops 1 (Sept. 2018) and 2 (April 2019). At the FANFAR Kick-off meeting, the FANFAR consortium partners elicited and discussed objectives for selecting and developing an operational flood forecast and early warning system in West Africa with the aim of building a master list of objectives (Haag, Zuercher, & Lienert, 2019). Many of these objectives were initially found in different parts of the FANFAR project proposal, even though not all had been explicitly formulated as an objective.

In co-design workshop 1 (Niamey, Sept. 2018), we chose a variety of approaches to brainstorm and select objectives. The 32 workshop participants were briefly introduced to the decision-making process (Figure 1). They were then split into three "similar" groups with both types of participants in each group (i.e. country representatives for hydrological services and emergency managers). One group identified objectives on their own and selected objectives from a master list with a pen & paper survey, assisted by a moderator. The second used the same approach with an interactive online survey and the third had group discussions with two moderators (Figure 5) using a means-ends network (Eisenführ et al., 2010). All three groups also ranked and rated the objectives according to importance.

Figure 5: Generating objectives in a group process in workshop 1 (Niamey, Sept. 2018).
The moderator actively guides participants through discussions to create a means-ends network of their most important objectives. Photo: Emilie Breviere.

The objectives from these three workshop sessions were compiled into a short list containing the ten most important, distinctly different and non-redundant objectives. This follows the standard best practice recommendations for “good objectives” in MCDA (Eisenführ et al., 2010). This consolidated list of objectives was presented and discussed in a plenary session two days later in workshop 1. The most important objectives were chosen by majority vote to further work with.

Between workshop 1 and workshop 2 in Accra (Apr. 2019), the objectives were discussed and further processed by the FANFAR consortium (Dec. 2018, Eawag with J. Andersson from SMHI). Care was taken to avoid common mistakes such as double-counting, overlaps of objectives and including means objectives (Eisenführ et al., 2010). We discussed, which of the objectives were of fundamental importance for the development of an operational flood forecast alert system within the FANFAR project, and included new ones that might have been overlooked by participants. This intervention from our side is unproblematic, because in MCDA, the stakeholders can later choose to dismiss objectives from the evaluation that they personally do not regard as important by assigning zero weights (see section 2.1.5). We also discussed which objectives help to discriminate between decision alternatives, and included only these.

At workshop 2 (Accra, Apr. 2019), in a plenary session on the first day, we again introduced the decision-making process to remind the participants of the context (Figure 3). We then presented the refined and structured list of the ten most important objectives. This included a clear definition of each objective and a description of the best and worst possible case. As one example: best case would be that the FANFAR system is available in several languages, as worst case only in English. We reviewed the objectives together with the participants in a plenary session, discussing their agreement with the proposed final list of objectives. We visualized the main discussion points on flipchart and gave feedback on their input. On the same first day of workshop 2, assisted by a moderator if needed, each participant again individually ranked the objectives and rated their importance as part of the behavioural analyses, not presented in this report (section 1.4).

2.1.3 Problem structuring: generating options (FANFAR system configurations)

System options were generated during workshop 1 (Niamey, Sept. 2018) using two structured brainstorming methods in three small groups. The aim was to widen the perspective of the workshop participants towards different options (FANFAR flood forecast and alert system configurations) and to think “out of the box”. Any configuration of different components of an operational system were considered an option. Two groups used the method of Strategy Generation Table (Gregory, Long, Colligan, Geiger, & Laser, 2012; Howard, 1988): one group of specialists from AGRHYMET and NIHSA for the Hydrology-TEP (H-TEP), the other for the Interactive Visualization Portal (IVP; Figure 6).

The third group used Brainwriting 635 (Litcanu, Prostean, Oros, & Mnerie, 2015; Paulus & Yang, 2000) combined with *cadavre exquis* (collection of words written on a paper that is folded before handing it over to the next person). The results of all groups were discussed in a plenary session and all strategies (options) were assembled. Additional options (FANFAR system configurations for H-TEP and VIP) were defined by the FANFAR team (J. Andersson, F. Silva Pinto; July 2019) to cover other interesting cases.

	A	B	C	D	E	F
	Forecasted variables	**Observed variables**	**Model performance / accuracy**	**Data download**	**Distribution channels**	**Language**
a	River discharge	None	No performance metrics shown	No option to download data	Website with interactive features	English
b	River discharge & water level	Water level from satellites	Display performance metric for forecasts	Tabular data for selected station in TXT format	Website with static images	English and French
c	River discharge, water level, & precipitation	Water level from in-situ measurements and satellites	Blank out areas where forecasting performance is too low	Tabular data for selected station in Excel format	SMS alert notifications	English, French, and Portuguese
d	River discharge, water level, precipitation, & evaporation	River discharge from in-situ measurements		Map of displayed variable(s), in PNG format	Email alert notifications	English, French, Portuguese, Arabic
e	River discharge, [illegible] level, [illegible]itation, [illegible]tion, soil moisture storage	In-situ water level and river discharge, and water level from satellites		Tabular data in TXT format and map displayed in PNG format	Website with interactive features, SMS and Email	

The one that can be implemented faster.

The most desired in an ideal world?

Figure 6: Example (only part) of strategy generation table used to generate options for the Interactive Visualization Portal (IVP) in workshop 1 (Niamey, Sept. 2019).
Columns indicate different variables or components of a fully functional flood forecast and alert system. Rows indicate different possible states that this variable could take. A suitable strategy is created by choosing one possible state from each variable and combining them. For this, different guiding questions were used such as: "What is the most attractive system for West-Africa?". Figure: F. Silva Pinto.

2.1.4 Predicting the performance of each option

An important step in MCDA is to predict how well each option achieves each objective (Eisenführ et al., 2010) (Figure 3). This was done with expert estimates (O'Hagan, 2019), mainly by SMHI (J. Andersson) and Eawag (F. Silva Pinto) in July 2019. Additionally, three other experts in the FANFAR consortium from IsardSAT, AGRHYMET and Terradue were interviewed by F. Silva Pinto (July–Aug. 2019). The expert estimates capture both the most likely level of each objective for each option (e.g. the estimated most likely costs to develop an option) and the uncertainty of this estimate (e.g. a normal distribution and standard deviation). In the MCDA, this uncertainty will be later propagated to the results with Monte Carlo simulation.

2.1.5 Eliciting the subjective preferences of stakeholders

An integral part of MCDA is the subjective preference of a decision-maker or stakeholder (Figure 3). Preferences are needed to convert the levels of attributes for each objective (e.g. the "total costs in €" to develop a system) to a neutral scale between 0 (objective not achieved) and 1 (objective fully achieved). This commons scale allows including very different objectives (attributes) in the one same mathematical model, for instance "Low development costs" (total costs in €) or "High accuracy of forecast information" (using an integrated indicator). The conversion of the attribute level to the neutral value scale is done with help of a single-attribute value function. In the simplest case, the single-attribute value function is linear. This means that the highest costs in this example receive a value of 0, half of the costs receive a value of 0.5, and the lowest costs (best possible outcome), and receive a value of 1. However, if stakeholders are directly asked, the shape of the single-attribute value function may be non-linear. For instance, stakeholders might find it more important to reduce costs when they are generally high, than further reduce costs by a same amount when they are low anyway.

Moreover, MCDA integrates the performance of each option on all objectives with a mathematical model (section 2.1.6). Model parameters include the weights assigned to objectives and – if a non-additive aggregation model seems more appropriate (as in FANFAR) – sometimes other parameters (Reichert, Langhans, Lienert, & Schuwirth, 2015).

In workshop 2 (Accra, Apr. 2019), we carefully elicited the weights and other preference parameters for the MCDA (see below in this section) from the workshop participants in five group sessions. We split the workshop participants into groups with similar areas of expertise (hydrological services or disaster management organizations) and language (English or French). The fifth group was composed of consortium members from AGRHYMET, who have a regional role and high expertise with the H-TEP.

Two groups of French-speaking participants gave their weight preferences using the standard Swing procedure (Eisenführ et al., 2010). The first group consisted of eight participants from disaster management organizations, the second of 11 participants from hydrological services organizations (Figure 7). Three English-speaking groups gave their preferences using the card procedure to elicit weights (Simos' revised procedure; Figueira & Roy, 2002; Pictet & Bollinger, 2008). The first group consisted of three participants from disaster management organizations, the second of 14 from hydrological services organizations, the third of three members from AGRHYMET.

Figure 7: Eliciting weight preferences with the Swing method in workshop 2 (Accra, April 2019). Photo: Resident photographer.

As additional preference information, we elicited the shape of a few of the most important single-attribute value functions (i.e. those with the highest weights) with the standard bisection elicitation method (Eisenführ et al., 2010). We also asked for (dis-)agreement with the implications of the additive aggregation model (Haag, Lienert, Schuwirth, & Reichert, 2019). Examples of such elicitation procedures can be found in our earlier publications (e.g. Schuwirth, Reichert, & Lienert, 2012; Zheng, Egger, & Lienert, 2016). We used specific tools for these group workshop sessions that have been developed in a project using MCDA in a Swiss case study (Beutler & Lienert, 2019).

2.1.6 MCDA model to integrate the performance of options over all objectives

The aggregation step in MCDA integrates the expert predictions (how well each option achieves each objective) with the stakeholders' preferences (Figure 3; sections 2.1.4 and 2.1.5). To do this, the predictions are "translated" to a common value scale between 0 and 1 with help of the single-attribute value function (see section 2.1.5, above). The weights are then needed to integrate across all objectives.

For this aggregation step, most often the weighted mean (= additive aggregation model) is used to calculate the overall value *v* of each option (= alternative) *a*:

$$v(a) = \sum_{i=1}^{m} w_i \cdot v_i(a_i)$$

Where:

$v(a)$	=	total value of alternative a (= option a)
a_i	=	attribute (objective) level of alternative a for attribute i
$v_i(a_i)$	=	value for attribute i of alternative a
w_i	=	weighting factor of attribute i; $\sum w_i = 1$

We refer to textbooks for further explanations of the MCDA modelling (e.g. Eisenführ et al., 2010). The result of the aggregation step is again a value between 0 (none of the objectives have been achieved at all) and 1 (all objectives have been fully achieved). This integration of complex interim steps into a single value is very helpful to assist decision-making in situations where intuitive decisions are no longer possible or suitable. The overall value allows to rank the options from best-performing to worst-performing for each stakeholder or stakeholder group. It allows to identify consensus options that perform acceptably well for all stakeholder groups, despite them having – possible strongly – different preferences.

In reality, we found in many applications that the additive aggregation model does not very well meet the stakeholders' preferences (e.g. Haag, Lienert, et al., 2019; Langhans & Lienert, 2016; Reichert, Niederberger, Rey, Helg, & Haertel-Borer, 2019; Zheng et al., 2016). The additive model relies on some strong assumptions, such as full preferential independence between objectives. It implies that the decision makers agree with the implication that a poor performance on one objective can be fully compensated by a good performance on another objective. Other aggregation models such as the geometric mean have less strict requirements and may thus better meet the stakeholders' preferences (Haag, Lienert, et al., 2019; Reichert et al., 2019). This is why we used targeted questions in the co-design sessions for preference elicitation (section 2.1.5), asking stakeholders whether they agree with the additive model implications (which they did not).

Therefore, it is important to test with sensitivity analyses, how robust the MCDA results are if other aggregation models are used. Other sensitivity analyses to test the robustness of the results include changing the weight sets, e.g. if some stakeholders disagreed with the weight assigned in the group elicitation process (see section 2.1.5, above). In the FANFAR elicitation process, we allowed to give a range for the weights in the case of disagreement within the group, and we will test the impact on the results. Finally, also the uncertainty of the expert predictions (section 2.1.4) needs to be propagated to the results to test the overall influence of uncertainty on the final conclusion about best-performing options. In FANFAR, we will carry out such detailed uncertainty and sensitivity analyses in the coming weeks (examples of systematic sensitivity analyses see e.g. Scholten, Maurer, & Lienert, 2017; Schuwirth et al., 2012; Zheng et al., 2016).

The results of any MCDA should always be discussed and reflected with the decision makers or stakeholders. This has been done already for preliminary results in the co-design workshop 3 (Abuja, Feb. 2020). We will present the final MCDA results and discuss them with the West African stakeholders in the last workshop 4 (planned for autumn 2020).

2.2 Experiences with flood events, forecast & alert systems, technical feedback

2.2.1 Experiences with flood events and with using the FANFAR system or other systems

Participants of workshop 1 (Niamey, Sept. 2018) and 3 (Abuja, Feb. 2020) presented their experience with flood forecast and alert systems, with flood events in general and with using the FANFAR system (if applicable) at the beginning of these two co-design workshops. To harmonize the presentations, we sent them guiding questions before workshop 1 ("baseline system"), and a very specific template before workshop 3 ("rainy season 2019 experience"). This template allows us to summarize and analyse the data over all the individual experiences.

Additionally, we collected feedback from each individual participants' experiences using surveys ("experience survey", "rainy season survey") during and between the co-design workshops 2 (Accra, Apr. 2019) and 3. The rainy season survey contained a similar set of questions, and was collected in between workshops 2 and 3. A similar survey is currently being carried out for the 2020 rainy season. Two main topics were covered by the questions in these surveys: (1) participants' frequency of use and satisfaction with the FANFAR system and (2) the occurrence of floods in their domain and FANFAR's accuracy to predict them.

2.2.2 Technical feedback during co-design workshops

Workshop participants were able to gain hands-on experience with the FANFAR prototype systems by practical instructions and training during the co-design workshops. To collect structured feedback on the user's experience working with the system prototypes, we prepared a feedback form (i.e. a questionnaire). This was handed out to the participants after their practical training. The practical training was divided into two user groups: H-TEP and IVP. The form guided the stakeholders through the feedback process and allowed the collection of structured and comprehensible feedback, and suggestions for improvement and addition of system functions.

In between the first and second user workshop in West Africa, the FANFAR project partners improved technical system components, both IVP and H-TEP.

At the second FANFAR workshop (Accra, Apr. 2019), the adaptations made to the FANFAR prototype systems, H-TEP and IVP, were presented in detail to the participants. This was followed by practical sessions where the updated prototypes were again tested. The IVP was first tested by all participants, and afterwards, in two user groups, H-TEP (hydrologists) and flood risk display on the IVP (disaster managers). The integrated support systems as well as the flood risk communication components were also assessed. The 35 participants were again asked to provide structured feedback regarding different aspects of the currently available system prototypes, using an adapted version of the feedback form (i.e. questionnaire) used in the first workshop. Unlike in workshop 1, where the feedback form was only completed *during* the practical sessions, the participants of workshop 2 were allowed to collect their feedback during the *entire workshop*. The third workshop followed a procedure similar to the second workshop.

3 Results and short discussion

3.1 MCDA problem structuring: stakeholder analysis

The information from the questionnaires on the stakeholder analysis has been analysed and the main results presented in the Deliverable D2.1. “Report activities to establish co-design committee, stakeholder analysis”. A summary was given to the workshop participants in the workshop 1 executive report (http://fanfar.eu/resources/). Below, we give a short overview.

The workshop participants listed a total of 249 stakeholders. A data cleaning process resulted in 68 stakeholder types, which we further analysed according to their information profile, decisional level, sector they belong to, and perceived main interest. We then analysed the “importance” of considering their interests in the FANFAR co-design process, their “influence” (power) on a sustainable uptake of the ICT system, and how strongly “affected” every stakeholder would be by a well-functioning (or not well-functioning) forecast and flood alert system (Figure 8).

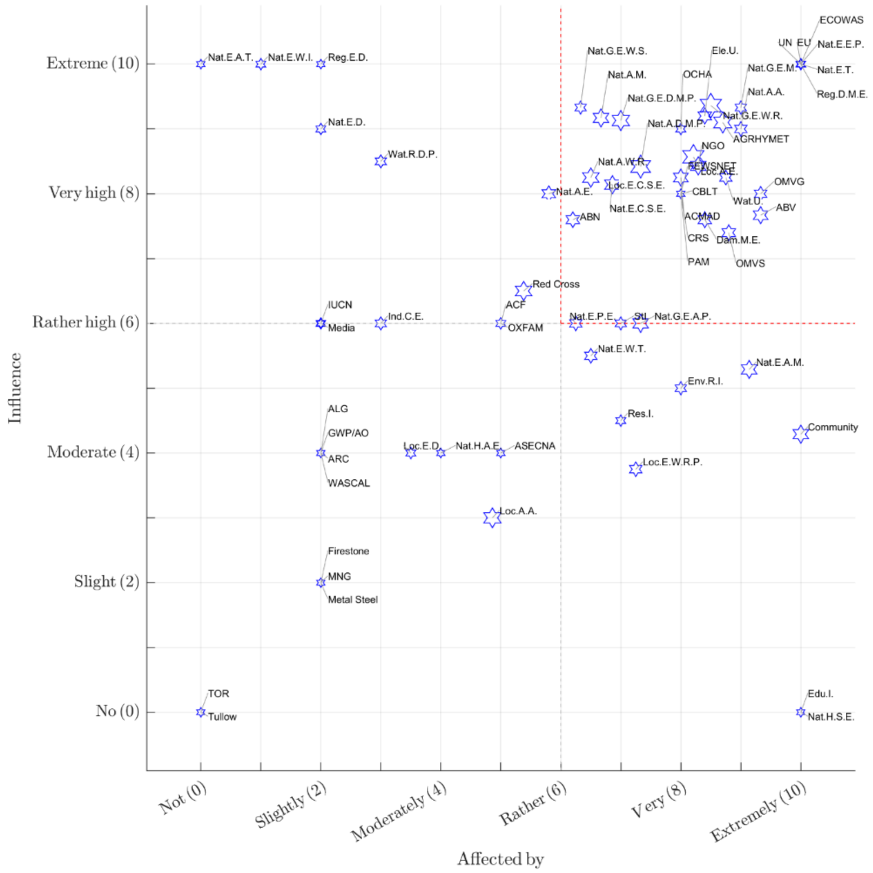

Figure 8: Stakeholder analysis. Perceived mean influence (y-axis) on contributing to a sustainable uptake of – and being affected by (x-axis) – a flood forecasting and alert system in West Africa.
Note: Scale from 0 (“stakeholder has no influence/ is not at all affected”) to 10 (“stakeholder decides/ is very strongly affected by”). Size of symbols: how often the respective organization or stakeholder was mentioned by the survey respondents (e.g. mentioned 10 times in the questionnaires regarding this question has a smaller symbol than if mentioned 20 times). Abbreviations not given for reasons of space (see Deliverable D2.1.). Figure: F. Silva Pinto.

The stakeholder analysis gives a good overview of which interests and parties should potentially be included in the FANFAR co-design process. As a summary, the interests of the stakeholders that were perceived as being of "high" importance on the three dimensions "importance", "influence" and "affected" were: "resource planning" (31%), "economic service and operations planning" (25%) and "rescue aid" (18%). Mentioned by fewer stakeholders were other important interests, namely "technical", "civil society", "disaster management" and "environment". Nearly half of the stakeholders (46%) would use the FANFAR flood forecast and alert system for "alert information", 21% for "forecast refinement", and 16% for "water related information". Only few would use it for "meteorological data" (8%) and "forecast production" (4%).

The stakeholder analysis revealed that we had already identified and selected many of the important stakeholders that produce the information and alerts in West Africa to participate in the FANFAR co-design process. This includes hydrologists and emergency managers. Most additionally identified stakeholders were downstream stakeholders (information end-users), who are at the "receiving end" of the flood forecast and alert information chain. For the co-design process in FANFAR, it is important to understand *how* (via which channels) they receive flood-related information, i.e. which distribution channels are effective in reaching them, and which content and format is suitable. This is part of the research that is currently being carried out in the task "Behavioural changes and sustainable uptake" that is not covered in this report (see section 1.4).

The results of the stakeholder analysis are very promising. They allow us to acknowledge the already existing high commitment of stakeholders to participate in the FANFAR co-design process. This is a precondition that the existing FANFAR ICT system will be fully integrated and adapted to West African institutions. This in turn strongly enhances the chances for a sustainable uptake of the FANFAR flood forecast and alert system in the mid- and long term.

3.2 MCDA problem structuring: objectives and FANFAR system options

Main results of the first MCDA steps of problem structuring are a consensus in workshops 1 (Niamey, Sept. 2018) and 2 (Accra, Apr. 2019) on the most important objectives (Figure 9). These objectives are used throughout the rest of the FANFAR project to elicit behavioural responses and preference changes (see section 1.4). The objectives are also used to model the MCDA results (see below).

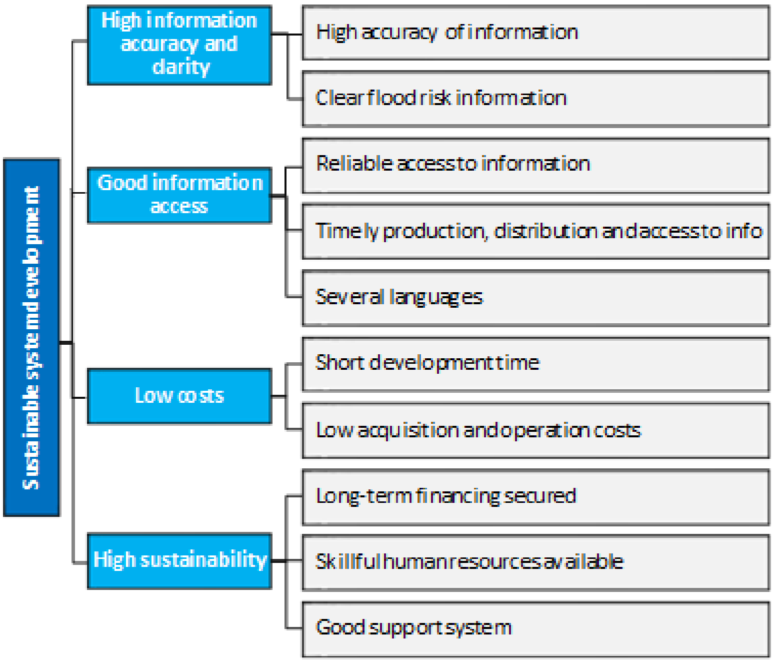

Figure 9: Consolidated list of objectives that are important for developing an operational flood forecast and alert system in West Africa. Result of workshop 2 (Accra, April 2019). Figure: F. Silva Pinto.

In workshop 1 (Niamey, Sept. 2018), including post-processing thereafter, we also generated a broad set of suitable system options that cover various extremes, but also possible compromise options (system configurations of the H-TEP and the IVP; Figure 10).

1. Least resources for development
2. Least resources for users
3. Most easy to use
4. Fastest
5. Highest consensus
6. Most robust
7. Most attractive
8. Fully equipped
9. Calibrated models
10. Calibrated models + earth observation data (EO)
11. Calibrated models + EO + in situ data

Figure 10: Names of the eleven options that cover a broad range of possible FANFAR system configurations. Result of workshop 1 (Niamey. Sept. 2018) and post-processing by FANFAR consortium. Figure: F. Silva Pinto.

3.3 Results of Multi-criteria decision analysis (MCDA)

In the co-design workshop 3 (Abuja, Feb. 2020), we presented the preliminary results of the MCDA to all participants in a plenary session (more-detailed preliminary results are available on the FANFAR website[6]). These include the weights, which had been elicited in five groups in workshop 2 (Accra, April 2019) by considering inevitable trade-offs that have to be made if not all objectives can be fully reached. Across all groups, the most important objectives of the entire set of FANFAR objectives (Figure 9) were "high accuracy of information", "clear flood risk information", "reliable access to information", and "timely production, distribution, and access to information" (Figure 11).

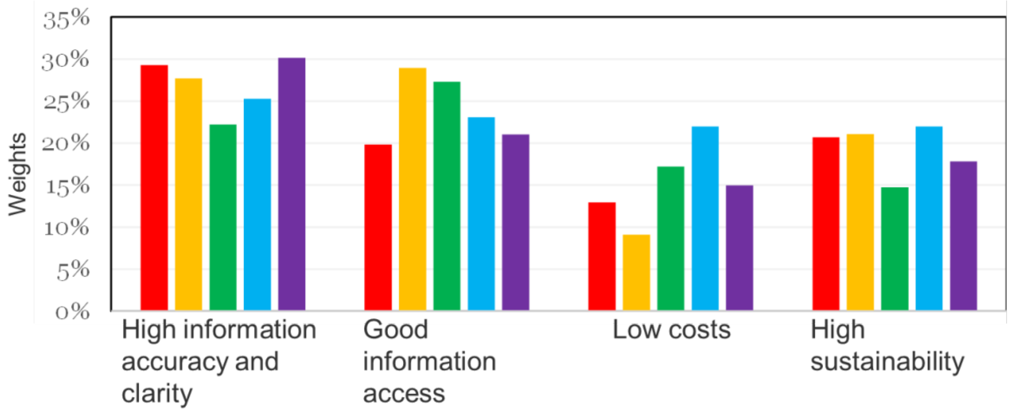

Figure 11: Weights assigned to the four main objectives in five user groups (coloured bars). Result of weight elicitation in workshop 2 (Accra, Apr. 2019). A higher weight indicates that this objective is more important to the respective group. A high weight means that a good (or bad) performance of a FANFAR system option on that objective more strongly affects the MCDA result, i.e. the overall performance of that system option. Figure: F. Silva Pinto.

Despite a relatively clear priority concerning the higher-level objectives over all groups (Figure 11), there were some strong differences regarding the priorities of the lower-level objectives between different groups. For instance, one group assigned more than 20% of the weight to "low costs", or to "human resources", while for the other groups the weights were around 5% ("low costs"), or 10% ("human resources") for these two objectives.

The MCDA modelling then combines the expert predictions (how well each system option achieves each objective) with the subjective preferences of the workshop participants. The output of the modelling is a ranking of the system options from best to worst, and an integrated evaluation of the performance of each system option (Figure 12). The results also provide insight into the reasons why some options might perform better or worse for some stakeholders.

[6] Executive Report from Workshop 3 (https://fanfar.eu/wp-content/uploads/sites/4/2020/03/2003024_FANFAR_ExecReport_v3.1.pdf)

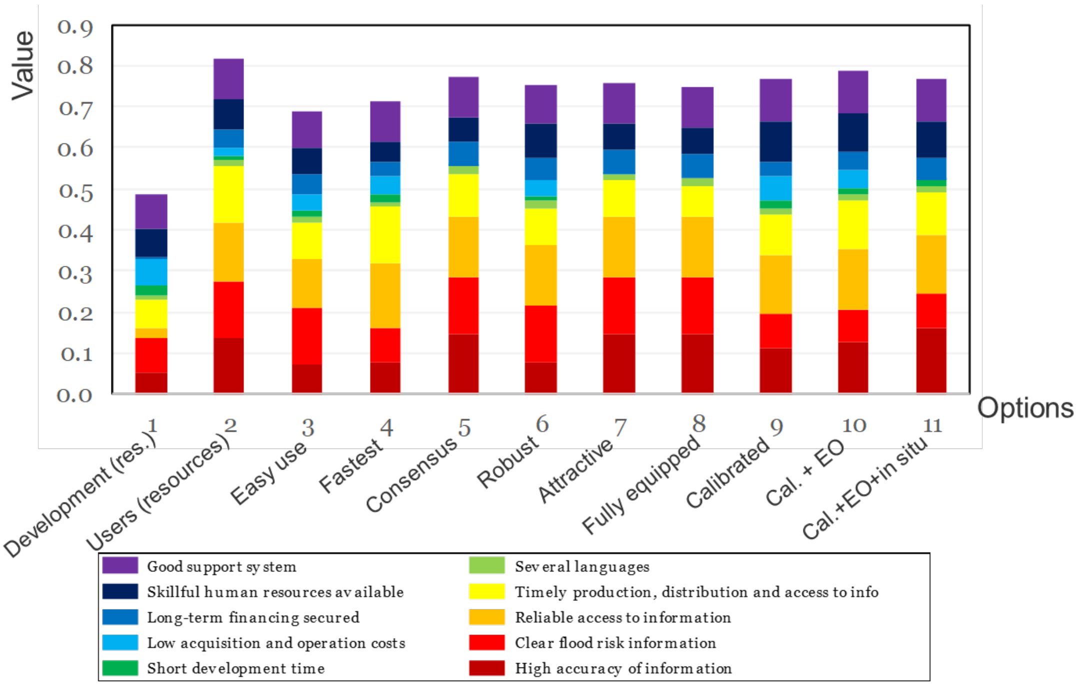

Figure 12: Main preliminary results of the MCDA for the group of English-speaking hydrologists. Many results for the other four groups are similar. Colours indicate the 10 objectives used in FANFAR. x-axis: 11 different FANFAR system configurations (options). y-axis: value between 0 and 1, where 0 indicates that none of the objectives is at all achieved, and 1 that all objectives are fully achieved. The length of the coloured stacked bars indicates how well the respective sub-objective is achieved by that system option, given the preferences of that stakeholder group regarding the importance of the respective objective. Figure: F. Silva Pinto.

Main results of the MCDA have been discussed with the FANFAR consortium to guide further improvement of the FANFAR system. The MCDA results need to be analysed in more detail, including the uncertainty of the predictions (with Monte Carlo simulation), and sensitivity analyses to challenge the model assumptions and test the robustness of the results.

Obviously, different options achieve FANFAR objectives to different degrees. As stated above, different users (i.e. workshop participants) have different priorities regarding what is important to them. Despite such differences in preferences, we were already able to identify similarities between the groups consisting of either hydrologists or emergency managers. Quite clearly, the option "1. Least resources for development" was outperformed by all the other 10 options in all groups (see Figure 12 for one group). We were also able to determine some options (FANFAR system configurations) that perform reasonably well over all five groups despite the different preferences and can thus be regarded as consensus options. These are the options "2. Least resources for users", but also "5. Highest consensus", "6. Most robust", and "9./ 10. Calibrated models (without and with earth observation data)" (options see Figure 10).

3.4 Experiences with flood events, forecast & alert systems, technical feedback

Participants from each countries presented their experience with floods and using FANFAR during the preceding rainy season at the start of the third workshop. Nearly all countries experienced flood events, some of them very severe, including casualties. Exception was Cap Verde, which is facing a very serious drought with severe water shortage since a few years. An overview of all flood events in the 2019 rainy season is presented in Figure 13. On average, there were five flood events in each country, about 100 people died in the 2019 rainy season in West Africa according to this source, and at least 400'000 people were affected.

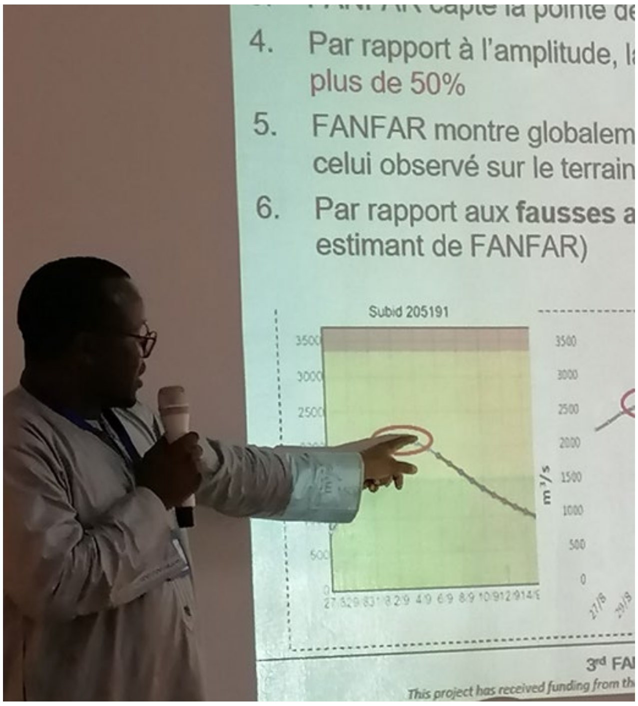

Figure 13: Performance of the FANFAR flood forecast and alert system during the 2019 rainy season. Presentation by M. Hamatan (AGRHYMET) at workshop 3 in Abuja, Nigeria (Feb. 2020). Photo: resident photographer.

Regarding the performance of the FANFAR flood forecast and alert system in the 2019 rainy season, feedback was mixed. Several countries reported that the flood location was quite well captured by the FANFAR system, but this was not the case for all locations. The timing of peak flows was in some cases too early, in others too late; and the magnitude in some cases over-, in others underestimated, compared to observations on the ground. There were some reports of false alerts.

Ten countries or regional representatives reported that they used the FANFAR system regularly and regarded it as useful, while the remaining six countries had not used it (see example in Figure 14). Reasons include the lack of accuracy, internet problems, missing human resources and the use of other systems. Indeed, most important suggestions for improvement include better accuracy, as well as adding extra information such as water level and the location name where the hazard would occur. Overall, however, there was much openness to further use the FANFAR system. The FANFAR systems' user-friendliness and simplicity were positively mentioned by various participants. Some participants also acknowledged the continuous improvement of the FANFAR system in response to the users' requests during the last workshops.

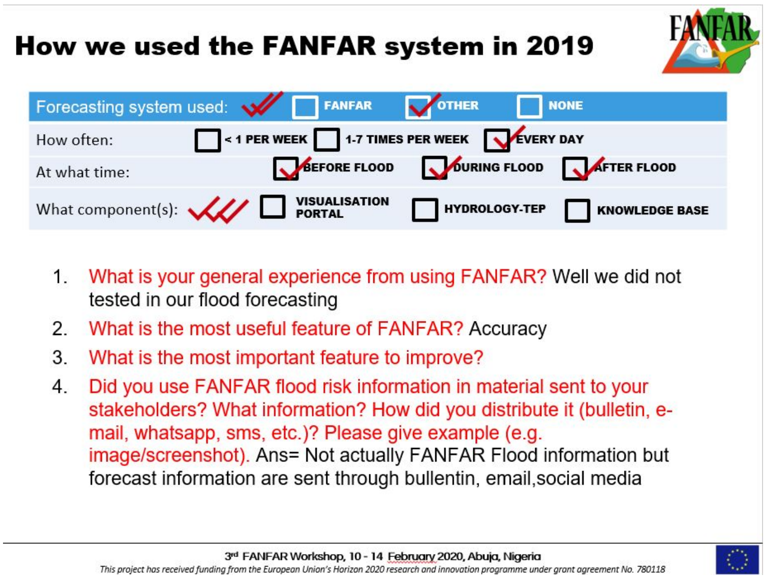

Figure 14: Example of slide from participant presentations on flood and FANFAR usage experience.

On the technical feedback received from participants, the main suggestions were commented by us in the executive reports of workshops 2 and 3 (http://fanfar.eu/resources/). A summary of these findings are given in Table **1**. Most importantly, participants suggested improved guidance and training, to improve the skills and human resources for the sustained use of the FANFAR system. The Hydrology-TEP and IVP will now again be refined based on the feedback received in the final development cycle. All will then gather at the final workshop 4 to again present the refined system, and give feedback on how it performed "on the ground" in each country in the 2020 rainy season.

Table 1 Suggested improvements across the topics/ technical components in order of occurrence.

Improvement	Count
Improve guidance / training	7
Accuracy level indication	3
Historical data	3
Accuracy of output	2
Accurate information	2
Add coordinates	2
Add water level	2
Data collection	2
Downloading output	2
Extend geographical scope	2
Improve resolution	2
Improve visualisation	2
Login	2
Accessibility	1
Add population diversity	1

Improvement	Count
Add station information	1
Change scales	1
Clear thresholds	1
Data sharing	1
Decrease complexity	1
Improve functionality	1
Moveable pin	1
Portal speed	1
Timely production	1

4 Conclusion

The FANFAR project will run until the end of 2020. We can already conclude that the innovative co-design process, which relies on iterative interactions with West African stakeholders in four one-week co-design workshops, is highly successful. The workshop participants, who were selected with help of a careful stakeholder analysis, are highly motivated to interact with the FANFAR consortium in co-developing an integrated, co-operated, sustainable forecast and alert system for West Africa. During all workshops, we received rich input from the participants that helps us to improve the FANFAR system and better adapt it to the stakeholders' needs and preferences, given the conditions in West Africa. We use a targeted selection of stakeholder interventions and methods that allow us to better understand the stakeholders' values, opinions and preferences. Using different methods and the structured MCDA framework, systematic results were obtained. These results provide detailed insight into the co-design process, which could not have been achieved by merely "asking for feedback" in a general way.

We believe that further (scientific) analyses of these decision analysis and structured feedback data will contribute to generalizing these results. This will allow tailoring of technical systems to the needs of stakeholders in other cases. The absence of stakeholder involvement has been identified as one of the greatest shortcomings of (flood) warning systems. Our co-design process contributes significantly to this shortcoming. To our knowledge, there is a lack of such structured systematic social science interventions in highly technical projects as FANFAR in developing countries.

Feedback from the workshops indicates that the participants recognised the updates to the FANFAR system between the co-design workshops. They widely expressed their appreciation for the incorporation of their requests into the system design. Going through the step-wise MCDA procedure and being forced to prioritize objectives fosters better understanding of the trade-offs between the achievements of wishes that one may have. This insight is of fundamental importance in any complex decision. Our results demonstrate better understanding of the complexities of creating an integrated flood forecast and alert system among the stakeholders participating in the co-design workshops in West Africa. They are thus more likely to strongly value such a system. Additionally, stakeholders showed a stronger sense of ownership of the FANFAR system, because they have fundamentally contributed to designing it in such a way that it better meets their requirements. We believe that this co-design process contributes to a long-term sustainable uptake of the FANFAR flood forecast and alert system, a system that is being operated and maintained by capable West African institutions in the long run.

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