QUANTIFYING TRADE-OFFS IN THE WATER-ENERGY-FOOD NEXUS FOR RIVER-BASIN MANAGEMENT

A novel approach to participatory and sustainable water resources management

This factsheet outlines a novel approach to participatory planning and management of transboundary water resources developed during the EU H2020 funded project DAFNE. The approach includes:

- ✓ **A robust Decision Analytic Framework** for optimizing the strategic trade-offs in the basin (p. 3)
- ✓ **An integrated WEF model** for detailed quantification of the WEF components (p.4)
- ✓ **Socio-economic models** for integrating anthropogenic impacts on the WEF nexus (p. 5)
- ✓ **Continuous stakeholder engagement** for reflecting the domain knowledge and interests of those involved in the management and use of resources (p. 6)
- ✓ **Knowledge visualization tools** for facilitating mutual understanding among stakeholders (p. 7)

BACKGROUND

Limitations of conventional approaches to water planning and management

Conflicting interests, power imbalances and the complexity of water use requirements all hamper the economic efficiency and political equity in governing international watercourses.

Competition for water resources crosses various lines, between sectors (e.g., the energy sector depends on water for power generation and the food sector for agricultural production) and between regions or countries (e.g. in transboundary river basins). Moreover, even in situations where watercourse management is based on an established tradition of consultation and cooperation, assessments of available policy options are not trivial undertakings. Because of the geographical and physical complexity of water systems and the interrelations among the sectors involved it is difficult to objectively seek potential trade-offs and synergies between social, economic, and environmental aspects. Conventional approaches to the planning and management of water resources are limited in their ability to address these cross-cutting issues.

Meanwhile, global trends in population growth and rising economic prosperity will likely increase the demand for energy, food, and water, with often severe impacts in fast-growing economies. The constraints on these resources hamper economic development, result in social and geopolitical tensions, and cause environmental damage. These issues may be exacerbated by the impact of climate change

The role of the DAFNE approach

The EU-funded DAFNE project has introduced a novel approach to sustainable water resources management. The DAFNE methodology directly addresses the water-energy-food (WEF) nexus in an integrated, adaptive, and participatory manner. It supports the objective identification of solutions that are beneficial to all stakeholders, address environmental considerations and improve economic efficiency. It has been tested in two transboundary case studies, the Omo-Turkana basins in eastern Africa and the Zambezi River basin in southern Africa. This approach is transferable to other regions with complex resource management issues and competing water needs.

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THE DAFNE APPROACH AT A GLANCE

DAFNE advocates an integrated water resources management methodology for the identification and assessment of alternative water governance options incorporating a 'Participatory and Integrated Planning' (PIP) procedure. This approach highlights the interdependence of water, energy and food security within the context of environmental considerations and limits. It relies largely on quantitative modelling procedures which ensure the objectivity and transparency of the results. Represented by a multi-step, iterative workflow (Figure 1), the approach combines several modelling techniques that are used in a complimentary way with continuous stakeholder involvement and knowledge visualization tools that support social learning.

Identifying issues in the basin and solutions to address them

DAFNE involves stakeholders from the outset of the process to identify issues in the river basin along with indicators that reflect the relative performance of different basin development and management strategies in maximising their sectoral interests. Through stakeholder consultations within a Negotiation Simulation Laboratory (NSL), possible actions (e.g., construction of a new dam, irrigation district expansion) and indicators to quantify the impacts of these actions (e.g., hydropower production, water deficits) are identified.

The sequencing of actions and choice of management strategies are informed by socio-economic and governance frameworks to produce a set of future basin development pathways subject to future drivers and scenarios (e.g. shared Socio-economic pathways (SSPs) to determine likely population growth and governance themes, emission scenarios for future climate drivers, etc.)

Evaluating a broad range of pathways with a strategic set of indicators

The basin development pathways, once identified, inform the Decision Analytic Framework (DAF). The DAF integrates a strategic level simulation model of the river basin including a) the infrastructure for extracting or using water resources, b) the water users, and c) a multi-objective optimization engine. The DAF supports the identification of a number of pathways (sequences of actions over time) through a process of 'optimization'. This process includes the balancing of a set of indicators representing the different stakeholders' interests across the WEF nexus. Via a simulated negotiation,

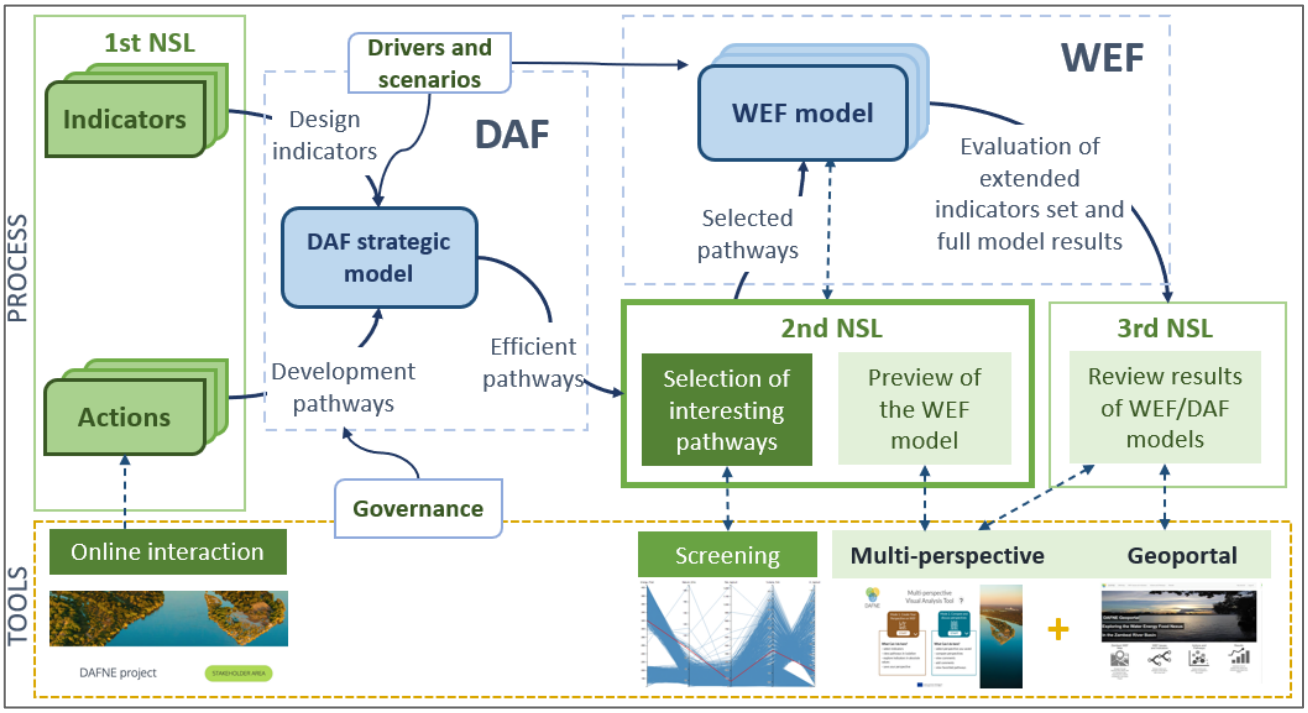

Figure 1: *The DAFNE methodological framework architecture illustrates its main elements.*

stakeholders select several promising pathways for further, more detailed exploration. The selection takes place within another NSL meeting during a moderated group discussion that ensures representation of all interested parties and is supported by a visualization tool that facilitates the comparison of the pathways and ultimately the identification of a reduced subset of negotiated solutions.

Evaluating interesting pathways in detail to achieve an informed consensus

The more comprehensive, integrated WEF model (Figure 2) is then used to quantify in detail the impacts of the pathways selected by stakeholders on the full set of evaluation indicators identified. These simulations provide more elaborate information on the expected effects of the actions considered. They also provide the basis for the next NSL meeting with stakeholders, in which the aim is to reach a properly informed consensus about the most suitable use and management of water resources. This final negotiation round is supported by other visualization tools that allow the users to explore detailed quantitative results and facilitate dialogue and understanding between stakeholders.

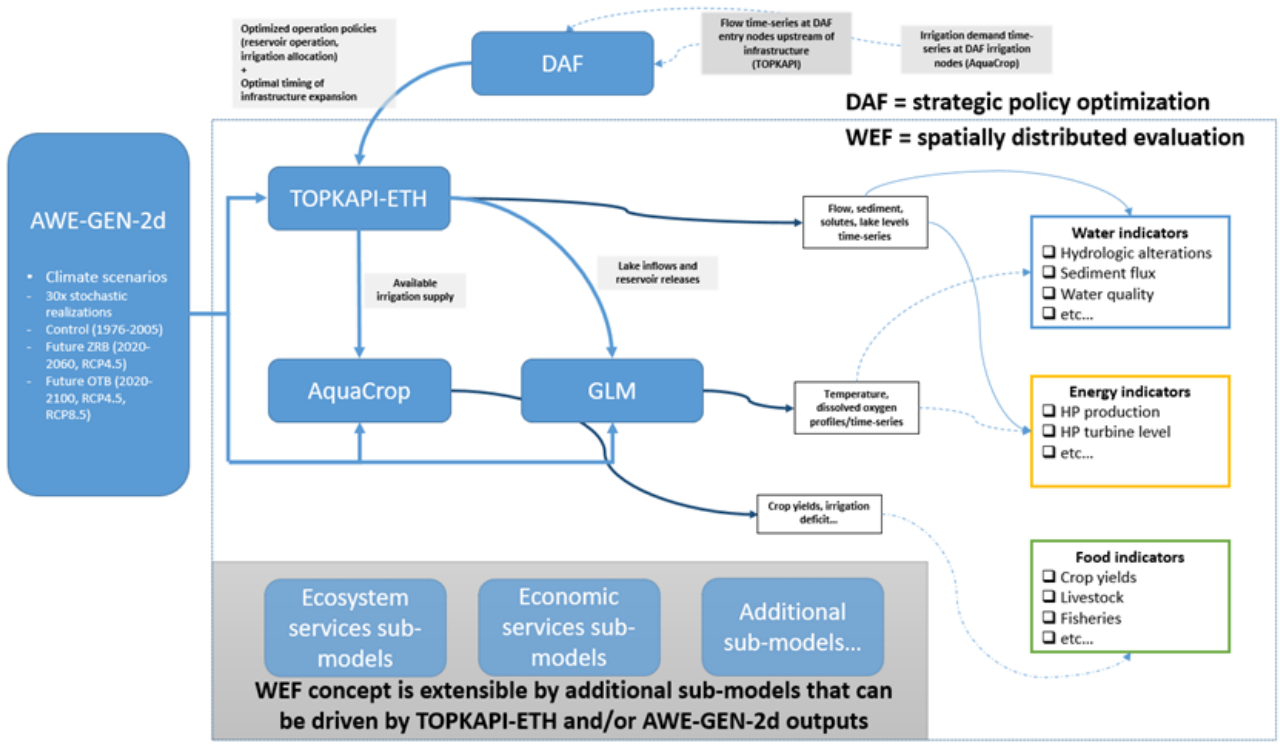

Figure 2. Illustration of the integrated WEF model concept

ROBUST DECISION-ANALYTIC FRAMEWORK

The design of development pathways by optimally sequencing multiple actions over time is a complex decision process. The robust Decision-Analytic Framework (DAF) is used to design efficient pathways addressing the trade-offs between competing water uses today and under plausible uncertain futures. An overview of the DAF components is provided here.

Strategic water system model

The water system model underlying the DAF is a mathematical conceptualization of the main natural processes and human decisions affecting the river basin. Because of the high computational requirements of the DAF optimizations, the DAF strategic model provides a concise representation of the water system both spatially and over time.

Management and planning actions

Development pathways are temporal sequences of management and planning actions that constitute decision variables in DAF. While management actions refer to the rules adopted for the operations of a given infrastructure (e.g., releases from a dam reservoir), planning actions correspond to decisions about infrastructure expansion (e.g., constructing a new dam). Following the PIP procedure in DAFNE the list of potential actions is developed by combining technical expertise with local experience through stakeholder consultations.

Sectoral objectives

In DAFNE, a broad set of evaluation indicators that are identified through stakeholder consultations provide quantitative measures of the impacts of alternative candidate pathways. In the DAF optimization, a subset of these indicators representing the main WEF interests is used to reduce the computational complexity of the procedure.

Future scenarios

In addition to the combination of planning and management actions that are considered, the performance of a given pathway also depends on processes that are beyond the control of the decision maker, such as climate change and other global socio-economic developments. The design of efficient pathways relies on a single, reference scenario and the DAF also identifies the main expected vulnerabilities of the designed solutions when exposed to different plausible futures.

Adaptable architecture

The architecture of the robust Decision-Analytic Framework is generic and can be easily adapted to support the design of development pathways in the different contexts as has been successfully demonstrated by its application in the two DAFNE case studies in Africa.

Efficient pathways design

The components described so far – the water system model, the management and planning actions, the sectoral objectives and the future scenarios - come together within the DAF's two-level optimization procedure:

1. **Optimization of the system operation:** In this step, the DAF designs a set of operating policies that balance the different stakeholder interests across the WEF nexus for each planning action (i.e. for different systems with an increasing number of infrastructures)
2. **Optimization of the sequencing of infrastructural interventions:** In this step, the DAF searches for the optimal sequence of planning actions that respond to the projected climate and socio-economic trends.

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INTEGRATED WEF MODEL

When presented with a broad set of development pathways identified with DAF, stakeholders select the most promising ones for further negotiation. The purpose of the integrated WEF model is to simulate these selected pathways to provide spatially- and temporally-detailed information on their expected impacts expressed with numerous evaluation indicators. This allows the parties involved to understand in detail the impacts in the region or timeframe that are of most interest to them.

Model characteristics

The integrated WEF model simulates in detail the selected pathways and allows the exploration of their impacts. Each simulation corresponds to a given physical configuration of the basin (reservoir operation and irrigation allocation policies, timing of infrastructure expansion). The model provides a complex description of the system that is spatially explicit and has a high temporal resolution. It consists of the hydrological model (its core) and can be customized with sub-models.

Hydrological model at the core

The spatially distributed hydrological model, TOPKAPI-ETH, is the core engine of the WEF model. It receives the basin specifications from the DAF for optimal and coordinated reservoir operation, irrigation allocation and timing of infrastructure expansion, and simulates the effects in basin hydrology of the system operation policies including the uncertainty of future climate scenarios. Its outputs feed into WEF sub-models and directly into the extended set of evaluation indicators.

Data considerations

The main prerequisite for adopting the DAFNE approach is the existence of a minimal data set necessary for model calibration and validation. While data availability is often a challenge, using modern techniques such as remote sensing makes it possible to adopt the DAFNE approach even in data-scarce regions.

Addressing climate uncertainty

The hydrological model at the heart of the WEF model is driven by a set of high-resolution climate scenarios that impact the available supply of water for irrigation and hydrological flows. Using a large set of climate scenarios, the model accounts for the uncertainty resulting from the natural variability of the climate. In DAFNE, these time-space explicit scenarios are generated from an ensemble of regional climate models using the AWE-GEN-2d model (Peleg et al., 2017).

Suite of complimentary models

The hydrological model alone cannot estimate the values of all desired indicators. Therefore, the WEF model includes a suite of complimentary (sub-)models. In DAFNE, the AquaCrop model concept (Vanuytrecht et al., 2014) allows estimation of the values of indicators related to the food sector, and the General Lake Model (GLM) (Hipsey et al., 2019) characterizes indicators of water quality dynamics in reservoirs. In addition, the philosophy of the WEF model foresees that the core model can be extended by further sub-models. This allows the model to be customized according to basin-specific issues and to include further indicators in the computation e.g., those corresponding to ecosystem services, economic services or other aspects.

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SOCIO-ECONOMIC MODELS

DAFNE advocates a holistic approach to water governance. Therefore, in addition to the bio-physical aspects of the WEF nexus, it considers human and institutional elements through a set of socio-anthropologic models, that are both quantitative and qualitative in nature. Their outputs support the identification of appropriate actions. In addition, they feed into the development of future scenarios that inform the DAF and WEF models and provide the boundaries to these models. Finally, they can be used in post-processing of WEF model results to calculate the values of indicators that cannot be directly estimated through WEF simulations.

Model of economic development

The economic model describes the economic development of the regions or countries with a focus on water use and its value to the functioning of the economies of the basin countries. The model is formulated as a *Stochastic Game Model*. It analyses transboundary water sharing between upstream and downstream economies and considers five key water-dependent sectors: agriculture, energy, mining, tourism and residential. In addition, it considers the variability of water availability resulting from climate change. The model can support the identification of optimal water sharing between countries as well as substantiate a decision to allocate water to one sector rather than another.

Model of environmental policy

The environmental policy model under DAFNE focuses on assessing the existing frameworks governing transboundary environmental resources and proposing solutions to address identified gaps and limitations. The assessment consists of the analysis of legal and policy documents with respect to the coverage of key environmental issues, their harmonization between countries within a basin, their coherence across sectors, and the transboundary cooperation. Such an approach is the basis for formulating environmental policies that can strengthen the institutional framework to enhance the potential for environmental sustainability.

Models of demographic, cultural, and social development

In DAFNE, social models formulated through stakeholder consultation facilitate the exploration of the links between societal and resource-related aspects of the WEF nexus. Developed as *System Dynamics Models*, they provide a relatively robust qualitative description of causal interactions between socio-economic phenomena and environmental components of complex systems. In addition, they support identification of critical issues and knowledge gaps. In that way, they represent a valuable tool to inform resource-related decisions concerning the WEF nexus.

Linking DAFNE to SDGs

The DAFNE socio-economic models are integrated under the unifying framework of Sustainable Development (SD). They represent the '4Ps' of SD: planet, people, profit, and policy. Also, their development followed the Sustainable Development Goals and in their final formulation, the models correspond in some form to 15 SDGs.

Models and principles of water governance

Robust governance structures are needed to ensure that actions related to water uses comply with the principles derived from international water law. The *Law and Policy Classification and Expectation Matrix* is a DAFNE tool developed to model the level of legal expectations regarding 13 key legal principles (e.g., equitable and reasonable use) within a river basin. The matrix is created based on an evaluation of legal documents with respect to their legal force and language used. The model supports identification of potential gaps in existing legal and policy frameworks. It can thus provide valuable observations to inform the DAF.

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TOOLS FACILITATING STAKEHOLDER DIALOGUE AND NEGOTIATION

Incorporating complex modelling results in the negotiations is challenging. Virtual tools can stimulate stakeholder participation and help them to visualize quantitative insights, and in effect facilitate dialogue. The DAFNE approach employs a suite of complimentary tools that are aimed at different user groups and serve different purposes.

Facilitate negotiations using knowledge visualizations

Knowledge visualization tools provide a visual overview of complex quantitative results in order to reduce information asymmetries, support negotiations and facilitate compromise solutions by highlighting the trade-offs between options. The screening tool (Fig. 3) gives an at-a-glance overview of sectoral impacts estimated with the DAF model and supports the selection of pathways to be analysed in more detail. The Multi-Perspective-Visualization Tool (Fig. 4) shows the results of the WEF model and helps to increase understanding of different sectoral perspectives, which in turn facilitates dialogue and the identification of widely-accepted solutions.

Screening tool

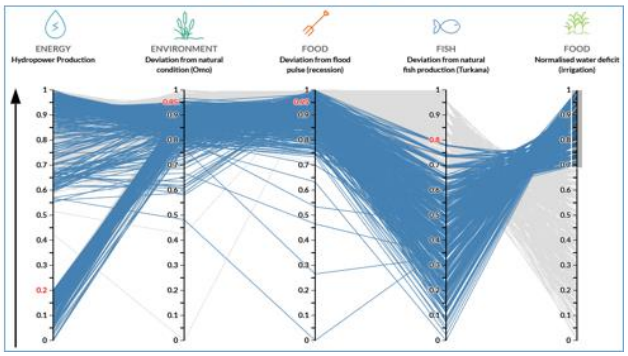

Figure 3: *The screening tool shows the impacts of multiple pathways (blue lines) on the strategic indicators. The filtering option facilitates the selection of alternatives that fulfil the minimum demands of stakeholders.*

Effective application

While the tools can be a powerful support, users might need guidance and additional resources to use them effectively. Options include online or offline training sessions, video tutorials explaining how to use the tools, the results and the underlying model, or additional explanatory data that help stakeholders to interpret the results.

Compile detailed results in the Geoportal

The DAFNE *Geoportal* (Fig. 5) is an online repository providing detailed information on the modelling process, extended description of the alternative solutions that have been analysed and their impacts on all evaluation indicators under high spatial and temporal resolutions. It allows stakeholders to further improve their understanding of the expected impacts and in effect substantiate their arguments.

Multi-perspective visualization tool

Figure 4: *The Multi-perspective visualization tool shows the impacts of a handful of pathways (coloured lines)based on a broad set of indicators. The option to compare perspectives of different stakeholders facilitates understanding between sectors.*

Geoportal

Figure 5: *The DAFNE Geoportal provides a detailed documentation including a spatial representation of the river basin, a full list of indicators and their hierarchy, as well as a detailed description of the analysed pathways analysed and of the modelling results.*

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CONTINUOUS STAKEHOLDER ENGAGEMENT

DAFNE is highly dependent on inputs and feedback from stakeholders in the basins. Therefore, active and continuous engagement of actors representing a wide array of interests from the outset of the process is indispensable. In this way more effective and enduring solutions can be identified and better-informed decisions that are more widely-accepted can be reached. In DAFNE, actors representing various resource sectors, regions and institutional types come together to collectively identify issues, develop solutions and reach agreement on their suitability and implementation. The design of this process is described here.

Stakeholder selection

Representation of the affected parties based on a careful actor analysis is critical. Local civil society organisations, businesses, the policy sector and scientific organisations are a good starting point. When selecting stakeholders, the level of power and active participation of women should be considered. At the same time, the stakeholder group size should be manageable. For participation over a longer time frame, small gatherings are considered more meaningful and productive.

Simulating negotiations and developing capacity

In DAFNE, stakeholder engagement provides both off- and online interactions. Face-to-face meetings in the form of Negotiation Simulation Laboratories, are a safe space to build trust and engagement, exchange on the process, and jointly develop and negotiate alternative solutions. The objective is to *simulate* negotiations so that this forum does not replace real negotiations, but provides stakeholders with the opportunity to substantiate their arguments for the real negotiations, as well as to better understand the arguments of other stakeholders beyond one's own sector. They also serve as a form of capacity building for data-driven, analytical approaches for analysing the nexus. Online interactions support continuity in the engagement with stakeholders in the time between face-to-face meetings. Though cost-effective, these online meetings may involve challenges, e.g. technical difficulties or reluctance to engage in live online meetings.

Continuity in engagement

Technical and organizational difficulties as well as lack of commitment can affect the willingness to participate over the longer term. This can be addressed by designing alternating online and face-to-face interactions, by inviting stakeholders to meetings who have a good knowledge of the issues and experience in the basin, by publishing a project newsletter and by making transparent from the outset the importance of their long-term commitment to the process.

A safe environment

A safe and constructive environment is needed for individuals to engage deeply and exchange their expertise and views freely, with a focus on identifying trade-offs and solutions. Brokering trust from the outset and maintaining this trust is key. For facilitators, this means operating with integrity and transparency, exercising neutrality, employing conflict resolution when needed, and ensuring that talks are held in confidence. For constructive engagement, discussions should be structured well so that there is a logical flow in when and how topics are handled.

Ensuring inclusion

Barriers to the equal involvement of all participants should be prevented or removed. For example, translation services facilitate interactions among participants who speak different languages and visualization tools help to engage actors without advanced technical expertise so that they can participate with a better understanding of the issues and solutions. The type of language used in discussions should also be understandable by all instead of using sector-specific jargon and terminology.

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THE DAFNE APPROACH IN PRACTICE: CASE STUDIES

Omo-Turkana Basin

To satisfy energy and water demands and enhance the national economy, the Government of Ethiopia is developing the Gibe Hydroelectric Cascade scheme (4,600 MW) and the Kuraz Sugar Development Project of about 175,000 hectares in the Omo-Gibe basin. These developments will lead to changes in water availability in the Lower Omo Valley and Lake Turkana, the inflow of which largely depends on the Omo River.

In the Omo-Turkana case study, alternative system operations lied at the centre of the analysis. The DAFNE approach was used to analyse how to manage the infrastructure that is currently under construction once it is operational. The purpose was to identify system operation policies that would satisfy energy and food demands while containing negative effects on other sectors. We found that a multi-sectorial assessment of potential development pathways disentangles sources of conflict across the WEF nexus. The river basin strategic model developed in DAFNE enables comparative assessment of hydropower development and agricultural expansion in the OTB and their impact on riverine ecosystem services.

Zambezi River Basin

The Zambezi River Basin (ZRB) is the fourth largest basin in Africa shared by eight countries and populated by almost 40 million inhabitants. In 2004 an agreement among the eight riparian states was signed to create the Zambezi Watercourse Commission with the purpose of enhancing cooperation over the shared water resource of the Zambezi River Basin in order to increase agricultural yields, hydropower production and economic opportunities.

Infrastructural planning, especially potential dam expansion, were the main focus of the ZRB case study. The DAFNE approach was used to explore whether, where, and when existing basin infrastructure should be expanded given current system management policy, so that the needs of all WEF sectors are met. We found that a coordinated and efficient operation of water infrastructures is more beneficial than optimal sequencing of dam expansion to adapt to global change. The river basin strategic model developed enables the comparative assessment of a multitude of alternative development pathways in the ZRB coupling infrastructure design, timing and operation.

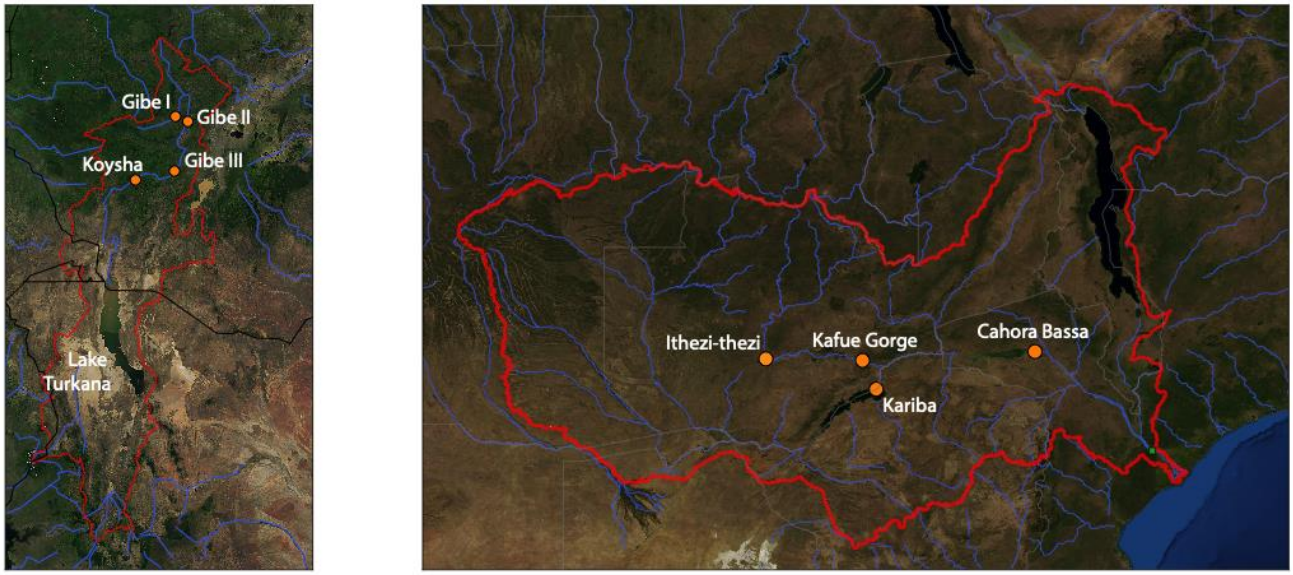

Figure 3: *Maps of the OTB (left) and ZRB (right) reporting the location of the main existing (and under construction) dams.*

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ABOUT THE DAFNE PROJECT

The DAFNE project advocates an integrated and adaptive water resources planning and management approach that explicitly addresses the water-energy-food (WEF) nexus from a novel participatory and multidisciplinary perspective that includes social, economic, and ecologic dimensions. In two cross-boundary case studies, the Zambezi River Basin and the Omo-Turkana Basins, the WEF nexus has been quantified and analysed as the trade-offs between conflicting objectives such as hydropower production versus irrigation or land exploitation versus conservation. DAFNE generates and explores alternative planning and management solutions based on the cooperation of public and private stakeholders, which fosters the profitable but equitable use of resources without transgressing environmental limits or creating societal conflicts.

The DAFNE project has been funded by the Horizon 2020 programme of the European Union and coordinated by ETH Zurich. For a full list of all partners involved, please visit http://dafne-project.eu/consortium/.

For more information on DAFNE visit www.dafne-project.eu

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