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Renewable plants integrated with pumped thermal energy storage for sustainable satisfaction of energy and agricultural needs of African communities

(JULY 2023 – MARCH 2026)

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LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Pillar-1 project

The LEAP-RE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

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Consortium

8 partners involved:

- ✓ University of Cagliari
- ✓ Smart city instruments
- ✓ University of Liege
- ✓ Green Energy Park
- ✓ Ecole nationale supérieure d'arts et métiers de Rabat
- ✓ Ecole nationale supérieure des mines de Rabat
- ✓ Federal University of Petroleum Resources Effurun
- ✓ Bucharest University of Economic Studies

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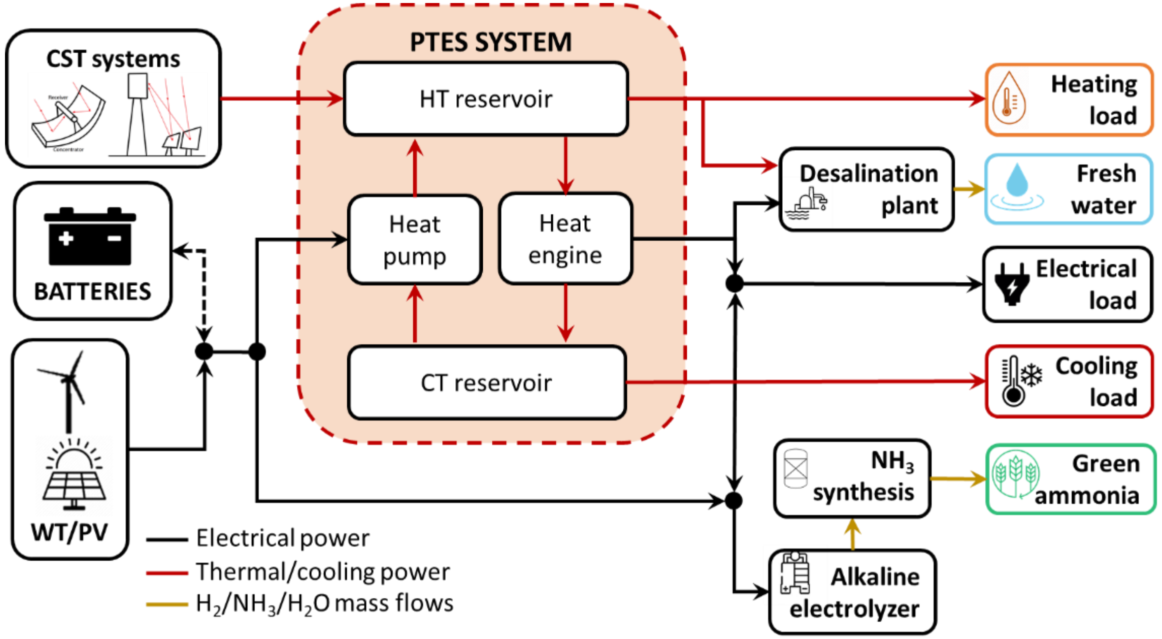
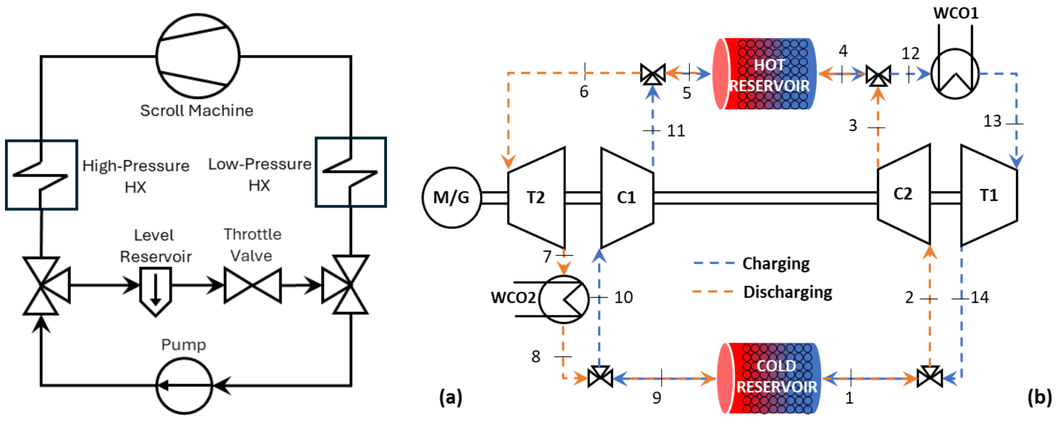
Aim of the project

Develop a **proof of concept** of innovative **RES-based multigeneration/storage systems** for covering both heat/cool and electricity demands of isolated and rural communities in Africa and for producing other **green commodities** for agriculture such as ammonia, desalinated water, and refrigeration energy for food conservation. The core of the system is the coupling between RES-based generators and **pumped thermal electricity storage** (PTES) system.

Overall system configuration



PTES system configurations



Reversible Rankine PTES

Brayton PTES

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Case nr	Location	Application	Grid connection	Size	Demands
1	Nigeria	Local farm	Off-grid	Small-scale (<50 kW)	Electricity, cooling for food preservation
2	Morocco	Local farm	Off-grid	Small-scale (<50 kW)	Electricity, fresh water, cooling for food preservation
3	Nigeria	Small village	Off-grid	Medium scale (>1 MW)	Electricity, cooling/heating, ammonia production
4	Morocco	Green ammonia plant	Grid-connected	Large scale (>50 MW)	dispatchable electricity and ammonia production

Relevance vs MARs

MAR3: the system completely based on RES and conceptualized for off-grid applications. This scheme is flexible both in terms of the energy generation systems as well as the produced outputs, in a manner that, the system's configuration is tailored to fit the environmental conditions of the concerned community

MAR4: the project will involve the assessment of the RES-PTES concept through four case studies representatives of small and medium-scale distributed generation.

CASE STUDY 1 - NIGERIA

CASE STUDY 2 - MOROCCO

CASE STUDY 3 - NIGERIA

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➢ *Scientific And Technical Objectives*

1. **Advance knowledge** in thermo-mechanical energy storage, developing innovative Pumped Thermal Energy Storage (PTES) concepts that are technically and economically viable for African contexts.
2. **Demonstrate synergies** between PTES, renewable energy sources, and batteries to deliver dispatchable green electricity, heating/cooling, and production of key green commodities (e.g., water, ammonia, refrigeration) under diverse climatic conditions.
3. **Assess techno-economic feasibility** of the integrated systems considering market needs, the Water-Energy-Food Nexus, and business potential for sustainable local value chains.
4. **Promote renewable energy adoption** as a strategic pillar for socio-economic development, particularly in the agribusiness and water sectors of African partner countries.

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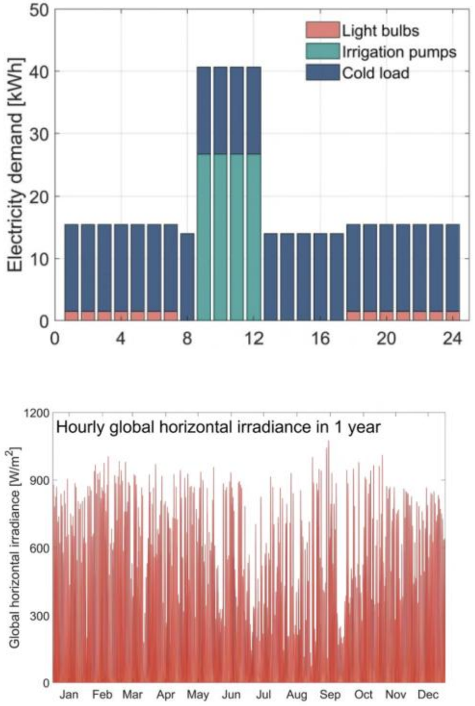
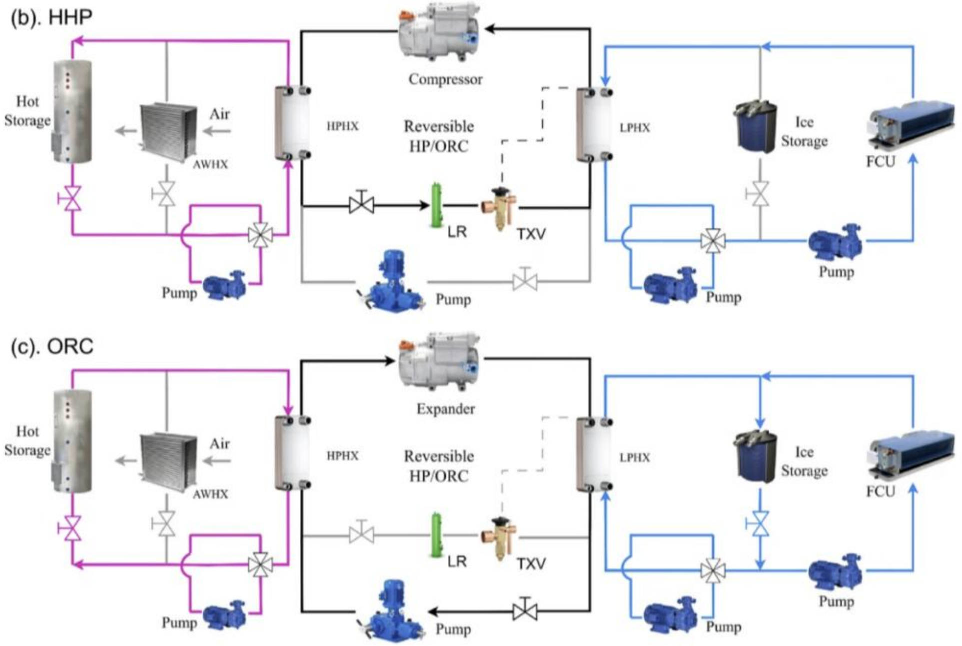
Main Results Achieved – Case Study 1 (Nigerian farm)

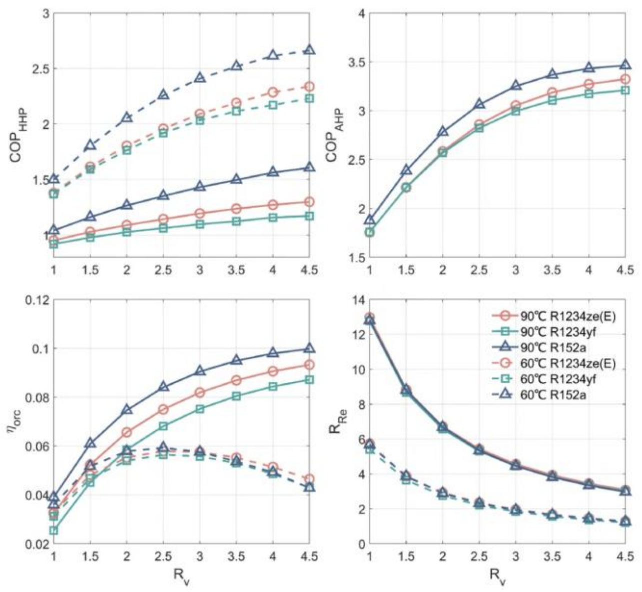
CASE STUDY DEFINITION



DEFINITION OF (VARIOUS) SYSTEM CONFIGURATIONS



PERFORANCE EVALUATION



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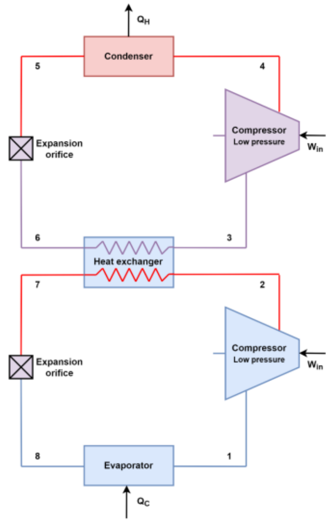
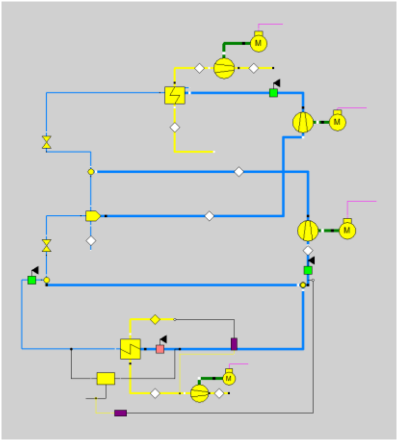
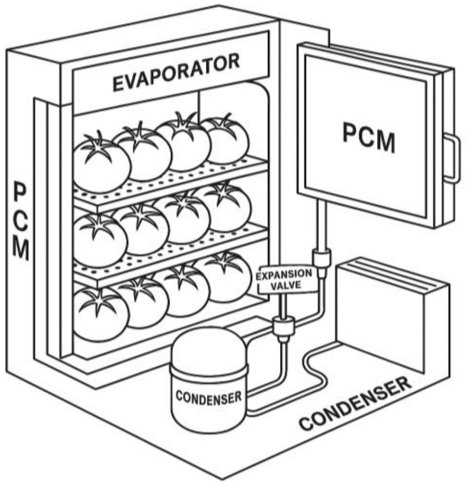
➢ *Main Results Achieved – Innovative cooling systems for food preservation*

DEVELOPMENT OF SIMULATION MODELS





DEVELOPMENT OF PROTOTYPE AT FUPRE



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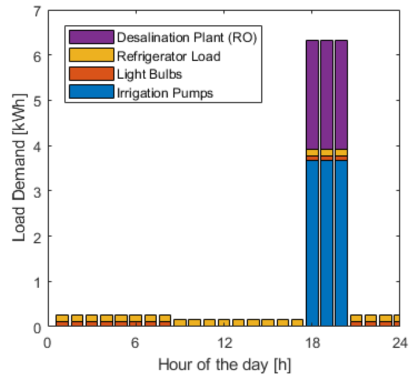
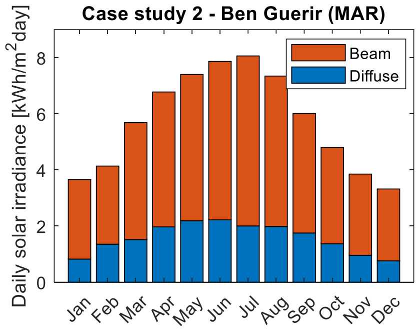
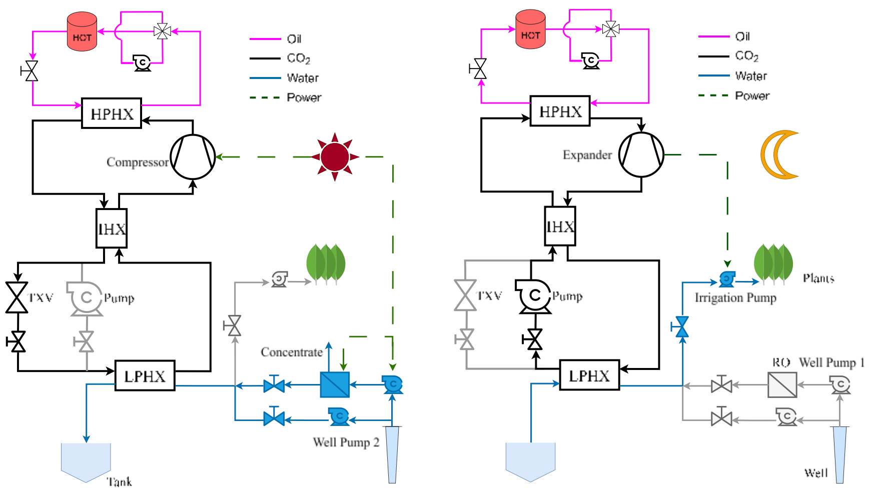
➢ Main Results Achieved – *Case Study 2 (Moroccan farm)*

CASE STUDY DEFINITION

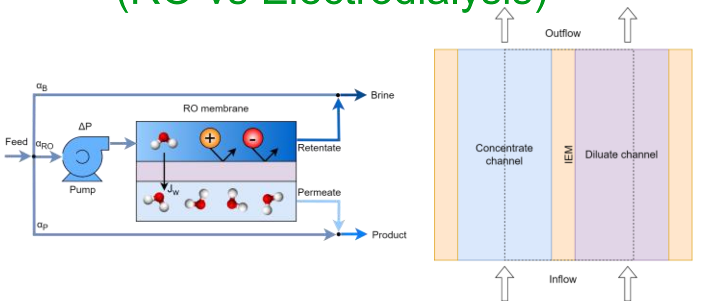


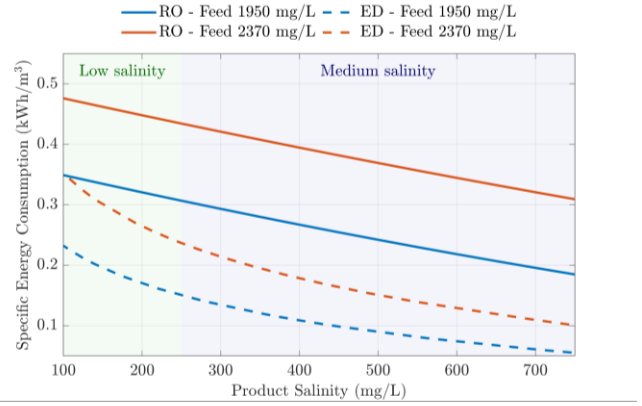


DEFINITION OF SPECIFIC SYSTEM CONFIGURATION (sCO2)



DESALINATION PLANT (RO vs Electrodialysis)





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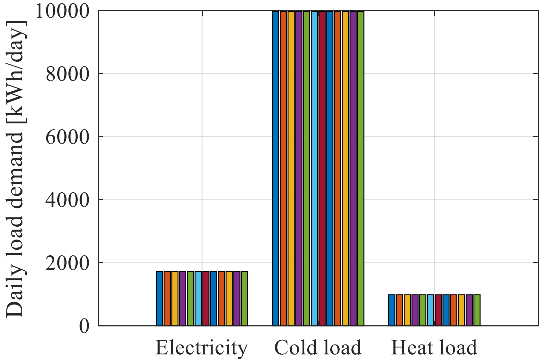
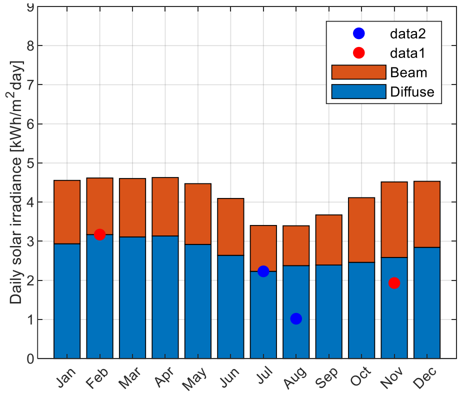
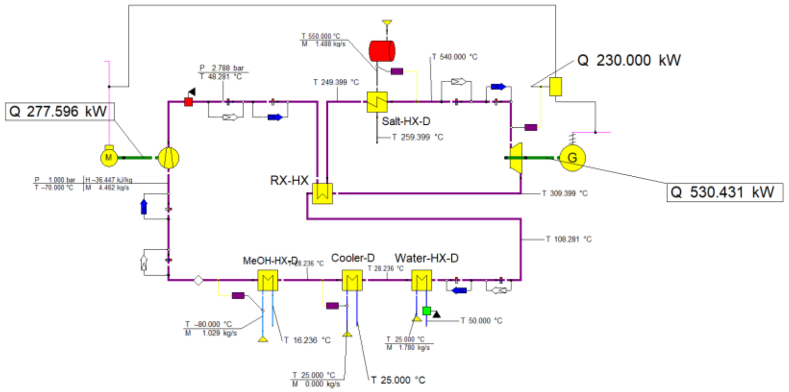
➢ Main Results Achieved – Case Study 3 (Nigerian small village)

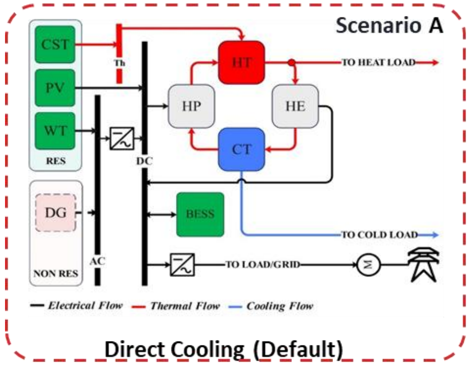
CASE STUDY DEFINITION

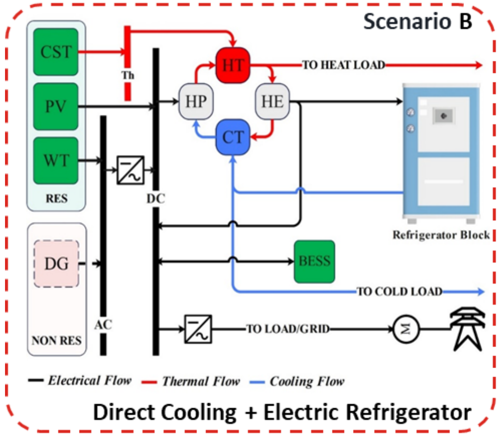




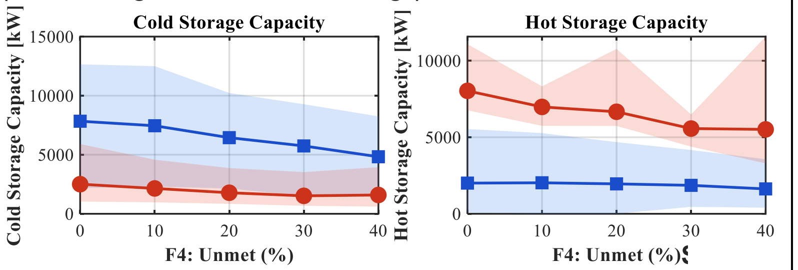
DEFINITION OF SPECIFIC PTES CONFIGURATION (Brayton based)

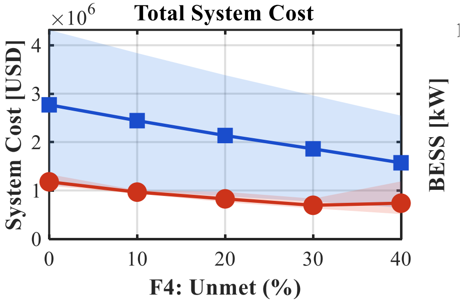






OVERALL SYSTEM PERFORMANCE





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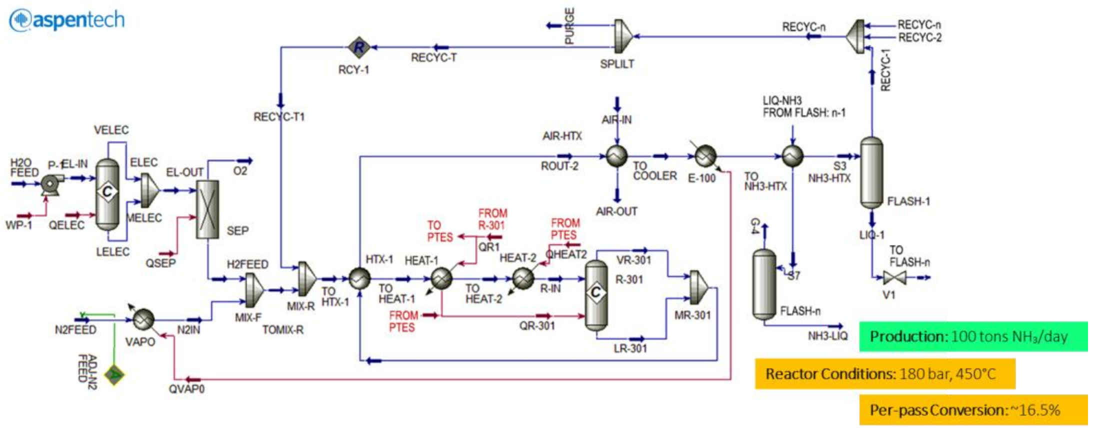
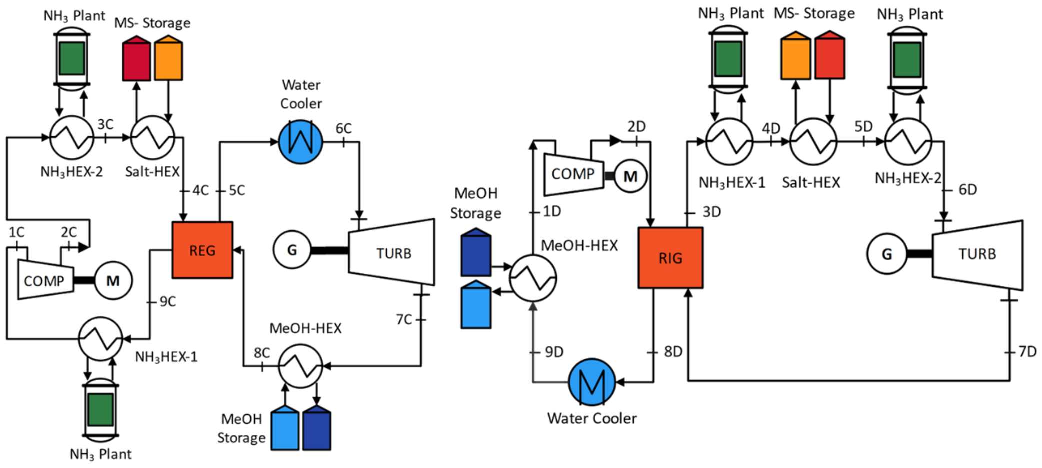
➤ *Main Results Achieved – Case Study 4 (Integration with an ammonia plant)*

AMMONIA PLANT SIMULATION



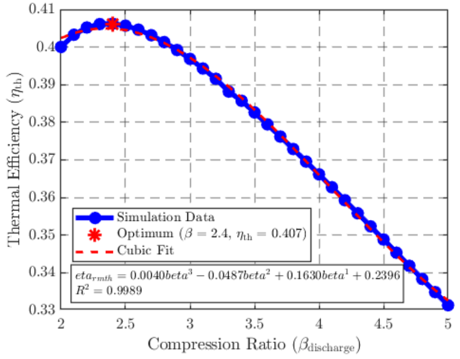
PTES CONFIGURATION

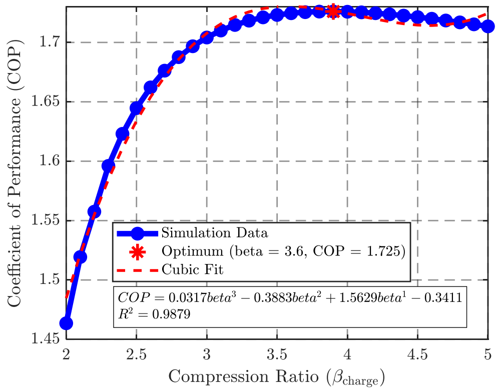


(a) Charging cycle

(b) Discharging cycle.

OPTIMIZATION OF THE PERFORMANCE

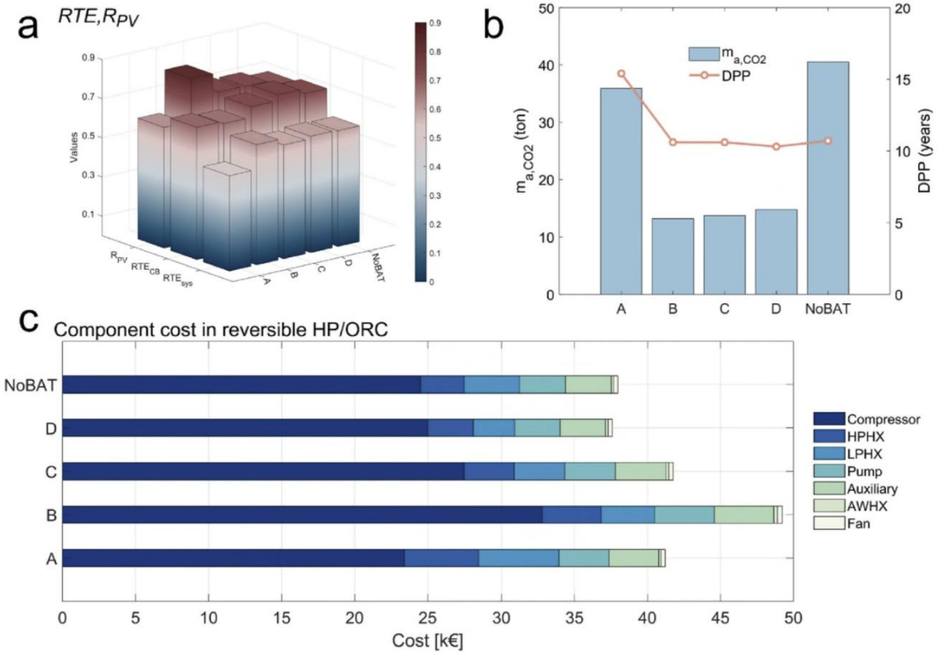




Scenario	B charge	B discharge	COP	η th	η round-trip
With WHR	3.6	2.4	1.725	40.7%	**70.2%**
Without WHR	4.7	2.7	1.484	37.9%	**56.2%**

Main Results Achieved – Economic and social-ecological assessment

COST-BENEFIT ANALYSIS



LCA

Indicator	Estimated Results	LCA Results	Difference	Remarks
Current System (Grid + Diesel)				
CO_2 emissions per kWh	0.8 kg CO_2/kWh	1.32500 kg CO_2/kWh	+65.6%	LCA shows a significantly higher impact than the initial estimate *Explanation*: The LCA value of 1.325 kg CO_2/kWh includes the full life-cycle emissions of diesel fuel (extraction, refining, transport, and combustion), as modeled in openLCA. The initial estimate of 0.8 kg CO_2/kWh only considered direct combustion emissions, excluding upstream supply chain processes.
Direct CO_2 emissions per kWh (parametrized)	0.8 kg CO_2/kWh	0.795038 kg CO_2/kWh	-0.6%	Excellent agreement between the estimate and the calculated value for direct emissions
Annual total emissions	137.8 t CO_2/year	228.2 t CO_2/year	+65.6%	Calculated based on annual consumption of 172,250.8 kWh *Explanation*: The difference arises because LCA accounts for the entire fuel life cycle, not just direct combustion.
Proposed System (PTES)				
CO_2 emissions per kWh	~0.07 kg CO_2/kWh	0.07221 kg CO_2/kWh	+3.2%	Results are very close
Annual total emissions	~12 t CO_2/year	12.4 t CO_2/year	+3.3%	Minor difference
Emission reduction – %	91.3%	94.5%	+3.2%	LCA confirms a greater reduction than initially estimated
Total reduction over 25 years**	~310 t CO_2 (estimated)	~5,395 t CO_2	+1,640%	Major difference due to higher baseline emissions in the LCA, which accounts for both direct and indirect emissions from fuel production and related activities

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Main Results Achieved – Publications

Mihai Dinu et al. Global Sustainable Development Targets with Local Implementation: Europe-Africa Collaboration on Renewable Energy LEAP-RE and REPTES Project Overview. Proceeding at the 7th international conference on economics and social sciences, June 2024

B Guo et al. , Designing of an Off-Grid Reversible Heat Pump/Organic Rankine Cycle System for Electricity and Cooling Demands of a Nigerian Family Farm, Proceeding at 37th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, July 2024

M. Petrollese et al. Sustainable off-grid energy solutions: pumped thermal energy storage modeling and its role in optimizing renewable energy utilization, Proceeding at ICEEE2024, August 2024.

B Guo et al. , Comparison of control strategies of an off-grid Carnot battery combined with renewable energy resources: Priority of electrical and Carnot battery. Proceeding at 4th International Workshop on Carnot Batteries, September 2024

M. Petrollese et al. Optimizing hybrid off-grid energy systems and reverse osmosis desalination with Carnot battery technology and model predictive control, Proceeding at Carnot 2024: 1st Belgian Symposium of Thermodynamics, December 2024

B Guo et al., Theoretical Applicability Evaluation of Carnot Batteries for Agricultural Energy Demands in Farms, Proceeding at Carnot 2024, December 2024

Ammar Mouaky, Techno-Economic Comparsion of Renewable Energy driven cooly system for food preservation in a Nigerian farm. Proceeding at the 19th International conference on Buisness Excellence, March 2025

Mihai Dinu et al. The Holistic Approach Of The Sustainable Renewables By Using The Life Cycle Assessment Tool. Proceeding at the 8th International Conference on Economics and Social Sciences. June 2025

B Guo et al. Control strategy and techno-economic optimization of a small-scale hybrid energy storage system: A reversible HP/ORC-based Carnot battery and an electrical battery, Energy Volume 329, August 2025

B Guo et al., Technical Feasibility Assessment of a Recuperator in Reversible Trans-critical CO_2 Heat Pump/Rankine Cycle: Considering Scroll Machine Operation Boundaries, Proceeding at 38th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, July 2025

B Guo et al. ,A Fixed-Charge Control Strategy of Trans-critical CO_2 Rankine Cycle, Proceeding at ORC2025, September 2025

M. Shayan et al. Thermodynamic Optimization of a Hybrid Pumped Thermal Energy Storage System and Haber-Bosch Plant for Waste Heat Recovery. Proceeding at SDEWES2025, October 2025

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➢ *Problems encountered during the project*

1. Funding delays and administrative heterogeneity: National disbursement differences (notably in Morocco) slowed activities; mitigated by reassigning analytical tasks and maintaining close coordination.
2. Balancing performance and economic feasibility: Challenge in keeping a balance between optimization of performance indicators (cutting-edge technologies, high-efficiency components) and economic constraints requiring reduced CAPEX and off-the-shelf materials.
3. Data integration across disciplines:Technical, economic, and environmental partners needed harmonized data and modelling formats.

➢ *Possible evolutions of the objectives in progress of the project*

1. Exploration of new PTES configurations:

   Based on current results, an additional effort is required to investigate innovative PTES configurations, other than those identified in the proposal, to meet the energy demands of the identified case studies

2. Increased Focus on Scalability:

   Based on initial findings, scalability and replicability of the REPTES system have emerged as crucial for successful deployment across diverse geographical regions, particularly in remote areas of AU.

3. Deeper Social Impact Assessment:

   More focus will be placed on assessing the social and community impacts of implementing RES systems in rural areas.

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- ***Specific role and achievement of the private sector member of the consortium***
  - **SMART CITY INSTRUMENT (SCI)** is a company specializing in consulting, design, prototyping, and development of smart technology solutions in the areas of energy, environment, and urban governance.
  - Within REPTES, SCI is WP leader on **application extension & replicability** of the proposed system. SCI is focusing on applying the developed methodologies to refining guidelines on the scalability and replicability of REPTES, to update the work plan and to address identified bottlenecks etc.

- ***Specify whether the project has resulted in new products or developments***

1. Energy Systems Optimization Models

   Validated modelling tools for reversible PTES systems (Brayton and Rankine cycles) under different operating and climatic conditions (TRL raised from 2 to 4–5).

2. Prototype design for solar-powered cooling unit

   Designed a prototype for an energy-efficient cooling unit tailored to agricultural needs, improving food preservation in remote areas.

3. Business Models and Environmental Assessment Tools

   Created business models and implemented life-cycle assessment (LCA) tools to evaluate both economic feasibility and environmental impacts.

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End of project expected results (end 2025)

Planned follow-up work & new pathway

From REPTES to REPTES-MART (2026–2030)

- *Evolution of REPTES results:* REPTES-MART builds directly on the modelling, design, and case-study results of REPTES, moving from conceptual development (TRL 3) to prototype validation (TRL 5–6).
- *Main goal*: Demonstrate a renewable, stand-alone energy system for off-grid farms integrating solar PV, solar-thermal, batteries, and a reversible HP/ORC-based PTES with multi-level thermal storage.
- *Focus*: Real-scale prototypes in Morocco and Nigeria, equipped with AI-based smart control systems and inclusive business models
- *Expected impacts:* Reliable multi-energy services (electricity, cooling, heating, desalination, crop drying). Strengthened African innovation capacity through on-site construction and testing.Inclusive socio-economic and gender impacts for smallholder farmers.

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➢ *End of project expected results (end 2025)*

➢ *Consortium Evolution*

The REPTES consortium has been successfully consolidated through the preparation of REPTES-MART, ensuring continuity of the core partnership between European and African institutions.• The consortium has been reinforced by new expertise in control systems and AI-based energy management, thanks to the inclusion of the University of Cape Town (UCT) and the University of Zululand (UNIZULU).

➢ *Future collaboration*

Scientific collaborations expanded through joint conference presentations and publications on hybrid PTES systems, techno-economic optimization, and renewable integration.

Planned industrial collaborations with enterprises already developing commercial reversible HP/ORC products such as Enerbasque and Kaymacor, aiming to bridge the gap between research prototypes and pre-commercial demonstrators.

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Expected outcomes in case of success of the project (2030)

1. **Enhanced Energy Access & Quality of Life**
   Reliable, sustainable energy for farms, reducing dependence on fossil fuels and improving food preservation and water desalination.
2. ***Community Empowerment***
   30% increase in adoption of renewable technologies through education and collaboration, improving rural quality of life.
3. ***Increased Agricultural Productivity***
   More reliable energy will boost food production, leading to higher yields, income, and investment opportunities.
4. ***Reduced Operational Costs***
   Energy optimization to cut energy costs by 15%, making agricultural activities more viable.
5. ***Job Creation & Economic Growth***
   Small-scale green ammonia production and renewable energy projects will generate jobs and stimulate local economies.
6. ***Environmental Impact***
   20% reduction in CO2 emissions by replacing fossil fuels with renewable energy systems.
7. ***Sustainable Practices***
   Improved resource efficiency and reduced environmental impact through integrated renewable energy and storage systems.

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Contribution of the project to AU – EU R&D partnership

Alignment with AU-EU Priorities

REPTES aligns with the "Pillar 2: Sustainable Energy" objectives from the AU-EU Roadmap for Research & Innovation in Climate Change and Sustainable Energy.

Catalyst for Future Projects

With its focus on low TRL (Technology Readiness Level) technologies, REPTES is paving the way for future EU-AU collaborations by developing reliable models and actionable results.

Pilot Plant Development

The project serves as a reference for scaling up, potentially leading to a pilot plant to demonstrate the feasibility of the REPTES technology.

Capacity Building

The project is committed to training 11 young scientists, with 7 from Africa, strengthening research capacity and fostering long-term scientific cooperation.

Interest of Consortium members in participating in LEAP-RE clustering activities

Modelling approach used for energy consumption forecasting of stand-alone systems

System configuration proposed and modelling approach used for off-grid applications

Business model used for investigating economic prospects

Methods adopted for analyzing social acceptance

THANK YOU

CONTACT US FOR MORE INFORMATION

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The LEAP-RE project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.