BONEX

NEXUS BRIDGING PLAN

Solar-powered hydroponics

Beqaa Valey **Lebanon**

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

This project is part of the PRIMA programme supported by the European Union.

NEXUS BRIDGING PLAN

Solar-powered hydroponics in AUB, **Lebanon**

Contributions

AMERICAN UNIVERSITY OF BEIRUT

Country team

American University of Beirut
Walid El Kayal
Lourd Abdel Ahad
Zein Kobeissi
Rami Abou Khalil
Joya Baradii

Methods team

Center for Environmental and Sustainability Research (CENSE), NOVA School of Science and Technology, NOVA University of Lisbon (NOVA FCT)
Paula Antunes, Irene Pérez Ramirez, Jessica Loureiro, Rita Lopes, Rui Ferreira dos Santos, Nuno Videira

University of Kassel
Nora Schütze, Andreas Thiel

Almeria University
Antonio Castro, Enrica Garau, Gabriela de Abreu Pérez

Future Water
Johannes Hunink, Tania Imran, Peter Droogers

Revision

Nora Schütze (University of Kassel)

Gabriela de Abreu Pérez (Almeria University)

Olfa Mahjoub (National Research Institute for Rural Engineering, Water and Forestry - INRGREF, University of Carthage – UCAR)

Jessica Loureiro (CENSE, NOVA FCT)

Project Coordinator

BIOAZUL
Antonia Lorenzo, Rafael Casielles, Ângela Magno

Design by POLPA
Alexandre Pereira

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PRIMA IN THE MEDITERRANEAN AREA

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Executive summary

The *Bekaa Valley* is Lebanon's agricultural hub, known for its fertile lands, vineyards, and diverse crop production. With time, the valley has been facing growing challenges, including water scarcity and pollution caused by over-extraction, wastewater discharge, and agricultural runoff. Land degradation has also become a major issue due to intensive farming, excessive chemical use, and poor soil management. Addressing these challenges requires sustainable technical and managerial solutions.

The WEFe Nexus Bridging Plan (NBP) for the Solar-Powered Hydroponics Demonstration Project (DP)at American University of Beirut (AUB), Lebanon, within the scope of the BONEX project, addresses critical interlinkages between water, energy, food, and the environment. Environmental corruption, driven by inefficient policies, market volatility, and limited education, was identified as the central Water-Energy-Food-Ecosystem (WEFe) nexus challenge by stakeholders. This has intensified two key issues: water pollution, highlighting the need for sustainable water sources, and high energy costs, stemming from outdated infrastructure, which impact food quality, production costs, and market competitiveness.

In the context of the BONEX project, stakeholders identified an intervention to solve the WEFe nexus problems in the area: a solar-powered hydroponic system. The intervention consists of a greenhouse containing three different hydroponic units: Nutrient film technique (NFT), vertical rotating towers, and gutters. The rooftop of the greenhouse is equipped with solar panels to generate energy for the system's operation [5]. This intervention addresses the WEFe nexus problem by integrating renewable energy and sustainable farming practices. The use of solar panels reduces reliance on outdated energy infrastructure, lowering costs and greenhouse gas emissions, while the hydroponic units optimise water use, minimising waste and pollution. By enhancing energy efficiency, protecting water resources, and boosting agricultural productivity, the system provides a holistic solution to environmental corruption and its related challenges. Another possible and necessary intervention identified by stakeholders is the greater enforcement of environmental regulations in the region, especially related to water accessibility and water quality. In order to facilitate the implementation of the intervention, stakeholders have suggested several key measures. Financially, support was recommended through governmental incentives — such as subsidies, tax reductions, or grants — as well as funding from donors and NGOs. Politically, the need to establish supportive policies was emphasised, with contributions from universities and NGOs, to make the intervention more accessible.

> **This Intervention addresses the WEFe nexus problem by integrating renewable energy and sustainable farming practices**

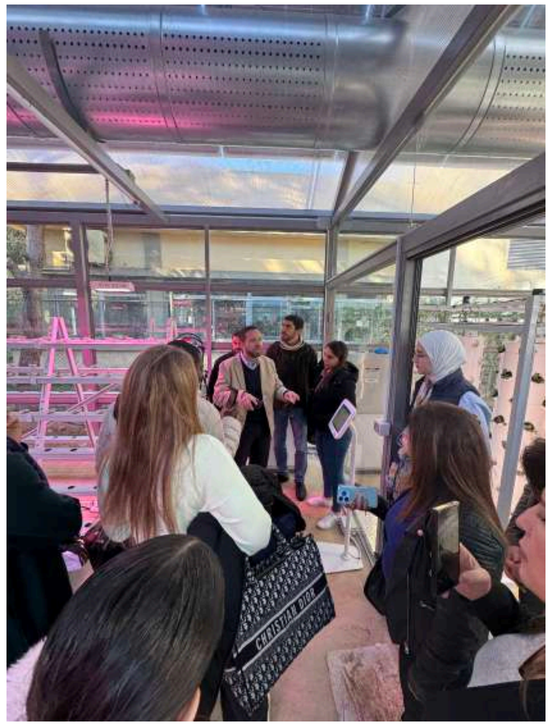
This includes reducing import costs for system components, relying on local products, and promoting renewable energy. Additionally, stakeholders highlighted the importance of raising public awareness about current environmental challenges, their long-term impacts, and the need for sustainable interventions like this one.

Methodological approach

The methodological approach of the DP was divided into two main components: **the technical intervention and the participatory activities.** The technical component involved studying and implementing the intervention, collecting data, and analysing it. Meanwhile, the participatory activities focused on, i) **scoping assessment** with surveys analysing the socio-economic context and local WEFe nexus perceptions; ii) a **collaborative workshop** where was mapped WEFe relationships within the study area, producing a **Causal Loop Diagram** (CLD), iii) in a **second workshop the CLD** was validated and refined while identifying barriers and facilitators for implementation; and iv) the **third workshop** was explored **complementary measures** to the technology' implementation in Lebanon.

The **stakeholder groups involved** included farmers and producers, private sector CEOs, managers, business founders, and employees operating in the energy, food, water, and environmental sectors, as well as representatives from the public sector, such as the Ministries of Agriculture and Environment. Equal consideration was given to the input and opinions of all stakeholder groups, ensuring a balanced approach to decision-making.

The solar-powered hydroponic DP aligns closely with BONEX's goals. The region is rich in natural resources and holds significant potential, especially being located in Lebanon, a Mediterranean country. However, the lack of effective resource management in the area has necessitated the development of technical solutions to improve efficiency. Solar-powered hydroponics are particularly promising in this context, as the system aims to conserve resources—primarily energy and water—while simultaneously boosting food production. The intervention requires a well-defined project framework, as it is a novel and rare approach in Lebanon. Many Lebanese farmers and environmental sector workers are unfamiliar with hydroponics, necessitating thorough research and planning to address all factors influencing its implementation. This is especially important given the high initial costs of the intervention, raising questions about its financial feasibility in the country. Such questions can only be adequately answered through structured projects like this one.



Solar-powered hydroponics are particularly promising in this context, as the system aims to conserve resources—primarily energy and water—while simultaneously boosting food production

One **challenge** that may have influenced the outcomes was the relocation of the hydroponics greenhouse from the *Beqaa Valley* to Beirut due to the war in Lebanon, which made regular travel to the *Beqaa* unsafe. However, since the intervention operates in a fully controlled environment, the relocation would not pose significant issues.

Context description

The Beqaa Valley *(Figure 1 and 2)*, Lebanon's primary agricultural region, spans 177 km in length, 10 to 16 km in width, and has an average elevation of 762 meters [1]. Situated within the *Baalbek-Hermel* and *Beqaa* governorates, it comprises approximately 45% of the country's agricultural land [2], making it critical for food production and rural livelihoods. However, the region faces numerous challenges. The presence of a large refugee population, particularly in the *Beqaa Valley*, intensifies pressure on resources while providing a labour force largely engaged in agriculture.

A lack of coordination and collaboration among federal government agencies, local municipalities, and NGOs has long been identified as a major issue, resulting in fragmented resource and human management. Additionally, Lebanon's prolonged financial crisis has devastated farmers' livelihoods and weakened the operational capacity of government employees. The *Beqaa Valley* faces severe water scarcity, with agricultural activities consuming approximately 72% of the country's water demand [3]. Groundwater extraction exceeds its annual recharge rate, and Lebanon's precipitation is concentrated in winter, leaving the region prone to drought conditions for much of the year [4]. Climate change further aggravates the situation by reducing precipitation and increasing evaporation [5]. Energy shortages present another significant problem. Lebanon heavily relies on oil for power generation [6], with electricity supplied by the public utility *Électricité du Liban* (EDL) and private diesel generators. However, constant power cuts hinder the operation of agricultural systems, which require a consistent energy supply to function effectively.
Future trends in the *Beqaa Valley* indicate significant challenges in the availability of water, energy, and land resources. By 2030, annual water withdrawals

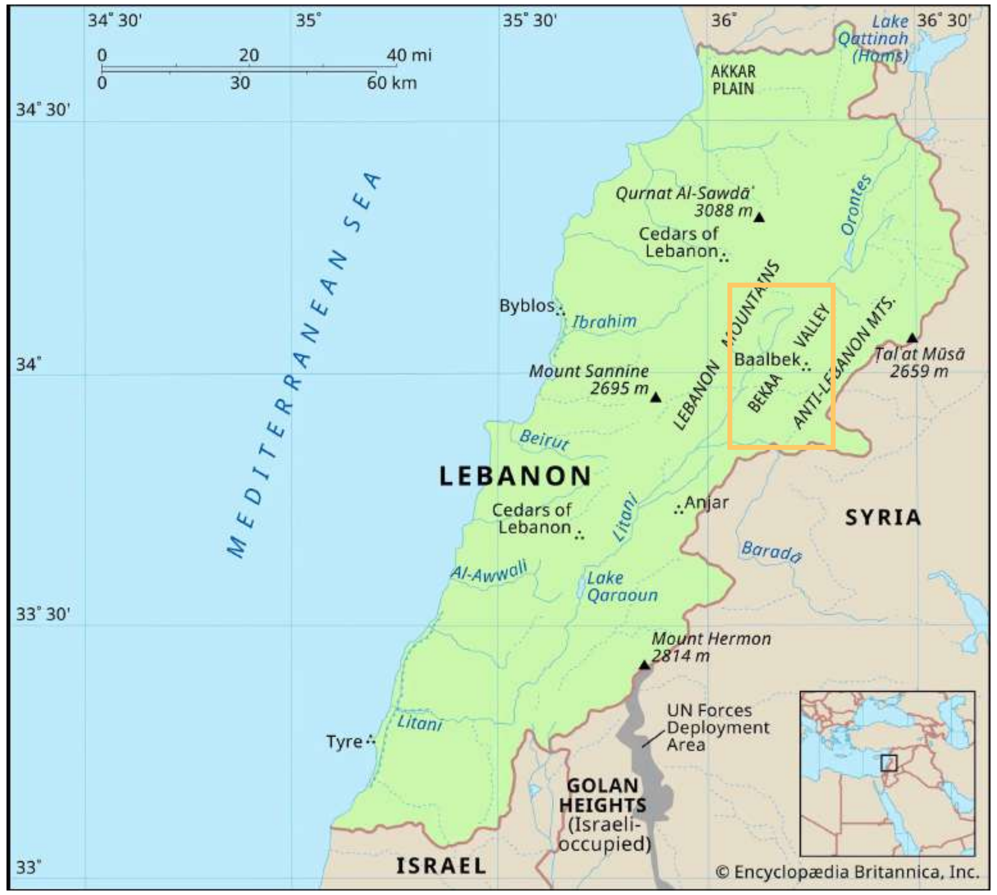


Figure 1 – Map of Lebanon showing the 'Beqaa Valley'.

Figure 2 –Beqaa Valley landscape.

are projected to surpass recharge rates, with this estimate likely understated due to widespread unlicensed well usage. While Lebanon has seen growth in solar power adoption due to the unreliable public electricity gridDOI [7], the sector lacks sufficient regulatory and financial support. Future expansion of solar energy in regions like the *Beqaa Valley* will require investments in infrastructure and training to ensure proper installation and maintenance. Land use pressures are expected to intensify as population growth drives urbanisation in the *Beqaa Valley*, one of Lebanon's least urbanised areas. According to UN Habitat [8], the valley will see continued population increases, leading to expanding urban development.

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WEFe Nexus issue

Through the participatory a activities, stakeholders developed a Causal Loop Diagram (CLD), which identified environmental corruption as the main WEFe nexus problem in this DP. *(Figure 3)*.

Environmental corruption is the abuse of power or authority that leads to environmental harm, often through illegal activities like bribery, falsified reports, or the bypassing of environmental regulations. This issue is driven by factors such as the inefficient execution of environmental policies, market volatility, and limited education. While environmental corruption is the primary challenge, it has led to two other significant problems within the WEFe nexus: water pollution and high energy costs. High energy costs are driven by outdated energy infrastructure and inefficient techniques, which adversely affect food quality, production costs, and the region's competitiveness in global markets. On the other hand, water pollution highlights the urgent need for sustainable clean water sources to protect biodiversity and produce healthier food.

The stakeholders involved in the WEFe Nexus in this DP include researchers, agricultural producers, farmers, private sector representatives, and public sector officials working in environmental or agricultural fields. According to our stakeholder analysis, all stakeholders in Lebanon's DP are affected and play significant roles in the WEFe Nexus. Farmers and agricultural producers are the most vulnerable stakeholders, as they have the

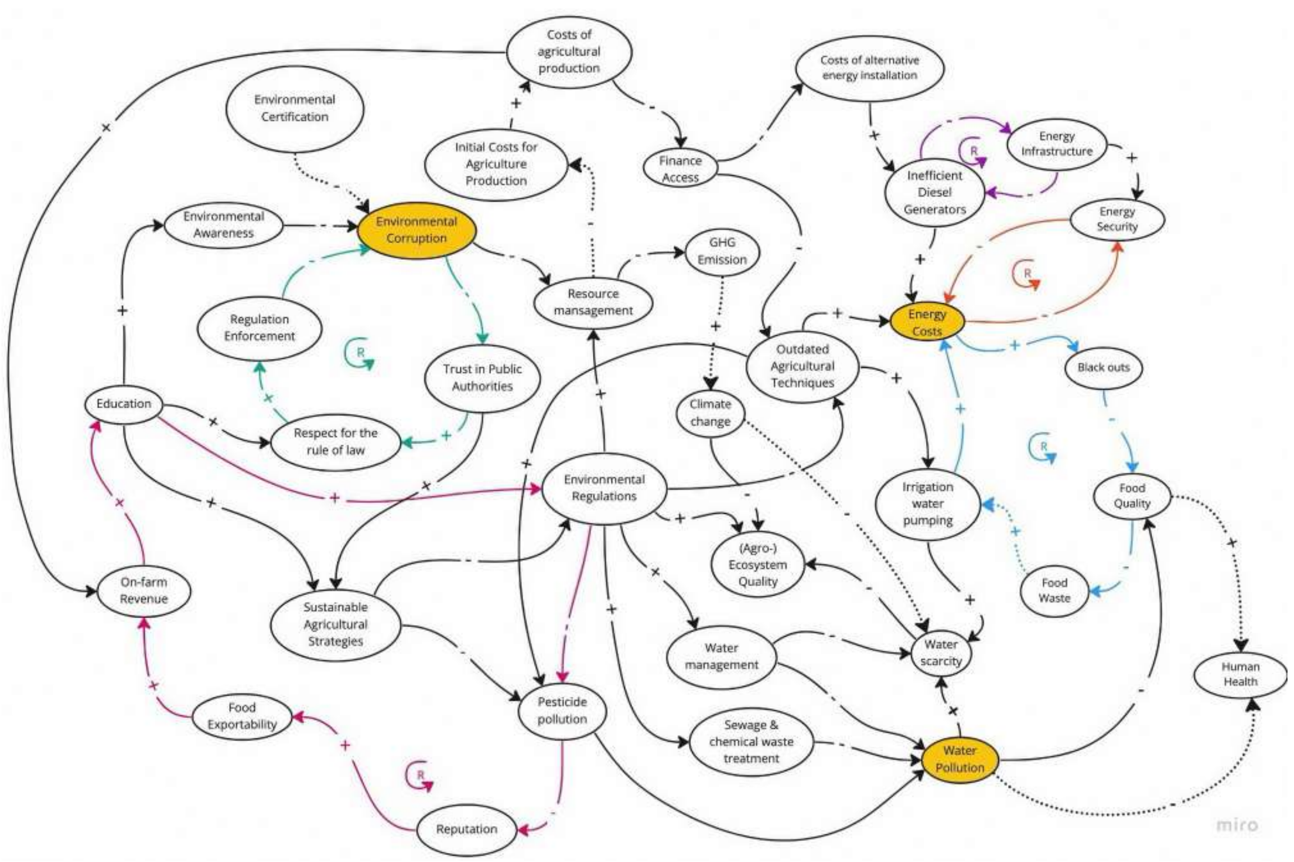

Figure 3 – Graph showing causal loop diagram constructed from three individual causal loop diagrams, perceived connections between the three, and insights and connections made during table conversations.

highest stakes in the system. Food production heavily relies on water quality and ecosystem health, while high energy costs and limited access to clean water further strain farmers' economic viability, reducing profit margins. Private companies and research institutions are also impacted financially and scientifically through their involvement in research and profit-driven activities. NGOs and public institutions contribute by investing in the WEFe Nexus, promoting environmental initiatives, and advocating for regulatory changes. Their actions have both political and social implications, shaping the dynamics of the WEFe Nexus in the region.

Non-monetary values

The main objective of this method is to identify and assess the various types of value and dimensions of human-nature connections, which extend beyond the monetary or market-based values associated with WEFe components. It seeks to uncover the additional benefits that the WEFe Nexus can generate within a specific social-ecological context or local community. In Lebanon, 13 surveys were conducted with stakeholders closely involved in the environmental sector. The findings highlight a strong emphasis on the practical importance of natural resources, particularly water and energy, which are seen as fundamental for sustaining agriculture, ensuring economic stability, and securing food supplies. While economic considerations dominate, some stakeholders also recognise the role of natural resources in fostering social connections and supporting traditional ways of life. However, the perception of ecosystems as valuable beyond their direct utility remains limited. This case study provides important insights into the WEFe nexus in Lebanon, illustrating how communities value their environment and offering key considerations for sustainable resource management *(Figure 4)*. Respondents expressed a range of perspectives shaped by their experiences and interactions with their surroundings. Considering each WEFe element, respondents expressed a range of emotions, benefits, and associations, shaped by their lived experiences and interactions with their environment.

The Lebanon case study highlights a strong reliance on material and economic aspects of socio-ecological systems. While experiential and cognitive dimensions indicate a generally positive relationship with the environment and a reasonable level of awareness, there is room to further enhance understanding and engagement. The emotional dimension reflects mixed perceptions, with some expressing a deep attachment to the land, while others voice concerns about environmental and socio-economic challenges. At the same time, the philosophical dimension reveals a widespread belief in the fundamental importance of nature and resources, reinforcing a cultural and ethical commitment to sustainability. These insights contribute to a more integrated approach to managing the WEFe nexus in Lebanon, ensuring that both economic needs and long-term environmental resilience are considered in future strategies.

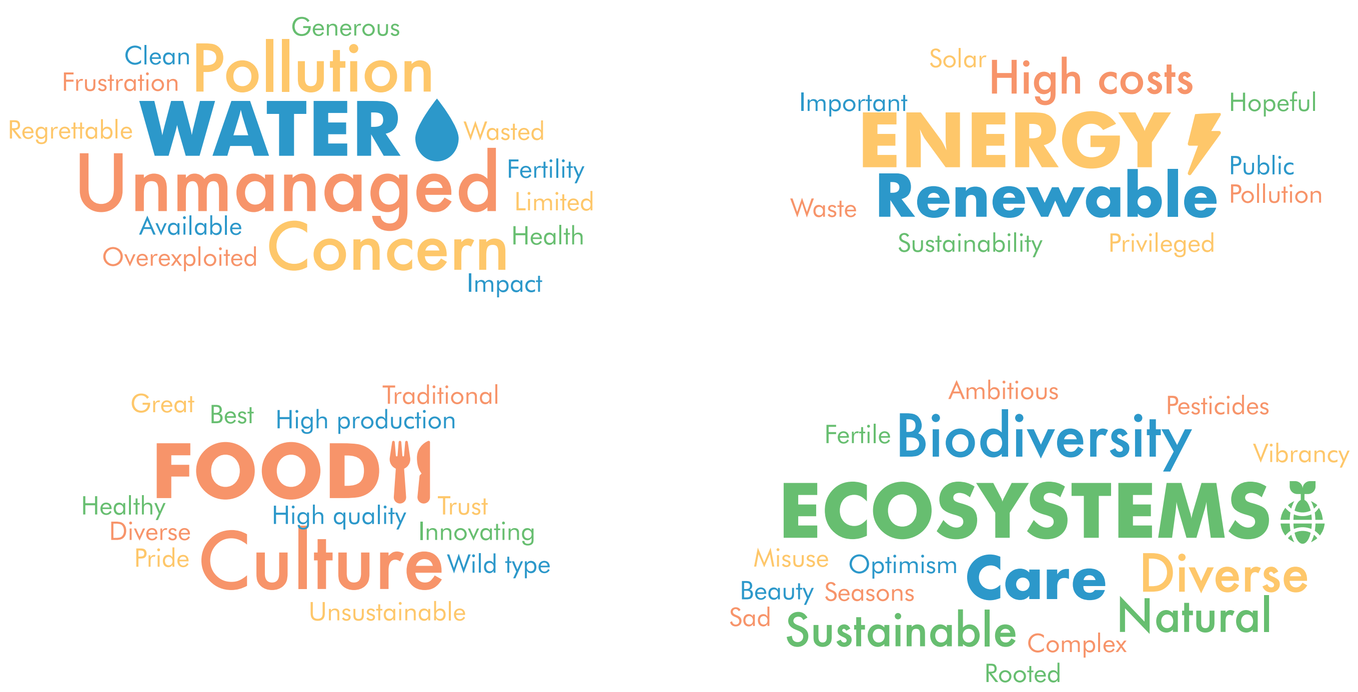

Figure 4 – Word cloud with the value identified by the interviewees to the four components of WEFe.

WEFe solution: Solar-hydroponic system

The intervention introduced in the Lebanon DP is a solar-powered hydroponic system built at the American University of Beirut and designed to maximise food production while minimising resource use. It features a glasshouse equipped with three hydroponic systems: a vertical system *(Figure 5)*, a gutter system *(Figure 6)* and an NFT (Nutrient Film Technique) system *(Figure 7 - next page)*. All three systems are designed for soilless cultivation, offering an efficient and sustainable approach to agriculture. The vertical system and the NFT are specifically used for growing leafy greens, while the gutter system is suited for cultivating vegetables. The plants are cultivated in a controlled environment where optimal temperature and light conditions are maintained to ensure efficient growth. The system employs a closed-loop water setup, recycling unused water to conserve resources. Nutrients dissolved in the

Figures 5 – Rotating Tower.

6 – Gutter System.

Figure 7 – NFT A-shape System

water are also fully utilised, as the solution is continuously recycled until completely absorbed by the plants. The greenhouse roof is fitted with solar panels that generate the energy needed to operate the automated systems, including water pumping. This integration helps reduce energy costs, which are typically high in hydroponic systems. Leafy vegetables such as lettuce, kale, basil, and arugula are cultivated in the vertical and NFT systems, where they thrive in a well-designed hydroponic environment. Meanwhile, the gutter system is used to grow fruiting vegetables like tomatoes, peppers, and strawberries, which benefit from the structural support and efficient nutrient delivery it provides. The system's main benefits include its adaptability to any environment due to its closed design, its suitability for soilless cultivation, and its ability to produce food using minimal resources.

Barriers and facilitator factors

The stakeholders identified several critical barriers and opportunities influencing the feasibility of the intervention. **Financially**, high initial and maintenance costs, limited access to loans, and broader economic challenges such as inflation and Lebanon's economic crisis present significant obstacles. However, these could be offset by possible opportunities such as grants for renewable energy, investor partnerships, international funding, and the potential for high returns and cost stabilisation over time. **Physical implementation** faces challenges including lengthy construction timelines, reliance on skilled labor and imported materials, and specific infrastructure requirements, compounded by seasonal climate instability. Conversely, opportunities lie in one-time construction efforts, controlled environments, space optimisation, and collaboration with research institutions to incorporate new solar technologies. On the **social, administrative, and political fronts**, barriers include limited public awareness, social acceptance, and administrative expertise. Yet, these can be addressed through awareness campaigns, training programs, policy advocacy, and fostering public-private partnerships. Regarding WEFe (water, energy, food, and ecosystems) dimensions, water scarcity due to over pumping and climate change poses challenges, while improved water-efficient irrigation, land-use optimisation, renewable energy integration, and policy support offer significant potential. While the intervention shows promise, its success hinges on addressing these barriers through strategic planning.

Complementary measures

To facilitate the successful implementation of the intervention *(Figure 8)*, stakeholders identified complementary measures across three key areas: technology, financial resources, and institutional arrangements. At the technological level, ensuring product price regulation, providing higher compensations, and offering targeted training programs for workers and supervisors are essential to enhancing efficiency and sustainability. The adoption of advanced manufacturing techniques, such as 3D printing and high-quality local production, along with securing funds for necessary materials, will further strengthen implementation. Additionally, integrating LEAN management programs, promoting diverse planting locations, implementing crop rotation strategies, and establishing a dedicated hydroponic school will contribute to long-term success.

From a **financial perspective**, maximising production efficiency to increase revenue, securing grants from international donors, and attracting investors are critical to sustaining the intervention. Cost-reduction strategies, such as preventive maintenance, resource-saving techniques in water and energy use, and reinvesting profits, will improve financial stability. Providing accessible financing options, including loans and incentives for workers, as well as developing cost-effective hydroponic systems, will further enhance adoption. Additionally, promoting the intervention through targeted advertising, exploring alternative heating solutions such as burning oil, subsidising solar energy systems, and ensuring the equitable

Figure 8 – Solar-powered hydroponics glasshouse in AUB.

distribution of investment and funds for both new and existing projects will support financial viability.

Institutional arrangements play a key role in ensuring long-term acceptance and adoption. Promoting seed sustainability by encouraging the use of local heirloom seeds, reducing taxes on imported equipment, and ensuring the recognition of hydroponics as a formal agricultural practice by the Ministry of Agriculture will provide the necessary regulatory support. Furthermore, integrating hydroponics education into school curricula, engaging municipalities and NGOs in awareness campaigns, and targeting farmers unable to cultivate land through traditional methods will foster wider acceptance. Attaining industry certifications to enhance market credibility, designing strategic marketing campaigns with tailored slogans and packaging, and establishing partnerships with hospitals and urban institutions as key consumers will further strengthen the intervention's impact.

The successful execution of these measures relies on the collaboration of various actors, including experts in farming, technical engineers, universities, and producers, who are responsible for technological advancements and training. Financial sustainability will depend on the contributions of funders, donors, public sector entities, financial institutions, and NGOs, while institutional support requires active engagement from policymakers, awareness organisations, research institutions, marketing teams, and consumer advocacy groups. Through coordinated efforts across these domains, the intervention can achieve greater acceptance, long-term sustainability, and widespread adoption at the local level.

Intervention performance

The intervention effectively addresses the WEFe nexus challenge by optimising natural resource use.

- The system consumes 600L per cycle for an area of 72 m², which translates to 40.6 mm of water per year. In comparison, studies indicate that leafy greens cultivated in a traditional greenhouse require between 150 to 200 mm of water per year[1]. This demonstrates significant **water savings**, as hydroponic systems recycle and reuse water, preventing losses through drainage.

- In terms of **energy efficiency**, the intervention generates 3,627 kWh of solar energy per planting cycle, contributing to the system's total energy demand of 7,600 kWh per cycle. Although solar production does not fully cover the energy requirements, it mitigates environmental impact by reducing reliance on non-renewable energy sources.

- Regarding **food production**, if all rotating towers were dedicated to lettuce cultivation, the system would yield 28 units of Romaine lettuce (larger) per square meter per harvest, compared to 24 units of Butterhead lettuce (smaller) in a traditional greenhouse [2]. This enhanced production efficiency positively contributes to food security and resource sustainability.

However, hydroponic systems require more energy than traditional greenhouses due to the need for automation, machinery, and system operation. The integration of solar panels offsets some of this demand, reducing CO_2 equivalent (CO_2e) emissions compared to non-solar-powered hydroponic units. Nonetheless, CO_2e emissions remain a factor in overall greenhouse operations, presenting a tradeoff between environmental sustainability and high energy consumption.

For the intervention to reach its full potential, achieve high performance, and be successfully upscaled, it is essential to establish a robust and dynamic link between academia and industry. The American University of Beirut (AUB) is leading in-depth scientific research aimed at identifying optimal conditions for plant growth while minimising water and energy inputs—key factors in ensuring the sustainability of the intervention. Complementing this academic effort, the industrial partner "Beirut Farm" brings invaluable hands-on experience and practical knowledge from the field. By offering business insights, operational know-how, and technical support, "Beirut Farm" is working closely with AUB to refine and apply research findings in real-world settings. This partnership not only enhances the effectiveness and relevance of the intervention but also fosters innovation and accelerates its adoption at scale. Thus, the close collaboration between research institutions and industry stakeholders emerges as a cornerstone for the intervention's long-term success and replicability.

REWEFe

To assess the status of water, energy, food and ecosystem sectors, both individually and jointly, the REWEFe (Rapid Evaluation of Water-Energy-Food-ecosystem nexus) tool was used as it provides quantitative insights on the balance and resource use (production, consumption, incoming and outgoing) of water, energy and food. It also accounts for the main positive and negative ecosystem impacts in monetary terms. For the application of the tool to this case study, three scenarios were defined to assess the effects of the Hydroponic system in the context of WEFe nexus in *Beqaa valley*. The REWEFe tool was deployed to quantitatively assess the impacts of enhanced hydroponic systems and coupling of solar-powered (scenarios S1 and S2), and an upscaled scenario where a higher adoption rate was assumed (S3) – *(Figure 9)*. From the results of the REWEFe tool (summarised in the bar charts of the above figure, but with more detailed outputs in terms of tables and indicators in the tool itself), the following key conclusions can be drawn:

- The three scenarios show positive impacts on the **ecosystem** as the use of solar energy reduces CO_2e emissions. However, CO_2e emissions are also associated to greenhouse operations and thus present a tradeoff.

- The upscaled scenario, which represents doubled greenhouse area and solar power generation, shows the highest **food** production but this is coupled with higher energy consumption and adverse impacts on the ecosystem due to the associated CO_2e emissions.

Observed synergies and trade-offs: solar-powered hydroponic systems minimise risks posed to the ecosystem as the system features the recirculation of nutrients, thereby limiting fertiliser application and subsequent nutrient leaching. Similarly, hydroponic systems are more energy efficient than traditional greenhouses, leading to reduced energy consumption and CO_2e emissions. However, scaling up the hydroponic system does pose a risk to the environment, even though food production increases, as energy demands also increase. If the solar energy is not sufficient to meet 100% of the demands, then the system will contribute to higher CO_2e emissions. Therefore, the tradeoff between increased food production and increased energy consumption (and associated CO_2e emissions) needs to be assessed before upscaling the technology.

Figure 9 – Results of the three REWEF scenarios. Scenarios: ***Baseline (B)*** *- Current conditions of the unit ('Beqaa valley' encompassing the 'Baalkbak-Hermel' governorates);* ***Scenario 1 (S1)*** *– Development of hydroponic system;* ***Scenario 2 (S2)*** *– Hydroponic system powered by solar energy; and* ***Scenario 3 (S3)*** *– Upscaled scenario indicating expansion of hydroponic systems across the nexus unit.*

Conclusion

The Solar-Powered Hydroponics system implemented in Lebanon offers a promising solution to the Water-Energy-Food-Ecosystem nexus challenges by conserving natural resources, increasing food production in limited spaces, and reducing pollution through the integration of renewable energy.

W**hile the system** increases energy consumption, it positively contributes to the Lebanon National Agriculture Strategy 2020-2025, aiming to enhance climate change adaptation and sustainability in the agrifood sector. One of its key pillars focuses on promoting sustainable resource management, improving irrigation efficiency, expanding water resources, and encouraging renewable energy use in agriculture. All of which align perfectly with the intervention's goals.

While the intervention does not directly address the primary WEFe issue in the DP—environmental corruption—it significantly contributes to mitigating two major concerns identified by stakeholders: water pollution and high energy costs. By efficiently recycling water and minimising consumption, the system helps alleviate water scarcity in Lebanon and reduces the risk of water depletion. Additionally, as nutrient-rich water is not leached into the groundwater, it plays a role in protecting water bodies from pollution. While the initial cost of renewable energy installations can be high, relying on renewable energy allows consumers to become independent from grid electricity and private generators, both of which are often unstable and costly.

For successful implementation, a collaborative framework involving researchers, donors, business teams, and awareness-raising initiatives is essential. Researchers can enhance the system's efficiency, donors can provide financial backing, business teams can drive market integration, and awareness campaigns can ensure public acceptance and adoption. Furthermore, policy support is crucial to making this intervention accessible and sustainable. Governmental incentives, such as subsidies, tax reductions, or grants, could encourage investment in hydroponic technology and ensure its scalability.

A particularly important factor in the long-term viability of the system is the establishment of a robust and dynamic link between academia and industry. The collaboration between the American University of Beirut (AUB), which is conducting in-depth research to identify optimal growing conditions with minimal inputs, and the industrial partner "Beirut Farm," which contributes practical expertise and market insights, is a key driver of the intervention's refinement and applicability. This partnership enhances both the technical performance and real-world relevance of the system, helping to bridge the gap between innovation and implementation. It allows research findings to be tested and adjusted in real-time, ensures that market needs are considered early in the development process, and promotes the co-creation of solutions that are both scientifically sound and commercially viable. Over time, this integrated approach builds trust, fosters adaptability, and strengthens the system's potential for long-term scalability and impact.

it positively contributes to the Lebanon National Agriculture Strategy 2020-2025

Despite its potential, the high initial investment remains a major barrier to adoption. Without financial support from public or private entities, upscaling will be challenging. Complementary measures such as low-interest loans, public-private partnerships, and integration into national agricultural strategies could potentially help bridge this gap. Ultimately, while the intervention offers a sustainable pathway to address key WEFe nexus challenges, a holistic approach is required to ensure its long-term viability.

Consortium

Spain	BIOAZUL University of Cordoba FutureWater Universidad de Almería
Germany	UNI KASSEL
Portugal	Center for Environmental and Sustainability Research (CENSE), NOVA University of Lisbon Natural Business Intelligence (NBI)
Italy	Consorzio della Bonifica Renana University of Bologna
Jordan	German Jordanian University IUCN-ROWA
Lebanon	American University of Beirut NOVAENERGIA
Morocco	Agronomic and Veterinary Institute Hassan II
Tunisia	SmartLOGGER National Institute for Research in Rural Engineering Water and Forests - INRGREF

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