AWESOME

WATER-ECOSYSTEM-FOOD

CANDIDATE PORTFOLIOS AND EVALUATION INDICATORS FOR WEF NEXUS ANALYSIS

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LIST OF ACRONYMS

Abbreviations

CS: Case Study
D: Deliverable
DAF: Decision Analytic Framework
DM: Decision Maker
DoA: Description of Action
ES: Ecosystem Services
GA: Grant Agreement
MAWGs: Multi-Actor Working Groups
MS: Milestone
NRB: Nile River Basin
PIP: Participatory and Integrated Planning
POLIMI: Politecnico di Milano
SH: Stakeholder
T: Task
WP: Work Package

1. INTRODUCTION

This document is Deliverable D4.1 - Candidate portfolios and evaluation indicators for WEF Nexus analysis, which reports the outcomes of the activities undertaken in task T4.1 Portfolios and evaluation indicators. T4.1 aims at defining multiple evaluation indicators and candidate planning portfolios to assess the impact of alternative water management solutions on the Water-Energy-Food-Ecosystems (WEFE) nexus. Note that we added an *E* to the WEF abbreviation indicated in the Description of Action (DoA, i.e., Annex 1 of the Grant Agreement – GA) to also represent the *energy* component, as it is embedded with the others and included in the whole project picture.

The broader goal of WP4 is to develop a Decision-Analytic Framework (DAF) running at the river basin scale and relying on a detailed characterization of different innovative technological solutions demonstrated in WP5 at the micro-level (e.g., aquaponics, hydroponics) and a realistic representation of macro-scale processes and regional policies influencing river basin dynamics in terms of land use, water and energy supply, and ecosystem services (WP2, WP3). Besides, the case study assessments and participatory processes initiated by WP6 support our activities, integrating stakeholders (SHs) views and inputs to shape our analyses according to their interests, expectations and capacities. The combination of systems analysis methods and advanced a-posteriori multi-objective optimization algorithms allows the discovery of a set of efficient solutions and associated performance with respect to the WEFE multidimensional assessment space, where SHs and policy-makers are able to explore multi-sectoral trade-offs and negotiate potential compromise alternatives. The workflow of WP4 and its interconnections with the other WPs are illustrated in Figure 1.

Specifically, the DAF employs a strategic river basin model coupled with an optimization engine (see Figure 2): the strategic model is a parsimonious model conceptualizing the main natural processes and human decisions at the river basin scale. The optimization engine implements a simulation-based optimization via multi-objective evolutionary algorithms [1], which iteratively improves a set of candidate solutions by optimizing their performance estimated via simulation of the strategic model with respect to a subset of the evaluation indicators (i.e., design indicators). More information on the meso level model architecture will be provided in D4.2 (Meso level model). The resulting set of Pareto optimal (efficient) planning portfolios (or a selection of them) will be finally re-simulated for mapping the candidate portfolios into their associated performance as quantified by the full set of evaluation indicators.

The WEFE portfolios and associated evaluation indicators presented in this document are identified for the AWESOME case study, namely the transboundary Nile River Basin (NRB). Its characterization and knowledge basis were built upon a wide literature research, including the revision of recent peer-reviewed publications and national reports issued by governmental bodies (e.g., [2–5]). Besides, the work conducted by WP5 and WP6 – respectively reported in D5.1 (Detailed characterization of innovative technological solutions), D6.1 (Case Study Report), and D6.2 (WEF Nexus Mental Model) – serves as guidance and additional support for our analyses.

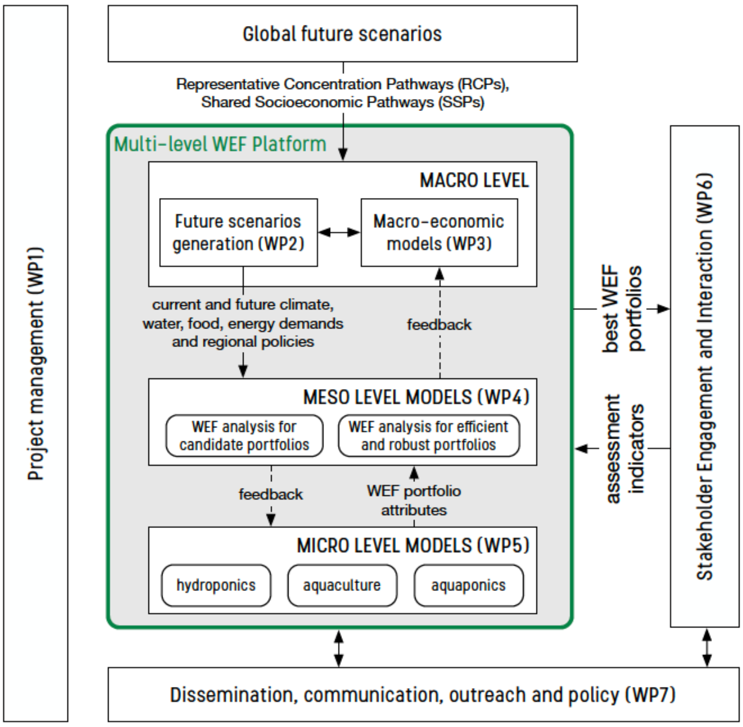

Figure 1 – AWESOME project structure.

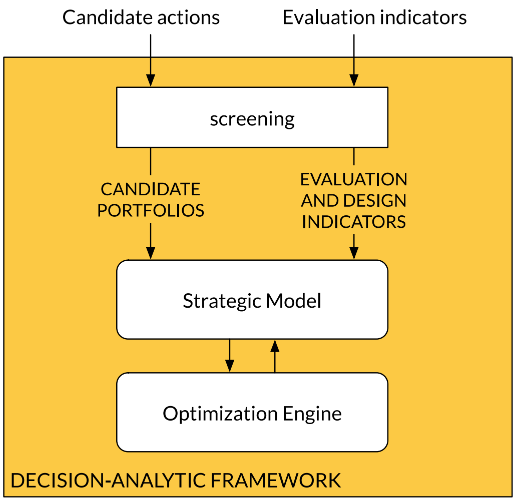

Figure 2 – DAF model at the meso level.

The report is structured as follows: the next section introduces the methodological aspects related to the definition of actions and portfolios, along with the formulation of the evaluation indicators. Section 3 describes the candidate portfolios identified for the NRB, whereby actions and decisions are presented. Section 4 reports the full list of evaluation indicators organized by sectors (Water, Energy, Food, and Ecosystem). Finally, Section 5 draws up some preliminary conclusions and presents the next steps of our work.

2. METHODOLOGY

2.1 ACTIONS AND PORTFOLIOS

Following the Participatory and Integrated Planning (PIP) procedure by Soncini-Sessa [6], actions are defined as elementary options of intervention on the system (e.g., the construction of a new dam or irrigation canal, and the imposition of an environmental flow in a specific river stretch) that are expected to allow the achievement of a pre-defined goal (e.g., water and food security). Each action can be completely and precisely identified through the specification of the values assumed by a set of attributes (parameters and/or functions), where each attribute is completed with the definition of a feasibility set (e.g., feasible capacities of the irrigation canal). Actions can assume values only within such feasibility set. These attributes are the decision variables of the design problem.

Actions can be classified as *structural* and *non-structural* ones. The first class of actions concerns the physical modifications of the system, such as siting and sizing of infrastructure for the collection, transportation, distribution, and use of water resources, e.g., dam or canal construction, irrigation system expansion, and wastewater treatment plant installation. The actions of the second category either modify the system only functionally or alter the effects that the system produces, e.g., a regulation setting water quality standards or environmental flows, setting tariffs for water services, encouraging less water-consuming crops with incentive programs for farmers, and modifying the operating policy of a reservoir.

A second distinction is made between *planning* actions and *management* actions. In this case, the discriminating factor is the time step with which the actions are decided. A planning action is decided over a very long time-horizon (e.g., years), sometime once and for all. A typical example of planning action is the construction of a new dam. Conversely, a management action is taken and revised periodically. A typical example of management action is the operation of a dam, which determines the volume of water to be released from the dam on an hourly/daily/weekly/monthly basis, with the action frequency depending on the water system characteristics.

Generally, rather than selecting a single action to implement, SHs and Decision Makers (DMs) are interested in selecting an alternative or a planning portfolio, which can be defined as a combination of actions traditionally designed with the support of a strategic model combined with an optimization engine (see Figure 2; details will be illustrated in Deliverable 4.2 - Meso level model) under the assumption of stationary boundary conditions. The ongoing nonstationary trends[7] suggest the need of more dynamic and adaptive solutions, able to better handle the uncertainty of future conditions; for this reason, future scenarios and portfolios' robustness against uncertainty will be analysed in the next WP4 Tasks (i.e., T4.3 and T4.4).

2.2 EVALUATION INDICATORS

The goal of the DAF is to support the design of Pareto optimal portfolios in addressing the trade-offs across the four components of the WEFE Nexus. This requires defining how to evaluate the performance of an action or a combination of actions (portfolio) and to assess their impacts in terms of the WEFE Nexus and, more broadly, with respect to the interests of DMs and local SHs in the AWESOME case study.

AWESOME follows the Participatory and Integrated Planning (PIP) procedure by [8] to elicit and model DMs' and SHs' preferences. SHs with similar issues and priorities are grouped into sectors (in this case, Water, Energy, Food, and Ecosystems). For each sector, an evaluation criterion is specified and associated to an index that DMs and/or SHs can use for the comparative assessment of the planning portfolios (actions) with respect to the criterion. The index can be defined either on an ordinal scale (qualitative index) or on a cardinal scale (quantitative index) and must be a function of the decision/action that describes the preferred direction of change embedded in the evaluation criterion.

The index supports the pairwise comparison of alternative portfolios. For example, given two portfolios P1 and P2, a DM should be able to select the preferred portfolio with respect to a given criterion by contrasting the values that the index assumes under P1 and P2. The repetition of such pairwise comparison across a set of portfolios allows the definition of their complete ranking with respect to the criterion expressed by the index. In principle, the index value can be directly estimated by interviewing the SHs or, when this is not feasible, a representative Expert (Figure 3a). Yet, this direct approach frequently leads to subjective and hardly acceptable evaluations, and its implementation might become extremely difficult when the planning process involves many alternative portfolios. An automated procedure, possibly using simulation models, is therefore more appropriate to reproduce the SHs/Expert evaluations for computing the index (Figure 3b). The strong participation of both DMs and SHs is crucial in this step to ensure the credibility of the results; models can in fact be developed by people who are familiar with both the problem and the institutional setting in which the problem is to be addressed[9].

The impacts of the alternative WEFE planning portfolios will be ultimately assessed via simulation of the river basin model that is under development in Task T4.2 (see Figure 4). Even if the strategic meso level model is under development within T4.2 details and will be illustrated in Deliverable 4.2 - Meso level model, we briefly report here its preliminary structure and main elements. The model is currently composed of 3 reservoirs and respective hydropower plants (i.e., Grand Ethiopian Renaissance Dam – GERD in Ethiopia, Merowe Dam – MER in Sudan, and High Aswan Dam – HAD in Egypt)[10], and 3 irrigation districts (indicated as i1, i2, i3) in Sudan aggregating multiple points of abstractions between reservoirs and tributaries of the Nile River. Downstream of HAD, we detailed the single irrigation district (indicated as i4) into 11 macro-districts, according to the data retrieved by the National Water Resources Plan of Egypt [2]. The selection of the model's components was performed by considering a monthly time-step; the reservoirs included should have a sufficient capacity of "moving" water volumes from one month to another.

Given the availability of this model, the index value can be therefore computed as a functional of the simulated trajectories of the relevant model variables (Figure 3c), such as water level in a specific river section, water flow in an irrigation canal, water flow through turbines in a hydropower plant. Such computation of the index is generally performed in two steps (Figure 3d): first, the effects of an action or portfolio are measured in physical units by an evaluation indicator, and then the value of this indicator is mapped into the actual satisfaction of the DMs or SHs criterion by means of a value function. It is worth noticing that the value of an indicator expressed in physical units could differ from the level of satisfaction of the associated criterion returned by the value function. E.g., if the indicator quantifies the water level excess above a critical flood threshold and portfolios P1, P2, and P3 produce different values of this indicator all above the threshold, the corresponding level of satisfaction can be null for all the three portfolios.

In some cases, it might be difficult to formulate an indicator directly associated to the index used by DMs or SHs for the evaluation of their criteria. For example an indicator related to flood protection could be the flood damage, which requires formalizing a relationship between the water level in a flood event and the economic damages produced by the flood (for more details, see [11]). Defining such relationship, however, is very site-specific and generally requires ad-hoc data collections that may prevent its use in practice. In these cases, the original flood damage indicator might be replaced by a proxy indicator measuring the flooded area rather than the economic damage (Figure 2e). The proxy indicator is a variable in a logical relationship with the evaluation criterion associated to the index and related to the effects of the portfolios through a functional, objective, and potentially quantifiable link [12]. Then, DMs/SHs can define a value function for the proxy indicator to map this latter into a level of satisfaction. The proxy indicator hence assumes the role of an indirect ordinal estimator of the evaluation criterion and the degree of satisfaction of such criterion can be quantified through the value assumed by the proxy indicator, ultimately replacing the need for computing the original indicator.

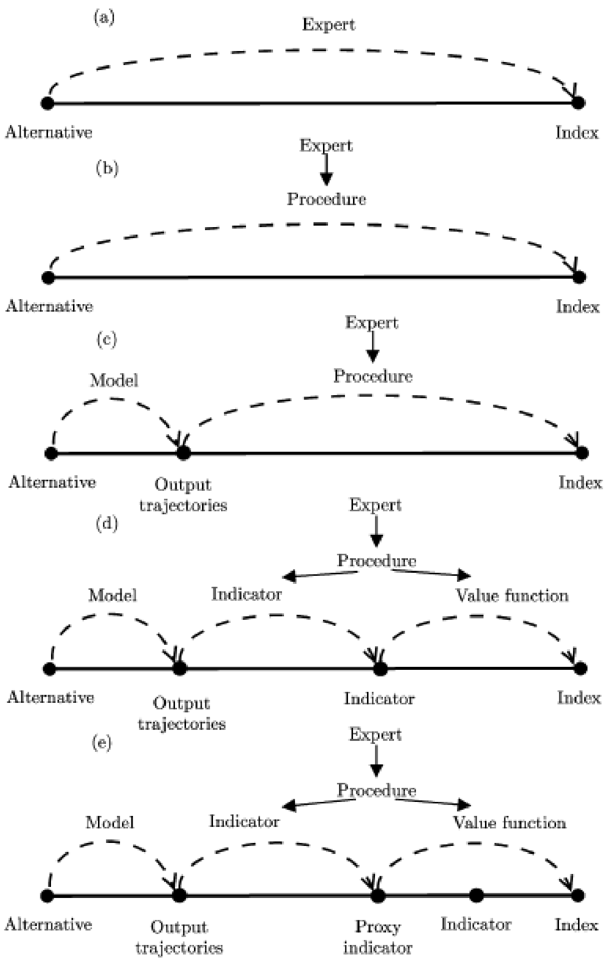

Figure 3 – Alternative approaches for the definition of an index evaluating the performance of a WEFE portfolio with respect to the evaluation criterion of a specific sector (adapted from [11]).

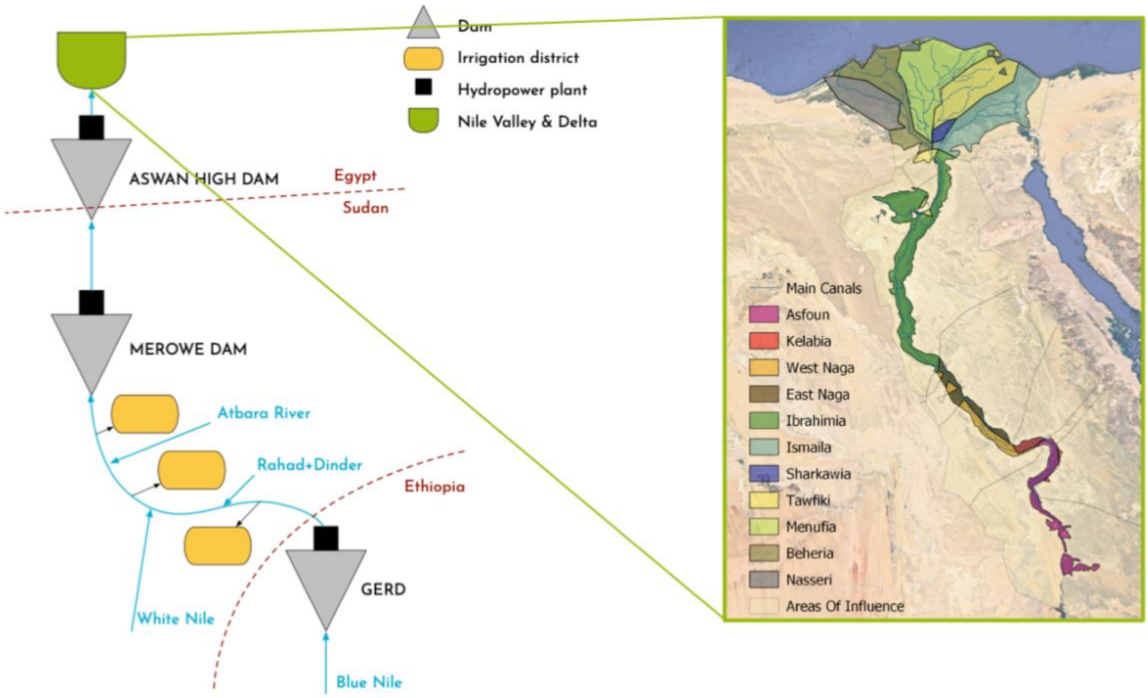

Figure 4 – Preliminary meso level model structure, with a zoom on the modelled irrigation districts in Egypt.

2.3 PARTICIPATORY IDENTIFICATION OF ACTIONS AND EVALUATION INDICATORS

In AWESOME, the SHs' and DMs' interests have been assessed through a participatory approach that involved not only WP4, but also activities undertaken in WP5 and WP6, as well as workshops, online meetings and semi-structured interviews with NRB experts and agri-business practitioners. Besides, we conducted a parallel accurate literature research, reviewing not only peer-reviewed journal articles, but also national reports and international agreements. More precisely, our understanding and knowledge basis on the case study and the detection of the main interests across different sectors has been built on the following cornerstones:

- the detailed characterization of the innovative technologies (e.g. soilless agriculture, hydroponics, aquaponics) that are being tested on site and fully described in D5.1;
- the direct participation of an industrial partner/ relevant SH (i.e., ZG) in the project – in particular, in WP5 – and the involvement of NRB experts (e.g., Dr. K. Wheeler from Oxford University and Dr. M. Omar from ICARDA) for guidance and advise;
- the SHs analysis and mapping along with its review from key micro and meso level actors and literature review yielded to the case study description, while the SHs workshops and interviews to the creation of the WEFE mental model, which are reported in D6.1 and D6.2, respectively;

- the critical literature review[i] conducted within WP4 on strategic water management in the NRB, cooperative (and not) river operations, soilless agriculture and efficient water supply measures in Egypt, economic evaluation of such measures, and related environmental aspects.

This foundation supported us in the identification of both the main actions to be combined into WEFE portfolios as well as the evaluation indicators for capturing the effects of alternative WEFE planning portfolios according to the SHs' interests.

3. CANDIDATE PORTFOLIOS

Combining information from scientific and gray literature with insights obtained from interactions with SHs, we identified the main actions to be combined into the WEFE portfolios. Following the methodology presented in Section 2, we first listed in Table 1 the actions that were identified as potential solutions contributing to water and energy availability, sustainable water management, food security, ecosystems preservation, and economic development in the NRB, while addressing challenges such as population growth, climate change, and transboundary agreements.

Subsequently, considering the feasibility of the implementation of such actions in the meso level model (see Figure 4) we selected the actions listed in Table 2 specifically for the AWESOME case study.

Table 1 – Reconnaissance table, highlighting the main SHs, sectors, interests, and recommended actions for the NRB.

SECTORS/ SHs	INTERESTS	RECOMMENDED ACTIONS
Water/ Municipal and industrial	Maximize water supply, minimize deficit/losses including the ones due to evaporation, minimize costs	Incentives to reduce household consumption, act on consumers' behaviour, canals system maintenance, insert sensors, artificial groundwater recharge, new subsurface dams and reservoirs
Food/ Agriculture (and Fishery)	Maximize crop (and fish) production, yield intensification, minimize water (irrigation) deficit, minimize costs, guarantee continuity of production	Implement innovative farming techniques, use less water-consuming and salt-tolerant crops, change irrigation techniques, diversify water sources (groundwater, reused, desalinated), develop of fisheries in storage systems
Energy/ Hydropower	Maximize production and profits, guarantee continuity	Optimize operating policy, Nile cooperative management, bi-lateral/multi-lateral energy export

[i] Corresponding literature sources have been collected on the project repository (link) and are also contributing to a working Excel file reporting an economic evaluation of hydro- and aquaponic systems (link).

		agreements, implementation of renewable energy sources apart from hydropower
Ecosystems/ Environment	Protect river life, coral reefs, and biodiversity, mitigate climate extremes, minimize water demand, limit eutrophication, preserve the role of swamp areas	Minimum environmental flow, water-efficient management measures (water supply), strategic planning for climate adaptation

Table 2 – Planning and management actions for the meso level Decision Analytic Framework.

ACTION	COUNTRY	PLANNING/MANAGEMENT	MAIN IMPACTS
Operation of GERD Dam	ETHIOPIA	MANAGEMENT	ENERGY
Operation of irrigation diversions	SUDAN	MANAGEMENT	FOOD, WATER
Re-operation of Merowe Dam	SUDAN	MANAGEMENT	ENERGY
Re-operation of High Aswan Dam	EGYPT	MANAGEMENT	FOOD, ENERGY, WATER, ECOSYSTEM
Implementation of soilless agriculture	EGYPT	PLANNING	FOOD
Construction of desalination plants	EGYPT	PLANNING	WATER
Water reuse from drainage agricultural systems	EGYPT	PLANNING	ECOSYSTEM, WATER
Groundwater pumping	EGYPT	PLANNING	WATER

4. EVALUATION INDICATORS

Combining information from scientific and gray literature with insights obtained from the stakeholders' interactions, we formulated different evaluation indicators to measure the impact of alternative WEFE portfolios (see Table 2) on the four components of the WEFE Nexus. The evaluation indicators formulated are reported in Table 3, along with the correspondent sector and location of interest.

Table 3 – Evaluation indicators formulated for the meso level Decision Analytic Framework.

SECTOR	EVALUATION INDICATOR	LOCATION
ENERGY	Total hydropower production at the basin scale	River basin
ENERGY	Hydropower production of GERD	Ethiopia
ENERGY	Hydropower production of Merowe dam	Sudan
ENERGY	Hydropower production of High Aswan Dam	Egypt
WATER/FOOD	Total irrigation deficit in the three districts in Sudan	Sudan
WATER/FOOD	Water supply deficit in Egypt	Egypt
WATER	Domestic water supply deficit	Egypt
WATER/FOOD	Irrigation water supply deficit	Egypt
FOOD	Construction and operation cost of soilless agricultural systems	Egypt or single district
FOOD	Annual production of vegetables from soilless agricultural systems	Egypt or single district
FOOD	Annual production of fish from aquaponics systems	Egypt or single district
WATER	Water consumption and saving of soilless agricultural systems	Egypt or single district
ENERGY	Energy consumption of soilless agricultural systems	Egypt or single district
FOOD	Distance of soilless agricultural systems from large urban centers	Egypt
WATER	Construction and operation cost of desalination plants	Egypt or single district
WATER	Desalination water supply cost (proxy)	Egypt or single district
WATER	Desalination water distribution cost (proxy)	Egypt or single district
ENERGY	Annual energy consumption of desalination plants	Egypt or single district
WATER/ECOSYSTEM	Annual reuse of drainage water	Egypt or single district
WATER/ECOSYSTEM	Annual use of groundwater	Egypt or single district
ECOSYSTEM	Groundwater use distance from the sea to avoid saline water intrusion	Egypt or single district
SUSTAINABILITY	Sustainability Index as defined by [13]	Egypt
SUSTAINABLE DEVELOPMENT GOAL 6	Level of water stress (SDG 6.4.2) [14]	River basin

SECTOR	EVALUATION INDICATOR	LOCATION
SUSTAINABLE DEVELOPMENT GOAL 6	Transboundary cooperation (SDG 6.5.2) [14]	River basin

5. FINAL REMARKS

This deliverable introduces the candidate WEFE portfolios and associated evaluation indicators as identified in Task T4.1. The WEFE portfolios presented in this document represent the main elements that will support the identification efficient solutions at the meso scale. Moreover, the evaluation indicators formulated in this document are key to evaluate the performance of alternative WEFE portfolios and support the exploration of multi-sector synergies and trade-offs.

The strategic policy and management practices and synergistic approaches (e.g., aquaponic systems, integrated modelling approaches) that are being explored in the AWESOME case study represent a great opportunity to improve efficiency of natural resource use and management within the WEFE nexus.

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