

Designing a Multi-stakeholder Analysis of Trade-offs in the Water-Energy-Food Nexus

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Introduction

The growing urban populations and economies in rapidly-developing countries inevitably lead to increased demand for water-energy-food (WEF) resources. Diverse interests regarding these resources among the stakeholders from different sectors in urban and non-urban areas often lead to conflicts and misunderstandings. The lack of transparency and information concerning the consequences of the different uses of the WEF resources prevent sustainable solutions. Nexus approaches call for cooperation and coordination through identification of interconnections between these resources and developing an understanding of trade-offs between different alternatives, in order to identify solutions that are beneficial for all involved stakeholders (Liu et al. 2018). Effectively implementing such nexus approaches requires novel toolboxes enabling non-technical stakeholders (with differing goals, backgrounds and information asymmetries) to identify and analyze trade-offs in the WEF nexus.

In this contribution, we present an approach that allows a multi-perspective visualization and analysis of trade-offs between the often-conflicting WEF issues and policy options in a way that promotes a more holistic view and cooperative decision-making in multi-stakeholder environments. The approach is informed by the theory of “perspective making and perspective taking” (Boland and Tenkasi, 1995) that demonstrates how interaction and cooperation between members of heterogeneous “worlds of knowledge” can be supported. Specifically, the developed prototype allows different stakeholders to formulate, visualize and compare their perspectives with respect to various alternative solutions and reflected in indicators representing their real-world impact. It provides both a holistic view of the WEF issues, useful for stakeholders with non-technical backgrounds, as well as detailed information on specific issues for stakeholders with special interests. By supporting both a

single-sector as well as multiple-sector perspectives the visualization tool allows the stakeholders to identify the interconnections between the different WEF issues, encourages communication and decision-making and also builds trust and increases willingness to use such tools.

The visualization tool has been developed within the DAFNE project (Decision analytic framework to explore the water-energy food Nexus in complex transboundary water resource systems of fast developing countries) funded by the EU Horizon 2020 program. The DAFNE decision-analytic framework provides scientifically-grounded data, models and simulation of different solution alternatives for the WEF nexus in the project's case studies (Zambezi and Omo-Turkana basins). This data is translated and visualized in the multi-perspective visualization tool in a form suitable for non-technical stakeholders and cross-sectoral group interaction. The data and the models underlying the visualization tool have been obtained through the project's participatory integrated planning approach (Castelletti and Sessa 2006), the main aim of which is to involve stakeholders representing various sectors and especially those coming from urban and non-urban areas early on in the design process.

In this contribution, we first describe the theoretical background and the participatory design process for the multi-perspective visualization tool. We then present the design and implementation of the current prototype and a preliminary evaluation of its suitability for supporting and stimulating the analysis of WEF trade-offs from a cross-sectoral perspective, undertaken with stakeholders from the Omo river basin case study.

Theoretical Background for the Design and Implementation of a Multi-Perspective Visual Analysis Tool

The use of computer-based information visualization to derive insights from large volumes of data has been extensively researched. Use of visualization techniques allows individual users to recognize patterns and relationships in data and thereby develop new knowledge (Card et al. 1999). In particular, the collaborative use of shared visualizations is gaining in importance (e.g. Heer et al. 2009). It allows the development of customized visualizations from predefined templates and the storing of specific visualization states (e.g. zoom, filter or time scale parameters). The advantage offered by collaborative use is that these visualizations can then be accessed by others and supported by textual comments and

graphical annotations can link the contributions of users to the related views and vice versa (Heer et al. 2009; Willet et al. 2011).

This “social data analysis” (Wattenberg and Kriss 2006) couples visualization with asynchronous social interaction, and thus supports the process of individual ‘sense-making’ in which people create new knowledge by collecting, organizing and interpreting information from their own stakeholder group but also from other stakeholders (Russel et al. 1993). Sense-making often involves a social process in which the meaning of data and information is socially constructed (Miranda and Saunders 2003) by sharing backgrounds, frames of reference, goals and perspectives (Boland and Tenkasi 1995). The use of tools that support this kind of social data analysis are especially important in heterogeneous stakeholder networks with conflicting perspectives on the meaning of information (Novak 2007).

The approach used in the DAFNE project is informed by the theory of “perspective making and perspective taking” (Boland and Tenkasi, 1995) that demonstrates how interaction and cooperation between members of heterogeneous “worlds of knowledge” can be supported. In line with this theory we propose that there are two processes by which stakeholders can develop new knowledge and establish a shared understanding in heterogeneous stakeholder networks. Perspective making (PM) refers to processes through which stakeholders express, develop and exchange knowledge. By internalizing the meaning of concepts and establishing relationships between them, members of a community develop their own perspective of the subject matter at hand. Perspective taking (PT) refers to the development of an understanding of the knowledge perspective of an unfamiliar community (e.g., stakeholders from a different sector). This comprises developing an understanding of the backgrounds and frames of reference of other community members by internalizing this knowledge within one’s own frame of reference and expressing it in one’s own way (PM). Therefore, social data analysis for NEXUS-related issues requires both perspective taking and perspective making: understanding “what and how the others know” (Bonifacio et al. 2002), learning how this is related to one’s own knowledge and then internalizing this information and thus developing the ability to view the problem from other’s point of view.

Previous research suggests that in order to enable perspective making and taking, specific requirements need to be considered (Novak 2007). In particular, this refers to the need to provide functionality that supports both perspectives: reflecting personal points of view of individual users and shared perspectives of specific user groups. This requires defining the individual and shared perspectives, determining the ways in which they can be best presented and which functionality should be useful in each case. Existing approaches often do not consider the importance of presenting the same information from various perspectives (Watteberg and Kriss 2006; Willett et al. 2011). In subsequent sections, we describe the approach used in the project to design and implement a tool that supports both of these processes: the multi-perspective visual analysis tool.

Design of the Multi-Perspective Visual Analysis Tool

There is often a substantial difference between stakeholders in terms of their affinity with technology, their professional background, and their experience with respect to using data-driven visualization tools that allow them to assess the merits of various solutions to WEF issues. To account for these differences, a user-centred design approach is used that considers the needs of different stakeholders, matches these against technological constraints and opportunities, and subsequently develops a visual analysis tool in an iterative way, alternating between development and stakeholder consultation. The user-centred design process that is adopted in DAFNE is depicted in Figure 32.

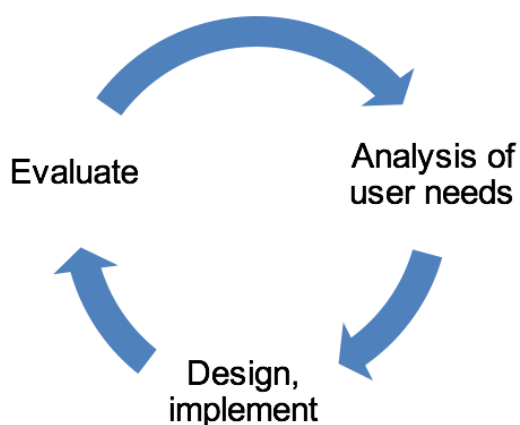


Fig. 32: User-centred design process.

In the first step, the analysis of user needs, the outputs of the stakeholder and actor analysis, as well as the results of the kick-off meetings yield insights into the needs of

stakeholders with respect to the visual analysis tool. Future stakeholder consultations will continue to refine the project's understanding of these needs, which feed into the design and development process.

In the second phase, the design and implementation phase, two processes converge: "user pull" and "technology push". While user pull reflects the specific needs and requirements of the stakeholders with respect to a visual analysis tool and its usefulness for their decision making in practice, technology push reflects the technological opportunities that the DAFNE project wants to employ (e.g. the Decision Analytic Framework and the underlying modelling approach for the water-energy-food nexus). In the first iteration, the result of these two processes is a conceptual design, a set of visuals resembling screenshots that reflect what the tools could look like (mock-ups), which features it will contain, and how users could interact with it. In later iterations, the outcome of this phase will be the subsequent versions of the tool that is then implemented as working software.

In the third phase, the output of the second phase is evaluated with stakeholders. The evaluation starts a new iteration as the feedback received provides additional information about the needs of stakeholders, as well as input for the design and development of the visualization tools.

The results of the stakeholder analysis distinguish between two types of users:

- Experts from the water, energy, and food domain who seek to obtain an in-depth understanding of solutions, pathways and indicators as well as gain insights into trade-offs between the sectors. Such users sometimes use analytical visualization tools in their daily work;
- Non-expert users who have a stake in the decisions that are made along the WEF nexus, but who are typically not using such visualization tools in their daily work.

Whereas visualization tools for complex geospatial and time series data often require background knowledge to grasp the information conveyed, in this case an easy-to-use, easy-to-understand solution it is necessary that users can:

- visually explore the interrelationships between water, energy and food perspectives and related sectors, based on selected indicators and underlying data;

- familiarize users with the concepts of the Decision Analytic Framework;
- support users in gaining a better understanding of the impact of certain solution pathways on different sectors and associated indicators.

Given these requirements, the main objective of the multi-perspective visual analysis tool is to make the main results of the DAF model available to a wide range of stakeholders in a way that allows them to easily explore, analyse and discuss the trade-offs of different WEF nexus solution pathways. Specifically, the tool allows stakeholders from diverse backgrounds to formulate, visualize and compare their perspectives with respect to various alternative solutions which are reflected in indicators representing their real-world impact. It provides both a holistic view of the WEF issues, useful for stakeholders with non-technical backgrounds, as well as detailed information on specific issues for stakeholders with special interests. By supporting both single-sector as well as multiple-sector perspectives the visualization tool allows the stakeholders to identify the interconnections between the different WEF issues. It supports communication and decision-making and also promotes trust-building and the willingness to use such tools for multi-stakeholder WEF analysis.

Implementation of the Multi-Perspective Visual Analysis Tool¹

In line with the perspective making and perspective taking theory, the tool has two main modes: “Create your perspective” mode and “Compare perspective mode”. A perspective can be defined as the set of relevant indicators used by each stakeholder to evaluate impacts of each pathway on their sector of interest. As depicted in Figure 33 the tool allows the stakeholders to create one or more perspectives, as well as to compare their perspectives to those of others in order to understand the trade-offs between the effects of different solution pathways on the indicators that each sector considers important.

1. Note that the visualizations presented in this tool use preliminary data and are only used for the purpose of illustration of the functionalities of the tool (and not for deriving conclusions about the NEXUS issues)

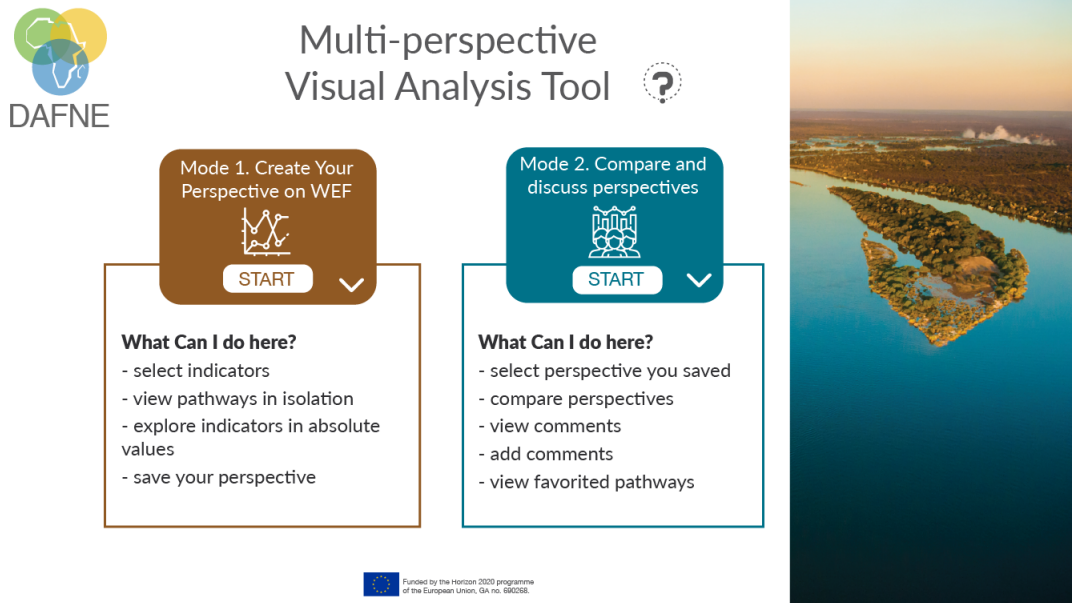


Fig. 33: The start screen of the multi-perspective visual analysis tool

The tool can be used in two main ways as illustrated in Figure 34. Normally, stakeholders begin to create their perspective(s) by selecting the indicators they would like to focus on and in the next stage, comparing various perspectives or exploring the perspectives of others (Way 1). However, if the stakeholders want to explore the perspectives of others or they have already created some perspectives, they can go directly to the “Compare perspectives” mode (Way 2). These different views can support two different types of interactions with the tool. “Create perspective mode” can enable sector-specific interactions, whereas the “compare perspectives” allows for multi-stakeholder interactions.

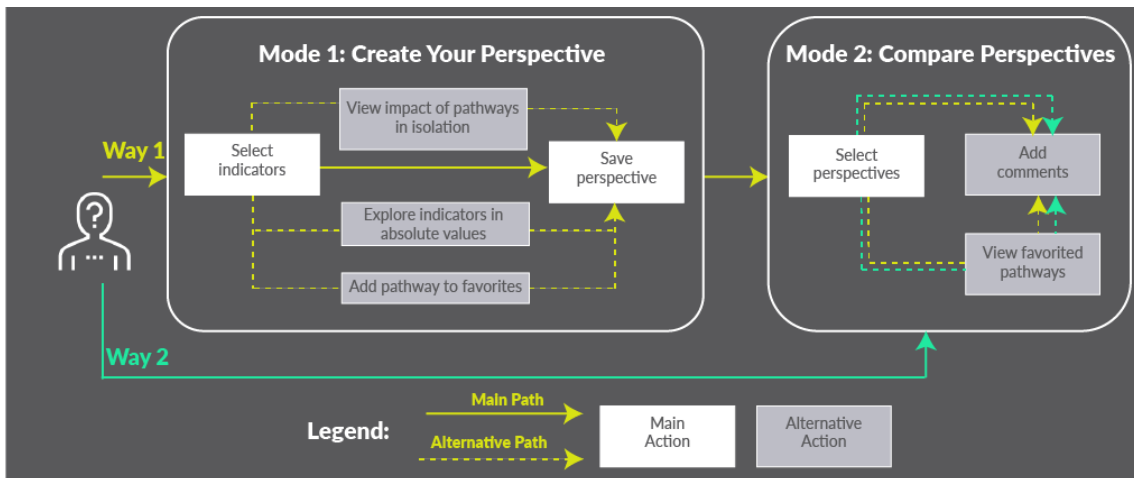


Fig. 34: Two primary ways in which the multi-perspective visual analysis tool can be used

In line with the main purpose of the tool, that of enabling the stakeholders to analyse and discuss the trade-offs of different solution pathways, the tool has two primary modes: “Create your Perspective” and “Compare perspectives,” which are accessible from the main menu. There is also one supplementary mode, “View impact of pathways and indicators in absolute values,” which is accessible through the “Create your perspective” mode. These are explained in this section.

“Create Your Perspective” Mode

In the ‘Create Your Perspective’ mode (Figure 35), the stakeholders can visually display a set of best candidate pathways. They can view the impact of the pathway classes and pathways on the indicators, create and save the perspective and view indicators in absolute and normalized values. A pathway class is a collection of pathways with the same set of structural actions. Each pathway within a pathway class represents the implementation of the same set of actions under a different (resource) management scenario.

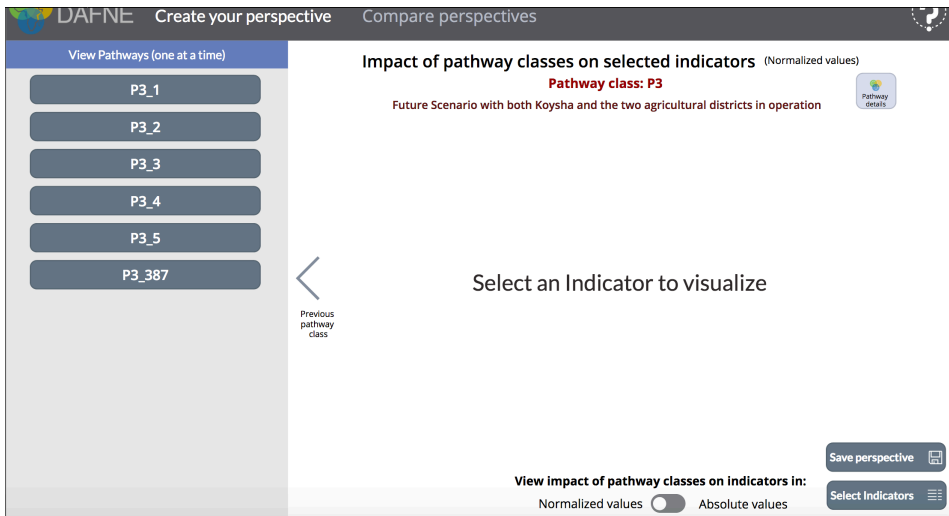


Fig. 35: Start screen of the “Create your perspective” mode

To create a perspective, stakeholders first select the indicators that interest them (Figure 36). Stakeholders can create one or more perspectives of the chosen sector by selecting the indicators for which they want to explore the impact through the “Select Indicators” window. Indicators are grouped by sector, but stakeholders can also choose from the complete list of indicators. They can then click on the indicators to select them. By selecting the indicators that the stakeholders want to focus on, either belonging to one or multiple sectors, they can view either the perspective of one sector or a multi-sector perspective, respectively.

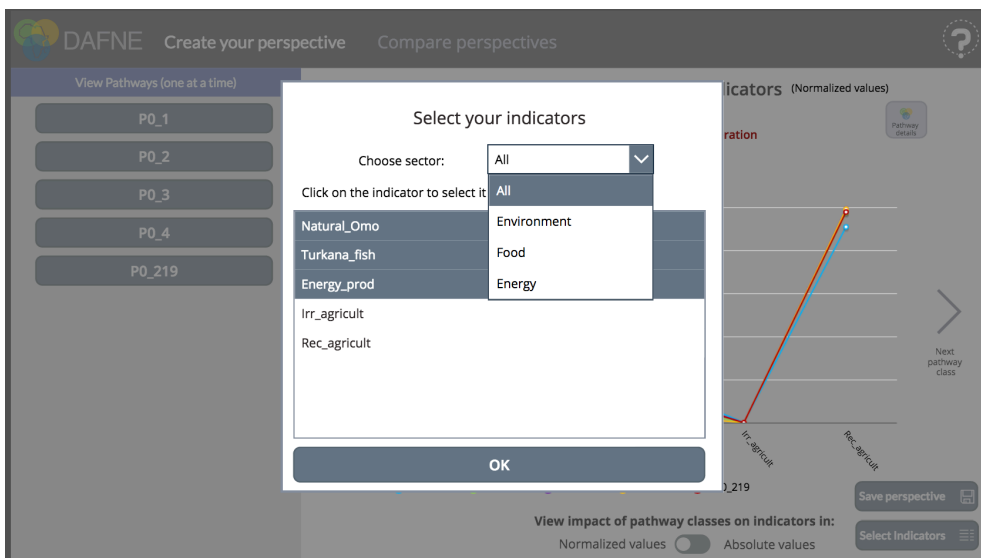


Fig. 36: Step 1 in creating the perspective: selecting the indicators

In the next step, the stakeholders can explore the impact of pathways on the selected indicators (Figure 37). They can click through the pathway classes to see the impact of the structural investments on the selected indicators. Stakeholders can view detailed information (e.g. which exact actions comprise the pathway class) by clicking on the DAFNE icon, which will redirect the user to the detailed pathway model.

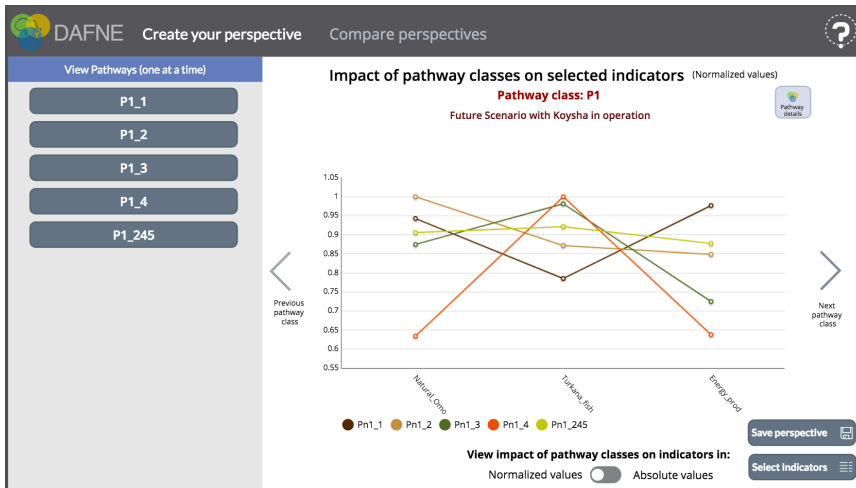


Fig. 37: Step 2 in creating the perspective: exploring the pathways

At this stage, some additional options to explore the pathways include: exploring one pathway at a time and exploring the impact of pathways in absolute values. On the right side of the screen the icon called “View Pathways (one at a time)” can be selected to filter out one pathway from the pathway class and explore its impact on the selected indicators. On this screen, stakeholders can also save one of the pathways to ‘favourites’ (Figure 38). By saving a pathway to favourites, stakeholders can later see which pathways were preferred by others.

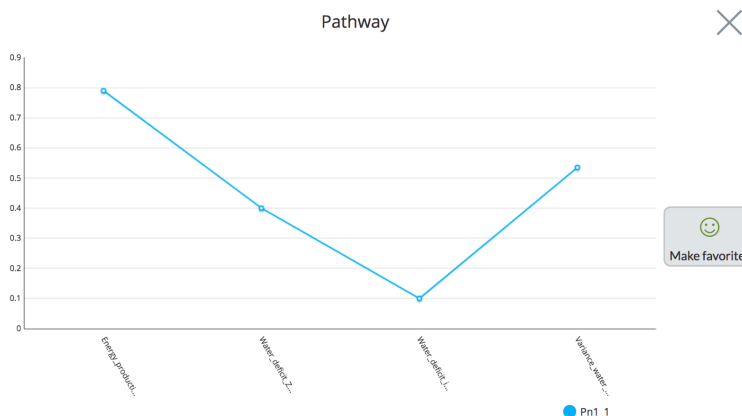


Fig. 38: View pathways one at a time and indicate a favourite pathway

The indicators which are explored do not always follow the same optimization function. To ensure comparability and to make the analysis easier, the values of the indicators are normalized on a scale from 0 to 1, where 0 represents the worst possible effect of the pathway on the indicator, and 1 – the best possible effect (across all simulated pathways). The disadvantage of the normalization is, however, that the seemingly small differences in normalized values can correspond with large differences in absolute values. If stakeholders would like to explore the impact of pathway classes on indicators measured in absolute values, this can be done by toggling the option at the bottom of the screen “View impact of pathway classes in absolute values”. In the ‘View impact of pathways on indicators in absolute values’ mode, stakeholders can explore the impact of pathways on the indicators in absolute values (Figure 39). As the absolute scale is different for each indicator, stakeholders can only explore the impact of the pathways on one indicator at a time. Stakeholders select an indicator they want to explore from the drop-down list. For each indicator, a short description is provided. If stakeholders want to return to explore the impact of pathway classes on indicators in normalized values, this can be done by toggling the option “View impact of pathway classes in normalized values”.

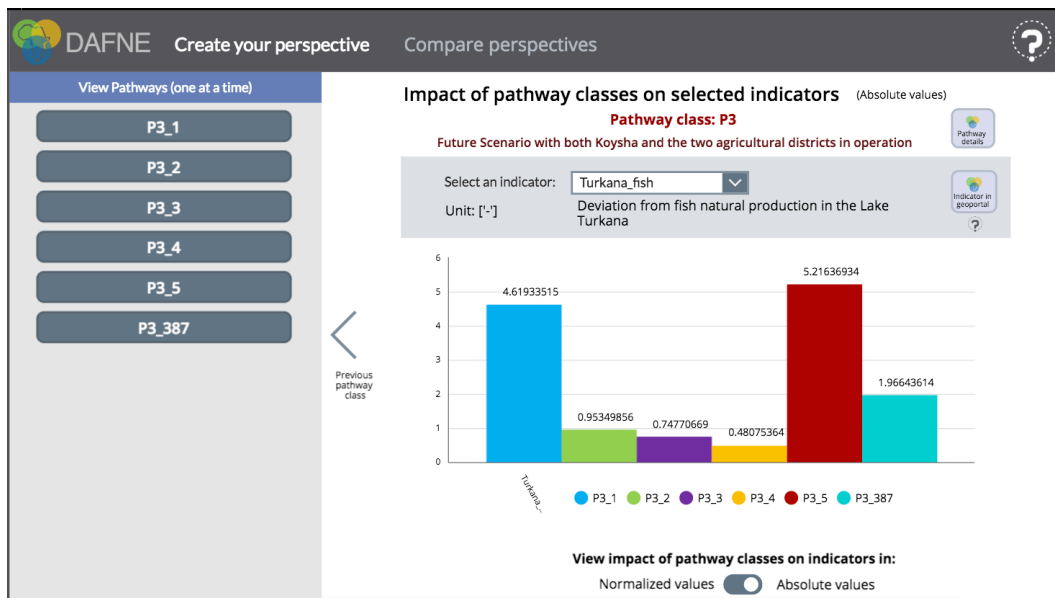


Fig. 39: “View impact of pathways on indicators in absolute values” Mode

Finally, in the third step, the stakeholders can save their perspective by clicking on “Save perspective” in order to compare it later in the “Compare perspectives” mode (Figure 40).

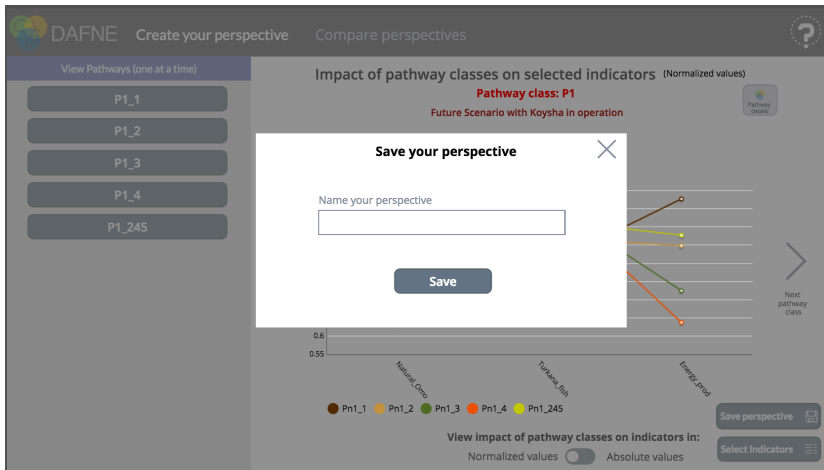


Fig. 40: Step 3 in creating the perspective: saving a perspective

“Compare Perspectives” Mode

In the ‘Compare Perspectives’ mode, stakeholders can compare and annotate perspectives as well as view pathways favoured by all other users. In this mode, stakeholders can choose to retrieve two perspectives saved in the “Create Your Perspective” mode and compare them with each other. They can also retrieve perspectives that other stakeholders have saved. In this way, they can take the perspective of other sector and anticipate the pathways that will be preferred by that sector. Additionally, by selecting two saved perspectives stakeholders can analyse and compare them to each other, thus supporting discussions between stakeholders representing different sectors (Figure 41). Stakeholders can annotate the perspectives by writing comments about them and/or reading the comments provided by others. If needed, the user can also make comments privately so that they are not seen by other users.

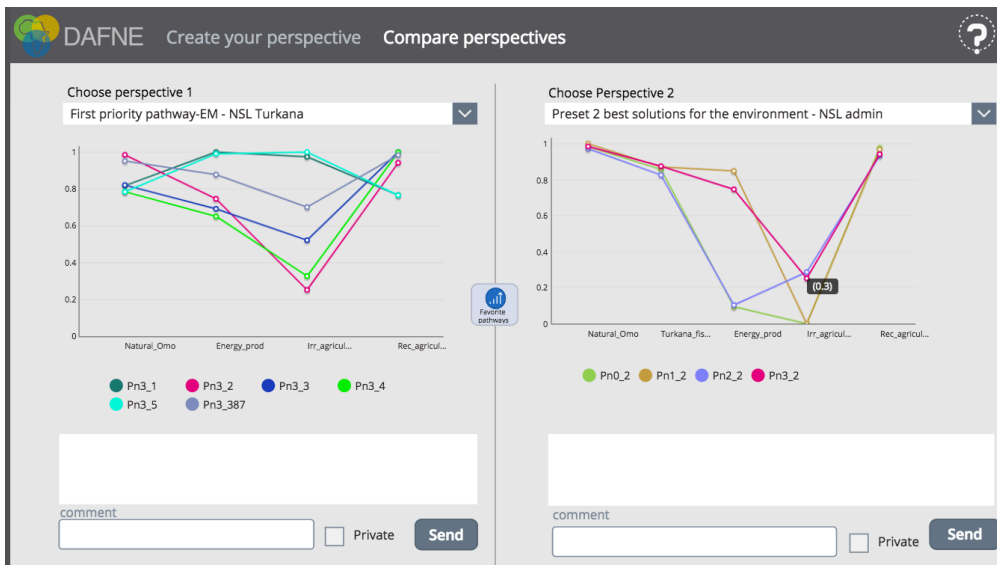


Fig. 41: “Compare perspectives” Mode

In addition, by clicking in this mode on the icon “Favourite pathways” in the middle of the screen, one can see how many times each pathway was favoured by all the users (Figure 42). In this way, one can see which pathways are preferred by other stakeholders.

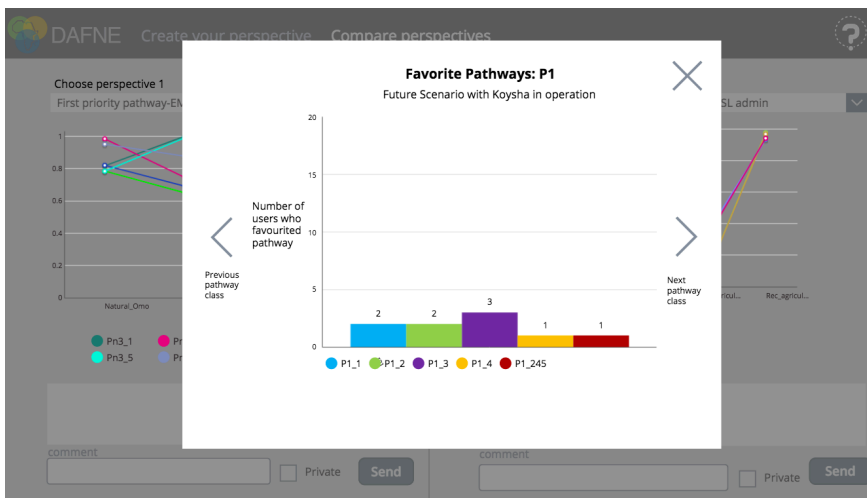


Fig. 42: “View Favourite Pathways” Functionality

Evaluation of the Multi-Perspective Visual Analysis Tool

A preliminary evaluation of the first prototype of the multi-perspective visual analysis tool was undertaken in February 2019 with the stakeholders from the Omo basin. In total, nine interviews were conducted with stakeholders from various sectors including energy, agriculture, environment, food, economy and tourism. The 45-minute long interviews were conducted in person in Addis Ababa. After a brief introduction to the purpose of the

session, the evaluation was performed. In an interactive session, the stakeholders were asked to perform tasks in the multi-perspective visual analysis tool similar to those they would be doing when using the tool on their own. The data used in the tool was preliminary and only for the purposes of illustrating of the main functionalities of the tool. The interviewer asked questions after every interaction. The goal of obtaining this intermediate feedback from the stakeholders was to verify that the prototype developed fits their needs and to identify any issues for further improvement.

As a starting point, the stakeholders were asked about their interests in the project and specific interests for the future of the basin. As expected, the interests of the stakeholders are very different: food security, food productivity, maintaining the livelihood and cultural heritage of communities in the Omo basin, sustainable land management, preserving the environment, preserving forests, promoting investment which complies with environmental requirements, avoidance of floods, good agricultural projects, no conflicts within and between the transboundary countries, etc. In this regard, the stakeholders view the DAFNE project in general and the multi-perspective visual analysis tool in particular, as potentially helping to support a variety of goals such as: optimizing food and water supply; obtaining scientific data to make informed decisions in the nexus; facilitating negotiations between policy makers, negotiating with the government including its ministries, identifying sustainable alternatives for investment, supporting infrastructure planning, promoting good relations with Kenya; and, finally, exploring the effects on culture. The stakeholders are especially interested in the multi-sectoral aspect of the project covering long-term considerations and enabling multi-dimensional analyses exploring the interaction between the various indicators.

Overall, the tool presented to the stakeholders was received positively. The stakeholders were eager to explore the results with the available functionalities of the tool. One stakeholder explained: *“I am fascinated by this tool. It is very interactive. I am very interested in it and also to learn how to use it and interpret all the pathways”*. They said that the tool is very useful for exploring trade-offs, making decisions based on evidence, considering the perspectives of other sectors and using it during negotiations. The interaction with the tool was also perceived to be quite easy with one stakeholder mentioning: *“Overall one can see the trade-offs clearly, easy-to-save perspectives, quite good interaction with the tool”*. The stakeholders could easily explore all of the

functionalities of the tool such as: selecting indicators, saving perspectives, viewing the indicators in isolation, saving a pathway to 'favourites', retrieving and comparing perspectives, and writing comments. The stakeholders were especially interested in the fact that the tool was available online. However, because not all areas of the country are equipped with (adequate) internet access, they asked if the tool would be available offline too. An export function could be very useful in this regard.

The Perspective-making ability of the tool was evaluated through interaction with the "Create your perspective" mode. This mode was perceived as useful and easy to use, with one of the stakeholders mentioning: *"Create your perspective mode is very useful, providing rich and comprehensive information with various options, and it can be used as a negotiation tool by the stakeholders"*. In this mode, the stakeholders selected the indicators they were interested in, viewed the pathways in isolation, and saved their perspective. All these tasks were carried out with ease by at least 80% of the stakeholders. The other 20% needed a bit of additional guidance in using the tool. In this mode, some stakeholders wanted to explore more indicators (which will be possible once the data becomes available) as well as asking about the possibility to 'make a perspective' for interdisciplinary sectors such as tourism and possibly include integrated indicators (value-added indicators) to convince the stakeholders from various sectors.

The Perspective-taking ability of the tool was evaluated through interaction with the mode "Compare perspectives". As with the perspective-making mode, the perspective-taking mode of the tool was perceived as useful and easy to use. As one stakeholder commented: *"Comparison mode is also very helpful, good visualization, can compare easily, to make trade-offs, and to have evidence for negotiation"*. The possibility to consider the impact on other sectors and comparing one's own to the perspective of others was regarded as especially useful to the stakeholders. All of the stakeholders could understand and use the functionalities of this mode of the tool such as: retrieving their perspective, making comparisons, identifying their preferred pathways, as well as providing feedback. We found that by putting the perspectives of the two sectors side by side, a trade-off analysis process for a cooperative selection of pathways can be effectively supported.

A few aspects were also observed that suggest potential for further improvement. These can be divided into those that relate to the usability of the tool and those related to the general understanding of the results of the DAF model. The former can be addressed when improving the tool for the final version. The latter will be addressed by making sure that enough background is provided for participants. This can be achieved within the context setting for the participants, by including explanatory meta-data in the visual analysis tool in order to aid stakeholders in interpreting the results of the model.

The stakeholders when interacting with the multi-perspective visual analysis tool uncovered a few minor usability issues. First, the stakeholders expected a bit more interaction with the pathways, by clicking on them and selecting them, or clicking on their labels. The ability to select one pathway should be explored in the next versions of the tool, and right now is supported by the extra menu that allows the exploration of the pathway in isolation. Second, when selecting the indicators, the stakeholders were a bit confused when the indicator is selected and when not, and suggested the use of a check box so that the interaction is clearer. Third, some stakeholders could not find the menu to switch between the create and compare perspectives modes, and this might be because the tool is slightly larger than the size of the screen that was used for the evaluation. An easy solution for this is to adjust the size of the tool to fit a screen. These issues require minor adjustments in the interaction design of the prototype and can be tackled in the next version of the tool.

What concerns understanding the results of the model, it was observed that some stakeholders could grasp the results of the model easily, while others required some more guidance into the interpretation of the results. Those stakeholders who required more explanations are the ones with less technical backgrounds who do not deal with a large amount of numbers in their daily work and are not familiar with the technicalities of WEF nexus modelling. Specific points scattered around understanding the concept of a pathway and the meaning behind it. As such, the stakeholders desired more details about the pathways and some simple description as to the actions that comprise it. They asked: *“How can the model be translated into action? What should the stakeholders do?”*. Access to the detailed information about the pathways and the indicators was already foreseen: this can be viewed in another tool with a direct link from the multi-perspective visual analysis tool; however, the stakeholder feedback suggests that it would be advantageous

to include some of this more detailed information already in the multi-perspective visual analysis tool itself. Another point was around understanding the impact on the indicators in absolute and normalized values. Overall, normalized values allowed for an easier way of understanding, but normalization in some cases can be misleading (e.g. in a case where a 0.8 normalized value corresponds to a very low absolute term). Finally, the stakeholders suggested that it would be helpful if there could be an overall simplification of the underlying model so it could be grasped without the detailed knowledge of the DAF model. One of the stakeholders mentioned: *"There should be a way to simplify it, add more details in the simplified language so that it is understood by many... someone very high level looking at these results will not be interested in the details"*.

There are several possible ways of addressing the issues outlined above. First, in the final version of the tool a short video tutorial will be available that explains how the results of the underlying DAF model can be possibly interpreted and how they are reflected in the tool. Additionally, there could be online and possibly offline training sessions offered for the stakeholders. All of the interviewed stakeholders expressed a wish to have training on how to use the DAFNE tools in general. Second, another idea could be to add another mode showing the impact of the pathways on a higher level, e.g. by displaying the aggregated impact on the sectors, or on the specific aggregated indicators. One of such options was explored with the participants: to include the potential impact of pathways on sustainable development goals set out by the UN (SDG indicators). The interviewees were presented with a mock up displayed in Figure 43, which shows an example of how the potential impact of the pathway could be shown on the SDG indicators (i.e. which ones could be influenced positively and which ones negatively). The stakeholders expressed a high level of interest in including the SDG indicators into the multi-perspective tool. For some of them, the SDGs give the high-level multi-perspective view by displaying the combined impact of various indicators. Others already use SDGs in their work, for example when planning infrastructural investments, so this additional information about the impact on SDGs would be especially important to them. Some of the most interesting SDGs were those relating to cultural and human aspects (such as no poverty, food security, etc.), as well as those that allow achievement of a sustainable ecosystem (e.g. poverty or gender balance) as well as partnerships between the sectors and the countries (Ethiopia/Kenya).

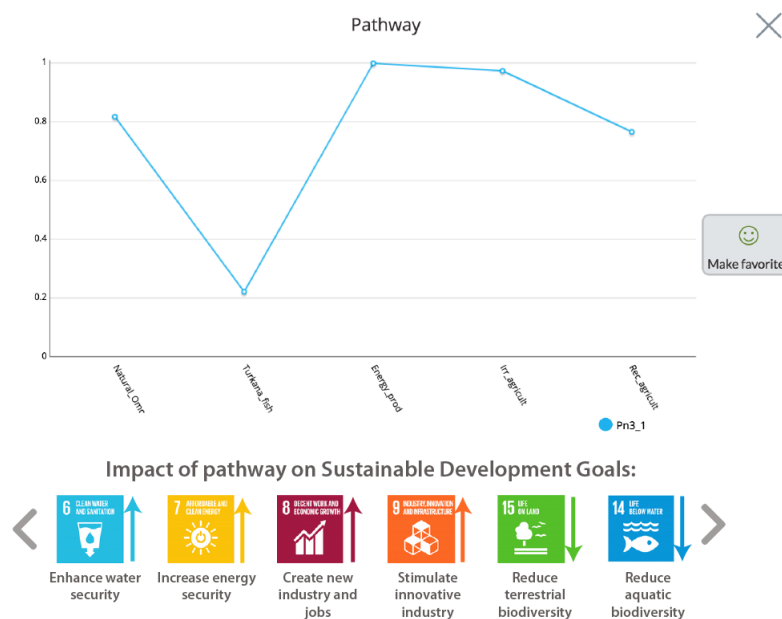


Fig. 43: Mock-up that illustrates including the impact of pathways on SDG indicators

Conclusion and Next Steps

Overall, according to the results presented in this article, the intermediate evaluation of the multi-perspective visual analysis tool confirmed its usability and the suitability of its conceptual design, allowing stakeholders to analyze, create and compare perspectives on the WEF issues in order to analyze the trade-offs of different solution pathways. The results suggest that the multi-perspective visual analysis tool the needs of stakeholder and satisfies their expectations on its value and ease of use. The feedback obtained also helped to identify several minor issues to be corrected and possible areas for further improvement.

The option of integrating the UN Sustainable Development Goals (SDGs) into the tool is an interesting avenue for further research. Currently, such a feature is not available in the existing prototype. The panel discussion of a recent *Resource Nexus Policy & Cluster Workshop* hosted by the European Commission¹ identified a number of challenges related

1. <http://dafne-project.eu/2018/12/11/resource-nexus-policy-cluster-workshop-27th-november-brussels/>

to development such a feature in a reliable way. They pointed to the need for further research projects to specifically addressing this issue. Accordingly, due to the complexity of the underlying challenge, this might be an objective to consider developing into a dedicated follow-up project.

Acknowledgements

The DAFNE project presented in this article has received funding from the European Commission's Horizon 2020 Research and Innovation Programme under Grant Agreement No 690268.

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