AI FOR WEFE NEXUS: STRENGTHENING CLIMATE RESILIENCE & WATER-SMART IRRIGATION

Prof. Dr. **JORDI MORATÓ**
Chairholder and Director
UNESCO Chair on Sustainability
Universitat Politècnica de Catalunya (UPC)

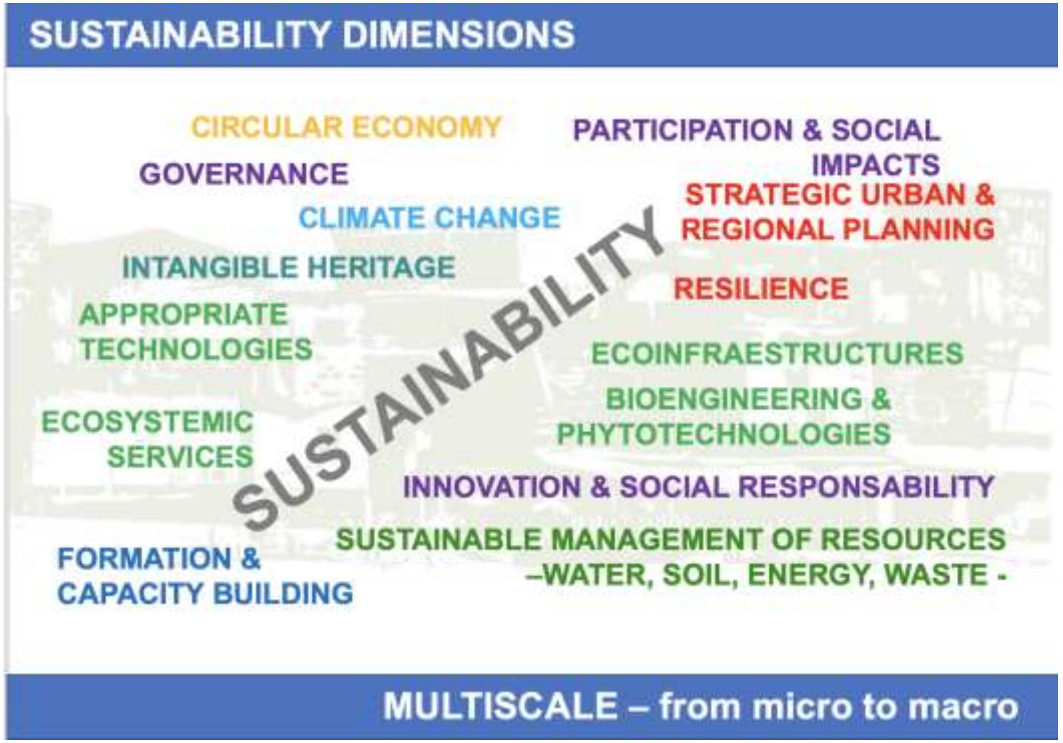
Also member of
Advisory Committee of UNESCO's Water Museums network

jordi.morato@upc.edu

Workshop on Artificial Intelligence (AI) for Sustainable Water Resources Management (WRM) in the GCC Countries
16 – 17 December 2025

UNESCO CHAIR ON SUSTAINABILITY

AT UNIVERSITAT POLITÈCNICA DE CATALUNYA - BARCELONATECH



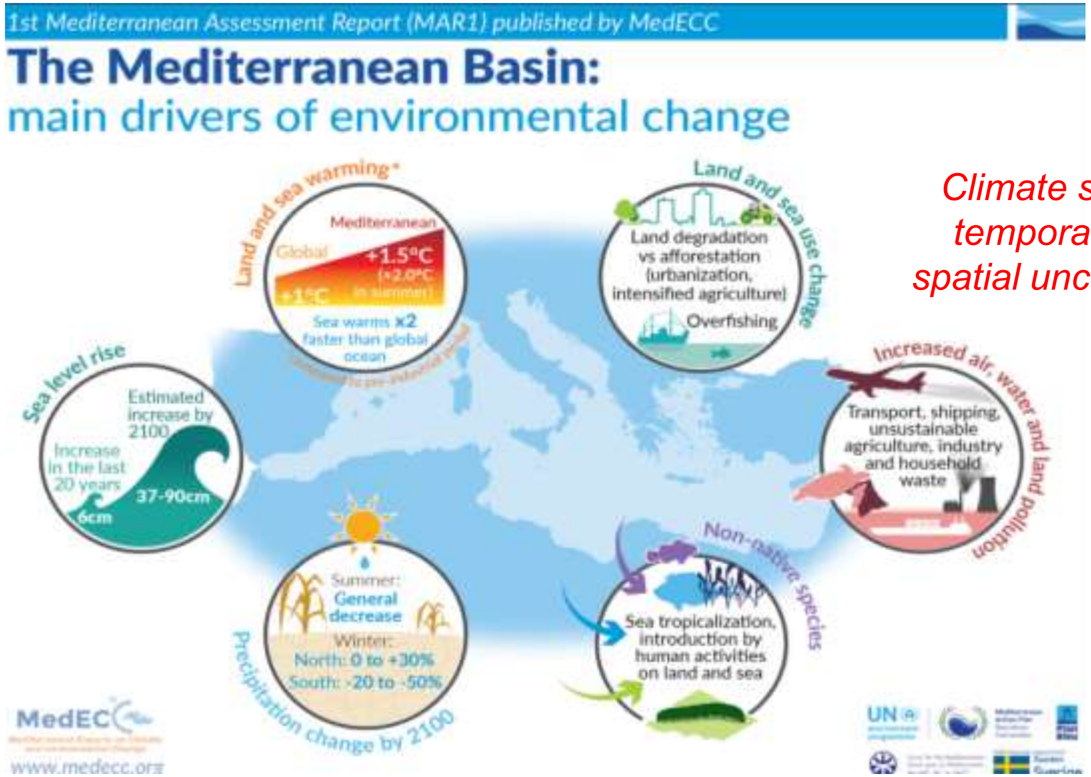
CHALLENGES

1) Challenge 1. **Climatic Reality**
2) Challenge 2. **Conflicts on Resources**
3) Challenge 3. **Complexity**
4) Challenge 4. **Black box AI**
5) Challenge 5. **Multi-transdisciplinarity**
6) Challenge 6. **Biodiversity Decline**
7) Challenge 7. **Inspired by the past: AHT**
8) Challenge 8. **Policy barriers**

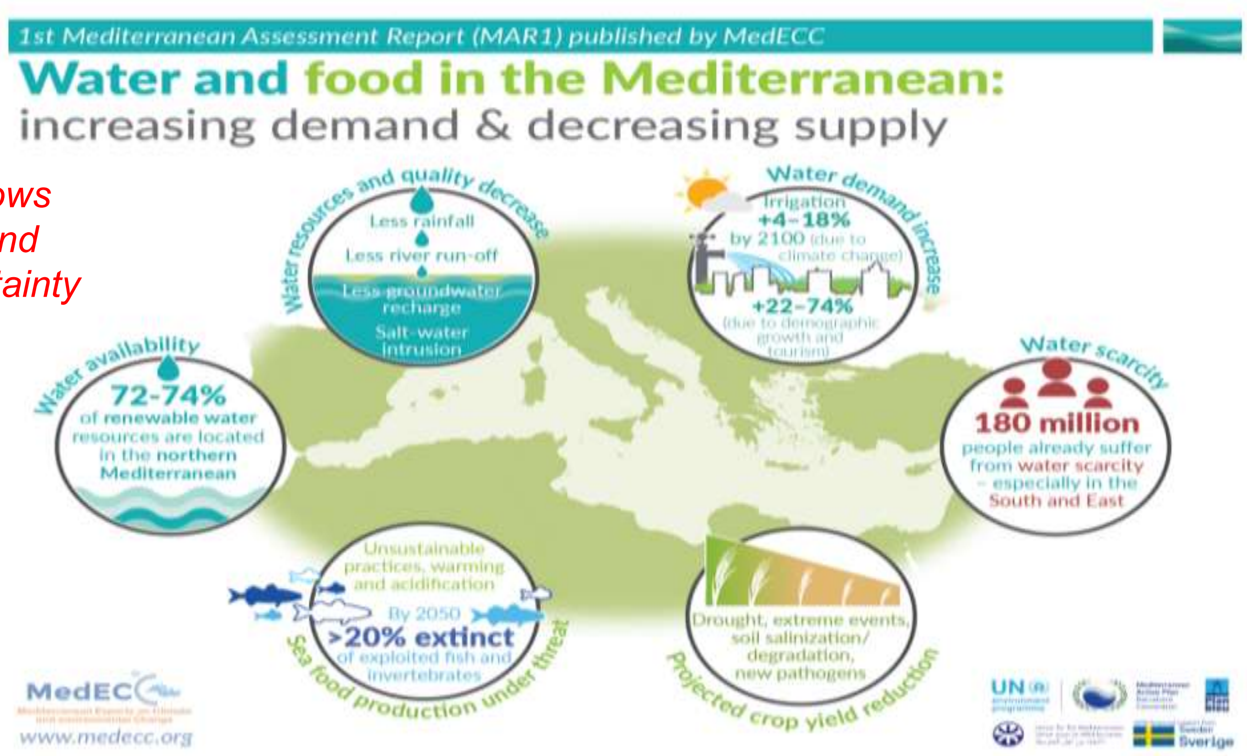
Càtedra UNESCO de Sostenibilitat (1996) – Universitat Politècnica de Catalunya – C/Colom, 1. Terrassa – 08224 (Barcelona)

Challenge 1. **Climatic Reality**

There is a climatic reality that is driving a social emergency.



Climate shows temporal and spatial uncertainty



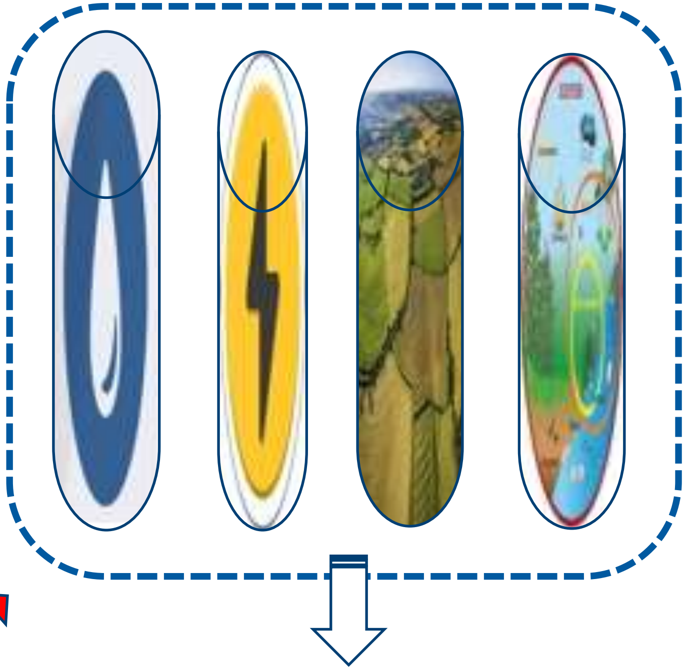
Climatic reality leads to lower agricultural productivity, both in quantity and in the organoleptic quality of products.

Fight against diseases varies because pathogens, hosts, vectors, environmental conditions, and products used to confront them have changed or are changing.

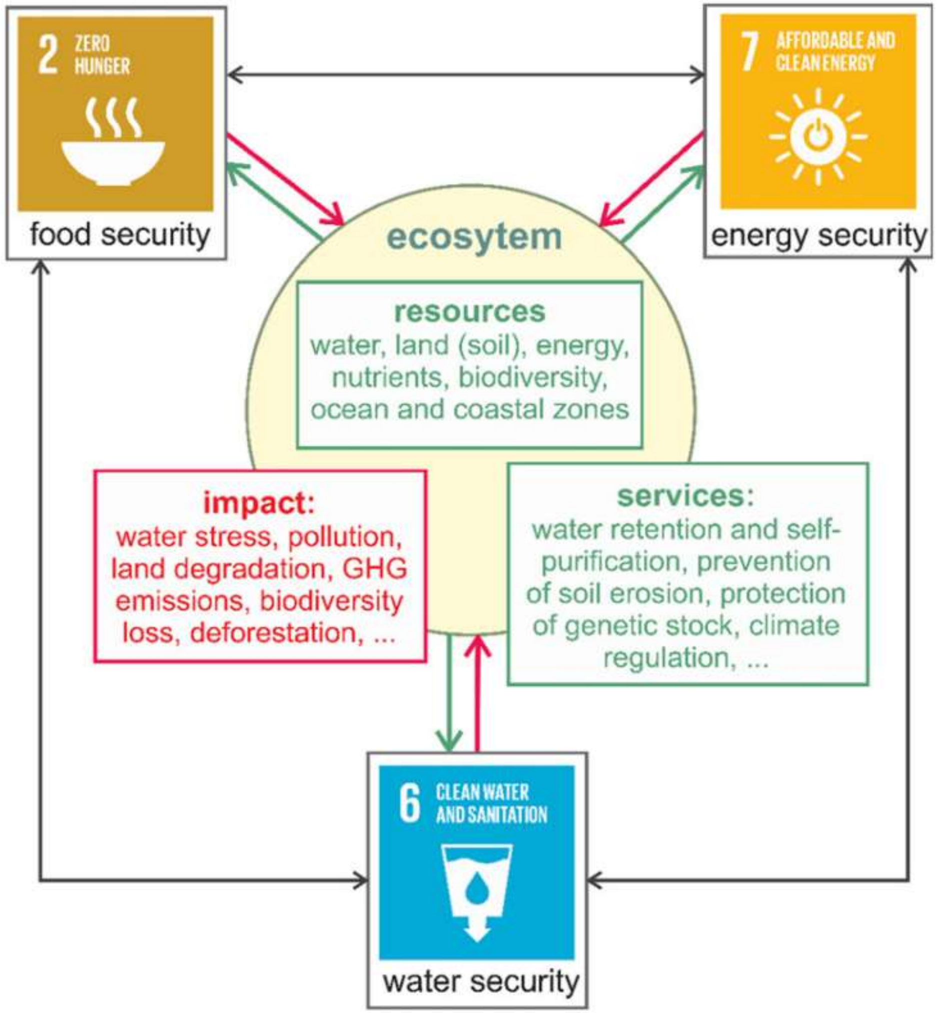
Different realities require different solutions—flexible, pragmatic, grounded in scientific and technical debate, and always guided by common sense.

Challenge 2. **Conflicts on Resources**

Strong Sectoral Silos (Business-as-usual)

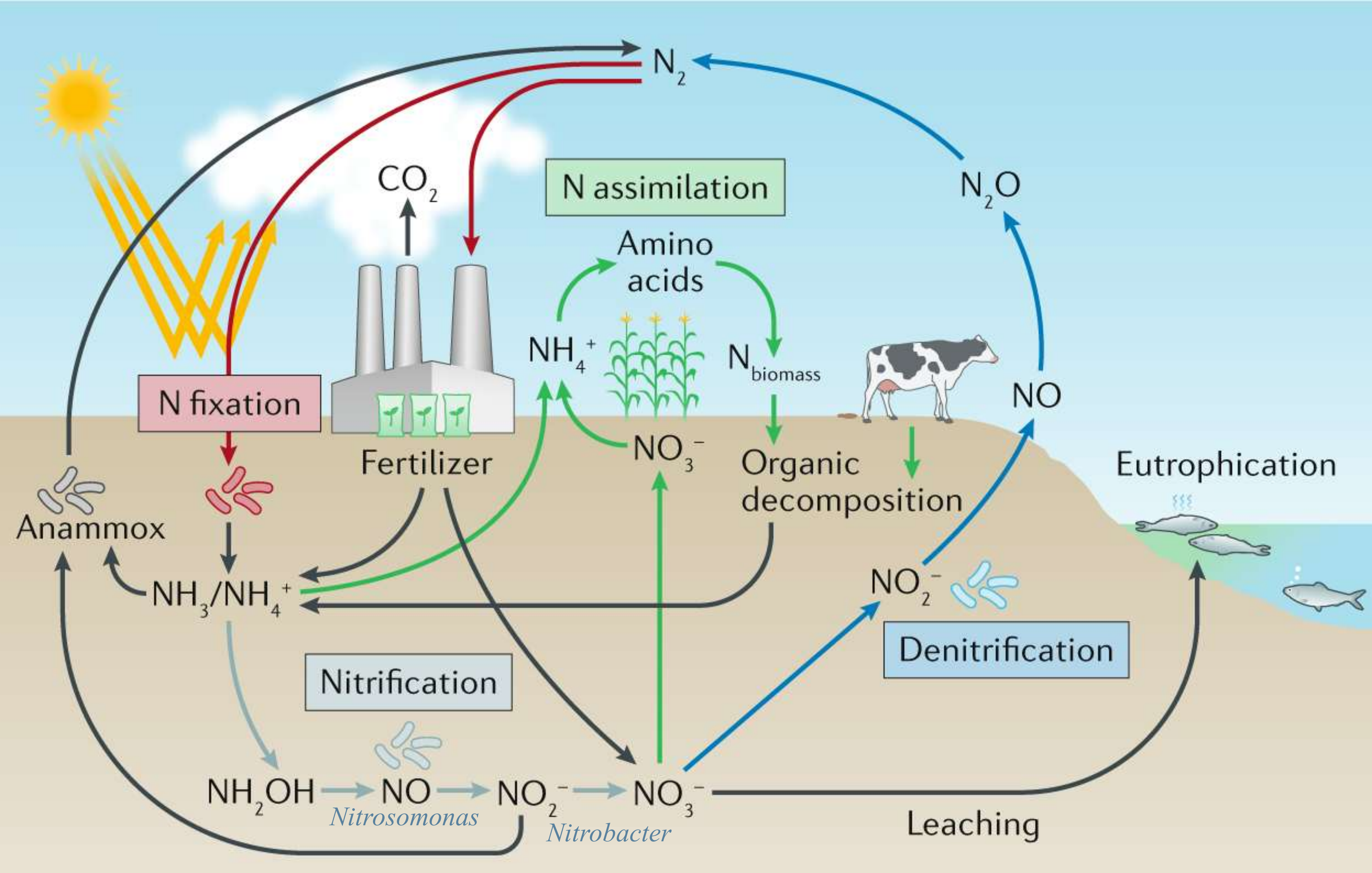


- ✓ Conflicts on Resources
- ✓ Water, Energy and Food Insecurity
- ✓ Poverty
- ✓ Migration



Water – Energy – Food – Environment (WEFE) NEXUS

Challenge 2. **Conflicts on Resources**



Annual cost of damages caused by **reactive nitrogen**, **more than double the income** obtained with the use of N fertilizers in European agriculture.

Challenge 3. **Complexity**

strong sectoral silos (Business-as-usual),

- ✓ Conflicts on Resources
- ✓ Water, Energy and Food Insecurity
- ✓ Poverty
- ✓ Migration

NEXUS IMPLEMENTATION STILL RARE

- ✓ **No incorporation of Nexus approach into policies, planning and management of resources**

NEXUS Operationalization

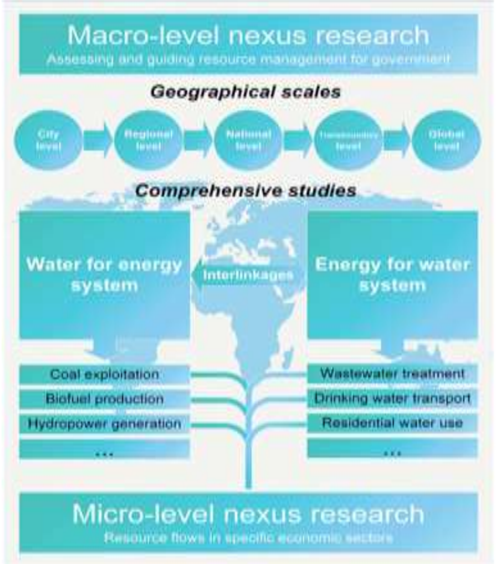
Extending knowledge on **interactions** between Nexus sectors

Overcoming **compartmentalization** among decision makers

Identifying and validating **solutions** which alleviate Nexus conflicts

Developing and evaluating measures that overcome **social, economic or technical barriers**

FROM MACRO



TO MICRO

Water – Energy – Food – Environment (WEFE) NEXUS

Challenge 3. **Complexity**

WEFE Nexus / Social / Environmental / Economic / Policy / Governance

Selection Technologies

W –E – F - E

Different Scales

Local / Regional /
Mediterranean / MENA

Qualify SETs

Resilience / Vulnerability /
Risk Assessment

Different Demo-sites / Cases

Smart Irrigation
Desalination
Wastewater treatment
Ecotourism
Water Harvesting
Agrovoltaics
Agroforestry
Biochar
…

KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

SURE NEXUS

Ensuring fair WEFE NEXUS transition for Climate Change Adaptation and Sustainable Development implementation, based on coupled Nature-based Systems and Bioeconomy

7 countries / 15 institutions

PRIMA
IN THE MEDITERRANEAN AREA

To deploy **small-scale innovative solutions as demonstrators of Socio-Ecological and Technical systems (SETs)** based on:

1) **Bioeconomy solutions (BES)**
2) **Nature-Based Solutions (NbS)**

for WEFE NEXUS, and evaluate their **productivity and value to the local community.**

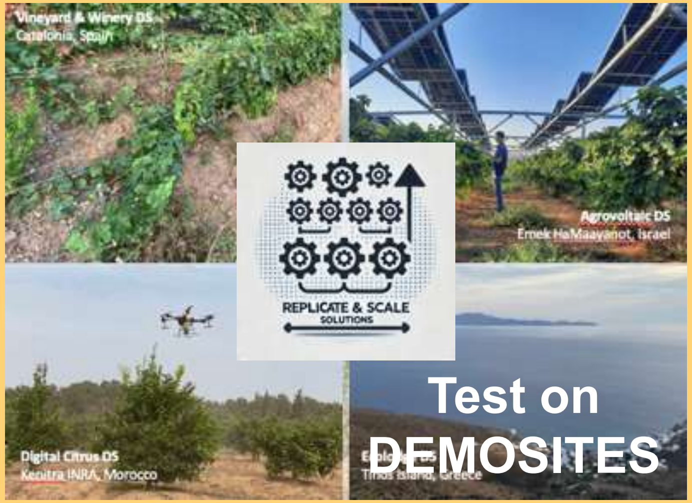
INTEGRATED SURENEXUS STRATEGIES FOR REGIONAL CLIMATE RESILIENCE

*Small-Scale **innovative solutions** as demonstrators of **SETs***

1

Identify & Qualify Practical Solutions

PROCESS INFORMATION
MODEL SCENARIOS & SIMULATION
SUPPORT REGIONAL DIALOGUE



Test on DEMOSITES

2

DEPLOYMENT OF METHODOLOGIES AND GUIDELINES

STRENGTHEN INSTITUTIONAL CAPACITIES

SHARE KNOWLEDGE

SURENEXUS DEMO SITES

validate the selected

NbS and Bioeconomy (BES) practices

following **WEFE Nexus approach**

in specific environments FROM **Med area**

SURE NEXUS

PRIMA IN THE MEDITERRANEAN AREA

Co-funded by the European Union

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
UNESCO Chair on Sustainability

unesco Chair

Comp DS: UNDERGROUND IRRIGATION FOR OLIVE CROPS (Bir Ami. Tunisia)

Tunisian Innovation

Patented

Conventional drip irrigation

Underground irrigation

WHY AI CAN HELP IN THE WEFE NEXUS

Challenge 3. **Complexity**

To demonstrate, validate and quantify the **performance of alternative bioeconomy practices and nature-based solutions** for conserving and restoring ecosystem services and biodiversity.

Replication of **practical solutions in the MED region in a context of climate emergency and water scarcity.**

Multi-transdisciplinarity

Complexity
WEFE Nexus / Social / Environmental / Economic

Multi-transdisciplinary
Participatory Co-design / SHP / Governance

Selection Technologies
W –E – F - E

Different Scales
Local / Regional / Mediterranean / MENA

Different Demo-sites
DS1/DS2/DS3/DS4/ConpDS

Qualify SETs
Resilience / Vulnerability / Risk Assessment

1. Data Analysis (data bases, IoT, literature)

2. Predictive Modelling for:

2.1. Water Management
NBS/Technologies for Wastewater treatment

2.2. Energy Efficiency
Technologies for Energy Recovery

2.3 Waste Management
Circular Bioeconomy : Added Value Chain Products

Environmental	Circularity	Economic	Social	Governance

Use of AI for NEXUS WEFE Management

Predictive Modelling and Scenario Analysis

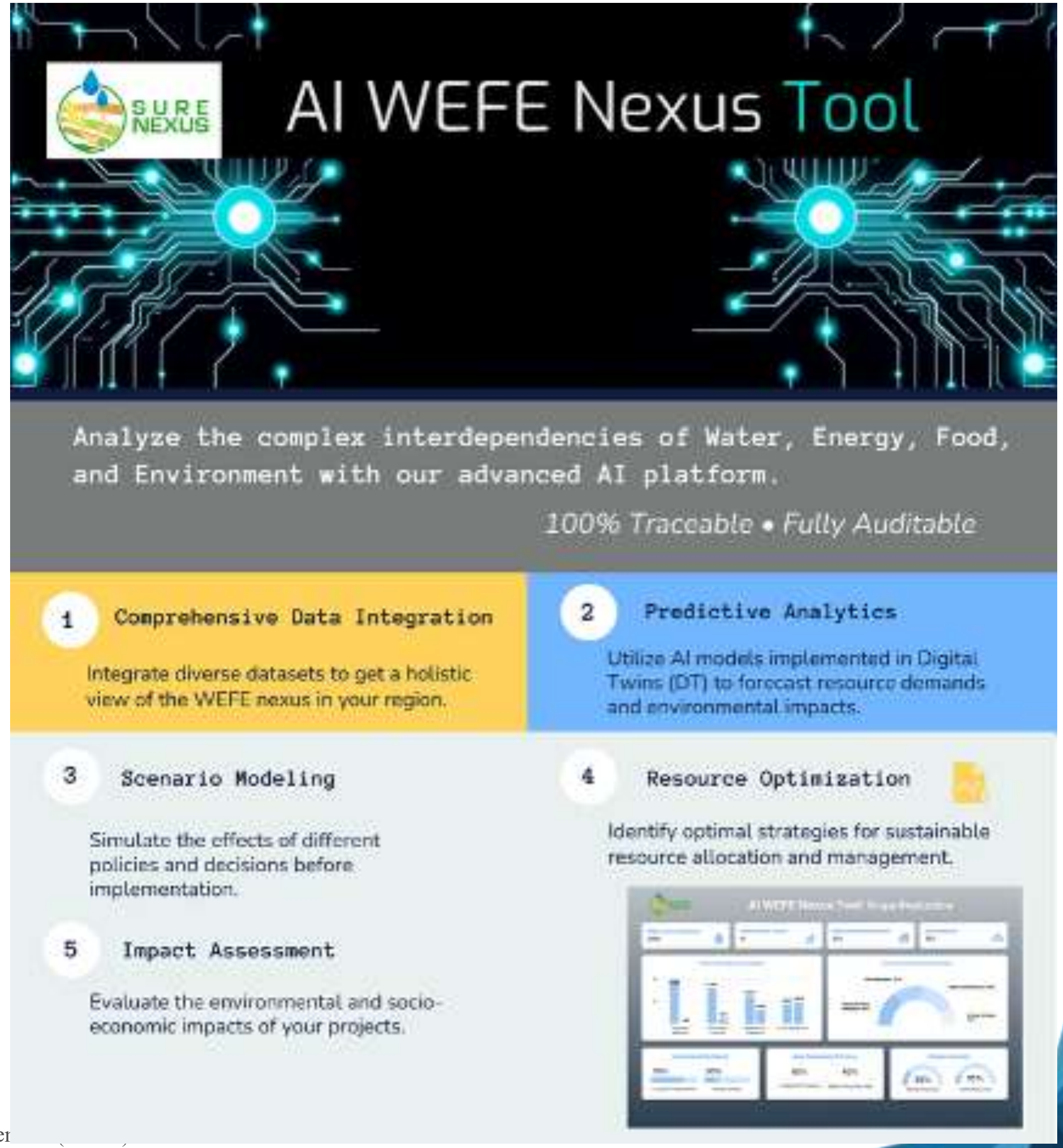
AI-driven models help understand the complex interdependencies between water, energy, food, and ecosystems (WEFE Nexus)

Scenario Modelling & Simulation
Anticipates outcomes from changes in water allocation, variations in agricultural yields, or modifications in energy production under different climatic or political conditions.

Resource Optimization
Identify optimal strategies for sustainable allocation and management.

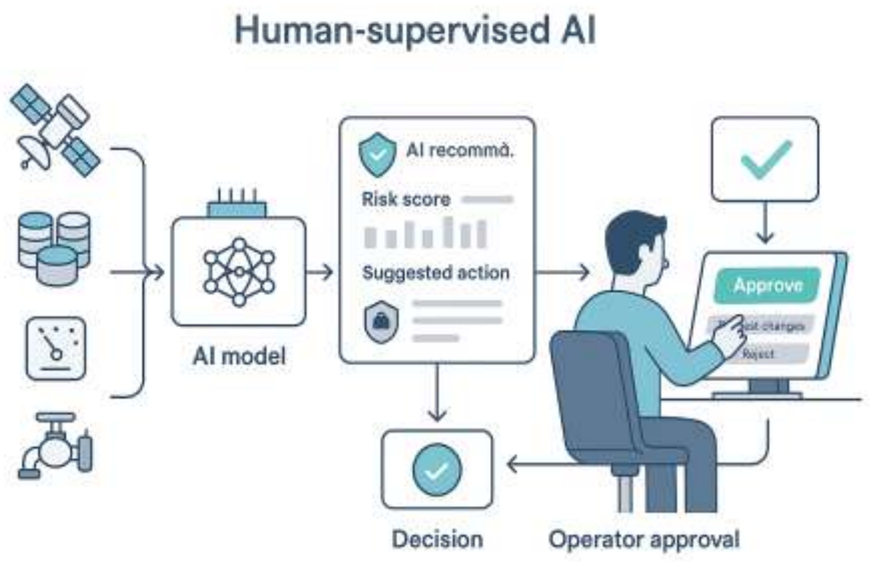
Impact Assessment
Evaluates the environmental and socio-economic impacts of any project.

Dialogue Facilitation
Provides an objective basis for dialogue on shared trade-offs between countries, facilitating collaborative decision-making



Challenge 4. **Black Box AI**

Artificial Intelligence: Expert system for predictive modeling, simulation and optimization of resource allocation, and early warning systems for climate and resource risks



Decisions are made by a **human-supervised AI system** with operator approval

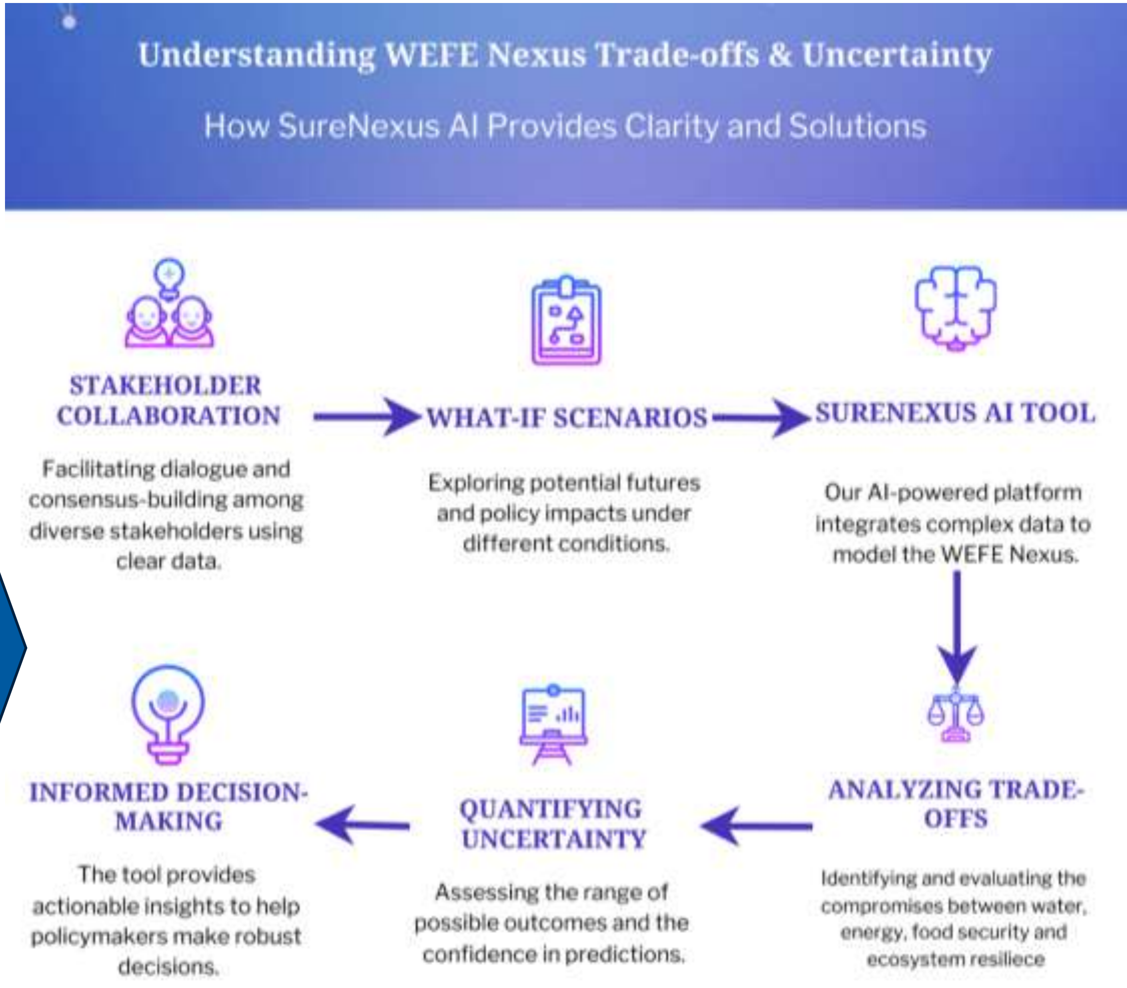
Challenge 5. **Multi-transdisciplinarity**

MODEL

CODESIGN

BY

STAKEHOLDERS



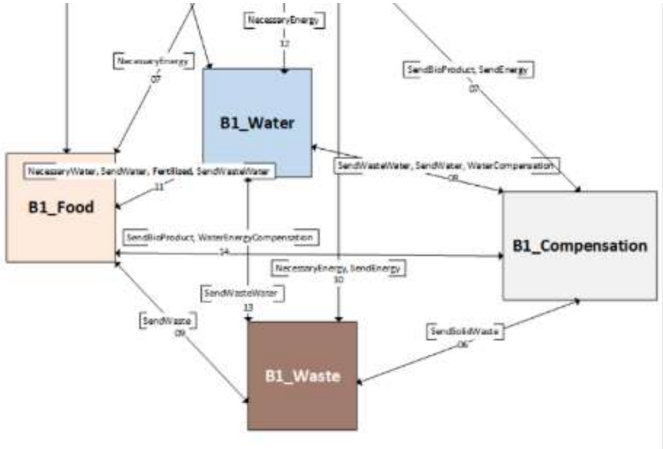
SURE NEXUS

PRIMA IN THE MEDITERRANEAN AREA

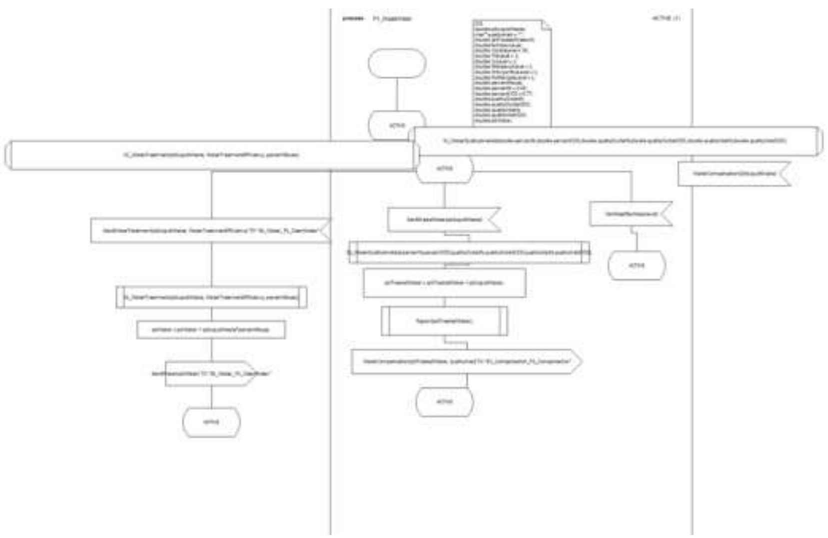
Co-funded by the European Union

STAKEHOLDERS ENGAGEMENT

conceptual model, co-designed with input from all relevant stakeholders



CodorniuDemoSite_1.png



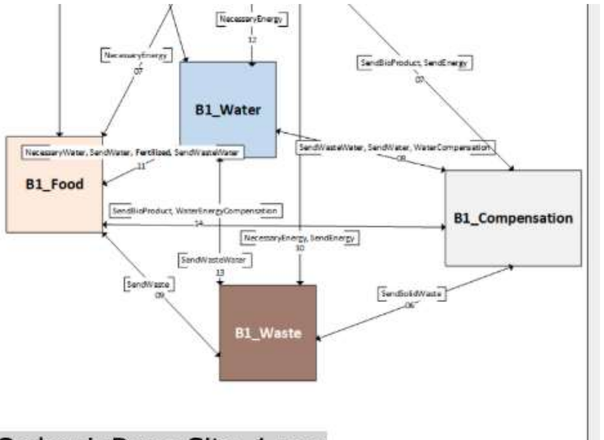
transdisciplinary approach to develop the model **assumptions document** and a **graphical SDL-based digital twin**, fostering teamwork by visually representing the real system's behavior.

SDL : Specification and Description Language

System With Blocks

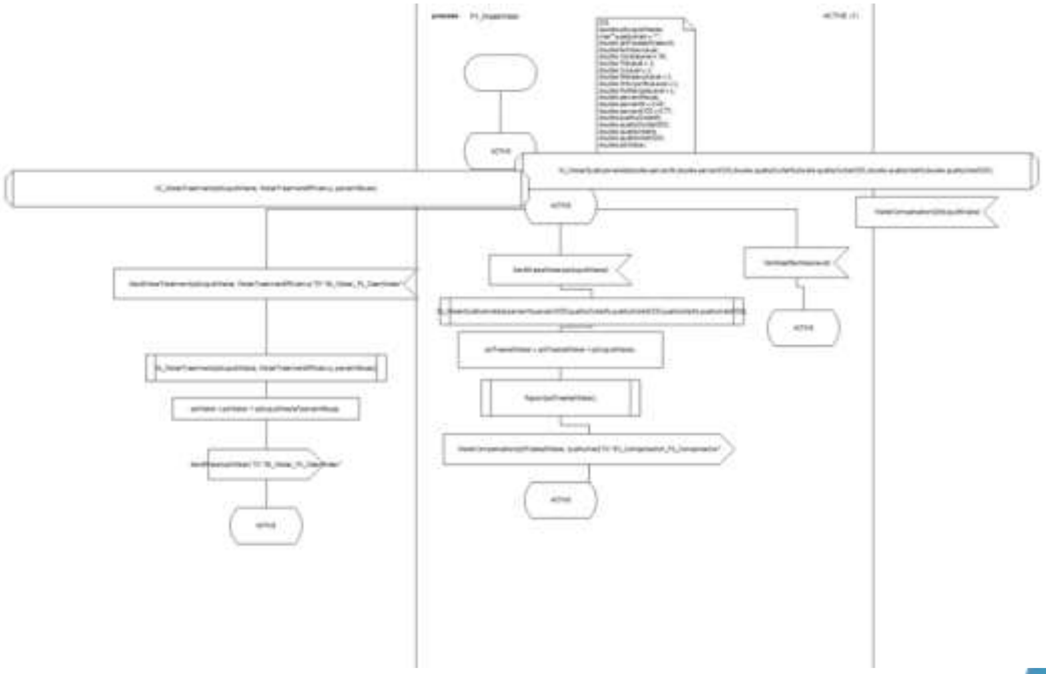
Process (P1)

Procedures (S1)



CodorniuDemoSite_1.png

- ☐ B1_Water.vsdx
  - ☐ P1_CleanWater.vsdx
    - ☐ S1_GetEnergyNeeded.vsdx
    - ☐ S1_GetWater.vsdx
  - ☐ **P1_WasteWater.vsdx**
    - ☐ S1_WaterQualityAnalisis.vsdx
    - ☐ S1_WaterTreatment.vsdx
- ☐ B1_Energy.vsdx
  - ☐ P1_Energy.vsdx
    - ☐ S1_AlternativeSupply.vsdx
    - ☐ S1_DayliEnergy.vsdx
- ☐ B1_Compensation.vsdx
  - ☐ P1_Compensation.vsdx
    - ☐ S1_EnergyRecoveringTechnologies.vsdx
    - ☐ S1_CircularBioproductRecovering.vsdx
    - ☐ S1_SelectBioProductTypeTreatment.vsdx
    - ☐ S1_SelectWaterTypeTreatment.vsdx



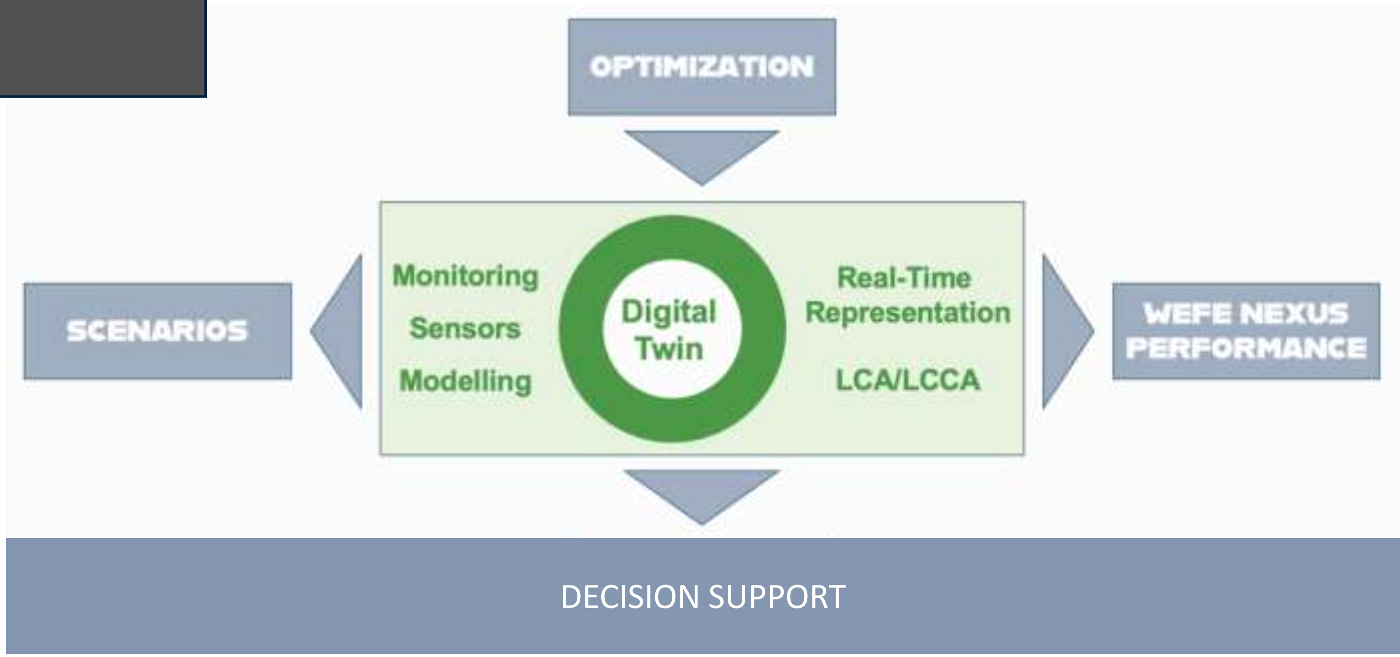
AI WEFE NEXUS TOOL

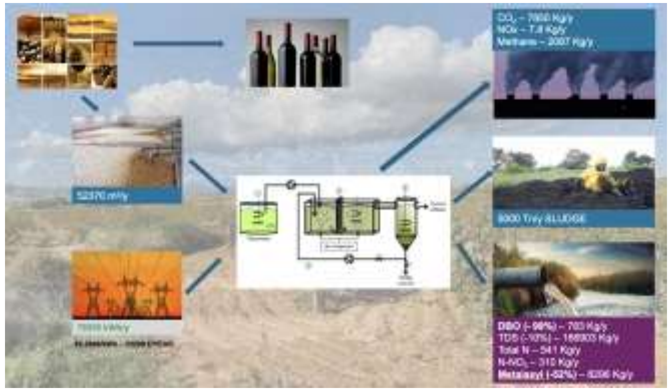
Step 1: **Define System (Transdisciplinary approach) Conceptual Model (SDL)**

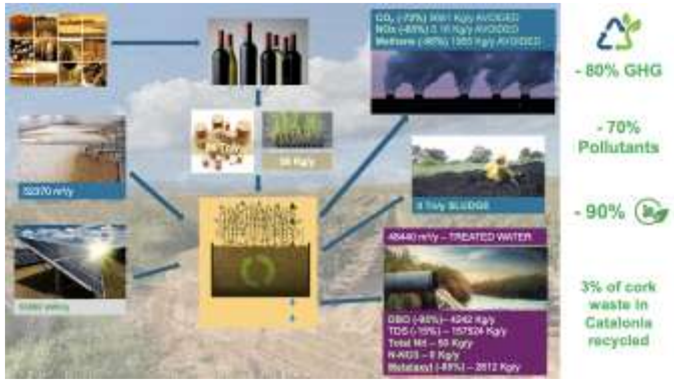
Step 2: **Model Validation by/with Stakeholders**

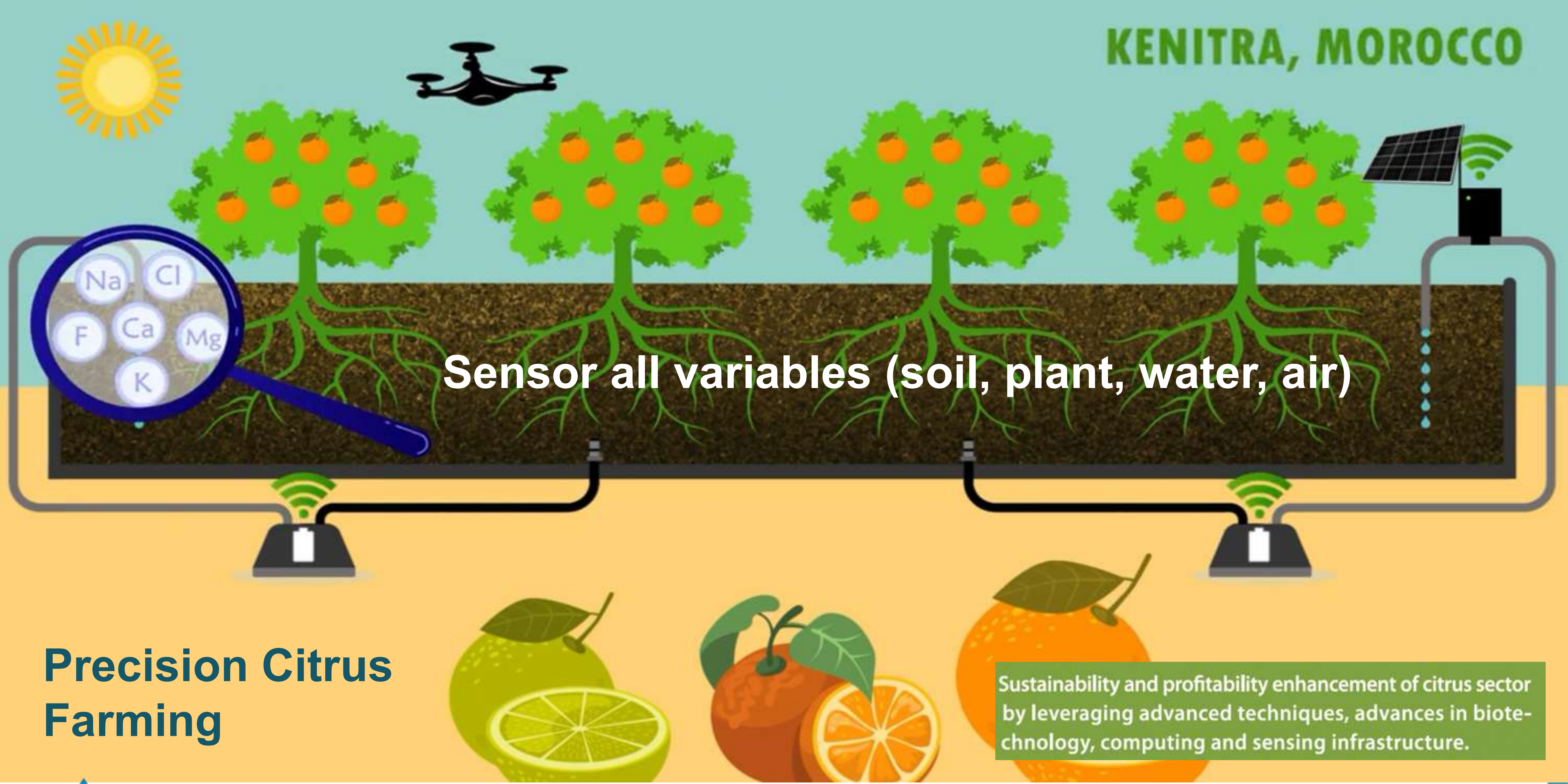
Step 3: **Implementation Computerized Model (SDLPS)**

Step 4: **WEFE Nexus Metrics Evaluation**









Sensor all variables (soil, plant, water, air)

Precision Citrus Farming

Sustainability and profitability enhancement of citrus sector by leveraging advanced techniques, advances in biotechnology, computing and sensing infrastructure.

Precision Citrus Farming

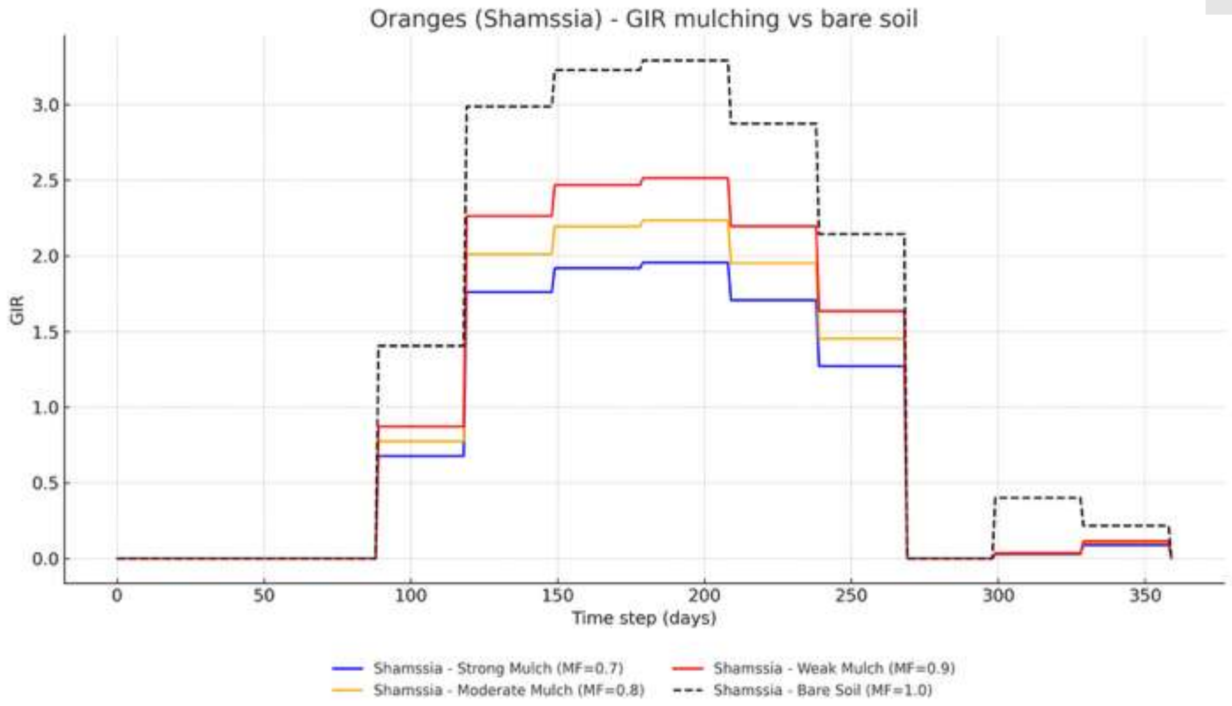
KENITRA, MOROCCO

Sustainability and profitability enhancement of citrus sector by leveraging advanced techniques, advances in biotechnology, computing and sensing infrastructure.

KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

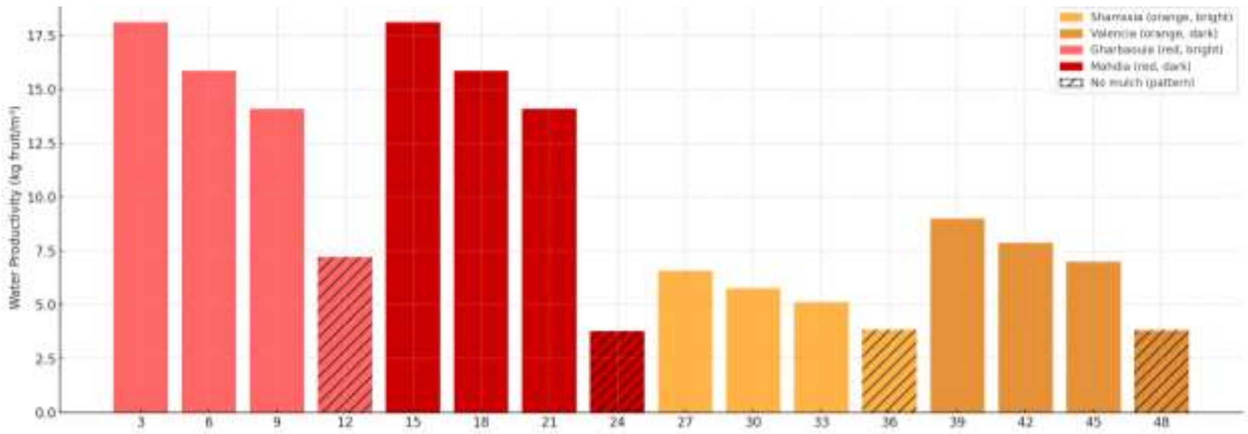
AI WEFE Nexus model is used to model Gross Irrigation Requirement (GIR), Net Irrigation Requirement (NIR), harvest and derived efficiency indicators for each combination of variety and mulching factor.

Scenario	GIR (mm/yr)	Water Saved vs Bare Soil
Strong Mulch (0.7)	282.3	43%
Moderate Mulch (0.8)	322.6	35%
Weak Mulch (0.9)	362.9	27%
Bare Soil (1.0)	496.5	0%

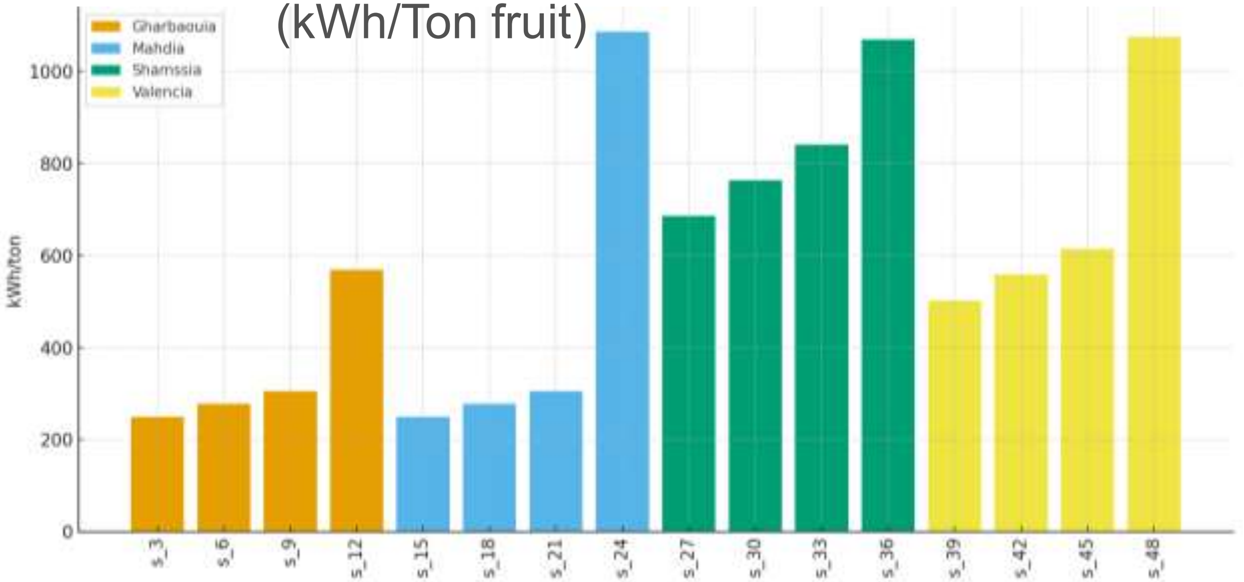


KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Water Productivity
(Kg fruit/m^3)



Energy Intensity
(kWh/Ton fruit)



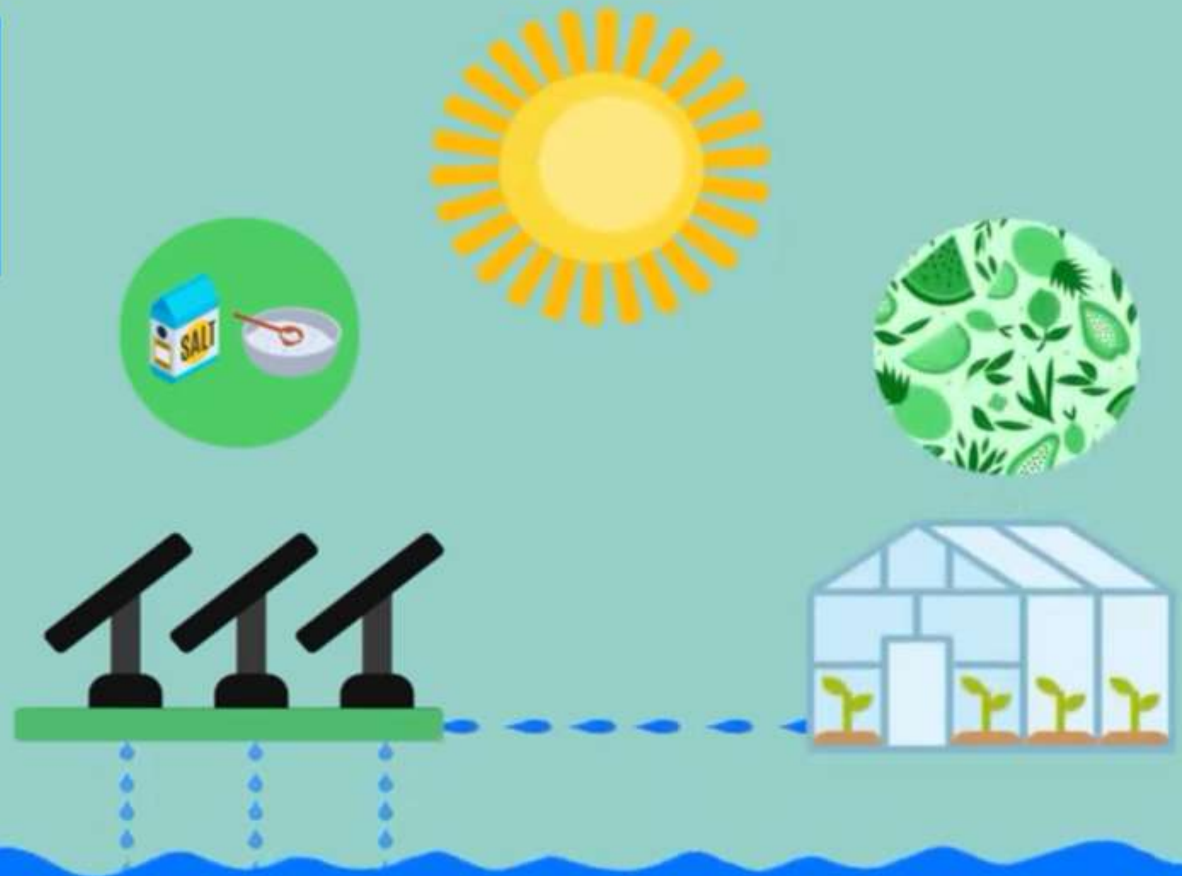
Gharbaouia
Mahdia

Shamssia
Valencia

Variety	Water Productivity Increase Kg fruit/m^3 water (no mulch vs mulch)	% Increase
Gharbaouia (Mand.)	7.2 vs 18	+150%
Mahdia (Mandarin)	3.8 vs 18	+374%
Shamssia (Orange)	3.8 vs 6.5	+71%
Valencia (Orange)	3.8 vs 9	+137%

Variety	Energy Intensity Decrease kWh/Ton fruit (no mulch vs mulch)	% Decrease
Gharbaouia (Mandarin)	570 vs 250	-56%
Mahdia (Mandarin)	1080 vs 250	-77%
Shamssia (Orange)	1070 vs 690	-36%
Valencia (Orange)	1080 vs 500	-54%

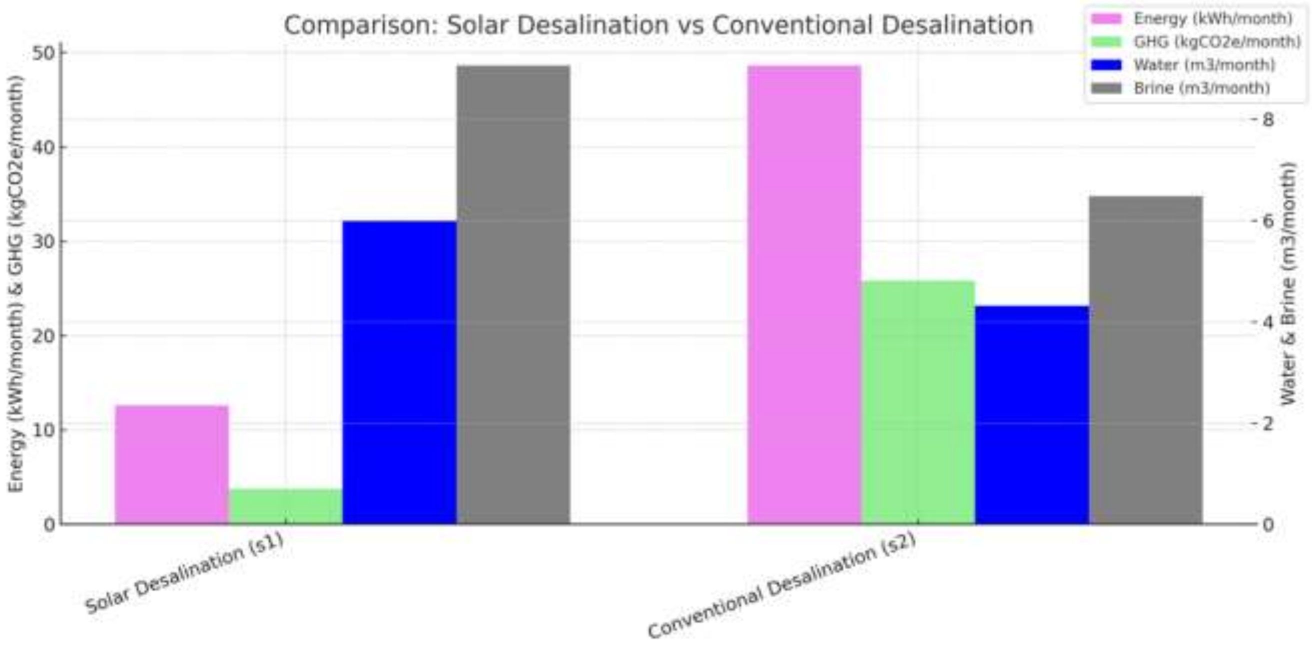
AGIOS FOKAS POTAMIA

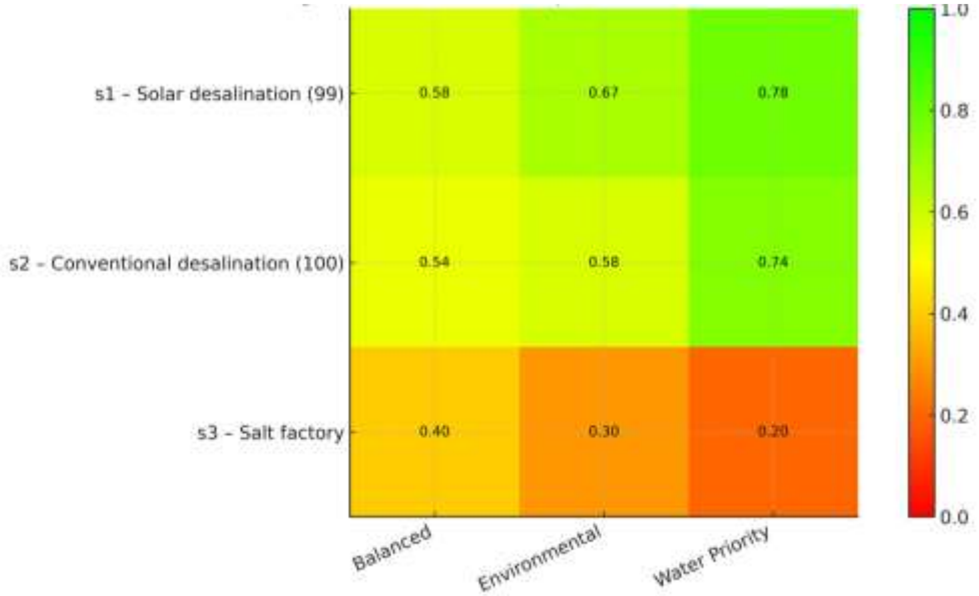


Reduce water and energy consumption in an island ecolodge

Mangrove Still System - Innovative solar desalination technology.

Organic greenhouse (*Horticultural produce, aloe, small fruits*)

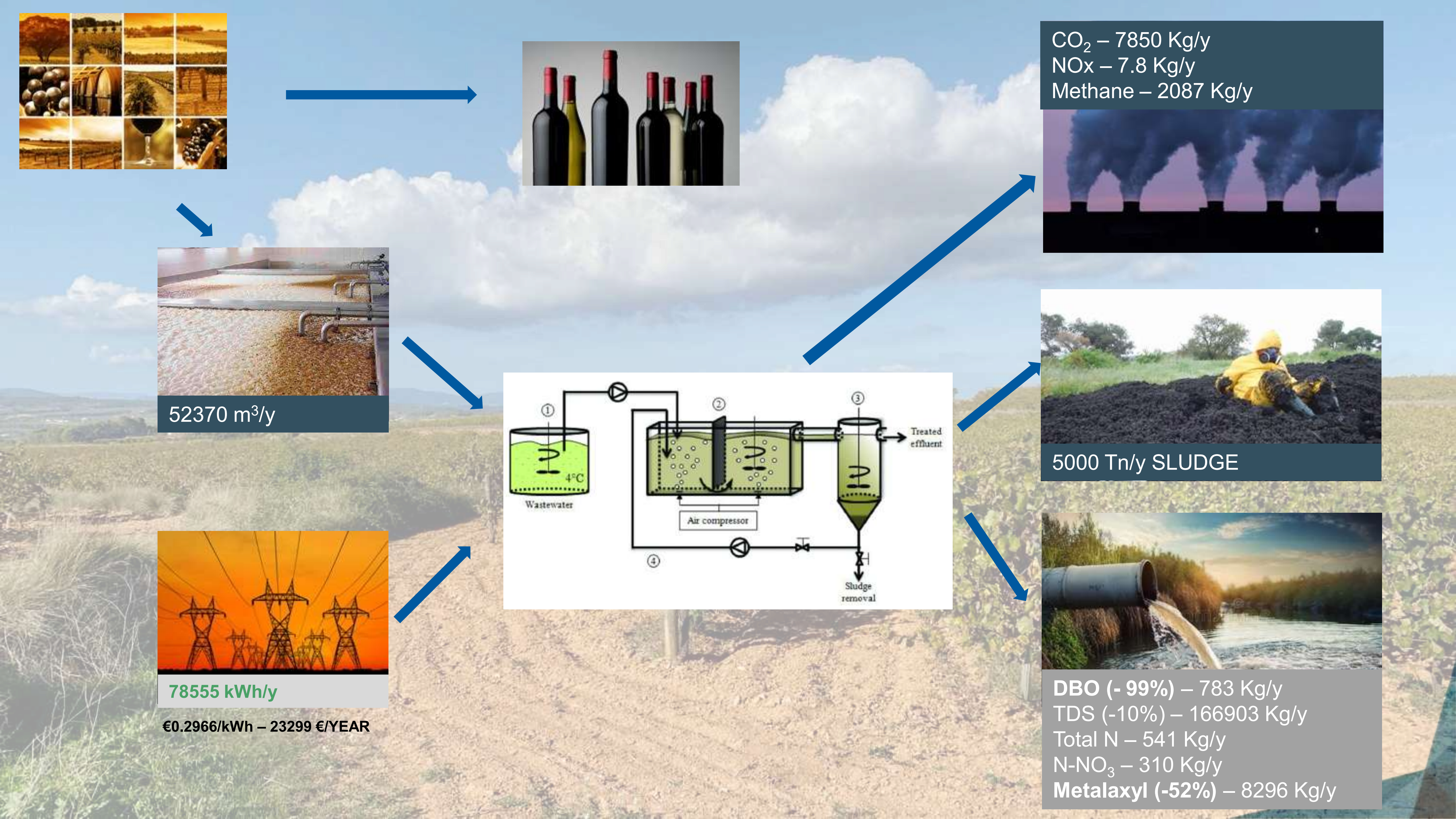




Multicriteria Decision Analysis (MCDA)

WEIGHTED MCDA HEATMAP WITH BALANCED, ENVIRONMENTAL AND WATER PRIORITY.

Challenge 6. **Biodiversity Decline**



CO_2 – 7850 Kg/y
NOx – 7.8 Kg/y
Methane – 2087 Kg/y
52370 m^3/y
1
4°C
Wastewater
2
Air compressor
3
Treated effluent
4
Sludge removal
5000 Tn/y SLUDGE
78555 kWh/y
€0.2966/kWh – 23299 €/YEAR
DBO (- 99%) – 783 Kg/y
TDS (-10%) – 166903 Kg/y
Total N – 541 Kg/y
N-NO_3 – 310 Kg/y
Metalaxyl (-52%) – 8296 Kg/y

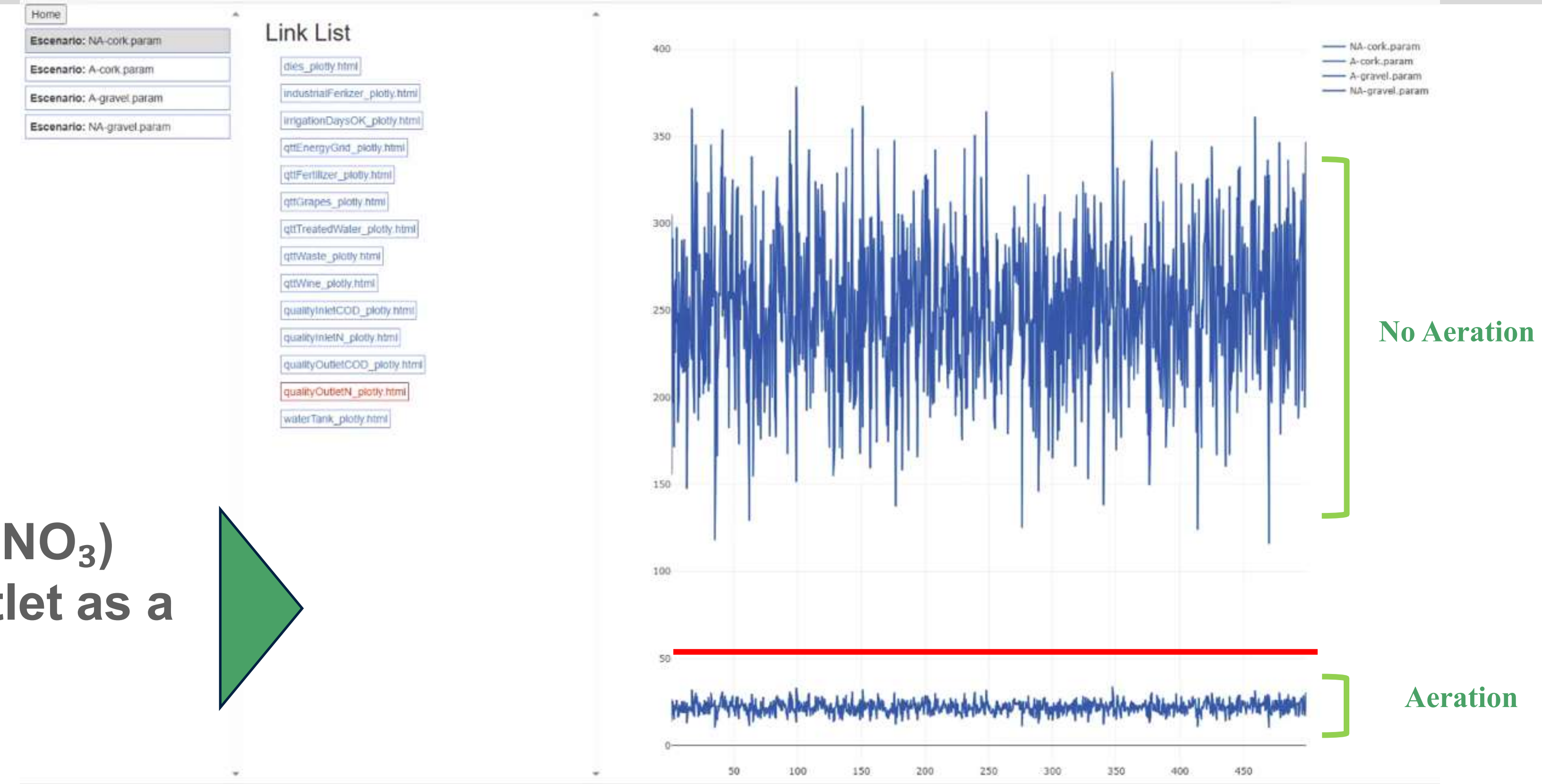
Challenge 6. **Biodiversity Decline**

Innovative <u>AERATED</u> VERTICAL FLOW SUBSURFACE TREATMENT WETLAND (TW)

Recycled cork as filter medium

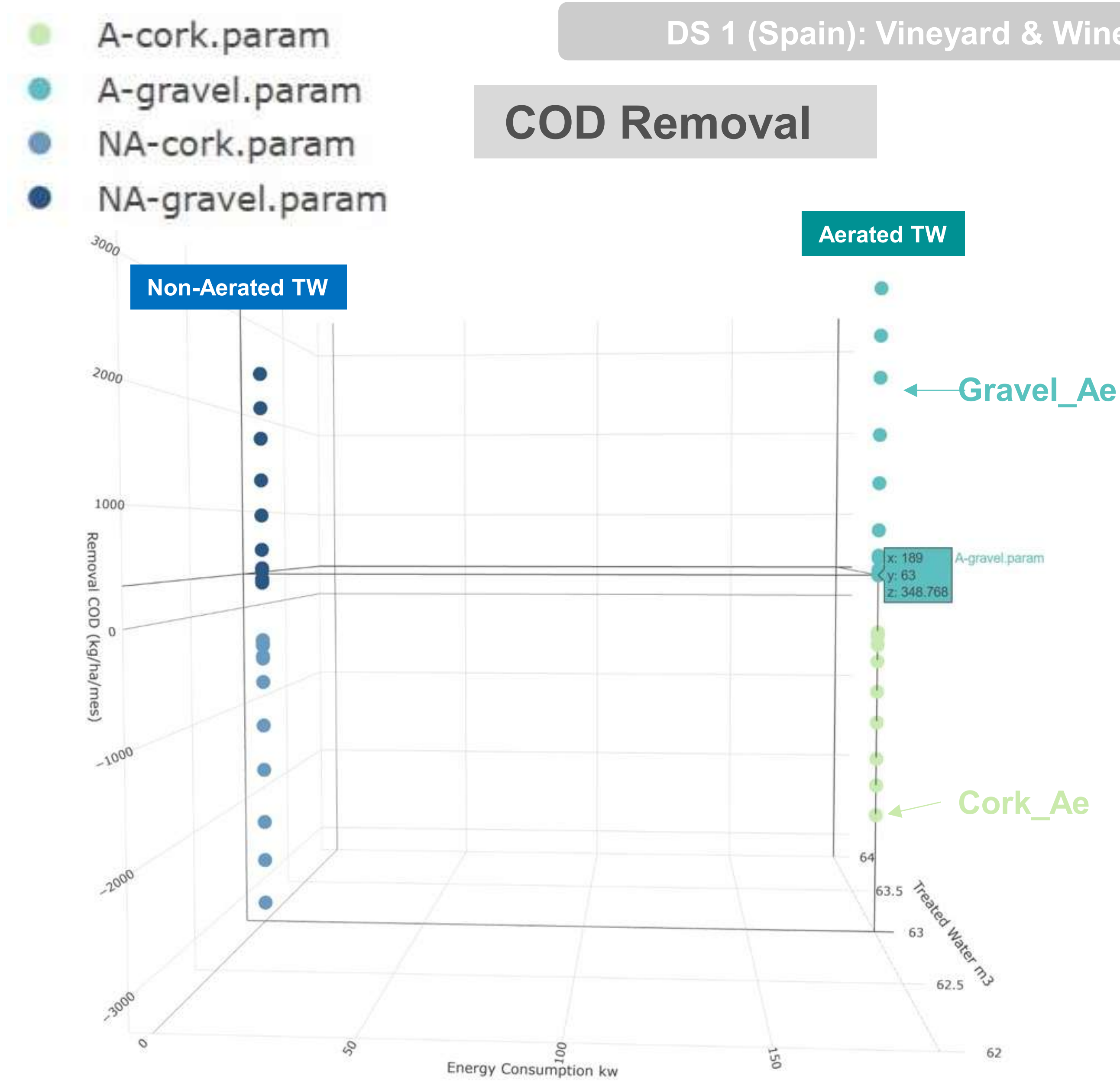
Removal of Nitrate pollution

Evolution of Nitrate (NO_3) Levels at the TW Outlet as a Function of Aeration

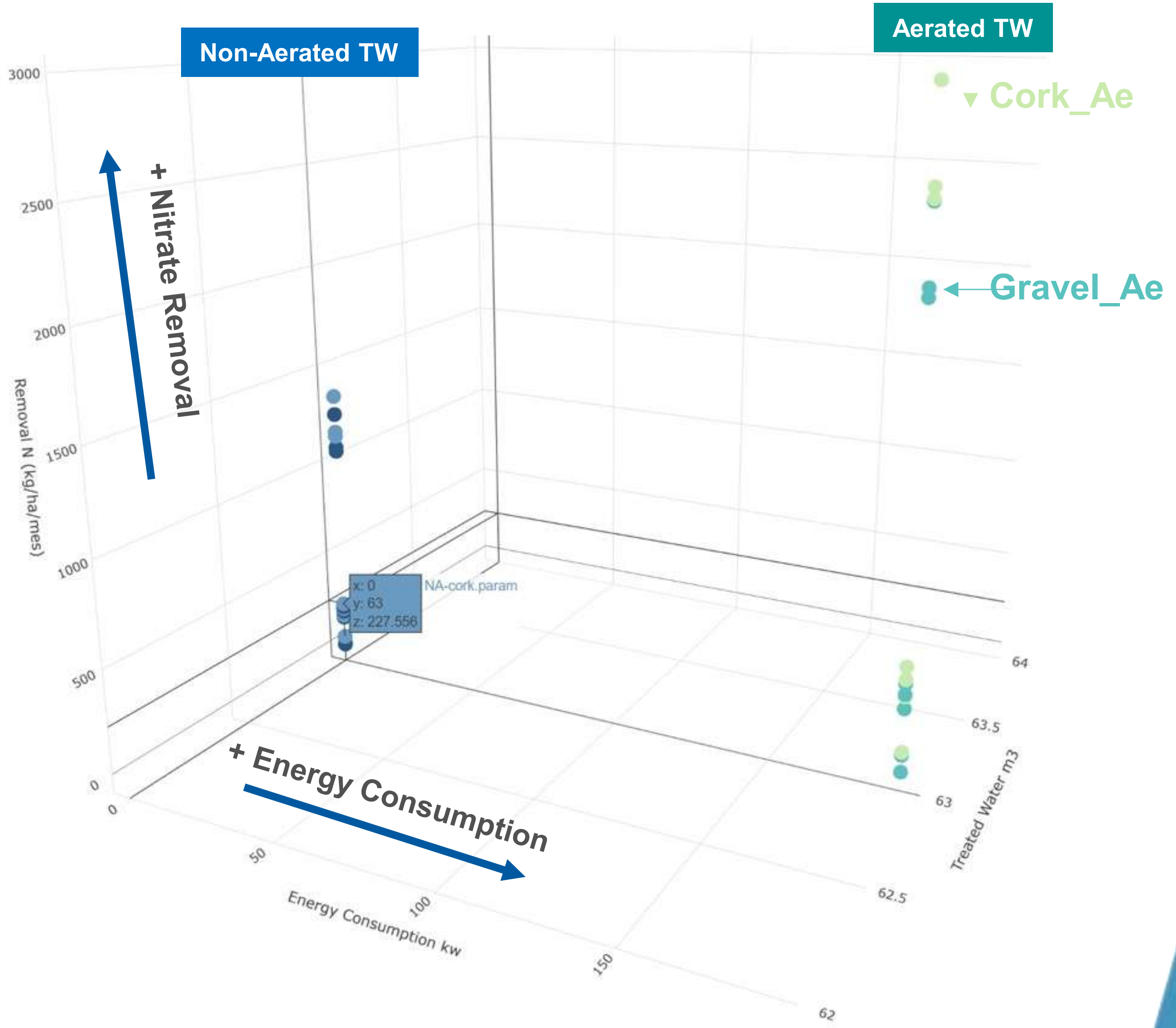


WEFE NEXUS PERFORMANCE ASSESS WITH AI

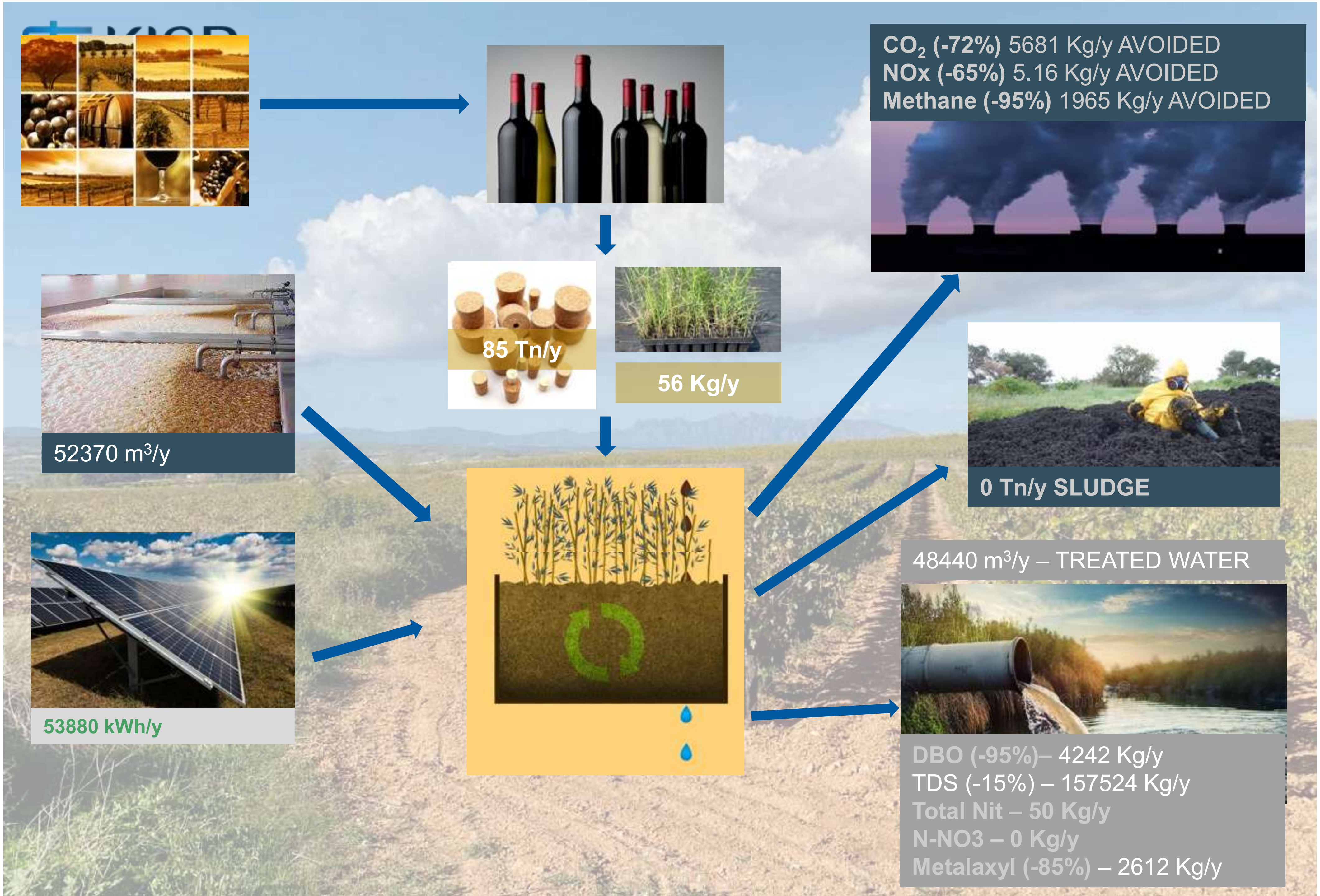
COD Removal



Nitrate Removal



Relation between Nitrate and COD concentration at the outlet, in function of aeration, filter material (cork or gravel) and cost.



- 80% GHG

- 70% Pollutants

- 90%

3% of cork waste in Catalonia recycled

Decision Support

AI-based expert Decision Support Systems provide tools to manage competing demands of the WEFE Nexus

Multi-objective optimization

Identify strategies that balance trade-offs between sectors, such as irrigation needs versus hydropower generation.

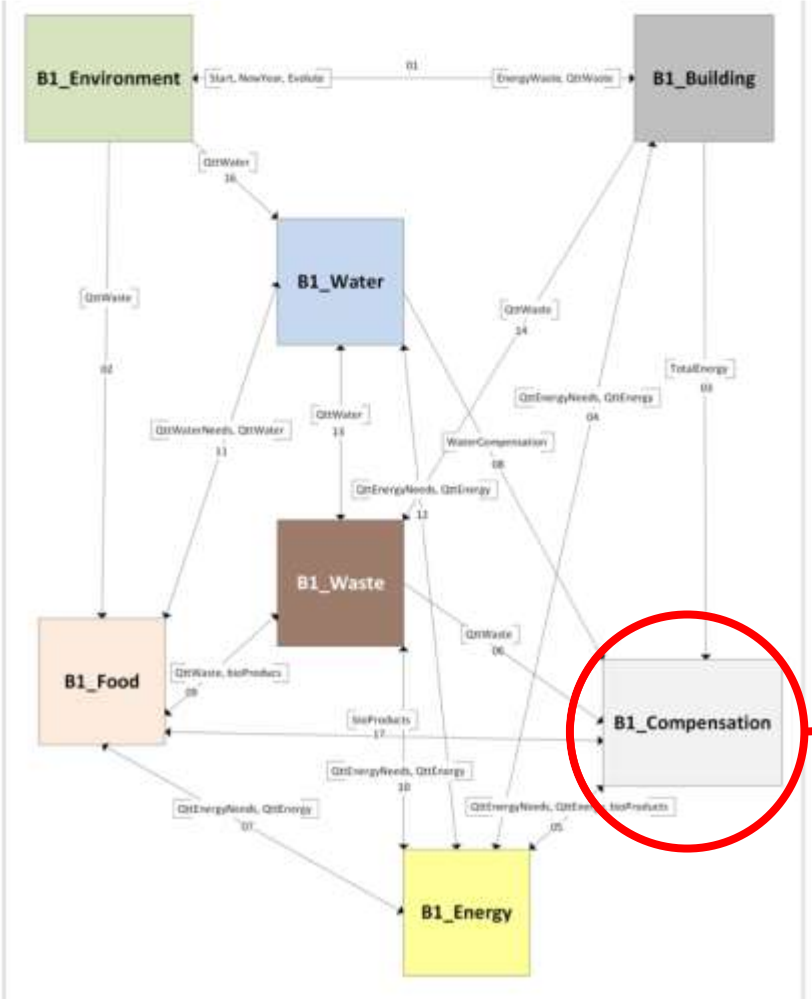
Recommendation solutions & practices

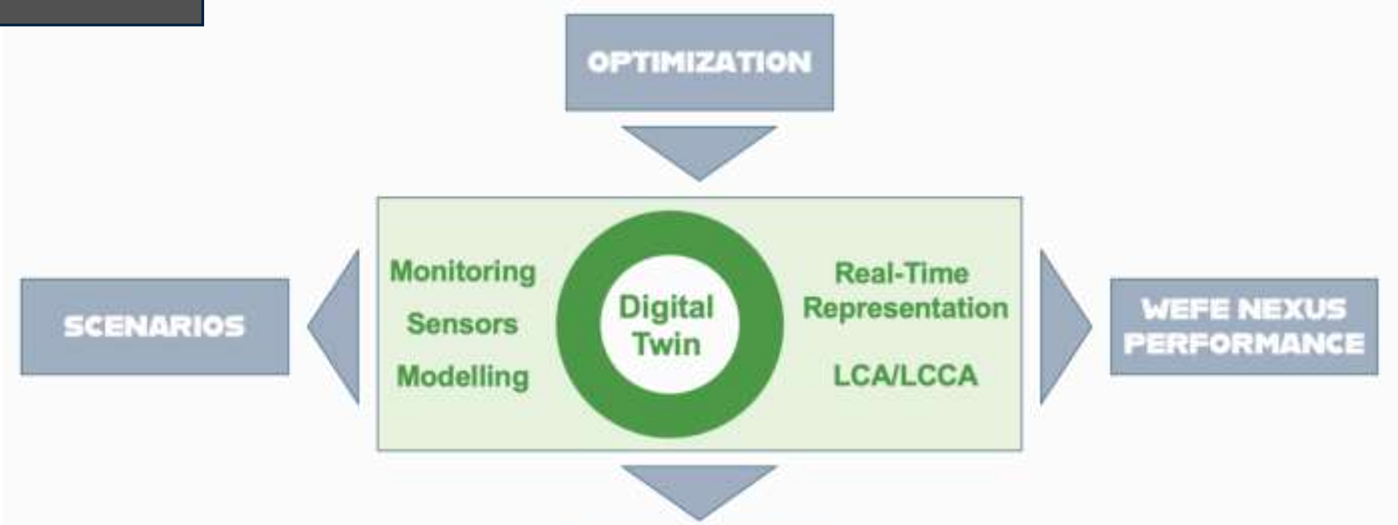
Guide stakeholders toward cooperative strategies with mutual benefits, based on historical data and simulations.

Detection of unsustainable practices

Ensure identifies anomalies in usage patterns, such as overexploitation of shared aquifers between countries.

AI MODEL FOR TECHNOLOGY SELECTION





Step 5 - Technology selection by compensation block

Identifying most effective strategies for

- **Water Security**
- **Energy Security**
- **Food Security**
- **Ecological Resilience**

DECISION SUPPORT

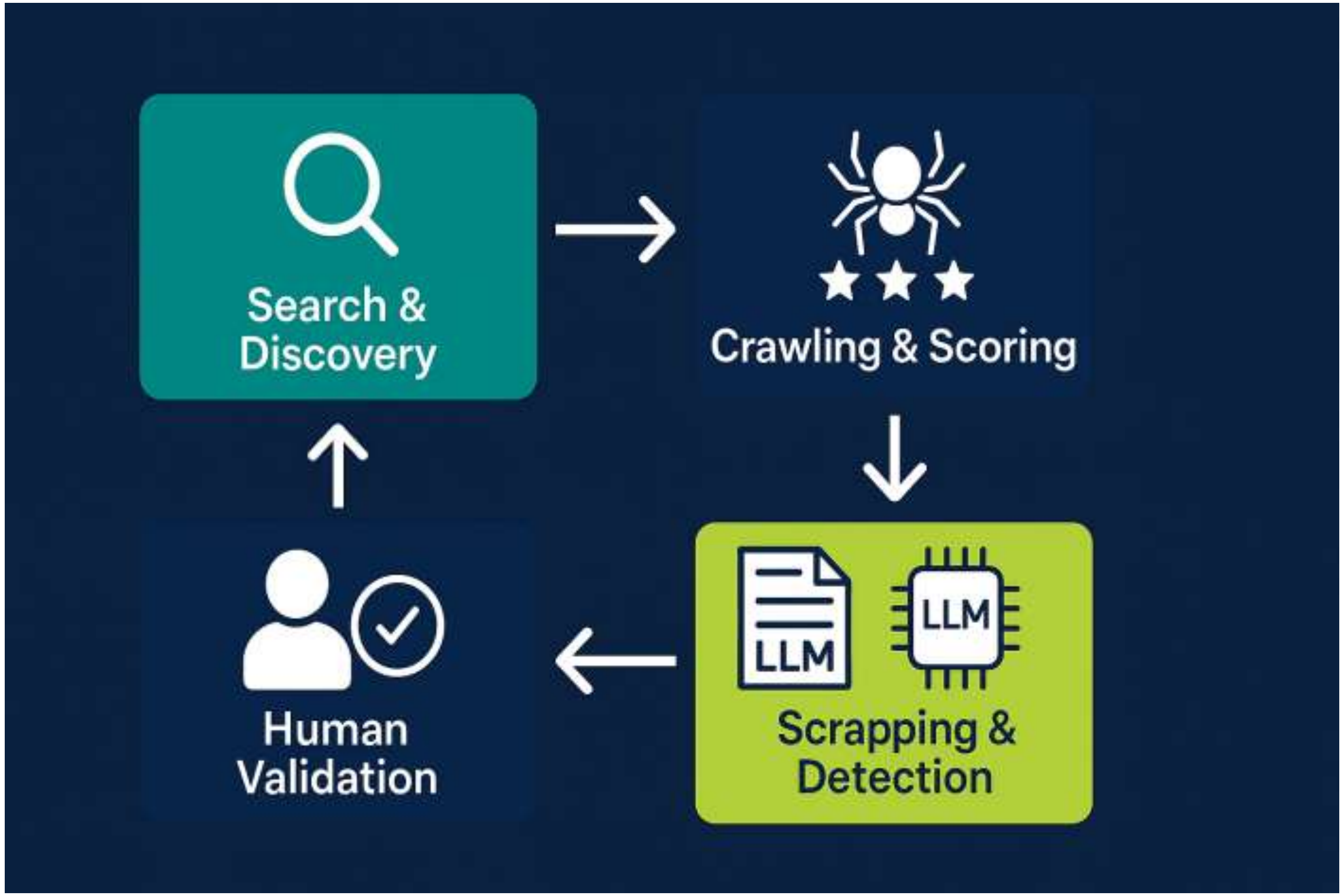
SEMI-AUTOMATED TECHNOLOGY SELECTION WITH LLM

Search & Discovery: Users launch concept/product searches; the system expands queries and records candidate URLs.

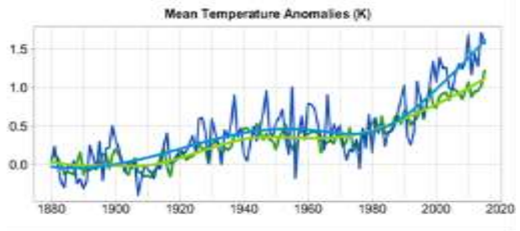
Crawling & Scoring: Pages are explored and ranked for relevance to the intended WEFE inputs/outputs.

Scraping & Detection (LLM): Content is extracted; an LLM determines whether a valid compensation exists and structures the data.

Human Validation: Experts confirm or reject detections; validated items remain traceable to sources and validation status.

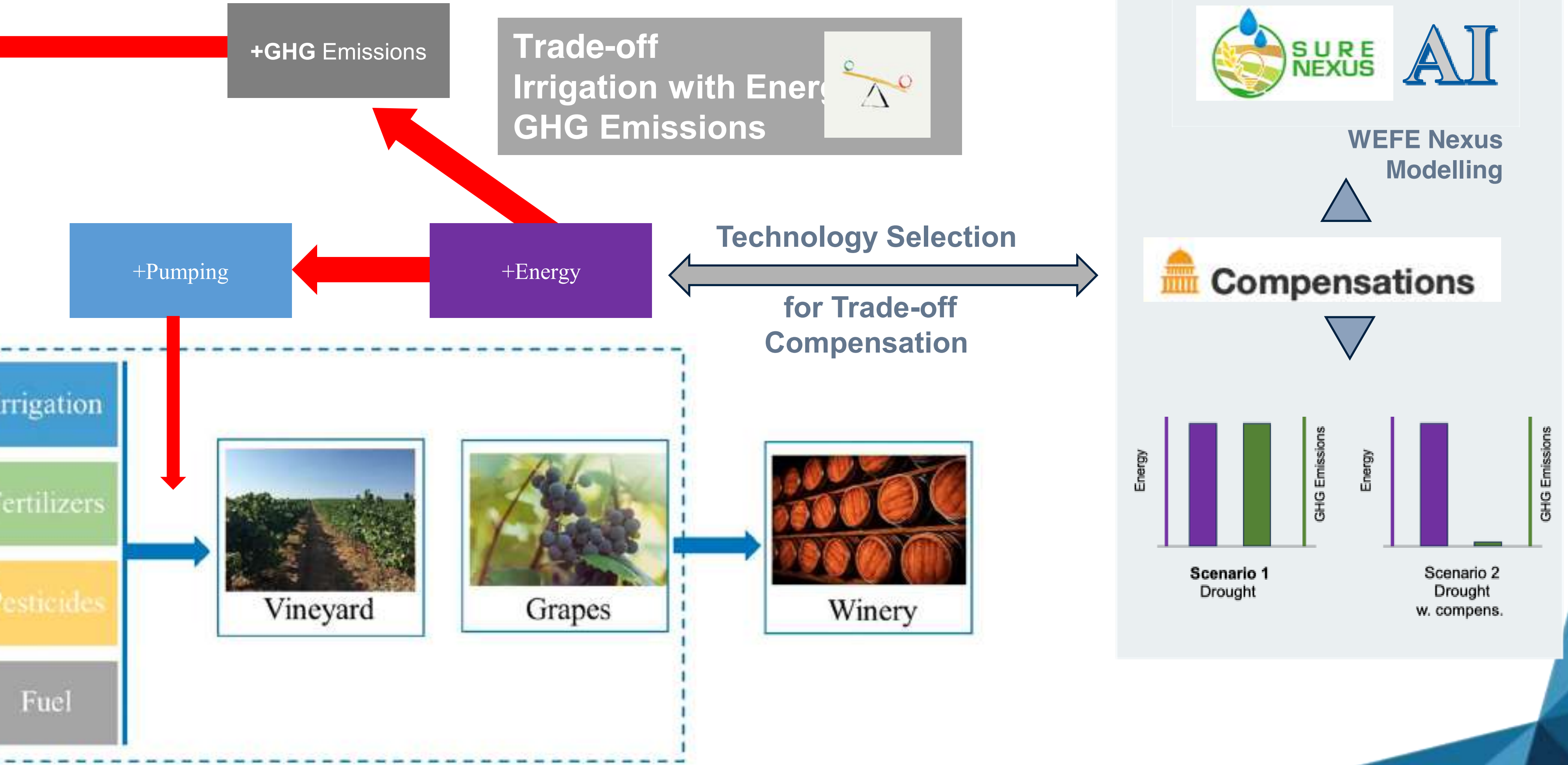


TECHNOLOGY SELECTION FOR TRADE-OFF COMPENSATION



CLIMATE CHANGE EFFECTS ON AGRICULTURE - Drought / Water Scarcity

TECHNOLOGY SELECTION FOR TRADE-OFF COMPENSATION



Challenge 7. **Inspired by the Past**

MEDITERRANEAN AREA **WATER HERITAGE**

EGYPTIAN Water Culture (ca 3150-31 BC)

ETRUSCAN Civilization – Tuscany, Umbria, Latium - Italy (Iron Age, ca 800-100 BC)

ROMAN Period (146 BC-AD 330)

MEDIEVAL Period (5th – 10th Century)

MINOAN Civilization Southeastern Greece (Bronze age, ca 3200-1100 BC)

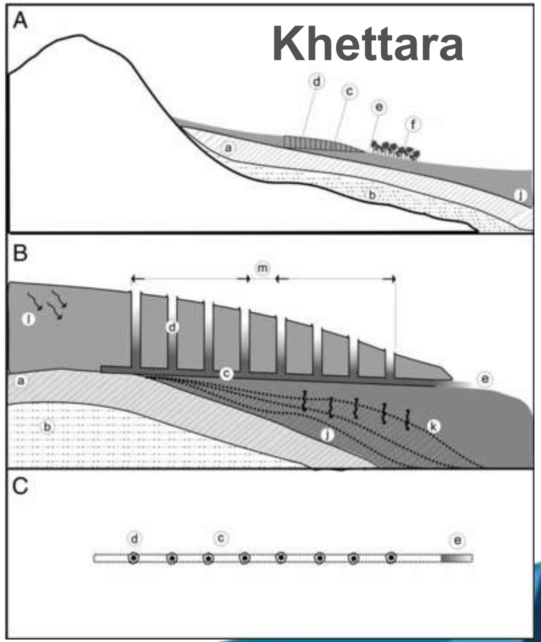
CLASSICAL AND HELLENISTIC Times Greece (ca 480-100 BC)

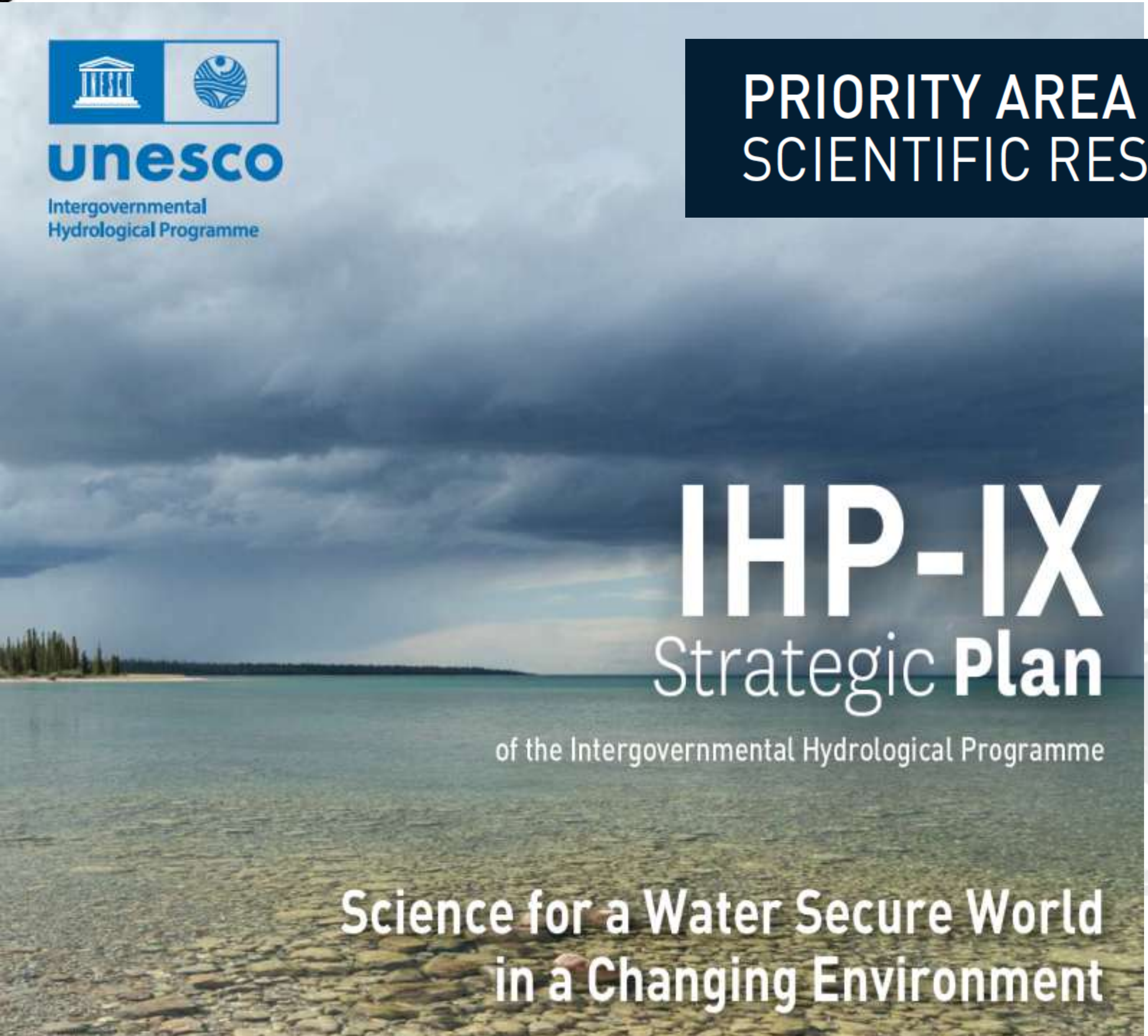
INDUS VALLEY Pakistan (Bronze age, ca 3200-1100 BC)

ZENU SOCIETY Colombia (ca 600-400 BC)

PREHISPANIC AMUNAS Peru (XII-XIII Century)

Convergent Evolution





PRIORITY AREA 1:
SCIENTIFIC RESEARCH AND INNOVATION

1.10 Conducting and sharing of research on **integrating citizen science in the hydrological discipline by the scientific community and other stakeholders** supported, to improve understanding of the water cycle enabling science based decision making.

IHP-IX will create the enabling environment and assist citizens and scientists, through enhanced water knowledge and education programmes to ensure scientific methods are used when participating in and reporting their findings to increase the contribution of citizen science to hydrology research. Training, in particular, will contribute to enhancing accuracy and validity of data.
Additionally, scientific tools should be developed to encourage citizen participation and other social applications that can improve water management, such as **integrating modern science with ancestral, indigenous and local knowledge.**

ANCESTRAL HYDROTECHNOLOGIES (AHT)

Enhance provision of Ecosystem Services

Low Resources Footprint

Low Energy Footprint

Preserve & Maintain Water Resources

Low Carbon Footprint

Manage Drought

MULTIFUNCTIONALITY

instrumental to Preserve & Restore Biodiversity

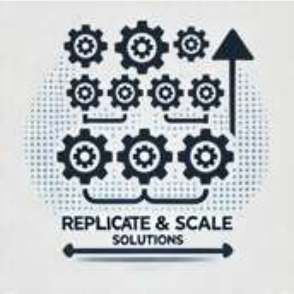
Contribute to Disaster Risk Reduction

Control Flooding

Support Climate Change Adaptation

SURENEXUS WEFE NEXUS STRATEGIC PROCESS

Challenge 8. **Policy Barriers**



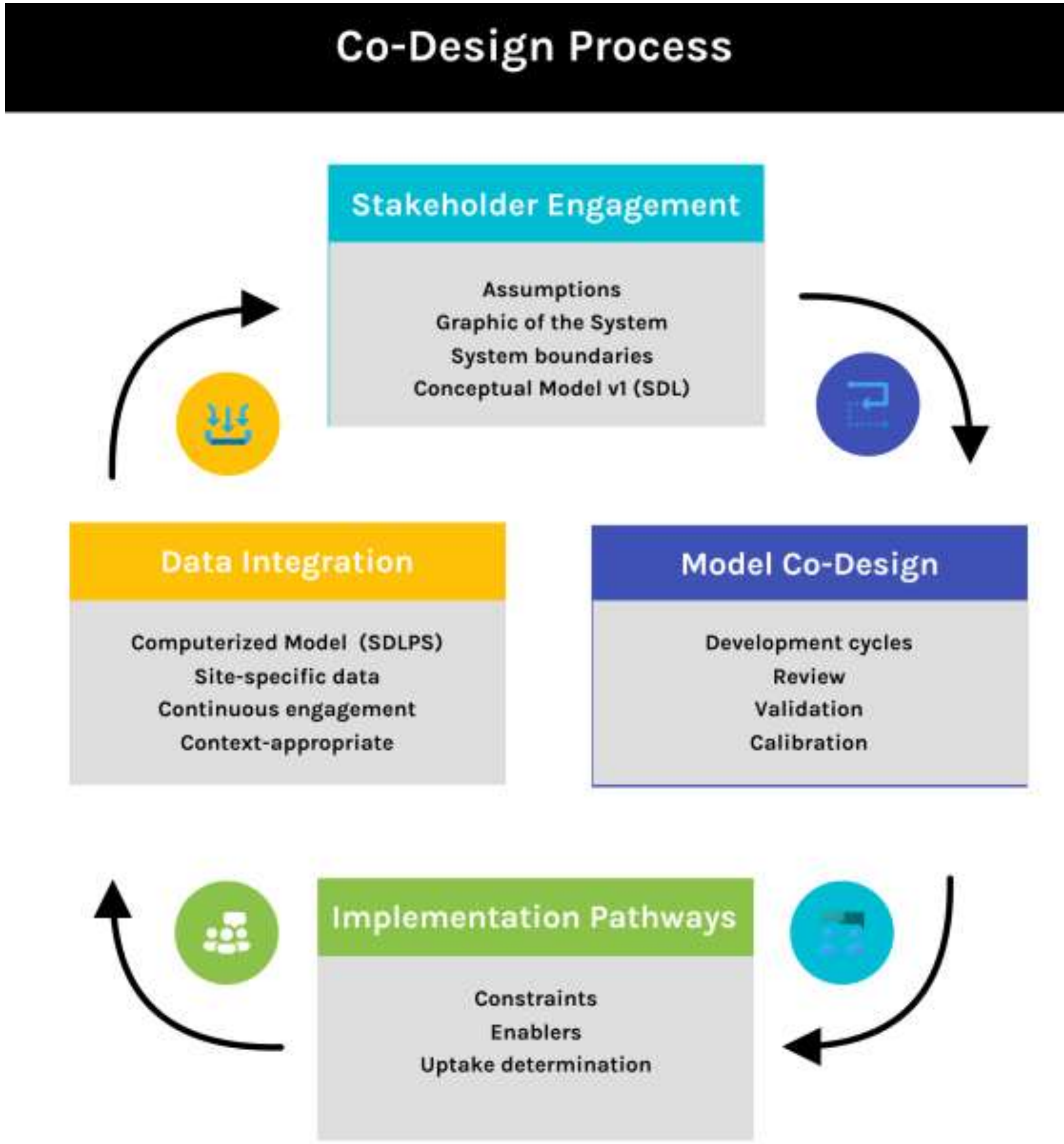
- **Foster Shared Understanding**
- **Select & Test Solutions**
- **Analyze Trade-offs & Synergies**
- **Assess Socio-Economic and Environmental Impact**
- **Replicate and Scale Solutions**
- **Integrate into Policy and Governance**

Challenge 8. **Policy Barriers**

SureNexus followed a structured and iterative pathway to select and validate the SETs. Candidate **technologies and practices were translated into the AI WEFE Nexus Tool, enabling consistent simulation of WEFE trade-offs, scenario testing, and KPI assessment.**

This process included multiple cycles of model development, review, validation, and calibration using site-specific data, **with stakeholders continuously engaged to ensure that assumptions, system boundaries, and the interpretation of results remained credible and context-appropriate.**

This co-design approach does not end at technical validation: it also serves to translate model outputs into *implementable* pathways by identifying the real-world constraints and enablers that determine uptake.



Challenge 8. **Policy Barriers**

Policy as Bridge - Evidence to Deployment

Policy connects evidence-based solutions to practical deployment, enhancing regulatory compliance, economic viability, and sustainable water management.

Policy bridges evidence and deployment by defining regulations, compliance standards like water reuse quality, and economic tools such as subsidies and investments.

70%
Regulatory compliance

Policy enables solutions by setting **regulatory conditions** and compliance requirements for water reuse and risk management.

75%
Risk managed

Policies directly affect deployment by ensuring risk management and quality standards in water reuse initiatives.

90%
Of solutions feasible

Effective policies drive economic feasibility through market design, subsidies, and investment for sustainable deployment.

Strengthening Policy and Institutional Frameworks

Legal text analysis
Identifies inconsistencies or overlaps between policies of different countries, facilitating transboundary regulatory harmonization.

Impact Simulations
Provide insights into the effects of proposed policies, supporting evidence-based governance.

Negotiation support
Through objective and transparent scenarios that aid diplomatic negotiations and consensus-building among riparian countries.

KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

1. From single technologies to Socio-Ecological and Technical Systems (SETs)

The comparative AI analysis across the five demosites clearly shows that isolated technologies rarely deliver optimal WEFE Nexus outcomes. Instead, **integrated SETs—combining water, energy, agricultural, and ecosystem interventions—consistently outperform single solutions**. This has direct policy relevance: funding, regulation, and planning instruments should **prioritise system bundles rather than standalone measures** (e.g. desalination without renewables, irrigation efficiency without soil conservation).

2. Energy-water trade-offs must be made explicit in policy decisions

AI modelling makes visible a recurring structural trade-off: **higher water performance often comes at higher energy demand** (e.g. aerated wetlands, desalination).

3. Low-cost, nature-based SETs deliver disproportionate benefits

Results from Catalonia, Morocco, Tunisia, and Tinos Ecolodge show that **low-capex, nature-based and management-focused solutions** (mulching, rainwater harvesting, subsurface irrigation) generate **large WEFE gains per euro invested**. AI confirms that these SETs are especially robust under climate variability, making them ideal candidates for **scaling through CAP instruments, rural development funds, and climate adaptation programmes.**

4. AI enables policy alignment rather than one-size-fits-all rankings

By applying weighted MCDA scenarios (balanced, environmental priority, performance priority), the AI WEFE Nexus Tool allows policymakers to **select SETs aligned with explicit policy goals**—for example: a) Climate mitigation: agrovoltaics, b) Water security with hybrid desalination and harvesting systems and, c) Rural resilience with conservation agriculture and water harvesting. This capability moves decision-making from static rankings to **goal-oriented planning**, a key requirement for integrated water, energy, and climate policies.

5. Reducing implementation risk through ex-ante scenario testing

Finally, AI scenario analysis significantly reduces policy and investment risk by **identifying failure modes, trade-offs, and thresholds before implementation.** Testing 37 solutions across multiple contexts enabled SureNexus to pre-define **replicable, context-adapted SETs**, providing policymakers with **actionable, evidence-backed options rather than theoretical best practices.**

KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Dr. Jordi Morató
jordi.morato@upc.edu

Jose Luis Martin Bordes

Olga Lucía Sánchez

Javier Collado

Brent Villanueva

شكراً لاهتمامكم، وجزيل الشكر لكم.

LinkedIn

@catunescosost

www.unescosost.org

PRIMA

The PRIMA programme is supported and funded under Horizon 2020, the Framework European Union's Programme for Research and Innovation

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
UNESCO Chair on Sustainability