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#EU GREEN WEEK

EU Green Week Partner Event

A Risk-Informed Modeling Framework of the Water-Energy-Food Nexus for Water Resources Management

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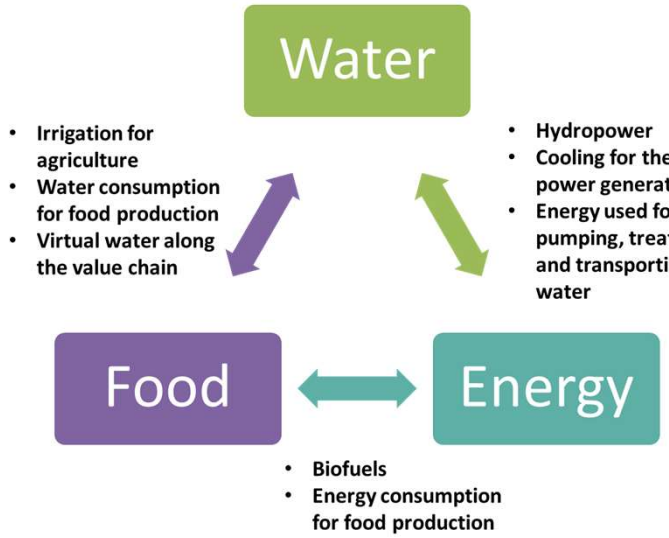
THE WATER-ENERGY-FOOD NEXUS: BUILDING RESILIENCE TO GLOBAL CHALLENGES

NexusNet

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

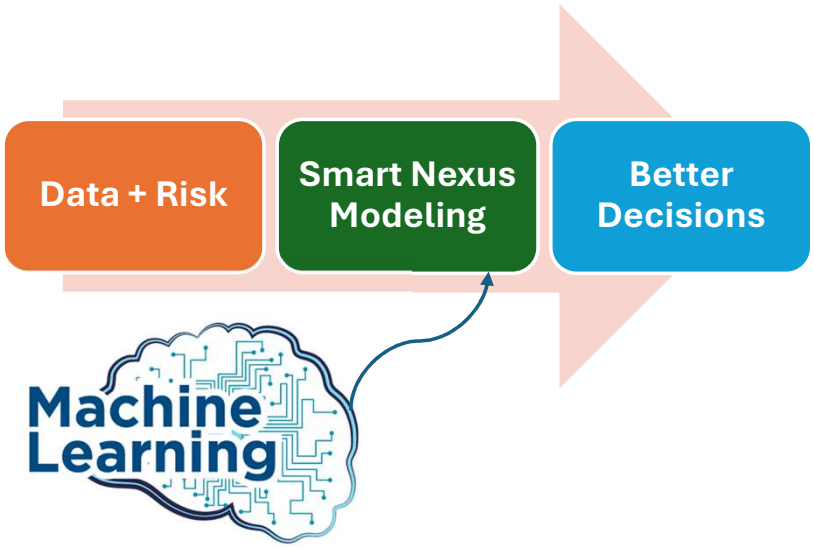
Background & Motivation

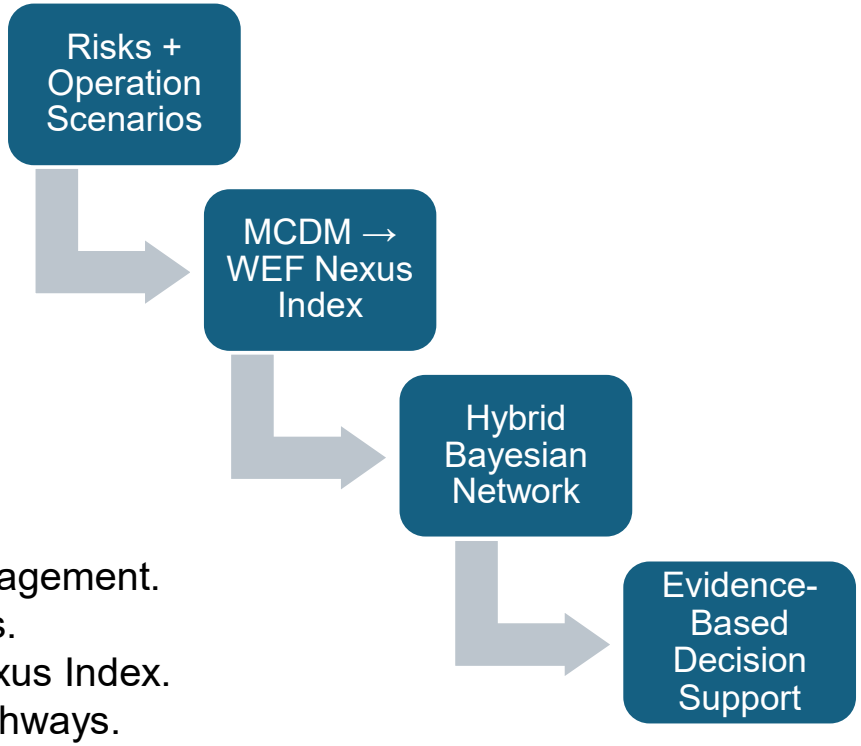
- Traditional surface water systems in irrigation areas often fail to:
- Ensure **fair**, **timely**, and **adequate** delivery.
- **Reduce groundwater overuse** and related energy burden.



- Climate and resource stress demand integrated planning.
- The WEF Nexus connects water use with food and energy security.
- Risk-informed approaches reduce inefficiency and support sustainable modernization.

Objective of the Study





- Build a systematic analysis framework for water resources management.
- Capture interdependencies across Water–Energy–Food sectors.
- Use multi criteria analysis (MCDM) to compute a composite Nexus Index.
- Apply a Hybrid Bayesian Network to model probabilistic risk pathways.

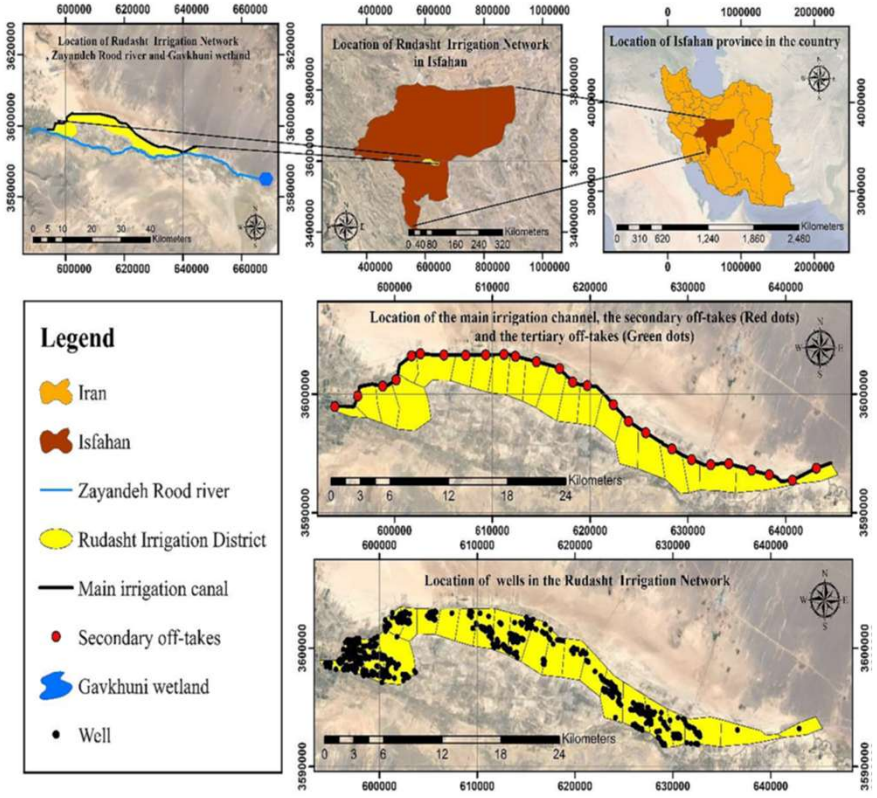
Study Area

- **Rudasht Irrigation District**, Central Iran
- Semi-arid, **severely water-stressed** agricultural zone

Problems:

- High **groundwater depletion**
- **Unequal water distribution** → upstream vs. downstream
- Frequent **water shortages**
- Main crops: Wheat & Barley

- Area: **~45,000 ha** irrigated via surface + groundwater



Framework Overview

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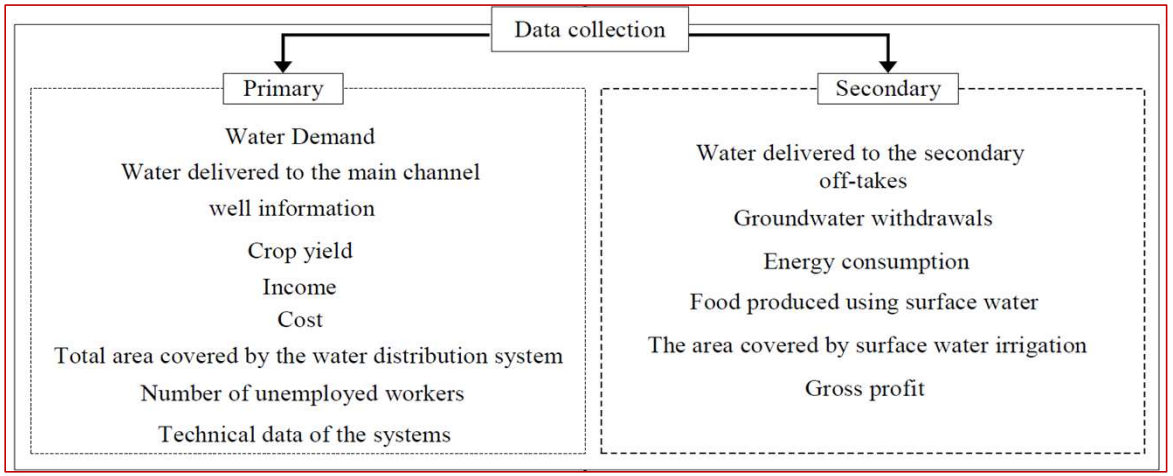

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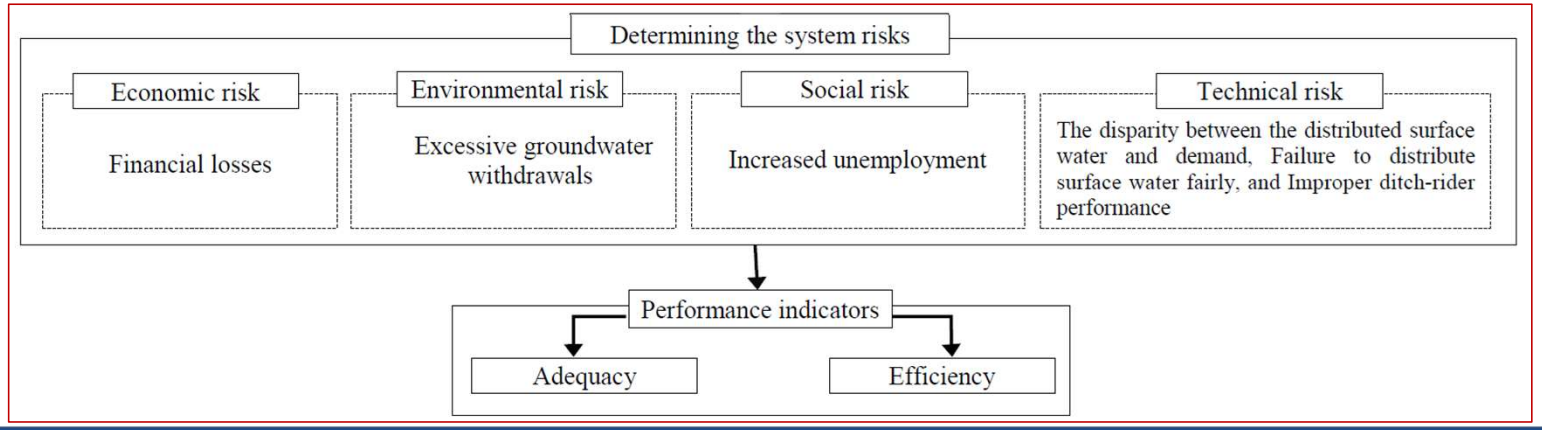

Framework Overview…

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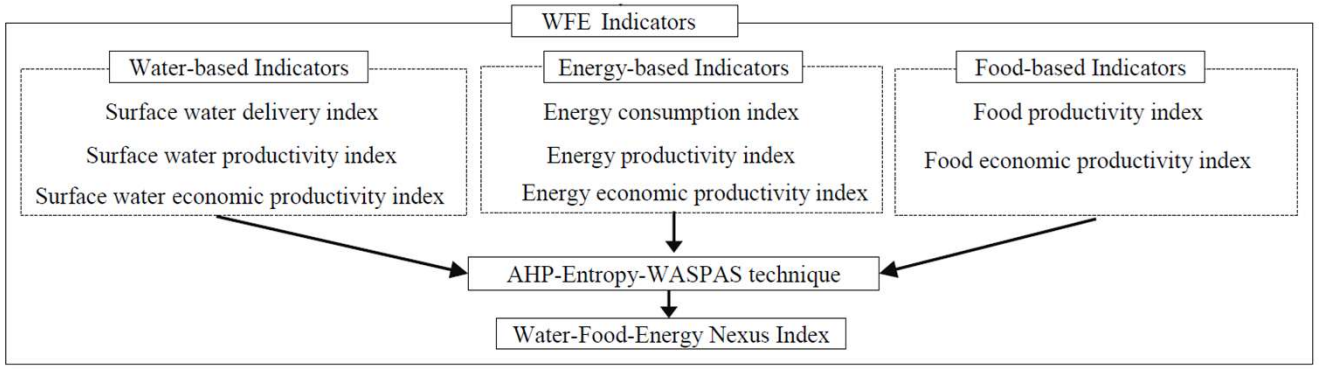

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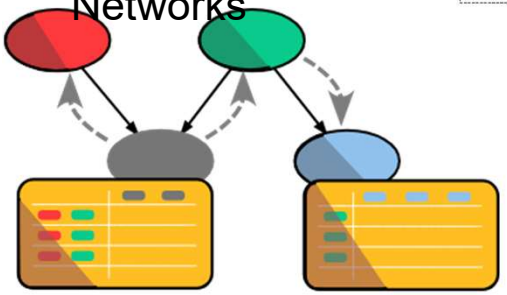
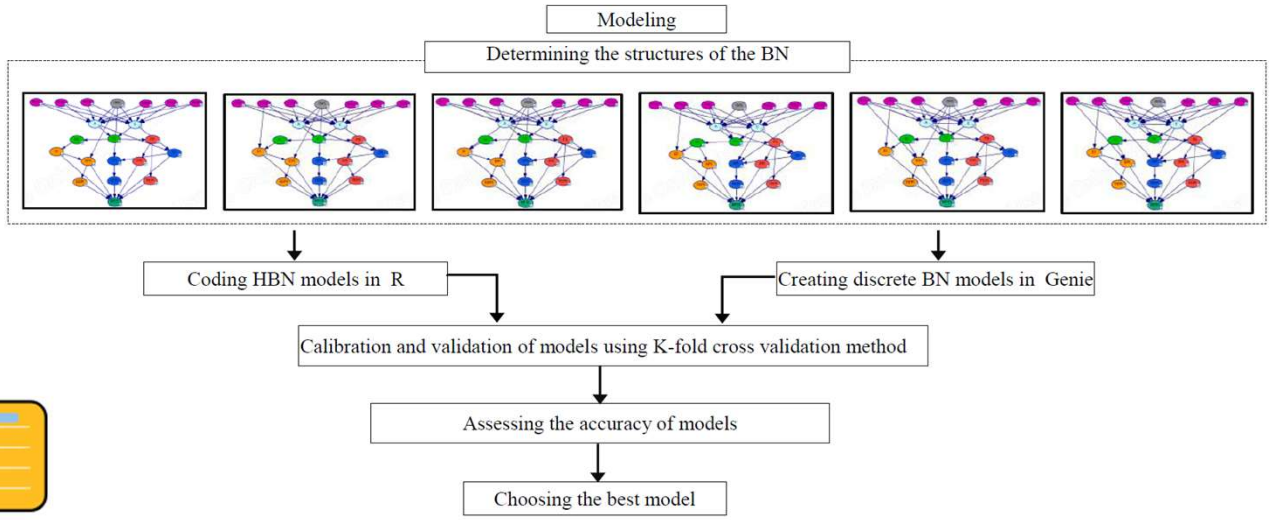
Bayesian Networks





Risk Assessment

Localized risks threatening water distribution

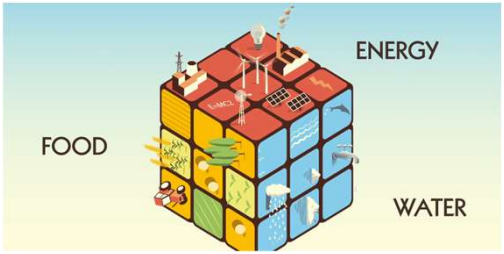
Type	Risk Description
Economic	Financial losses
Environmental	Excessive groundwater withdrawals
Social	Increased unemployment
Social	Unfair surface water distribution
Technical	Supply–demand mismatch
Technical	Ditch-rider operational error

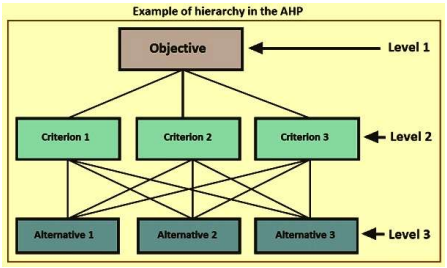
- ✓ Based on **WEF Global Risk Report** + **local expert input**
- ✓ Risks **quantified using equations** tailored to irrigation context
- ✓ Each scenario was evaluated under **normal & water shortage** conditions

WEF Nexus Indicator

Water	Energy	Food
Surface Water Delivery (DI)	Energy Consumption (EI)	Food Productivity (FPI)
Surface Water Productivity (SPI)	Energy Productivity (EPI)	Food Econ. Prod. (FEPI)
Surface Water Econ. Prod. (SPEI)	Energy Econ. Prod. (EEPI)	

- **8 indicators** across water, food, and energy sectors.
- Combined using **AHP (expert input)** and **Entropy (data-driven)**.
- Final WEF Index computed via **WASPAS method**.
- Enables **scenario comparison** under multi-dimensional criteria.





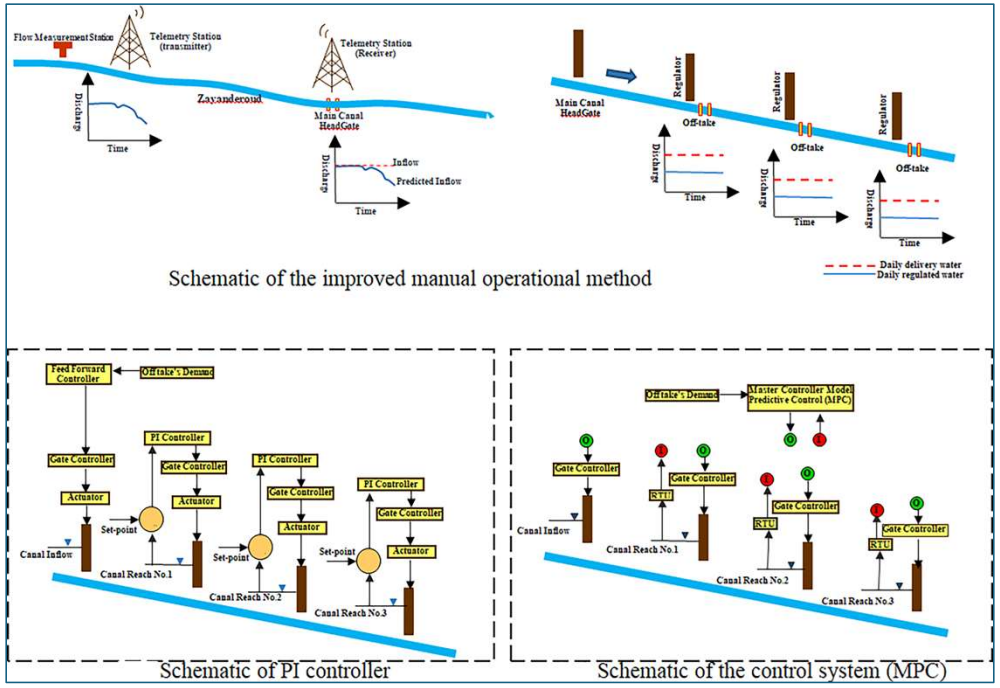
Weighted Aggregated Sum Product Assessment method (WASPAS)

WEF NEXUS Index

Operation Scenarios

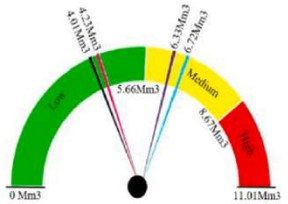
System Type	Description
Manual (Baseline)	Traditional, ditch-rider operated
Improved Manual	Manual + real-time flow monitoring
Decentralized Auto (PI)	Local PI controllers regulate individual gates
Centralized Auto (MPC)	Central controller uses data from all gates to optimize flows simultaneously

*The hydraulic behavior of all systems was simulated using **HEC-RAS**, supported by calibrated models from field data.*

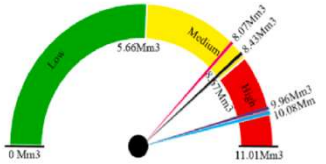


Risk Assessment Results

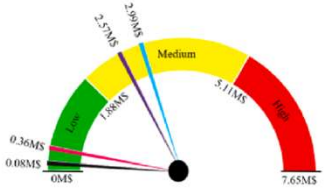
- **Manual systems** had the **highest risks** across nearly all indicators.
- **Improved manual** showed *minor* risk reductions only.
- **Decentralized PI** control reduced some risks but caused **inequity** under water shortage.
- **Centralized MPC** consistently achieved:
  - ✅ Lowest **ditch-rider error** (0.02%)
  - ✅ Lowest **groundwater use** (4.01 MCM)
  - ✅ Lowest **financial losses** ($0.8M)
  - ✅ Most **equitable distribution**, even under shortage



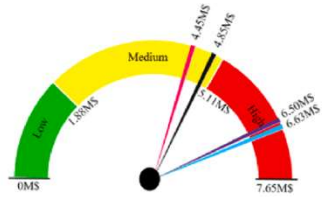
Excessive groundwater withdrawals(Normal scenario)



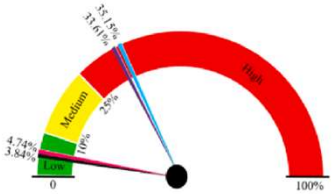
Excessive groundwater withdrawals(Water shortage scenario)



Financial losses(Normal scenario)



Financial losses(Water shortage scenario)



Failure to distribute surface water fairly(Normal scenario)

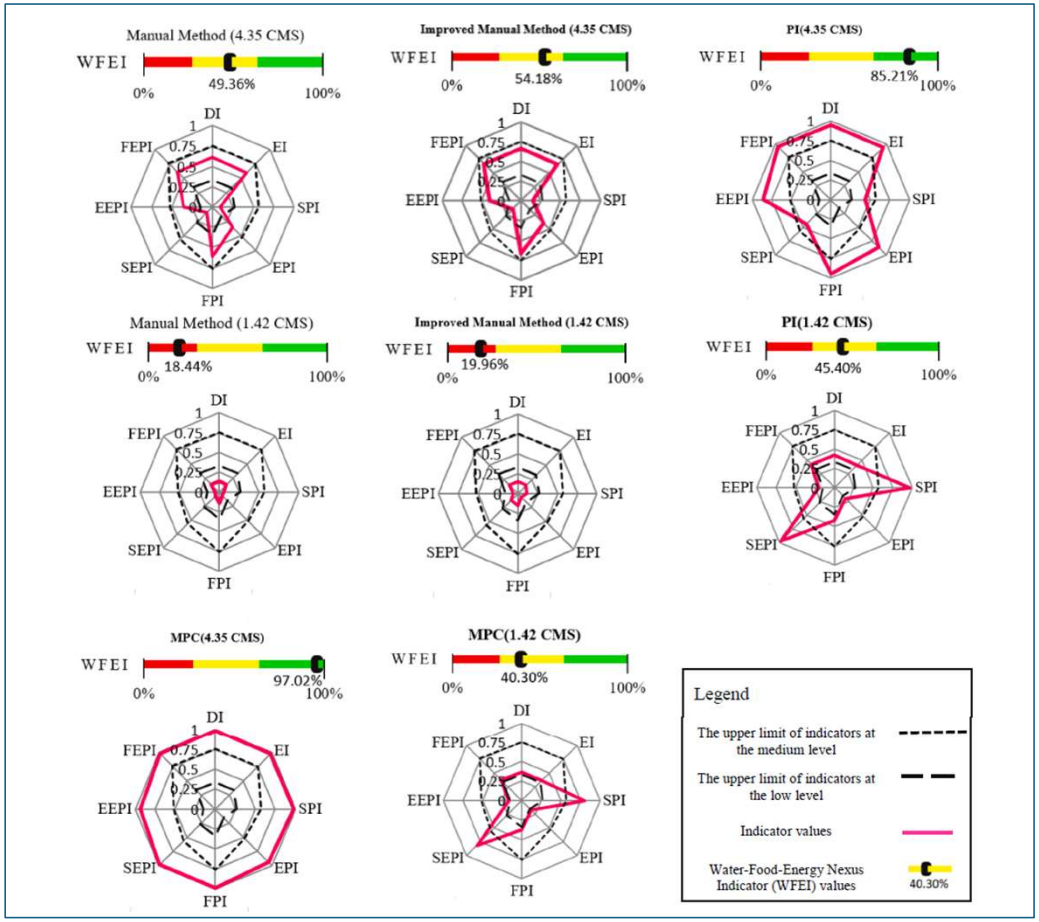
Failure to distribute surface water fairly(Water shortage scenario)

WEF Nexus Index Results

WEF Nexus Index (WEFI) captures multi-dimensional performance:
Water delivery & productivity
Energy use & efficiency
Food yield & profit

MPC outperformed all systems:
WEFI = **0.97** (Normal)
WEFI = **0.40** (Shortage)

Manual system had the weakest results:
WEFI = **0.49** (Normal)
WEFI = **0.18**(Shortage)

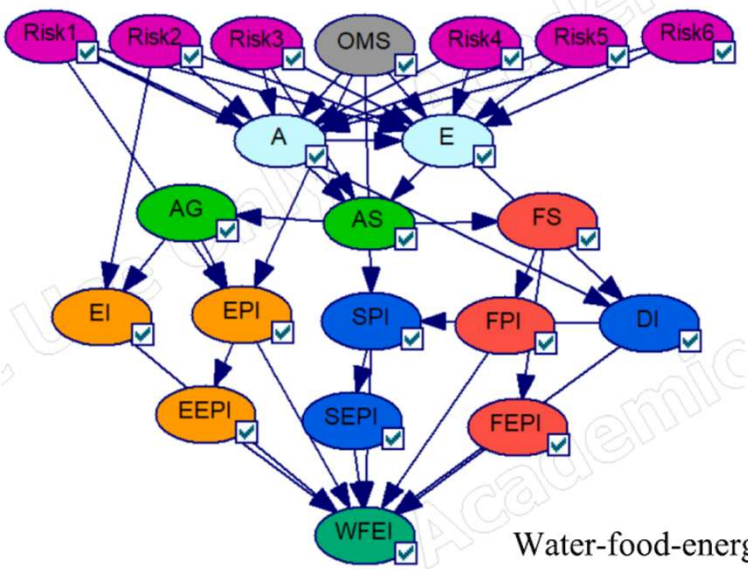


Machine Learning for Nexus Modeling

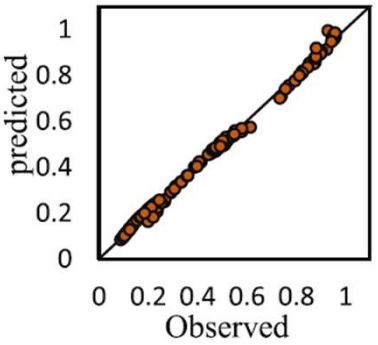
- **Bayesian Network** trained on the risks, WEF indicators, and the composite Nexus Index from the MCDM process.

- Best Structure achieved the best performance:
R^2 = 98.49%, MAPE = 1.71%, NRMSE = 6.53%.

- BN captured **probabilistic dependencies** to enable **scenario-based forecasting** and support uncertainty-aware decision-making.



Water-food-energy Nexus Index



Conclusion

Risk-Informed Operations	Nexus-Based Scenario Planning	Scalable Tool for Europe & Beyond
Supports resilient water management by quantifying WEF-related risks and trade-offs.	Compares resource management strategies under uncertainty to guide sustainable modernization.	Offers a practical ML-based framework for integrated water resource planning and Nexus-aligned policy support.

Further development could expand the framework to include **climate** and **environmental** dimensions!

For more Information:

Bayat, F., Roozbahani, A., Hashemy Shahdany, S.M. (2025). "An integrated risk-based water-food-energy nexus assessment framework for surface water operation governance", *Computers and Electronics in Agriculture*, 229: 109659.

Thank you for your attention

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