Demand Side Management for Microgrids: Experiences from the Re-empowered Project

Prof. Nikos Hatziargyriou
National Technical University of Athens, Greece

e-mail: nh@power.ece.ntua.gr

Introduction

- Overview
- Demand side management in off-grid Microgrids: Kythnos/ Gaidouromantra (Greece), Ghoramara island (India) and Keonjhar (India)
- Flexibility from district heating systems: Bornholm island (Denmark)

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Overview of the RE-EMPOWERED EU-India project

Partners					
European			Indian		
1	ICCS - NTUA (European Coordinator)	Greece	8	Indian Institute of Technology Kharagpur (Indian Coordinator)	
2	Imperial College London	United Kingdom	9	Indian Institute of Technology Bhubaneswar	
3	Danmarks Tekniske Universitet	Denmark	10	Visvesvaraya National Institute of Technology	
4	Bornholms Varme As	Denmark	11	CSIR - Central Mechanical Engineering Research Institute	
5	Protasis Sa	Greece	12	Indian Institute of Science	
6	Deloitte Advisory, S.L.	Spain	13	Indian Institute of Technology Delhi	
7	DAFNI	Greece	14	Lab Concern India (LCI)	

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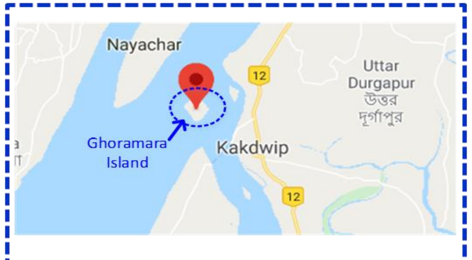
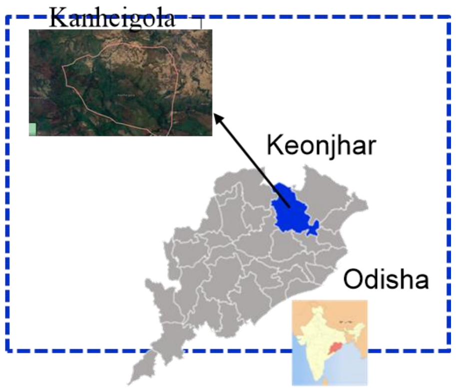
Pilot sites

4 pilot sites, 2 in EU and 2 in India. Demos range in size and technical maturity.

- ***Bornholm Island (Denmark):***
  - *Synergies of integrating energy vectors (power/heat) were explored*
- ***Kythnos island (Greece):***
  - *Gaidouromantra microgrid (first microgrid in Europe): Reduction of operational costs*
- ***Keonjhar (India):***
  - *Isolated rural Villages*
  - *Existing renewable facilities were upgraded to improve the living standards of the community. Biomass and biogas were integrated. 24-hour electricity supply for 75 households*
- ***Ghoramara Island (India):***
  - *Not interconnected island, residents live in very poor conditions, severe cyclonic storms every 5-10 years*
  - *Microgrid was built to electrify more than 650 households of the island*



Ghoramara Island, West Bengal India



Bornholm island, Denmark

Kythnos island, Greece

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Ghoramara island (India)

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Population of 3,000.

Energy sources added in Ghoramara island to provide electricity to 1100 houses along with school, shops and health center:

PV 240 kWp, Wind Turbine 10 kWp.

-2 larger microgrids (155 kW + 75 kW) using commercial equipment.

-1 microgrid (20kW) using RE-EMPOWERED developed technologies.

Several power electronic devices will be developed/installed:

- Partial Power Converter to integrate PVs (for higher capture of solar energy during partial shading)
- SiC based dc-dc converter to integrate BESS
- Load Flow Controller to transfer power between 2 microgrids
- Power Conditioner multilevel converter

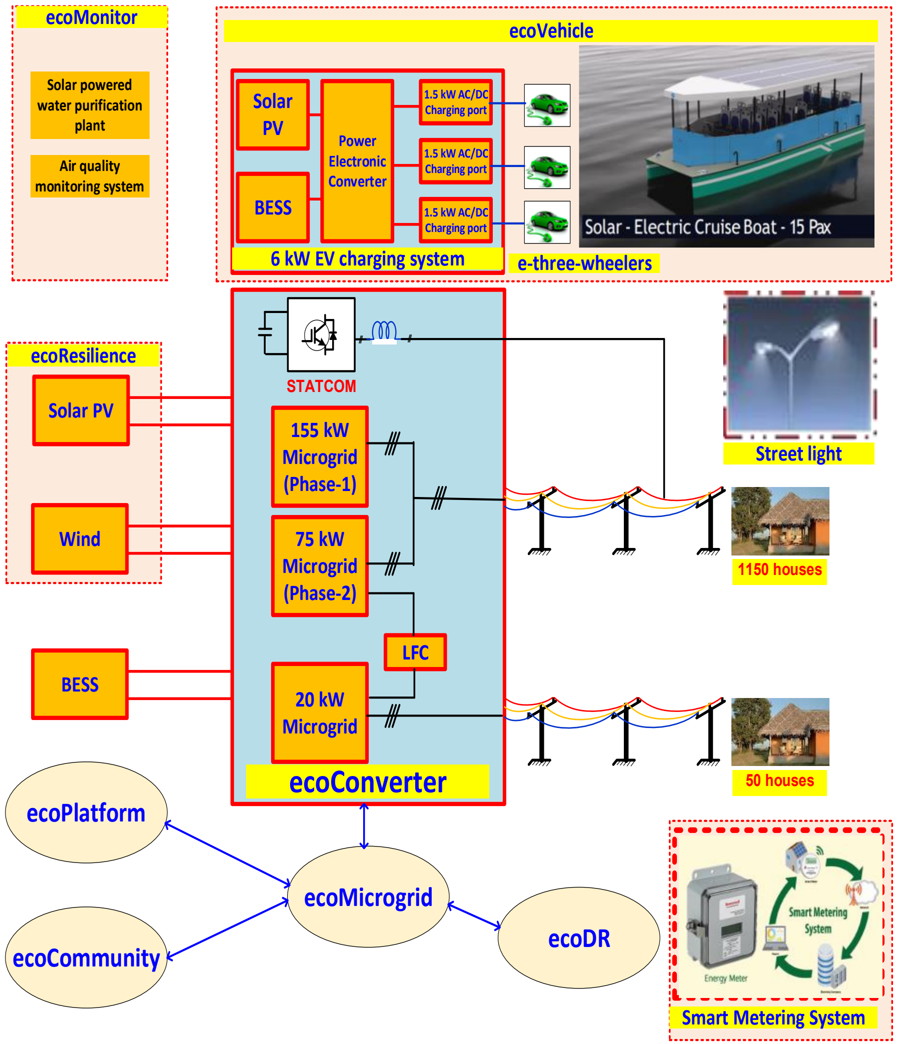
Charging station with local PV and BESS for electric three wheelers

Electric boat to carry 15 passengers

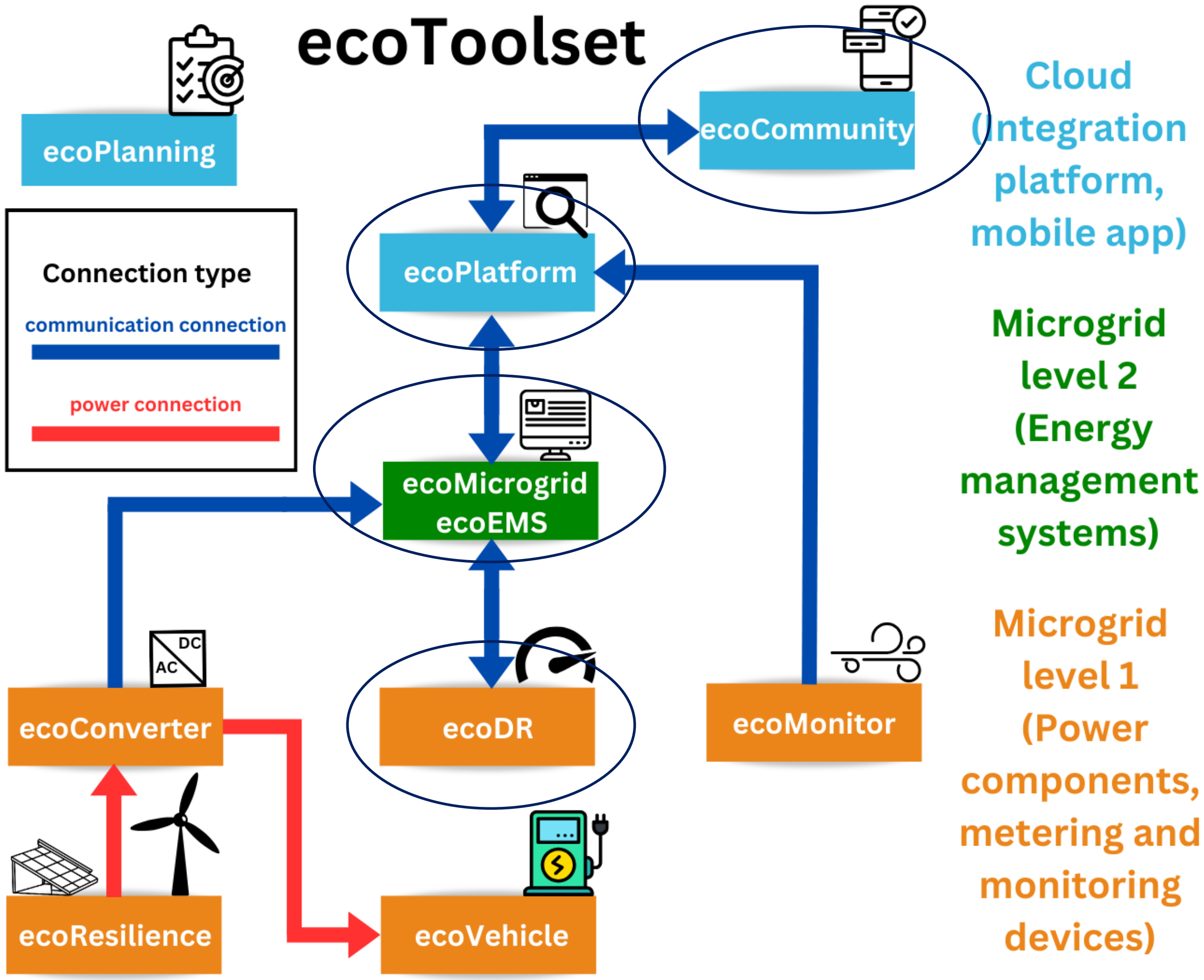
Dimmable street lights

Cyclone resilient structure for PVs and Wind Turbine

Special focus on optimization, demand side management, community engagement.



Ecotools



- ***ecoPlanning***: *Energy planning tool*
- ***ecoPlatform***: *Cloud-based interoperable platform*
- ***ecoCommunity***: *Citizen engagement digital platform*
- ***ecoEMS***: *Energy Management System for isolated and weakly interconnected systems*
- ***ecoMicrogrid***: *Energy Management System for smaller off-grid systems*
- ***ecoConverter***: *Power electronic converters for dc/ac microgrids*
- ***ecoDR***: *Smart Meter - Load controller*
- ***ecoMonitor***: *Air quality monitoring*
- ***ecoResilience***: *Cyclone Resilient infrastructure for wind turbines and PV*
- ***ecoVehicle***: *Electric vehicle charger*

Demand-side management (DSM) in off-grid microgrids

Load classification - critical, non-critical (flexible), controllable-uncontrollable, residential, commercial, community, etc

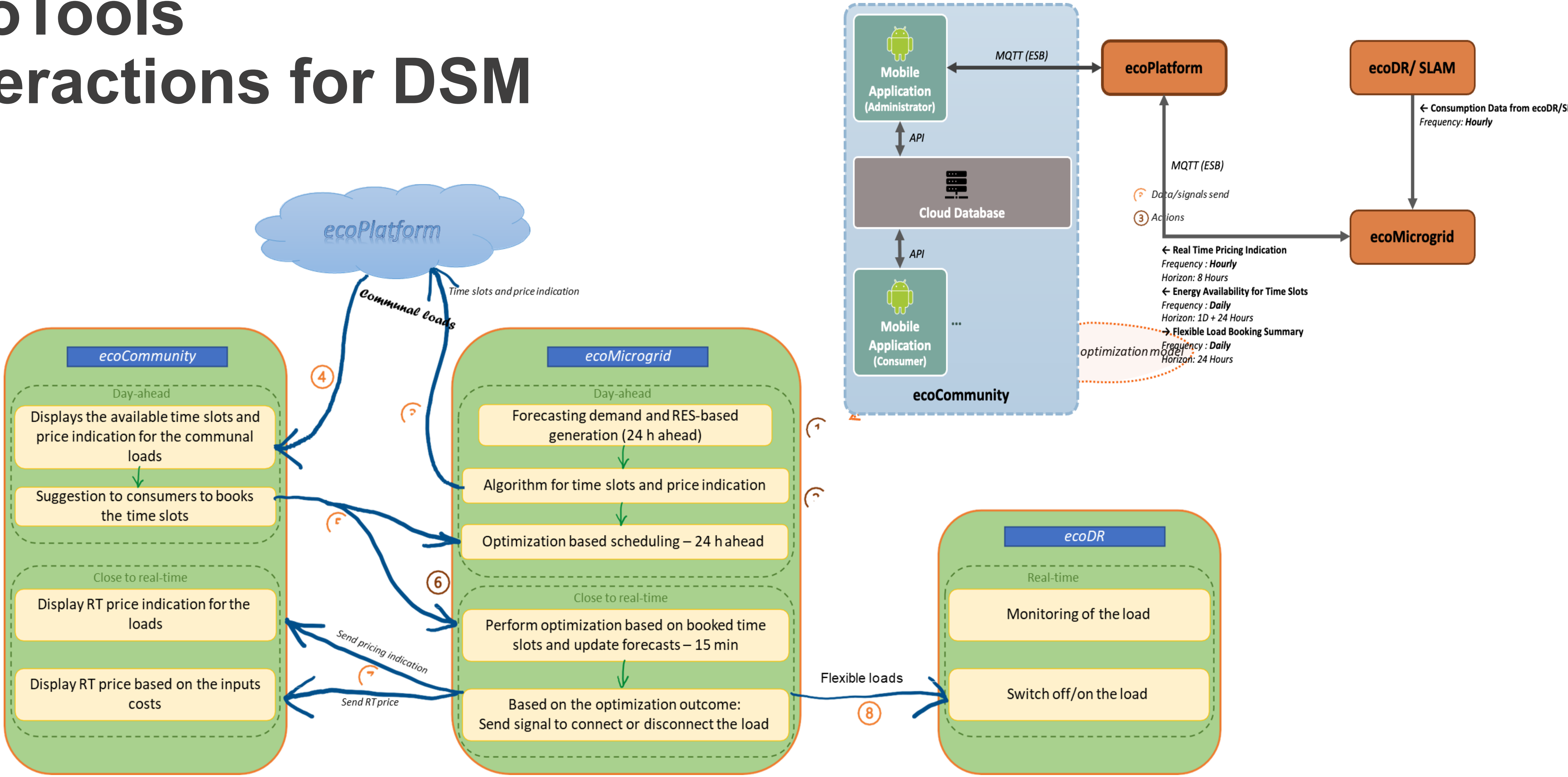
DSM strategies were tailored for all pilot sites, including:

1) **Day-ahead** DSM based on algorithm generated **time slots**

2) DSM based on **price indications**

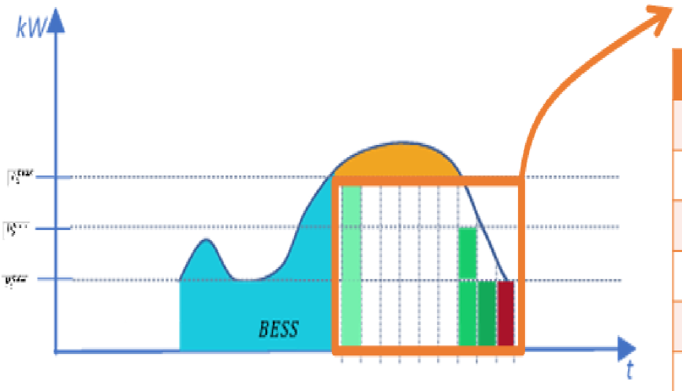
3) Emergency actions based on the microgrid optimization

ecoTools interactions for DSM



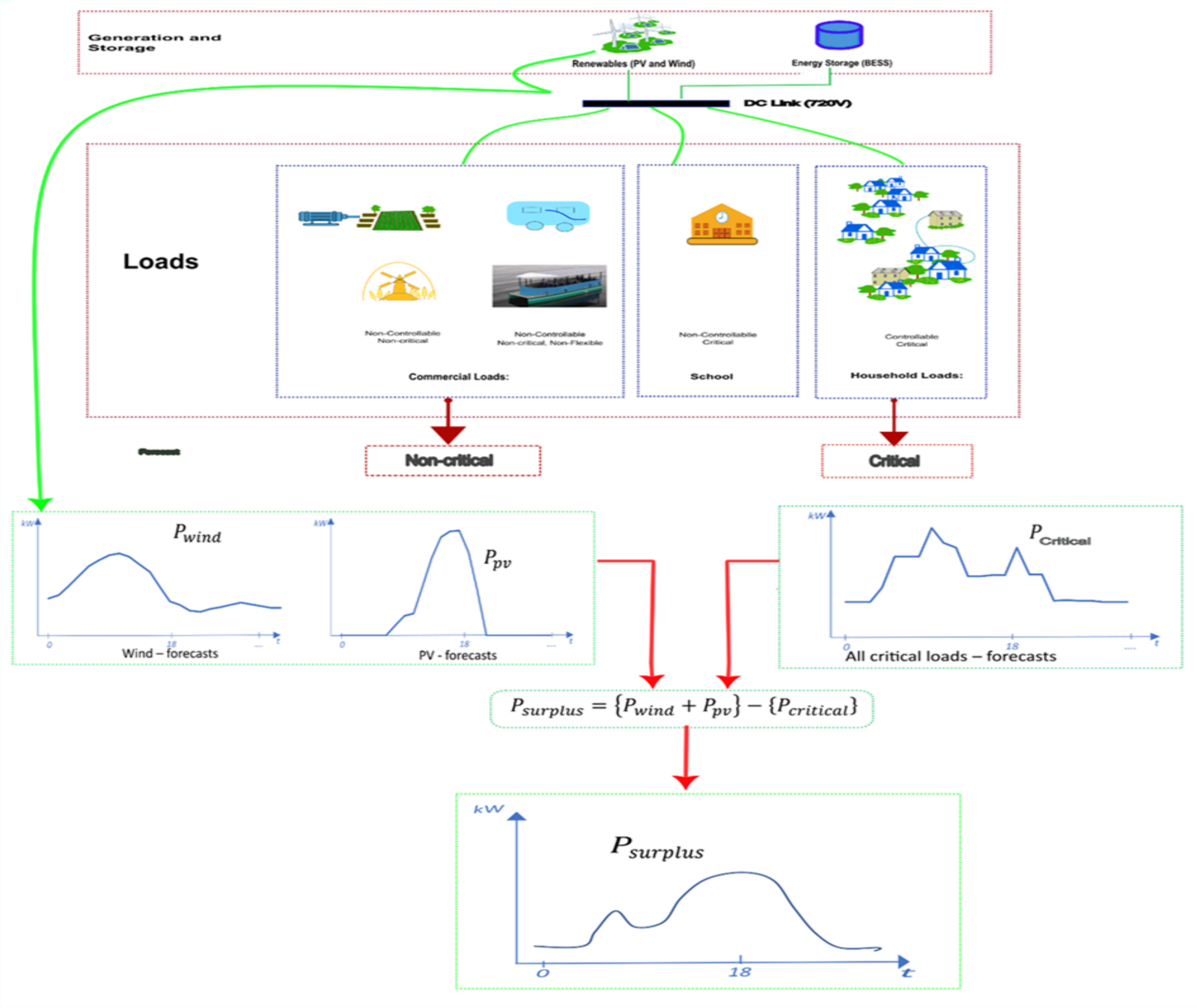
DSM operation

- Forecasts of RES and critical loads for 24 hours ahead.
- ecoMicrogrid sends time slots and available units that can be activated during the time slots. Sends price indications
- ecoCommunity displays available time slots and price indications and provides suggestions to consumers about when to block the time slots.



Send time slots and number of units to *ecoCommunity*

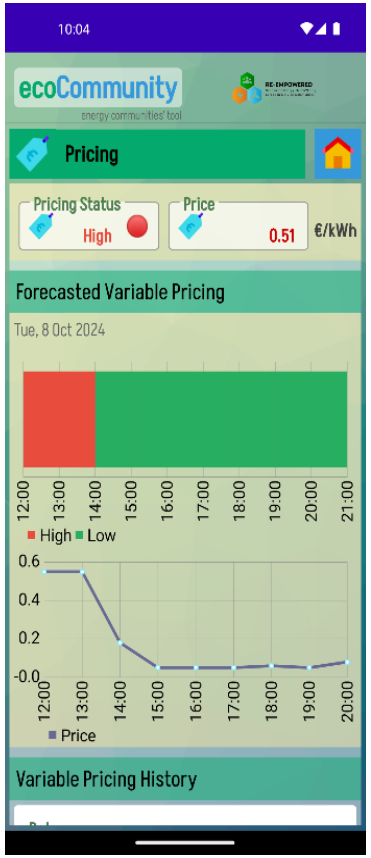
Time (h)	Color	Units
11	Green	3
12	Green	3
....	.....	.....
17	Green	2
18	Green	1
19	Red	-



ecoCommunity smart phone app

Modules:

- Energy Consumption
- Variable Pricing Indication
- Load Booking
- Problem Reporting
- Forum
- Help



- **50%** of consumers engaged with smartphone application.
- Ease of use for end-users is rated as **5 / 5.**

Dynamic Pricing Module: Forecasted pricing for next set of hours.

Co-optimization (Kythnos)

- **Enhances energy efficiency** by remotely monitoring and controlling the HVAC system at the demo site's central control station.
- **Integrated with ecoMicrogrid**, enabling effective energy management of the cooling vector.

- **Multi-Vector Optimization Validation:** During the summer months, the ecoMicrogrid system demonstrated its ability to significantly enhance RES utilization by leveraging the cooling vector. Key results included:
- **22% Increase in RES Utilization:** Achieved through strategic use of cooling systems.
- **18% Reduction in RES Curtailment:** Excess renewable energy was effectively redirected to the cooling vector.
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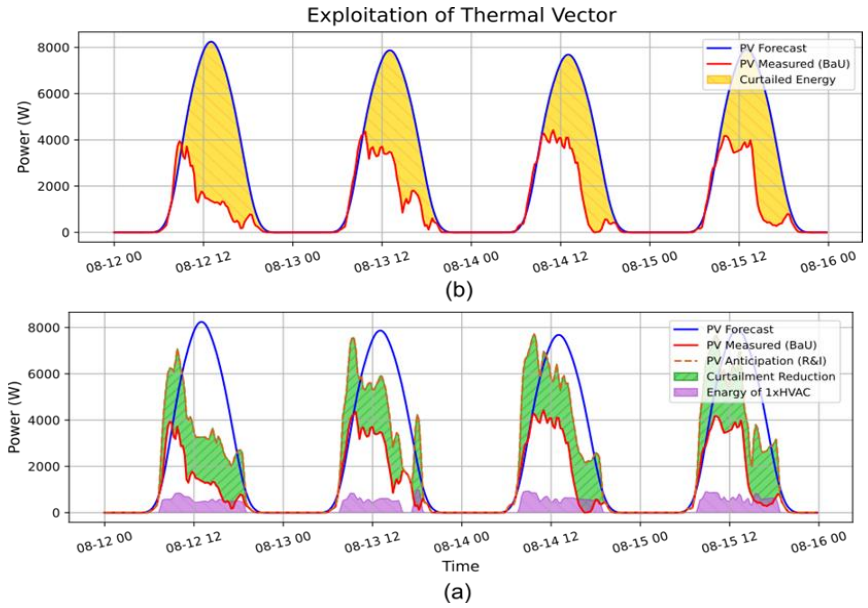
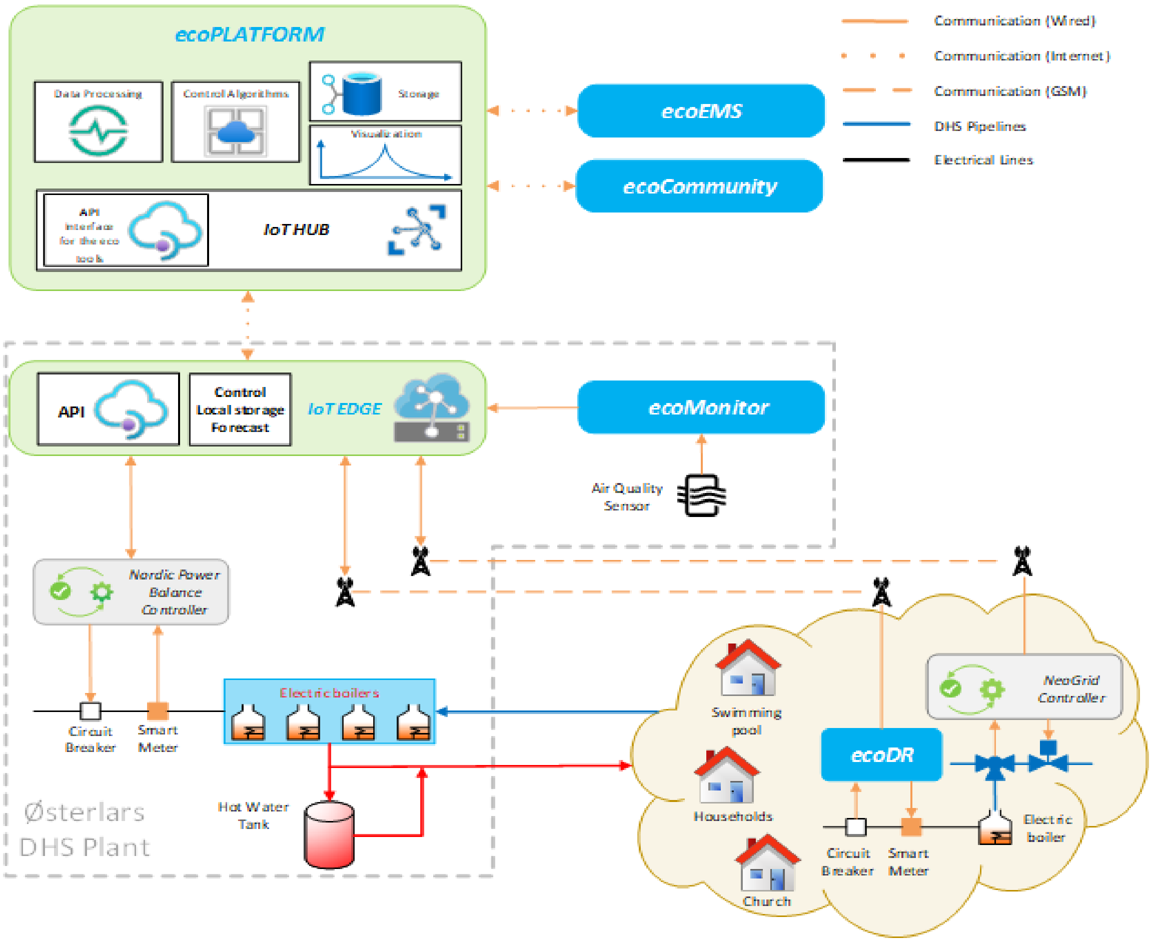
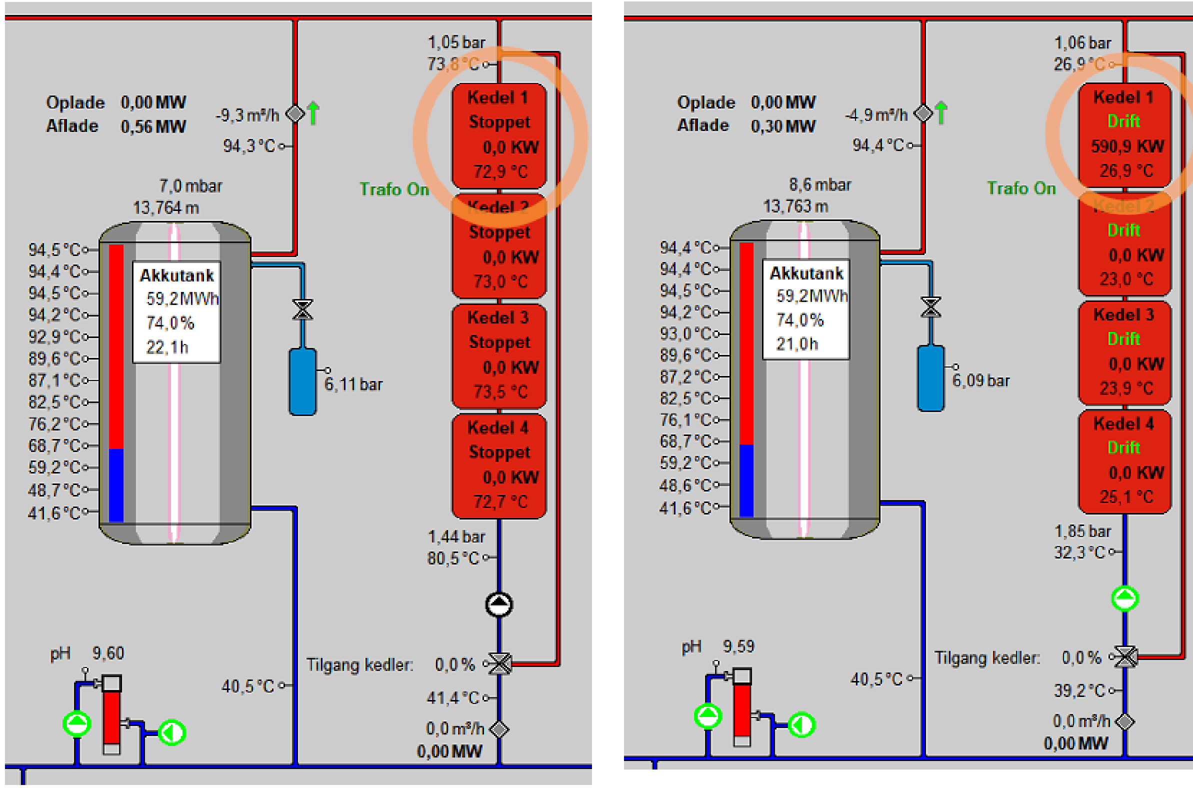


Bornholm Island: District Heating System

- Østerlars heat plant : 4 MW boiler fueled by locally produced straw, 4*0.6 MW electric boilers (EBs) for reserve and peak loads, and a 1,500 m3 hot water storage tank with a capacity of 80 MWh. Those are the heat sources that provide the heat to the local DHN.
- Electric Boilers were activated when there was excess production from PV to avoid RES curtailment. The excess PV power was provided as heat to the District Heating Network, leading to a reduction of the utilization of the straw boiler.
- Controlling electric boilers considering demand, electricity prices, cost of biomass and weather forecasting



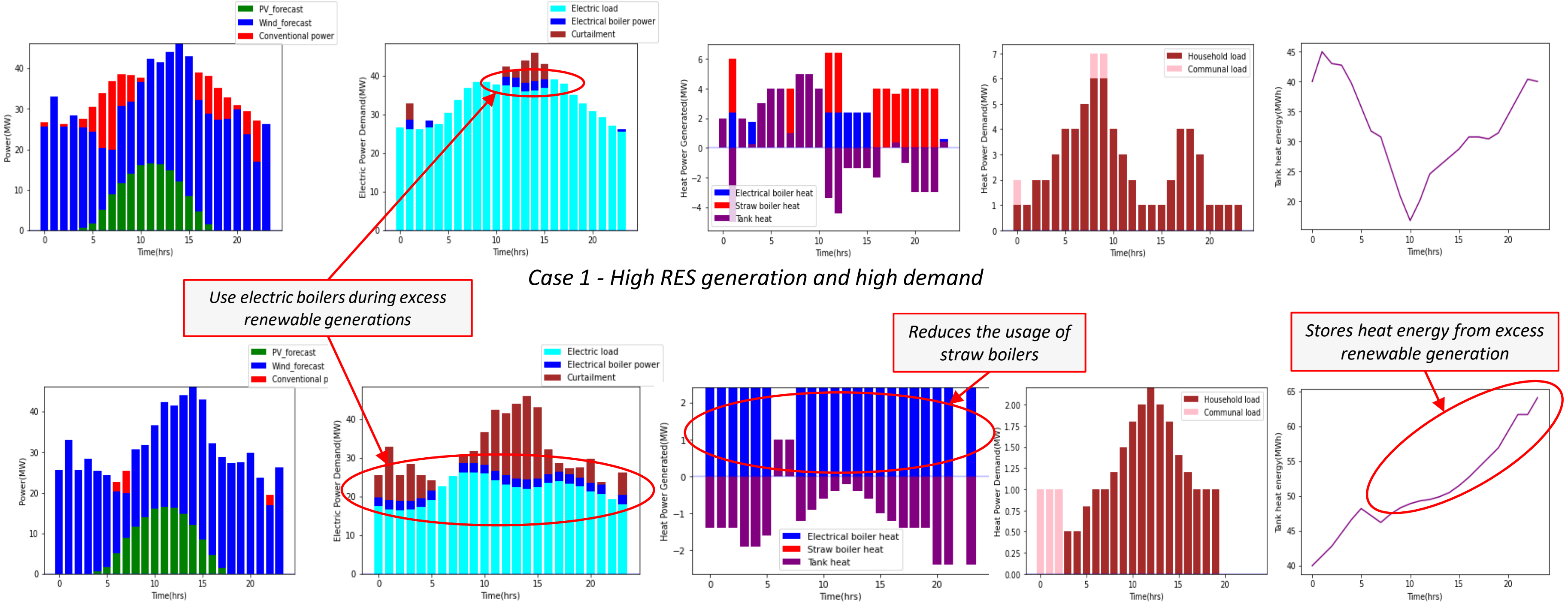
Installations at consumers – SCADA interventions



SCADA system at Østerlars heat plant. Left: Electric boiler 1 is stopped and a consumption of 0 kW. Right: The electric boiler is active with a consumption of 591 kW corresponding to given setpoint.

ecoEMS: Bornholm application

- The objective is to **utilise the flexibility of the district heating network** to **reduce renewable curtailment** in the electrical system and **reduce the use of conventional generation**.



Case 1 - High RES generation and high demand

Case 2 - High RES generation and low demand

ecoEMS: Bornholm application

- The implementation of co-optimisations leads to the following advantages:
  - **Reduces renewable curtailment** during excess renewable generation
  - **Reduces the usage of straw boilers** by utilising the electric boilers
  - **Stores the heat energy** in the hot water tank during excess renewable generation
  - Effective utilisation of hot water storage and flexible heating demand to **minimise the operating cost**.

Table 1.1: Reductions in renewable curtailment, straw cost and emissions per day

Cases	*Case 1 (High load – High RES)*			*Case 2 (Low load – High RES)*		
Optimisation	*Independent*	*Co-optimisation*	***Change***	*Independent*	*Co-optimisation*	***Change***
Renewable Curtailment	42.7 MWh	25.9 MWh	**39.2 %** ▼	224.8 MWh	174.5 MWh	**22.4 %** ▼
Fuel cost of Straw boiler (EUR)	1146	846	**26.2 %** ▼	902	0	**100 %** ▼
CO_2 emissions from Straw Boiler (ton)	23.04	17.01	**6.03** ▼	18.14	0	**18.14** ▼
Gain in energy in the hot water tank (MWh)	0	0	-	0	23	**23** ▲

Approximate operational cost of Straw Boiler = 17.9 EUR / MWh
Approximate emissions of Straw Boiler = 360 kg CO_2 / MWh

Conclusions

- Demand-side management supports the efficient operation of local energy systems and islanded microgrids
- Actual implementation of DSM involves hardware infrastructure (smart meter, smart phones etc) and appropriate software (smart phone app, EMS or similar, interoperability, cloud, etc)
- The social dimension is very important: community engagement from early stages (also in the design process) and proper training are important
- DSM at the Indian remote communities was challenging
- Co-optimizing electricity and heating leads to improved results

Thank you for your attention!

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N. Hatziargyriou, P. Kotsampopoulos, S. Maiti, S.B. Karanki, C.N. Sørensen, A. Vasilakis, S. Kumar Giri, G. Yang, B. Pal, G. Milionis, R. Keshri, M. Thangadurai, P. Bhola, *"Renewable Energy Empowering Remote Communities Through Microgrids: Control and management strategies to provide sustainable and cost-effective electricity,"* ***IEEE Electrification Magazine, 2025***

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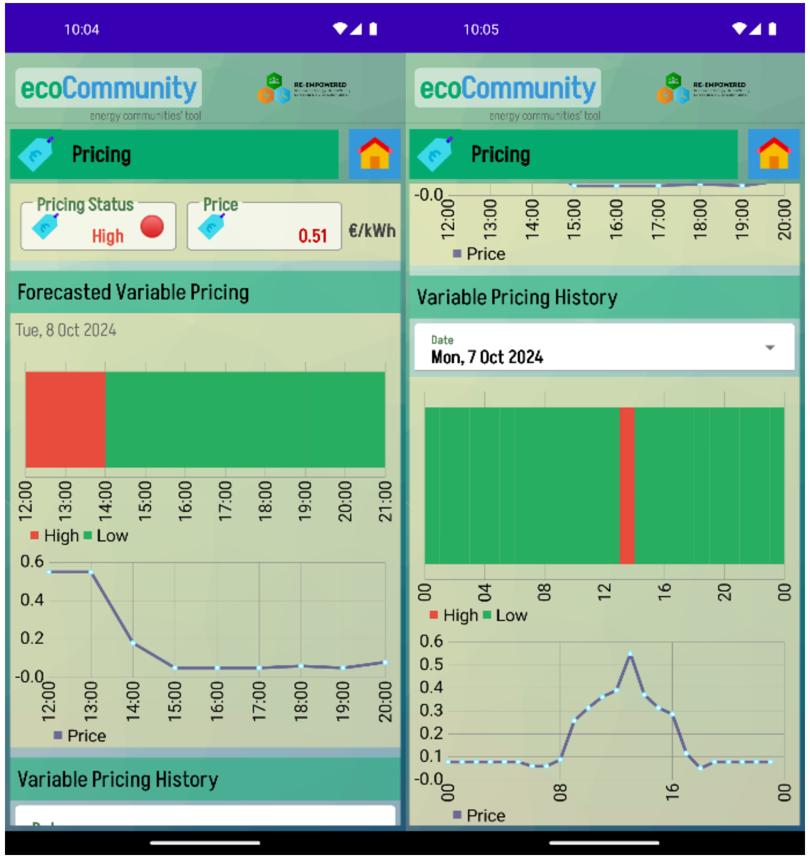
Demonstration and results of ecoCommunity

Results:

- **Smart Consumption Decisions**: Consumers receive real-time guidance on using noncritical loads based on dynamic pricing.
- **Voluntary Demand Response**: Encourages users to adjust their consumption to maintain system stability and efficiency.
- **Energy Monitoring**: Users can access their electricity consumption data anytime.
- **Flexible Load Scheduling**: Consumers can schedule and shift loads (e.g., water pumps) using ecoCommunity's recommended time slots.
- **Enhanced User Experience**: The app offers a forum, problem reporting, guides, and training materials while ensuring privacy protection.

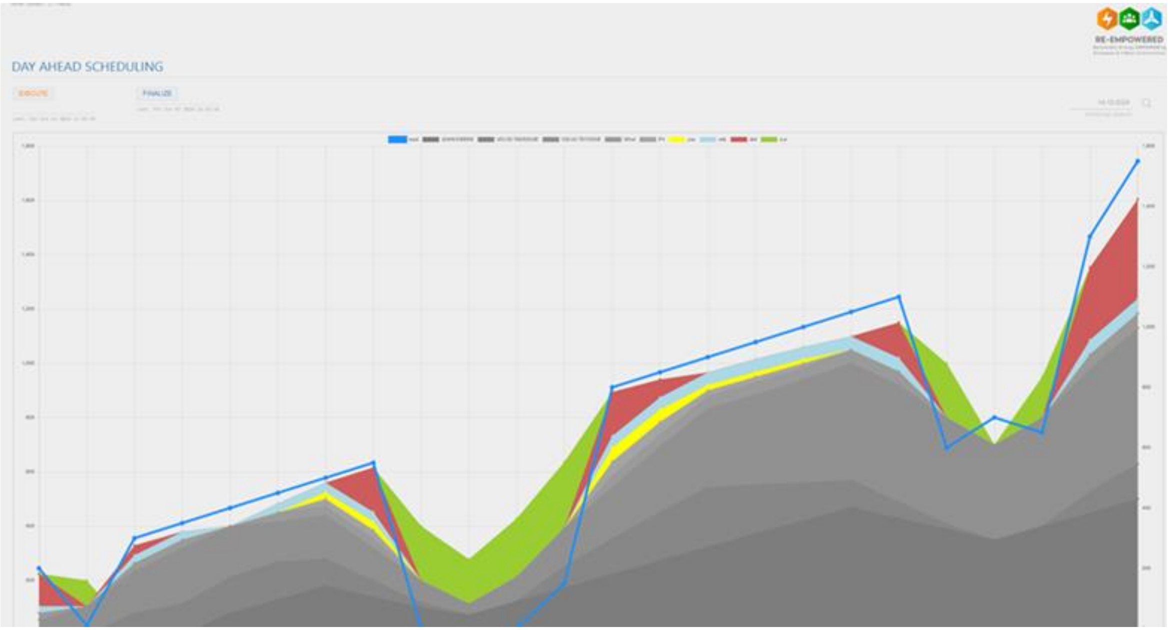
Metrics:

UC: "Displaying the dynamic pricing based on shape of energy profile"



Screenshots of ecoCommunity Dynamic Pricing Module for Gaidouromandra demo site: (Left) Forecasted pricing for next set of hours. (Right) pricing variation during the previous day.

Deployment of ecoTools: ecoEMS



Output of ecoEMS scheduling algorithm for Bornholm demo site.

Site measurements sent to the ecoEMS database through ecoPlatform for data processing and optimization.

Demonstration activities: ecoEMS

Selected use case - EMS_ 2UC2.2:
Unit Commitment and Economic Dispatch algorithms

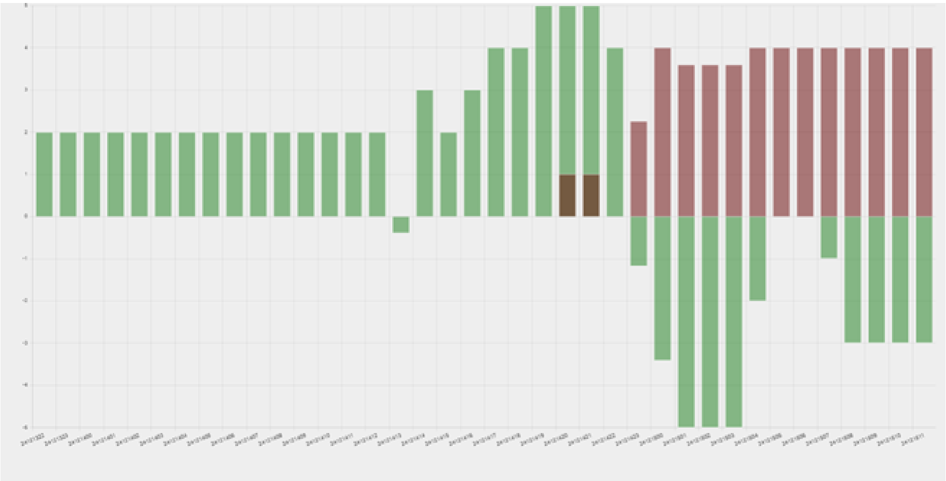


Figure: ecoEMS displaying the suggested temperature adjustment to a district heating unit control device

01	**Simulation Preparation**	Utilized forecasts, community engagement, and data from Neogrid devices for daily simulation setups.
02	**Pre-Day Ahead Scheduling**	Executed scheduling, issued orders, and visualized results for energy dispatch decisions.
03	**Day Ahead Scheduling Execution**	Performed hourly scheduling with a 24-hour horizon to optimize energy dispatch.
04	**Temperature Adjustment Optimization**	Adjusted Neogrid devices' temperatures based on water return temperature for enhanced efficiency.
05	**Data Integration and Processing**	Used MQTT module for seamless data transfer and processing in the ecoPlatform.

Demonstration activities and results ecoTool: ecoCommunity

(a) (b) (c) (d)

Figure. ecoCommunity: (a) Consumption is displayed on a daily basis, (b) monthly basis, (c)&(d) Menu presented to user to accept/reject timeslots to participate in project operations.

Integration Success

Integration of district heating units with ecoTools ecosystem, including ecoCommunity, achieved. Monitoring variables such as return temperature and flowrate established early.

User Interaction

Users can track daily and monthly consumption via ecoCommunity. User-friendly interfaces enable tracking of energy usage efficiently.

Operational Participation

Users can schedule participation in ecoTools operations via ecoPlatform, choosing specific hours for ecosystem operations, enhancing user control and engagement.