proceedings

MDPI

Proceeding Paper

Multidimensional and Multiscale Evaluation Framework Considering Water–Energy–Food–Ecosystem Nexus †

Leonidas Sotirios Kyrgiakos [1,*], Dimitra Despoina Tosiliani [1], Vasileios Angelopoulos [1], Veronica Bonomelli [2], Georgios Kleftodimos [2], Marios Vasileiou [1], Christina Kleisiari [1], Asimina Oikonomou [1], Paolo Prosperi [2], Hatem Belhouchette [2] and George Vlontzos [1]

[1] Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Fytoko, 38446 Volos, Greece; ditosiliani@uth.gr (D.D.T.); vangelopoulos@uth.gr (V.A.); mvasileiou@uth.gr (M.V.); chkleisiari@uth.gr (C.K.); asioikonomou@uth.gr (A.O.); gvlontzos@uth.gr (G.V.)

[2] Mediterranean Agronomic Institute of Montpellier (CIHEAM-IAMM), Route de Mende, 34090 Montpellier, France; bonomelli@iamm.fr (V.B.); kleftodimos@iamm.fr (G.K.); prosperi@iamm.fr (P.P.); belhouchette@iamm.fr (H.B.)

* Correspondence: lkyrgiakos@uth.gr

† Presented at the 11th International Conference on Information and Communication Technologies in Agriculture, Food & Environment, Samos, Greece, 17–20 October 2024.

Abstract: The agricultural sector in the Mediterranean Basin is the largest consumer of water, using 70% of freshwater resources for crop irrigation, which accounts for 85% of the region's agricultural output. With climate change and population growth expected to reduce water availability, energy management also poses a significant challenge, as 7% of commercial energy is used for freshwater supply. The DIONYSUS project aims to develop practical adaptation solutions for efficient resource use through innovative business models, focusing on four demonstration sites in Egypt, Greece, Morocco, and Italy. It seeks to promote a transition to a Green Economy by engaging stakeholders and utilizing a Cross-Sectoral Nexus adaptation tool.

Keywords: evaluation framework; water; energy; food; ecosystem; sustainability

Academic Editors: Thomas Bournaris and Athanasios Ragkos

Published: 21 April 2025

Citation: Kyrgiakos, L.S.; Tosiliani, D.D.; Angelopoulos, V.; Bonomelli, V.; Kleftodimos, G.; Vasileiou, M.; Kleisiari, C.; Oikonomou, A.; Prosperi, P.; Belhouchette, H.; et al. Multidimensional and Multiscale Evaluation Framework Considering Water–Energy–Food–Ecosystem Nexus. *Proceedings* **2025**, *117*, 12. https://doi.org/10.3390/proceedings2025117012

1. Introduction

The Mediterranean region is particularly vulnerable, facing a range of significant challenges, including water pollution, natural resource degradation, water scarcity, substantial food loss and waste, and rising demand for both energy and food [1]. More specifically, the agricultural sector is the largest water consumer in the Mediterranean Basin, using 70% of freshwater resources for crop irrigation, which supports 85% of the region's total agricultural production. Energy is the second largest constraint on food production, with around 7% of commercial energy used to manage freshwater supplies. In light of global and regional impacts of climate change and population growth, water resource availability is expected to decrease extensively.

According to the above urgent issues, the need for the management of water, energy, food, and other ecosystem resources is fundamental to eliminating poverty, improving social welfare, increasing sustainability, and raising economic growth [2]. The WEFE Nexus highlights the strong interconnections between water, energy, and food security and ecosystems, illustrating the strong dependence among them (Figure 1). This approach involves a holistic way of thinking, considering long-term impacts across the four nexus pillars, while simultaneously balancing social, economic, and environmental goals. The implementation of the WEFE Nexus is critical for the development of a sustainable and

secure future in the Mediterranean area [3]. The WEFE Nexus adopts a systems approach to ensure that all four sectors are given equal priority, while promoting sustainable and resilient socio-economic development worldwide. To ensure the successful implementation of the WEFE Nexus, it is important to utilize management tools and instruments that contribute to decision making, actions, and financial investments. The purpose of the WEFE Nexus is to accomplish the Green Economy and Sustainable Development, through local and regional initiatives, including the participation of all key stakeholders.

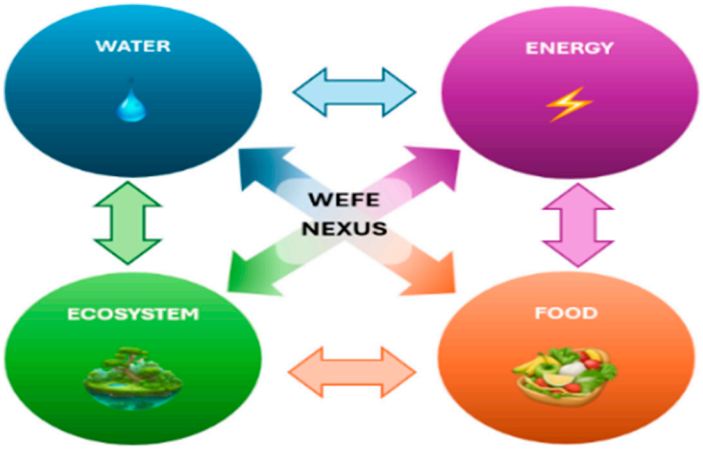

Figure 1. Water–Energy–Food–Ecosystem (WEFE) Nexus.

2. Methodology

In this section, the methodology of the multiscale evaluation framework is analyzed, encompassing the WEFE Nexus approach. This involves extensive interaction and discussion among stakeholders to determine the key variables impacting the WEFE Nexus. Considering this, specific demonstration sites (DSs) were selected (Greece, Italy, Egypt, Morrocco) to assess the implementation of the WEFE Nexus approach in practice, embodying data of each region's unique identity. More specifically, this was accomplished by gathering data and site-specific information from each region to develop an evaluation framework for assessing the countries under analysis. The primary categories of the collected data referred to the following categories: (a) General Description, (b) Demographic Data, (c) Climate Conditions, (d) Agricultural Data, (e) Stakeholders, (f) Competing Sectors, and (g) WEFE Challenges. Focus was directed towards the DSs to distinguish the unique characteristics of each location and the challenges they face. After the data collection, the information was analyzed based on the three sustainability principles of economy, environment, and society to explore additional dimensions. The data obtained from each location will eventually be used for the implementation of innovative WEFE solutions in the Mediterranean areas, with special emphasis on the DSs using the dynamic bio-economic model DAHBSIM.

3. Results

Multidimensional impacts of the collected data have been assessed, aiming to provide a holistic perspective on the WEFE Nexus and promote sustainable development within the DSs. Particularly, this section describes how demographic, agricultural, and climate factors influence the challenges and solutions related to the WEFE Nexus approach.

Regarding the environmental impacts, it was found that all DSs were affected in distinct ways. The main source of water for the Karditsa region in Greece is Plastiras lake, which is about to reach its biological limitation; therefore, an inadequate quantity of precipitation will lead to water scarcity. In Italy, in the Sicily region, four artificial reservoirs contribute to the management of water resources, but due to the recent decrease in rainfall,

citrus cultivation is facing potential risks. In Egypt, although Luxor is close to the Nile River, it faces challenges in the irrigation of cereal cultivation, mainly due to outdated irrigation techniques that are being used. In Morocco, the examined region varies in water availability within the growing season, while subsidies have not contributed to the decrease in vulnerability water deficit levels. Rational water management and innovative irrigation technologies need to be established to improve water savings and increase water efficiency.

Analyzing the economic impacts, both water availability and increased energy cost have a complex effect on local economies. In the Greek DS, due to the absence of reliable infrastructure, significant investments were made to establish individual boreholes and combined with the increased costs of inputs and energy prices, led farmers to shift their primary crops and search for new occupations. In the Italian DS, citrus cultivars are highly susceptible to the external environment, as half of the cultivated citrus lands are not irrigated. Egypt's economy depends on cereal production, yet due to climate change and the absence of Nile floods, there has arisen a need for additional inputs, which increase the production costs. Both in Italy and Egypt DSs, the ratio of smallholder farmers is increased, leading to reduced productions and incomes, so either the implementation of new technologies is necessary or the improvement in the existing infrastructure is. In the Souss-Massa region of Morocco, the agricultural sector is a key driver of the local economy, with the argan oil on top of the economic pyramid.

Concerning the social impacts, the lack of water for irrigation affects both agricultural land and the social welfare of the locals. The Municipality of Karditsa faced the detrimental effects of the severe floods in September 2023, which damaged crops, residents, and agricultural equipment and infrastructure. On the other hand, the Sicily Region needs to balance the requirements of residents in mountainous and valley areas. In Luxor, tourism continues to grow as a prominent sector and residents, communities, and government authorities need to establish an unambiguous action plan. In Souss Massa, as the challenges of sustaining life in rural Moroccan areas grow, more people are likely to migrate to urban centres, shifting the current rural–urban population balance.

4. Discussion

According to relevant studies, it has been reported by stakeholders how population growth, land degradation, and huge amounts of crop inputs contributed to the reduced water quality and quantity, which agrees with the findings of this paper [4]. One of the main issues [1] highlighted in their study was the economic impacts of declining water quality, which led to the increase in water treatment costs. A study conducted by [5] examined the connections between climate change and the WEFE Nexus, pointing out the need for integrated resource management strategies at a regional level, in response to shifting climate conditions. The findings of a study that took place in the Mediterranean region, implementing a holistic WEFE Nexus approach, showed that to maximize positive impacts on the economy, environment, and society, it is essential to guarantee that both people and ecosystems have access to a baseline level of resources and quality standards. Moreover, the use of appropriate technologies and practices was necessary [3]. According to [6], a comprehensive approach that considers all stakeholders, and the environmental impact of water production, distribution, and sectoral allocation, such as energy costs, is essential for making sustainable, long-term management decisions. The above findings are in complete agreement with the results of the topic analyzed in this paper.

5. Conclusions

This paper analyzes the holistic evaluation framework encompassing the WEFE Nexus approach. In the research process, the key stakeholders were identified, and the required

data were collected from the four DSs, to provide long-term solutions under the WEFE Nexus. A deeper analysis of these data highlights the multidimensionality of impacts in each location. Water scarcity, climate change, and the global rise in energy prices affect each DS differently. The implementation of the adapted WEFE solutions is crucial for maintaining sustainability in the Mediterranean region, especially at the DSs. Embracing new technology plays a key role in improving water use efficiency and minimizing water wastage at the same time. Although climate change effects are visible in all Mediterranean regions, it is evident that adopting new technologies and creating partnerships to achieve common goals are the key elements for a sustainable future.

Author Contributions: Conceptualization, L.S.K., P.P., V.B. and G.V.; methodology, L.S.K. and D.D.T.; validation, L.S.K. and G.V.; writing—original draft, L.S.K. and D.D.T.; writing—review and editing, L.S.K., V.A. and C.K.; visualization, L.S.K., D.D.T., G.K., M.V., H.B., A.O. and G.V.; supervision, G.V. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the General Secretariat for Research and Innovation of the Ministry of Development and Investments under the PRIMA Programme. PRIMA is an Art.185 initiative supported and co-funded under Horizon 2020, the European Union's Programme for Research and Innovation (Grant No: 2341). Acronym: DIONYSUS.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are given in the text.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

WEFE	Water-Energy–Food Ecosystem
DS	Demonstration Site
DAHBSIM	Dynamic Agricultural Household Bio-Economic Simulation Model

References

1. Malagó, A.; Bouraoui, F.; Grizzetti, B.; De Roo, A. Modelling nutrient fluxes into the Mediterranean Sea. *J. Hydrol. Reg. Stud.* **2019**, *22*, 100592. [CrossRef] [PubMed]
2. Abera, W.; Getaneh, Y.; Balcha, Y.; Assefa, T.; Mulatu, C.A.; Ebrahim, G.Y.; Tesfaye, M.; Dawit, M.; Abebe, W.B.; Taye, M.T. Framing water–energy–food–ecosystem (WEFE) nexus interactions in the Tana-Beles Sub-basin of Ethiopia. *Sustain. Sustain. Sustain. Nexus Forum* **2024**, *32*, 2. [CrossRef]
3. Malagó, A.; Comero, S.; Bouraoui, F.; Kazezyılmaz-Alhan, C.M.; Gawlik, B.M.; Easton, P.; Laspidou, C. An analytical framework to assess SDG targets within the context of WEFE nexus in the Mediterranean region. *Resour. Conserv. Recycl.* **2021**, *164*, 105205. [CrossRef] [PubMed]
4. Juma, D.W.; Wang, H.; Li, F. Impacts of population growth and economic development on water quality of a lake: Case study of Lake Victoria Kenya water. *Environ. Sci. Pollut. Res.* **2014**, *21*, 5737–5746. [CrossRef] [PubMed]
5. Liu, Q. Interlinking climate change with water-energy-food nexus and related ecosystem processes in California case studies. *Ecol. Process.* **2016**, *5*, 14. [CrossRef]
6. Zarei, M. The water-energy-food nexus: A holistic approach for resource security in Iran, Iraq, and Turkey. *Water-Energy Nexus* **2020**, *3*, 81–94. [CrossRef]