RE-EMPOWERED

Renewable Energy EMPOWERing
European & InDian Communities

Deliverable 8.4: Assessment of demos and tools and replication potential

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DEM Demonstrator, pilot, prototype	**CO** Confidential, only for members of the consortium (including the Commission Services)
DEC Websites, patent fillings, videos, etc.	**EU-RES** Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)
OTHER ETHICS Ethics requirement	**EU-CON** Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)
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Authors: Jesús Rubio Conde (Deloitte), Enrique Doheijo Lozano (Deloitte), Sofía de Palacios Pérez-Maffei (Deloitte), Santiago Murube Crego (Deloitte), María Rey Marhuenda (Deloitte), Miguel Pérez Merelles (Deloitte), Prabha Bhola (IIT KGP), Alexandros Chronis (ICCS-NTUA), Alkistis Kontou (ICCS-NTUA), Aris Dimeas (ICCS-NTUA), Athanasios Vasilakis (ICCS-NTUA), George Milionis (ICCS-NTUA), Ilias Katsampiris (ICCS-NTUA), Panos Kotsampopoulos (ICCS-NTUA), Vasilios Mouzas (ICCS-NTUA), Christian Nygaard Sørensen (BV), Andreas Soggard (BV), Konstantinos Karanasios (DAFNI), Petros Markopoulos (DAFNI), Aysegül Kahraman (DTU), Guangya Yang (DTU), Stratis Batzelis (Imperial), Thomas Joseph (Imperial), Firdous Ui Nazir (Imperial), Sai Pavan Polisetty (Imperial), Santu Giri (CMERI), Murugan Thangadurai (CMERI), Anirudh Kumar (CMERI), Srinivas Bhaskar Karanki (IIT BBS), Suman Maiti (IIT KGP), Bikram Kumar Samanta (IIT KGP), Ritesh Kumar Keshri (VNIT).

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Reviewers

Description	Name	Partner	Date
1	Maria Valliou	ICCS-NTUA	18.12.2024
2	Ravi Ranjan	IIT BBS	18.12.2024

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EXECUTIVE SUMMARY

Tasks 8.4 and 8.5 of the RE-EMPOWERED project focus on conducting a comprehensive assessment of the demo Sites and application of the ecoTools. This assessment considers technical, economic, social, and environmental perspectives. The impacts are measured using a set of Key Performance Indicators (KPIs), some of which were initially defined in Deliverable 2.1 “Report on Requirements for Each Demo, Use Cases, and KPIs Definition”, while others were developed throughout the project.

Task 8.6 focuses on evaluating the replication potential of RE-EMPOWERED's ideas and solutions for islands and isolated microgrids across the EU and India. Replicability is assessed through KPIs measured for each Demo Site. Additionally, replicability events have been organized and a comprehensive Replication Plan has been developed, outlining how each ecoTool can be applied to specific example islands.

For each Demo Site, KPIs are measured by comparing the Business as Usual (BAU) scenario with the scenario where RE-EMPOWERED solutions are implemented.

These assessments are carried out as follows:

- The technical assessment is based on the measurement of the different KPIs in the Demo Sites, by the Demo Site leaders and the ecoTool developers, and the comparison of the values before and after the installation of the ecoTools.
- The economic assessment has been carried out using data obtained directly onsite by the Demo Site leaders and tool developers. It should be noted that in Deliverable 8.2 “Report on the business models and financing tools (V2)”, a complete economic assessment of all business models can be found.
- The social impact assessment has been performed according to the feedback received from the Demo Site leaders.
- The environmental impact assessment has been carried out based on the increase in the RES production in each Demo Site and the air quality measurements of the ecoMonitor tool.
- A replicability assessment has been produced considering the replication potential of the use of the ecoToolset in other microgrids or islands with weak or no connection to the grid.

The tools developed in the RE-EMPOWERED project have demonstrated significant benefits, particularly in increasing the penetration of renewable energy in microgrids and areas with limited or no connection to the main grid. These tools have also effectively boosted citizen engagement with renewable energy adoption and demand response measures.

The tested solutions have successfully enhanced renewable energy integration while reducing curtailments, leading to notable decreases in fossil fuel usage, greenhouse gas emissions, and associated economic costs. In the Indian demo sites, the implemented solutions have further improved citizens' quality of life by significantly enhancing access to electricity, providing lighting at night, and fostering increased economic activity in these regions.

KEYWORDS:

Technical assessment, Economic assessment, Social assessment, Environmental assessment, Replicability, Key Performance Indicators, Renewable Energies, Demand Response, Business-as-Usual, Smart Grids, Energy Communities

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Acronyms

Acronym	Description
€	Euro
₹	Rupee
° C	Degree Centigrade
µg	Microgram
ρ	Density
AC	Alternating current
Ah	Ampere hour
AMRI	Air Quality Measurement Reliability Index
APE	Average Percentage Error
API	Application Programming Interface
AQI	Air Quality Index
b	Base scenario
BAU	Business as Usual
BESS	Battery Energy Storage System
BLDC	Brushless Direct Current
BO	Bornholm Island Demo Site
CE4EU Islands	Clean Energy for EU Islands Initiative
CERTH	Centre for Research and Technology, Hellas
CHP	Combined heat and power
CO	Carbon monoxide
CO_2	Carbon dioxide
CPMR	Conference of Peripheral Maritime Regions
C_r	Rated capacity
$C_{\mathfrak{R}S_{R\&I}}$	RES Curtailment for the RE-EMPOWERED scenario
$C_{RES_{BaU}}$	RES Curtailment for the BAU scenario
Cx	Force coefficient
DC	Direct current
DG	Diesel generator
DHN	District heating network
DK2	East Denmark grid
DKK	Danish Krone
DoD	Depth of discharge
DR	Demand response
DSO	Distribution System Operator
DSM	Demand side management
DST	Department of Science and Technology
EMS	Energy Management System

Acronym	Description
EnC	Energy Community
ESCO	Energy Services Company
E_t	Forecast error in the calculation
EU	European Union
FCR-D	Frequency containment reserve for disturbances
FD	Functional Downtime
FOS	Factor of Safety
F_t	Forecast value of load or generation, at period "t"
g	Gram
GA	Gaidouromantra Microgrid
Gbps	Giagabyte per second
GDPR	General Data Protection Regulation
GH	Ghoramara Island Microgrid
GWh	Gigawatt hour
h	Hour
HEDNO	Hellenic Electricity Distribution Network Operator
HLS	House Lighting System
HP	Horse power
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
INR	Indian Rupee
IoT	Internet of Things
IPTO	Independent Power Transmission Operator
J	Total number of scenarios / incidents
KE	Keonjhar Microgrid
kg	Kilogram
km	Kilometer
km^2	Square kilometre
kN	Kilonewton
KPI	Key performance indicator
kV	Kilovolt
kVA	Kilovolt ampere
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt peak
KY	Kythnos Power System Demo Site
I	Number of facilities under consideration

Acronym	Description
LED	Light-Emitting-Diode
LMSWT	Locally Manufactured Small Wind Turbine
L_t	Actual, real value of load or generation, at period "t"
$\bar{L}$	Average of the actual values of generation
m/s	Meters per second
m3	Cubic meter
MAD	Median Absolute Deviation
MAE	Mean Absolute Error
MB	Megabyte
ME	Mean Error
MAPE	Normalized Mean Absolute Percentage Error
MGCC	Microgrid central controller
MJ	Mega Joule
min	Minute
mm	Milimeters
MPa	Mega Pascal
MQTT	Message Queuing Telemetry Transport
MVA	Megavolt-ampere
MW	Megawatt
MWh	Megawatt-hour
MWp	Megawatt peak
n	Number of samples/observations
N	Newton
N/A	Not applicable
NGO	Non-governmental organization
Nj	Number of customers interrupted per incident
nMAE	Normalized Mean Absolute Error
nMAPE	Normalized Mean Absolute Percentage Error
NO_2	Nitrogen dioxide
Nº	Number
NT	Total number of customers served
O_3	Ozone
ODI	Operational Downtime Index
PCB	Production Control Board
$P_{i,t}^{prod}$	Available energy production of the ith RES facility at period t
$P_{i,t}^{inj}$	Injected energy in the ith RES facility at period t
PHC	Primary Healthcare Centre
PM	Post meridiem

Acronym	Description
PM2.5	Particulate matter with a diameter lower than 2.5 micrometres (Fine particles)
PM10	Particulate matter with a diameter lower than 10 micrometres (Inhalable particles)
PPC	Public Power Corporation
ppm	Parts per million
PU	Public
PV	Photovoltaics
Qmax	Maximum charge available in the battery
R	Report
R^2	Coefficient of determination
RE	Renewable Energy
RES	Renewable Energies / Renewable Energy Sources
REST	Representational state transfer
Ri	Restoration time for each interruption
S	Solar panel area
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory control and data acquisition
SMAPE	Symmetric Mean Absolute Percentage Error
SO_2	Sulphur dioxide
SoC	State of Charge
SoH	State-of-Health
SRI	System Replication Index
SSL	Secure Sockets Layer
STUCO	Statia Utility Company
T	Set of time intervals of period under consideration
TLS	Transport Layer Security
TSO	Transmission System Operator
V	Version
V	Volt
v	Velocity
vs	Versus
W	Watt
WP	Work Package
WP	Wind Power
Wp	Watt peak
WRP	Wind Load Reduction Potential
yi	Actual value
$\hat{y}$	Forecasted value

1. Introduction

1.1 Purpose and scope of the document

The main objective of the RE-EMPOWERED project is the development and demonstration of new tools, which can maximize the integration of renewable energies in microgrids, energy islands, and multi-microgrid applications, focusing specially on energy communities. This set of tools, known as "ecoToolset", has introduced new functionalities, such as demand response and dynamic pricing, supporting the decarbonization of multi-energy local energy systems. The ecoToolset has been tested in four European and Indian Demo Sites: Bornholm Island (Denmark), Kythnos Island (including the Gaidouromantra microgrid) (Greece), Ghoramara Island (West Bengal, India), and Keonjhar (Odisha, India).

Tasks 8.4 and 8.5 of Work Package (WP) 8 are focused on the technical, economic, social, and environmental impact assessment for the use of the ecoTools in each Demo Site. These assessments are carried out by measuring a set of key performance indicators (KPIs) as defined in WP2, specially designed for each ecoTool, Demo Site, and Use Case. Task 8.6 focuses on the analysis of the replicability of the use of the ecoTools in different islands or isolated microgrids, both in India and in the EU.

The objective of this document is to present the results of the Tasks 8.4, 8.5 and 8.6. Specifically, an assessment of the impact of the use of the proposed ecoTools in each Demo Site is carried out, from a technical, economic, social, and environmental perspective. Therefore, in RE-EMPOWERED, a holistic evaluation of all impacts has been carried out, as shown in Figure 1. This document includes the overall evaluation of the five demo sites.

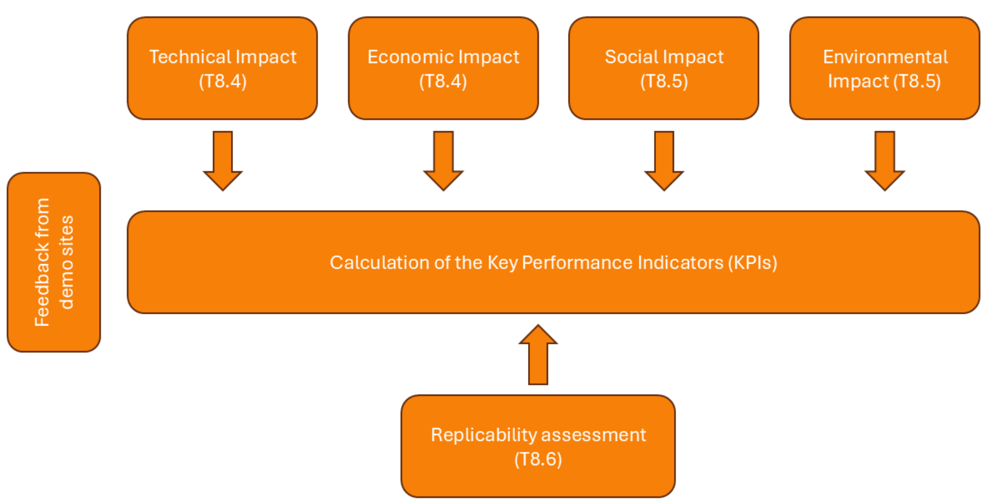

Figure 1 Methodology developed in RE-EMPOWERED for the evaluation of the impact of the ecoTools.

The **technical impact assessment** is based on a set of technical parameters, which are calculated for each Demo Site. Then, a comparison between the situation before the implementation of the ecoToolset (the baseline, or the Business-as-Usual scenario), and after the implementation of the ecoTools is carried out, once they have been implemented and tested (the RE-EMPOWERED scenario). This offers a clear view of the impact derived from the use of the ecoTools.

The **economic impact assessment** has been carried out considering up to key performance indicators, such as reduced overall cost. It can be mentioned that a complete assessment of the business models for each Demo Site, including the net present value, internal rate of return, and payback, as well as a description of the investment cost, the operation and maintenance costs, and the expected incomes, can be found in the Deliverable 8.2 “Report on the business models and financing tools (V2)”.

As for the **social impact assessment**, it has been based on the evaluation of the impact of the creation of energy communities/engagement on the demo sites, and on the implementation of demand response mechanisms. The social impact has been measured considering the employment, which is created, as well as the increase in the participation of citizens in energy communities, and their involvement in the project and satisfaction with its results. Most notably, for the Indian demo sites, the significant impact in terms of an increase of the number of citizens and businesses which are connected to the electricity supply, or which receive a better-quality electricity supply is measured.

Regarding the **environmental impact assessment**, it considers the reduction of greenhouse gas emissions, derived from a higher level of penetration of renewable energies, and the replacement of fossil fuels for renewable energies. Besides, the effect in terms of environmental awareness for the population is considered. In some of the demo sites, the emissions of gases such as PM2.5, PM10, NO_2, CO, O_3, SO_2 are measured.

Finally, the replicability of the proposed ecoTools is evaluated, by considering if standardized protocols are used in the ecoTools, and how they can be implemented in other islands, among other. Replicability events are also described. An Appendix is included which presents a Replication Plan tailor made for the islands of the Clean Energy for EU Islands Initiative, including example islands where the solutions could be replicated.

A preliminary selection of KPIs was carried out in December 2021 and is described in detail in Deliverable 2.1 “Report on requirements for each demo, use cases, and KPIs definition”. However, in these three years, the KPIs have been updated and re-evaluated, and they have been calculated and included in this report.

Each KPI is associated with one or more ecoTools, recognizing that the impact of each ecoTool becomes measurable only when applied to a specific scenario. Defining KPIs at the Demo Site level, rather than for each individual ecoTool, enables precise estimations without attempting to isolate the impact of each ecoTool—a challenging task, given their integrated operation.

1.2 Structure of the document

The rest of the document is structured as follows.

Section 2 focuses on the technical impact assessment of demos and tools. Firstly, the methodological aspect of the technical impact is described, along with a table which includes the specific KPIs that are measured in each Demo Site. Then, the detailed calculation of each KPI, for each Demo Site, is presented. Section 3 includes the results which are obtained from the economic assessment of the Demo Sites. Section 4 focuses on the social assessment of the Demo Sites. Section 5 includes an analysis of the environmental impact of the use of the ecoTools in each Demo Site.

Finally, Section 6 is centred on the assessment of Replicability for the use of the ecoTools, in other relevant cases, similar to the Demo Sites which have been evaluated. This Section focuses on the application of ecoTools in microgrids and zones with weak connection to the main grid, in other situations in the European Union or in India.

The Deliverable is concluded with Section 7, which includes the main conclusions and results from the evaluation of the KPIs.

Finally, a detailed Replication Plan is included in the Appendix.

2. Technical assessment of demos and tools

2.1 Methodology to carry out the technical impact assessment of demos and tools

In this chapter, the methodology to calculate the different technical KPIs is included. It is based on the detailed description included in Deliverable 2.1 “Report on requirements for each demo, use cases and KPIs definition”.

The results for the evaluation of the KPIs come from the activities which have been developed in WP7 “Deployment and demonstration”, and have been provided by Demo Site and ecoTool leaders.

The following figure shows the interrelationship between the different tasks:

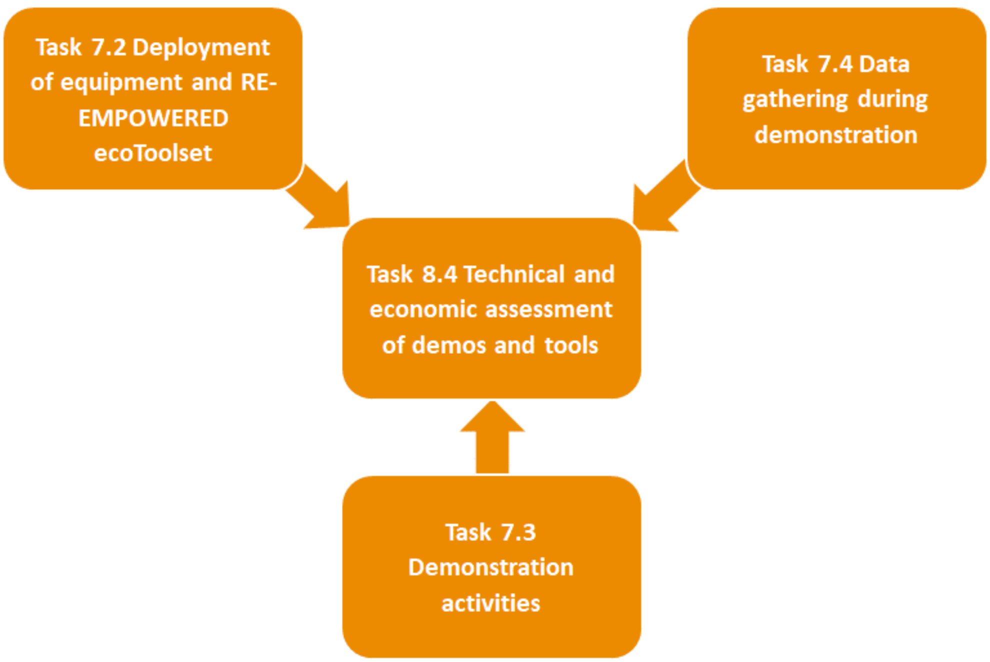

Figure 2. Graph showing how the different tasks of WP7 are related to Task 8.4, Technical and economic assessment of demos and tools.

The goal of the project is to develop a set of solutions, called the ecoToolset, for efficient, decarbonised and RES-intensive multi-energy local energy systems. These tools should allow to make profit of synergies between energy vectors, such as heat and power, and increase demand flexibility using customer engagement, by digitalization, and the development of energy communities.

The ecoToolset has been designed to cover the specific needs of the pilot cases in the EU and India, but it can be replicated in other situations and sites. In each Demo Site, the objective is different:

- Bornholm: The objective is to unlock the demand flexibility for increasing the use of renewable energies in district heating systems of grid-connected islands.

- Kythnos: In this case, improving the whole system efficiency is targeted, as well as the reduction of fossil fuels usage. Kythnos Island is not connected to other islands or to the mainland.
- Gaidouromantra microgrid: This specific settlement in Kythnos Island consists of 14 vacation houses, which are totally isolated from the rest of the Kythnos grid. The supply is provided by a permanently islanded microgrid, which operates based on renewables and storage.
- Ghoramara Island microgrid: This island is totally isolated from connection to the utility grid, and the main energy supply are kerosene lamps for lighting, and a reduced number of solar PV panels installed in the rooftop of individual houses and shops. A local microgrid system has been developed to provide the island with a secure and sustainable electricity supply.
- Keonjhar Microgrid: The Demo Site consists of three villages or hamlets in the mainland, in Odisha, India. They are not connected to the main utility grid, and the electricity supply is provided by 77 kWp solar PV installations. The demo site also makes use of other energy sources, such as biomass, biogas energy storage and e-mobility.

In the technical assessment, a set of parameters is compared before the implementation of the ecoToolset (in a baseline or Business as Usual scenario), and after the ecoTools have been implemented and tested.

The use of the ecoTools make a relevant impact in different fields, such as technical, economic, environmental and social.

The methodology follows the below steps to evaluate the different KPIs. This methodology is graphically shown in the next figure, which is explained hereinafter.

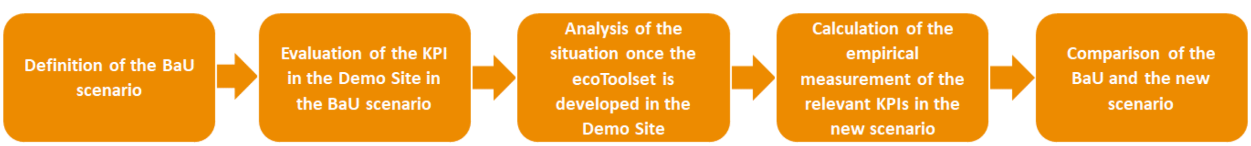

Figure 3. Evaluation phases for technical assessment of demos and tools

The steps which are included in the methodology are as follows:

- Definition of the reference or Business as Usual scenario, and analysis of this scenario.
- Evaluation of the KPI in the Demo Site before the RE-EMPOWERED project has been developed, and before the implementation of the ecoToolset. This is the value of each KPI in the BaU scenario.
- Analysis of the situation once the ecoToolset is developed and implemented in the Demo Site.
- Calculation or measurement of the relevant KPIs, after installing and testing the ecoToolset in the Demo Site.
- Comparison of the two scenarios, based on the calculation or measurement of the KPI.

The following table includes a summary list of the detailed KPIs which have been used, in each Demo Site, to evaluate the technical impact of the use of the ecoTools in the Demo Sites.

BO: Bornholm

KY: Kythnos

GA: Gaidouromantra (in Kythnos)

GH: Ghoramara

KE: Keonjhar

Technical KPIs						
#	**Name**	**BO**	**KY**	**GA**	**GH**	**KE**
1	SAIFI			X		
2	SAIDI			X	X	
3	Peak load reduction	X	X			X
4	RES curtailment reduction	X	X	X		
5	RES curtailment					X
6	RES penetration percentage (annual)					X
7	RES increase in the energy mix	X		X		X
8	Solar PV utilization factor			X		
9	Hours with non-served load or non-observed reserve (h)		X			X
10	Total non-served load and non-observed reserve (MWh)		X			X
11	Hours with underload of conventional units (h)		X			X
12	Reduction of thermal power production unit operation			X		
13	Reduction of battery degradation			X		
14	Wind Turbine capacity factor (%)		X	X		
15	Wind Turbine Annual Energy Production			X		
16	Forecasting accuracy	X		X		X
17	Factor of safety for Solar PV				X	
18	Factor of safety for the wind turbine structure				X	
19	Wind load reduction potential for solar PV				X	
20	Wind load reduction potential for wind turbine				X	
21	Functional downtime for solar PV				X	
22	Functional downtime for wind				X	
23	Operational downtime index (ODI) during overload cut-off				X	
24	Number of electric three wheelers operating in the island				X	X
25	Availability of the communication infrastructure	X	X	X	X	X
26	Digital solutions integrated	X		X		X

Technical KPIs						
#	Name	BO	KY	GA	GH	KE
27	Customers engaged with smartphone application	X		X		X
28	Data Access Control	X		X		X
29	Personal Data Consent	X		X		
30	Booking Summary Publishing Accuracy			X		
31	Tool Modules Deployed	X		X		X
32	Data reliability		X	X	X	X
33	Energy data transfer		X	X	X	X
34	Increased access to own metering data			X	X	X
35	Automatic metering of consumers			X		X
36	Average Percentage Error (APE)				X	

Table 1. List of detailed KPIs used for the evaluation of the technical impact.

2.2 Bornholm Island: Denmark

Bornholm Island is located in the Baltic Sea, South of Sweden, Northeast of Germany, and North of Poland.

The Demo Site is focused on three towns in the eastern part of Bornholm: Østerlars, Østermarie and Gudhjem, which are connected with a District Heating Network (DHN), and a heart plant in Østerlars, which uses straw as fuel. The total population in the Demo Site is 2,500 inhabitants, which have a full access to electricity.

Bornholm Island is not isolated, as it is connected to the Scandinavian electricity grid through a 60 kV AC submarine power cable. With a 60 MW transmission capacity, this cable can provide the island with all the electricity it needs.

Additionally, the island has its own local resources to produce electricity, using a combined heat and power (CHP) plant in Rønne.

Focusing specially on the demo site, the district heating network consists of the following heat infrastructure:

- The Østerlars heat plant, including a 4 MW boiler fed with locally produced straw. The total production of the plant is around 18,000 MWh/year.
- Four electric boilers of a rated power of 0.6 MW (a total of 2.4 MW) for reserve and peak loads.
- 1-2 MW wood pellet boiler for backup.
- A 1,500 m^3 hot water storage tank, with a capacity of 80 MWh.

The heat production system is optimized, as the hot water which is fed into the radiators or heat exchangers owned by the consumers, is recirculated to the straw boiler and the electric boilers, to be heated again. Combustion gases are also condensed by heat exchange, to make profit of the heat they have.

The excess heat which is produced in moments with low demand is stored in the hot water storage tank. This heat can be used when the demand is higher and cannot be covered by the heat plant.

On the other hand, the electricity is produced with the following generation plants:

- 93 kW of rooftop solar PV in the Østerlars heat plant.
- Two 10 MW_{DC} (7.5 MW_{AC}) solar PV plants near Østerlars, in Aakirkeby, connected to the grid. They make a total of 20 MW_{DC} and 15 MW_{AC} in inverter capacity. These power plants are owned by European Energy A/S, which has the operation and maintenance contract for the plants, and potential access to high quality production data from the two solar PV plants.
- 6 small solar PV plants between around 15 kW_{AC} and 325 kW_{AC}, owned by Bornholms Varme and its sister companies, for peak shaving and production-side flexibility.
- A new 20 MW solar PV plant near to the Østerlars heat plant is being planned. It will be built if the business case turns out to be positive.

The proposed business model for Bornholm involves the full use of the synergies which exist between the different energy sources, reducing the use of biomass to produce heat, replacing it with solar PV plants and, in the future, offshore wind energy.

To reach this objective, it is necessary:

- To increase the production of electricity with renewable energy (solar PV and offshore wind).
- To balance, as much as possible, power demand and generation in the Demo Site. This can be done with demand response mechanisms.
- To use the electric boilers to produce heat when the power generation is higher, the demand is lower, and the electricity spot prices, and grid fees are lower. To do so, the use of the district heating systems and the electric boilers should be totally automated, to adapt continuously their behaviour to power generation, demand and electricity prices.
- To use the district heating network and the accumulation hot water tanks as an energy storage system, reducing renewable energy curtailment, as well as the use of biomass to produce heat.
- To adapt the hours when the district heating network provides heat to the clients, to the hours when electricity generation with renewable energy is higher.

An important drawback for this model is the fact that heat produced with straw is, in general, much cheaper than using electricity. Approximately, each MWh heat produced with straw has a cost of €17.9, while the cost of each MWh heat produced with electricity is €31.49/MWh.

Two alternatives are proposed to reduce the cost of using electricity to produce heat:

- To offer balancing services to the TSO with the 2.4 MW electric boilers, receiving payments for this service.
- To directly connect the new solar PV plants, and the future offshore wind farm, to the electric boiler, avoiding the payment of the TSO and DSO tariffs, which make around 75% of the electricity price.

Hereinafter, the summary table with the values of the technical KPIs for the Bornholm Demo Site is presented:

Bornholm Island Demo Site			
KPI #	**Name**	**Value**	**Description**
1	Peak load reduction	-7.4% (47.1 MW BAU 43.6 MW R&I)	It is the decrease in the highest demand for electricity or energy (energy in our case), during a specific time period.
2	RES curtailment reduction	3.5 MWh (-7.4%) (R&I) 14.1 MWh (-29.9%) (Theoretical R&I)	It is the reduction in the amount of renewable energy generation (from sources like wind, solar, hydro, etc.) that is curtailed or wasted due to grid constraints, oversupply, or other operational limitations.
3	RES increase in the energy mix	+8% (day with high RES) +11% (day with low RES)	It measures the proportion of total energy consumption that is supplied by RES.
4	MAE, SMAPE, ME and R^2 (forecasting accuracy)	MAE solar PV: 0.0185 MAE wind: 0.1524 MAE electric load: 0.0564 MAE thermal load: 0.0476 SMAPE solar PV: 40.5 SMAPE wind: 51.64 SMAPE electric load: 11.7954 SMAPE thermal load: 16.8021 ME solar PV: 0.003 ME wind: 0.0043 ME electric load: 0.0087 ME thermal load: 0.017 R2 solar PV: 0.6164 R2 wind: 0.5541 R2 electric load: 0.8176 R2 thermal load: 0.1248	They are various error metrics, including Mean Absolute Error (MAE), Symmetric Mean Absolute Percentage Error (SMAPE), Mean Error (ME), and R^2 which represents the coefficient of determination.
5	Availability of communication infrastructure	99.90%	It measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.

Bornholm Island Demo Site			
KPI #	Name	Value	Description
6	Digital solutions integrated	100%	It measures the number of digital solutions installed because of the development of the project.
7	Customers engaged with digital solutions	8	It measures the customer's involvement with the developed tool.
8	Data Access Control	100%	It evaluates the level of authorised vs unauthorized access to the tool or tool data.
9	Personal Data Consent	100%	It evaluates the percentage of engaged customers who have provided explicit consent for data processing in compliance with the GDPR requirements.
10	Tools Modules Deployed	60%	It measures the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project

Table 2 List of technical KPIs for the Bornholm Island Demo Site.

2.2.1. KPI 1: Peak load reduction (ecoEMS).

Peak Load Reduction refers to the decrease in the highest demand for electricity or energy (like energy in this case) during a specific time period, typically during peak usage hours.

This reduction is often the result of efforts such as demand response programs, energy efficiency initiatives, or the adoption of renewable energy sources. By reducing peak load, utilities and energy providers can avoid the need for additional power generation capacity, reduce grid stress, and lower operational costs.

For the case of Bornholm demo site, the demand is not configured at all, while the peak production that satisfies the demand can be tackled, so that stored energy in the heat tank could substitute the production of energy during the peaks of demand.

This KPI is crucial for optimizing energy distribution and ensuring a more sustainable and cost-effective energy system.

The Peak Load Reduction is calculated with the following formula:

$$Peak\ Load\ Reduction = Baseline\ Peak\ Load - Achieved\ Peak\ Load$$

On the other hand, the Peak Load Reduction Ratio is:

$$Peak\ Load\ Reduction\ Ratio = \frac{Baseline\ Peak\ Load - Achieved\ Peak\ Load}{Baseline\ Peak\ Load}$$

The following table includes the results for this KPI:

	BAU (at example days)	RE-EMPOWERED (at example days)	Change
System peak - ecoEMS	47.1 MW	43.6 MW	**-7.4%**

Table 3 System peak reduction for the Bornholm Island Demo Site.

Peak load reduction was achieved through various methods such as:

- Demand-side management: Encouraging consumers to use less energy during peak times, often through incentives, rebates, or time-of-use pricing. The signals to Neogrid devices to adjust the temperature based on their engagement sourcing from the signals of ecoEMS slots.
- Distributed energy resources: Using decentralized energy sources like solar panels and local power generation to reduce the demand on the grid during peak times, by powering the electric boilers which heated water for the hot water tank, instead of using expensive fuels.

2.2.2. KPI 2: RES curtailment reduction (ecoEMS)

This KPI measures the reduction in the amount of renewable energy generation (from sources like wind, solar, hydro, etc.) that is curtailed or wasted due to grid constraints, oversupply, or other operational limitations. Curtailment occurs when renewable energy is generated but cannot be utilized or transmitted to the grid, usually because the demand is too low or there is insufficient grid capacity to accommodate the renewable power.

The goal of this KPI is to track efforts to reduce curtailment, which can be achieved through better grid management, energy storage systems, or improvements in forecasting and scheduling of renewable energy. Reducing curtailment is important as it maximizes the use of clean energy, minimizes waste, and enhances the overall efficiency of the energy system.

- RES Curtailment: Refers to the amount of energy produced by renewable sources that is not used due to limitations in the grid, either because of too much generation compared to demand or due to lack of sufficient transmission capacity.
- RES Curtailment Reduction: The reduction in this unused or wasted renewable energy. A reduction can be achieved by optimizing grid operations, enhancing forecasting, improving energy storage capabilities, or increasing grid flexibility.

Tracking this KPI is important to understand how effectively the grid is integrating renewable energy, ensuring that maximum clean energy is used and minimizing reliance on fossil fuels.

$$RES\ Curtailment\ Reduction\ (MWh) = RES\ Curtailment\ Before\ Improvement\ (MWh) - RES\ Curtailment\ After\ Improvement\ (MWh)$$

Where:

- RES Curtailment Before Improvement (MWh): The total amount of renewable energy that was curtailed (wasted) before any measures were taken to reduce curtailment.
- RES Curtailment After Improvement (MWh): The total amount of renewable energy curtailed after implementing strategies to reduce curtailment, such as grid enhancements, energy storage, better demand forecasting, or improved renewable energy integration.

Depending on the value of the KPI, there can be two situations:

- High Reduction in RES Curtailment: A significant reduction in curtailment indicates that the system has successfully integrated renewable energy, improved grid flexibility, and reduced wasted clean energy. This is a positive sign for both environmental sustainability and operational efficiency.
- Low or No Reduction in RES Curtailment: If there is little or no reduction, it may suggest that the grid is not effectively utilizing renewable energy, and improvements are needed in storage, transmission capacity, or demand forecasting to better accommodate fluctuating renewable generation.

This KPI is crucial for assessing the progress of integrating renewable energy into the grid, improving the overall sustainability of energy generation, and ensuring that clean energy is not wasted. It highlights areas where grid infrastructure or operational strategies need to be enhanced to maximize the potential of renewable resources.

The KPI is calculated with data from a week of demonstration round B, during November. Since the current renewable penetration in Bornholm demo site is moderate, to prove the impact of ecoEMS on the RES curtailments, a parallel theoretical demonstration was considered, with much higher penetration, with the use of heuristic methods.

Therefore, as is shown in the next table, the effect of the ecoTool is expected to be much higher under conditions of high-RES penetration.

	RE-EMPOWERED	**Change**	**Theoretical RE-EMPOWERED**	**Change**
RES curtailment reduction (MWh)	3.5 MWh	**7.4%**	14.1 MWh	**29.9%**

Table 4 RES curtailment reduction for the Bornholm Island Demo Site.

2.2.3. KPI 3: RES increase in the energy mix (ecoEMS).

The RES Penetration Percentage measures the proportion of total energy consumption that is supplied by RES. It provides an insight into how much of the energy consumed by the grid is generated from renewable resources such as solar, wind, hydro, geothermal, and other ones.

This KPI is crucial for tracking the progress of the energy transition toward more sustainable and environmentally friendly energy sources and is used for assessing the success of energy policies and strategies that aim to increase the share of renewables in the energy mix.

$$RES\ Penetration\ Percentage = \frac{Renewable\ Energy\ Generation\ (MWh)}{Annual\ Energy\ Consumption\ (MWh)} \times 100$$

Where:

- Annual Renewable Energy Generation (MWh) is the total amount of electricity generated from renewable sources (in MWh).
- Total Annual Energy Consumption (MWh) is the total amount of electricity consumed by all sectors (in MWh)

Depending on the value of the KPI, there can be two situations:

- High-RES Penetration Percentage: A high percentage indicates that a significant portion of the total energy consumption is being met by renewable energy sources. This reflects a strong commitment to sustainable energy production and consumption, and it may signal a country, region, or utility progress toward meeting climate goals and decarbonizing the energy grid.
- Low-RES Penetration Percentage: A low percentage suggests that the share of renewable energy in the overall energy mix is still limited, and more efforts are needed to transition to sustainable energy sources. This might indicate the continued reliance on fossil fuels or other non-renewable sources to meet energy demand.

Since this is usually an annual KPI, yet the demonstration took place for a specific range of days during December, the annualization of the KPI would introduce high errors. To avoid that, yet provide a bulletproof conclusion, days with high RES and days with low RES were examined as categories.

The following table includes the results for the RES increase in the energy mix in the Bornholm Demo Site:

	BAU (day with high RES)	RE-EMPOWERED (day with high RES)	**Change**	BAU (day with low RES)	RE-EMPOWERED (day with low RES)	**Change**
RES penetration percentage (%)	78%	86%	**+8%**	17%	28%	**+11%**

Table 5 RES penetration percentage and its increase in the Bornholm Demo Site

It is evident that ecoEMS achieves higher RES penetration, thanks to RES curtailments management, as well as to optimal scheduling. During high-RES days, that RES high percentages are already achieved, larger flexibility seems to be necessary, to succeed adequately higher RES penetration. On the other hand, when RES have less contribution to the energy mix, because of low wind or cloudy days, ecoEMS may achieve higher relatively penetration, due to larger margin.

2.2.4. KPI 4: Forecasting accuracy (ecoEMS).

For these KPIs, various error metrics, including Mean Absolute Error (MAE), Symmetric Mean Absolute Percentage Error (SMAPE), Mean Error (ME), and R^2 which represents the coefficient of determination, are used to evaluate the accuracy of 24-hour-ahead forecasts against actual data on a normalized scale to provide a comprehensive evaluation of forecasting accuracy. The formulas for each metric are provided below:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

$$SMAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{(|y_i| + |\hat{y}_i|)/2}x100$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

Where:

- y_i: actual value.
- $\hat{y}$: forecasted value.
- n: number of samples/observations.

24 hours ahead forecasting accuracy with respect to different error metrics, including MAE, SMAPE, ME and R^2 are given for PV, wind, electric load and thermal load forecasting in Table below.

	Forecasting accuracy			
Error metric	**PV Forecasting**	**Wind Forecasting**	**Electric Load Forecasting**	**Thermal Load Forecasting**
MAE	0.0185	0.1524	0.0564	0.0476
SMAPE	40.5	51.64	11.7954	16.8021
ME	0.003	0.0043	0.0087	0.017
R^2	0.6164	0.5541	0.8176	0.1248

Table 6 Forecasting accuracy for PV, wind, electric and thermal load forecasting by MAE, SMAPE, ME and R^2 at Bornholm demo-site.

The following figure shows the forecasting data for the solar PV generation in the Bornholm Demo Site:

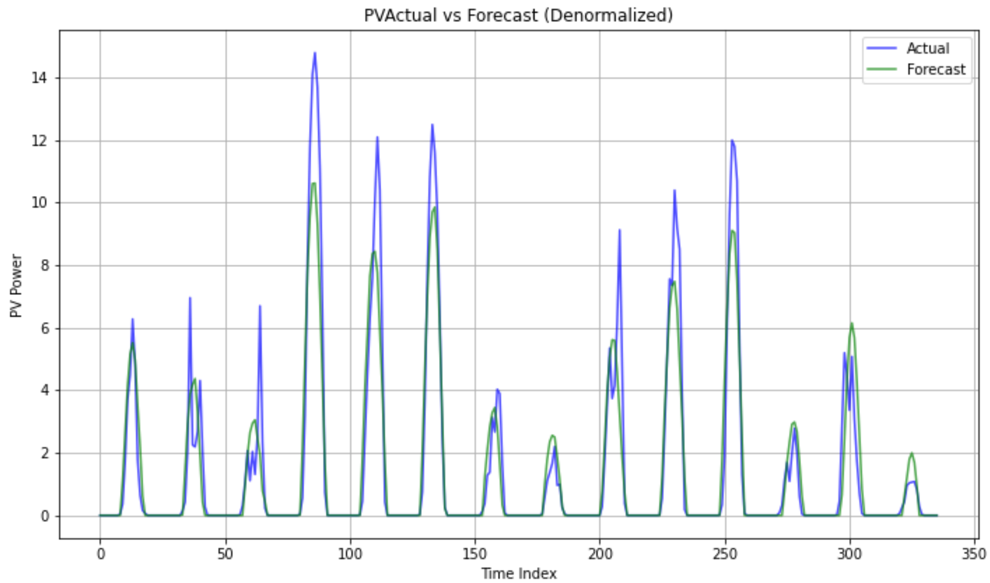

Figure 4 Solar PV generation forecasting data for the Bornholm Demo Site.

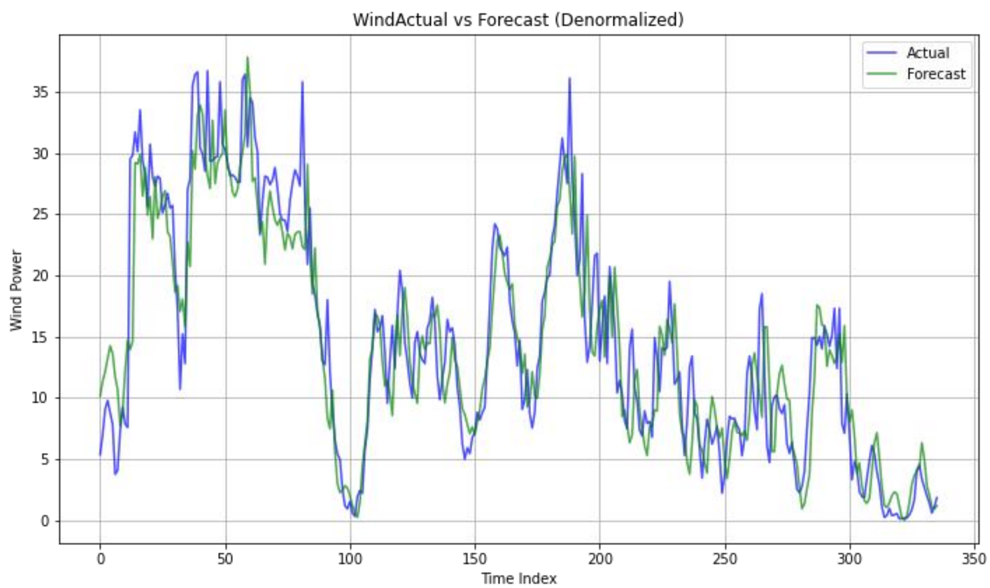

Figure 5 Wind power generation forecasting data for the Bornholm Demo Site.

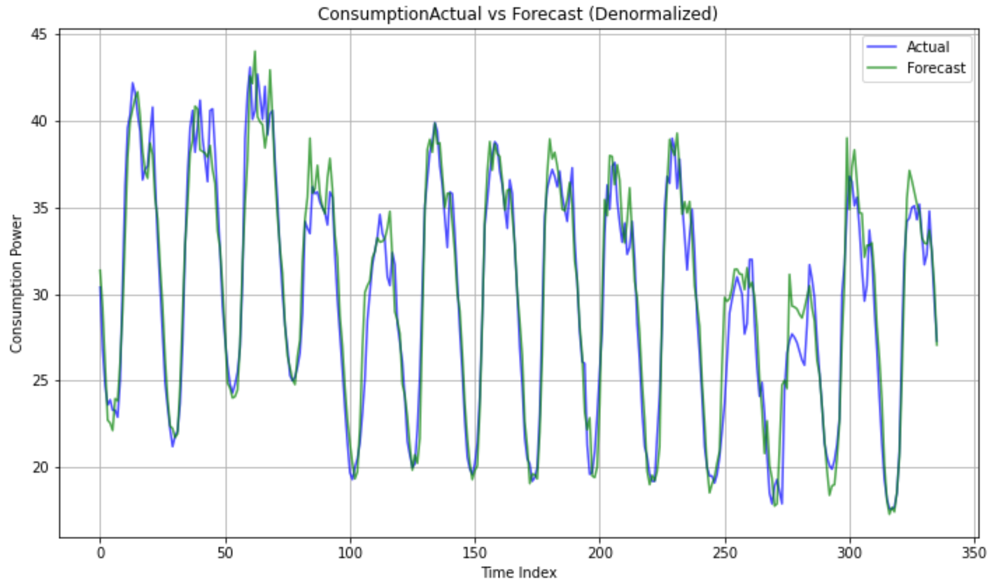

Figure 6 Electric load consumption forecasting data for the Bornholm Demo Site.

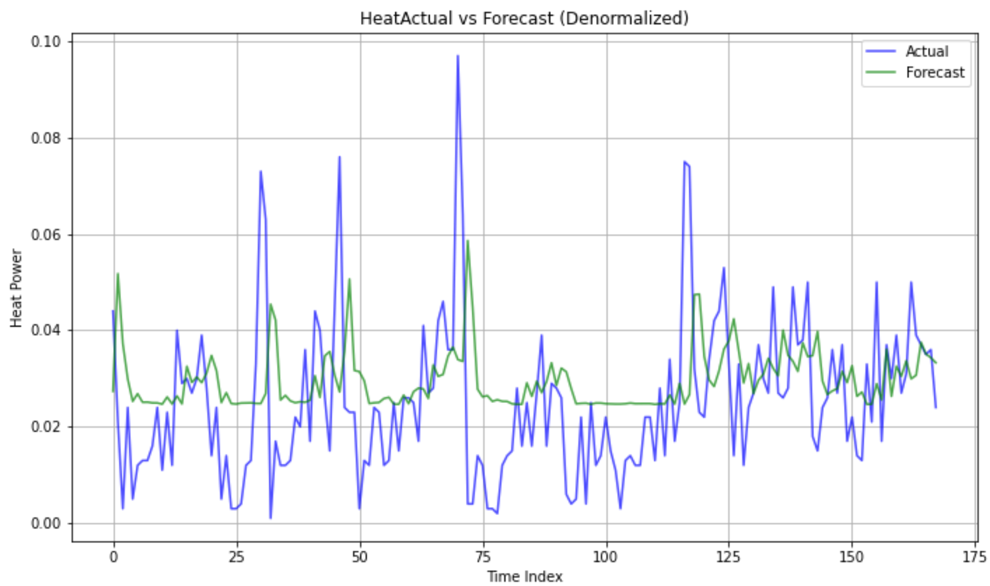

Figure 7 Heat load consumption data for the Bornholm Demo Site.

2.2.5. KPI 5: Availability of communication infrastructure (ecoEMS, ecoPlatform).

The availability of communication infrastructure KPI measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.

This KPI specifically quantifies the percentage of time the communication system (e.g., ecoPlatform, its APIs, and data exchanges) is operational and accessible during a given observation period. After resolving the major issue related to the SSL certification update, the ecoPlatform has operated without any significant issues, except for one brief interruption that was quickly resolved by updating a package on the server. Therefore, this KPI calculation is based on the system performance after the primary issue was resolved and consistent operation was achieved from June 8th, 2024, up to December 19th, 2024.

The availability of the communication infrastructure can be calculated using the following formula:

$$Availability(\%) = \left(\frac{Uptime\ in\ hours}{Uptime\ in\ hours + Downtime\ in\ hours}\right) x100$$

Where:

Uptime in hours: The total time during the testing period when the communication system was operational.

Downtime in hours: The total time during the testing period when the communication system was not operational (e.g., due to failures, maintenance, or unexpected outages). In the testing period for ecoPlatform:

- Uptime was 4,648.26 hours.
- Downtime was 4.83 hours.

Therefore, the availability of the communication infrastructure for the ecoPlatform during the testing period was: 99.90%.

The following table summarizes this result:

	BAU	RE-EMPOWERED	Change
Availability of communication infrastructure	N/A	99.90%	**N/A**

Table 7 Availability of communication infrastructure, for ecoPlatform for the Bornholm Demo Site.

2.2.6. KPI 6: Digital solutions integrated (ecoCommunity)

The KPI measures the number of digital solutions installed because of the development of the project. The list of digital solutions installed is given in the following table.

Sl. No.	Tool	Digital Platform
1	ecoCommunity	Android Mobile
2	ecoPlatform	Interoperable ICT tool
3	ecoEMS	Energy Management System

Table 8 List of digital solutions integrated, for ecoCommunity, for the Bornholm Demo Site.

The following formula is used to calculate the KPI:

$$Digital\ Solutions\ Integrated\ Ratio = \frac{Solutions\ Integrated\ as\ part\ of\ RE - EMPOWERED}{Total\ Solutions\ Integrated}$$

The following table gives the value of the KPI Digital Solutions Integrated:

	BAU	RE-EMPOWERED	Change
Digital Solutions Integrated	0	100%	**+100% of solutions integrated are digital**

Table 9 Digital solutions integrated, for ecoCommunity, for the Bornholm Demo Site.

2.2.7. KPI 7: Customers engaged with smartphone application (ecoCommunity).

This KPI measures the customer's involvement with the developed tool. The introduction of a new solution and its features can attract consumers to register for their use.

It is important to note that all registered consumers of the tool might not be actively engaging with the tool after the registration. This might be due to various reasons like customer lost interest to functionalities, tool failing to meet the customer expectations, customer might not have the time/patience for an active engagement, etc.

The following table provides the number of customers registered with the tools during the demonstration activities.

Solution		Registered
ecoCommunity	Administrator	1
	Consumer	8

Table 10 List of digital solutions integrated in the for the Bornholm Demo Site.

The following table includes the KPI for customers registered in the digital solutions developed for the demo site.

	BAU	RE-EMPOWERED	Change
Customer Registration	0	8	**+8 customers**

Table 11 Customers engaged with digital solutions, for ecoCommunity, for the Bornholm Demo Site.

2.2.8. KPI 8: Data Access Control (ecoCommunity)

The KPI evaluates the level of authorised vs. unauthorized access to the tool or tool data. In the case of ecoCommunity the access to the tool and the data is restricted using username-password based authentication.

The KPI is evaluated using the formula:

$$Access\ Control\ Ratio = \frac{No\ of\ Authorised\ Access}{Total\ Number\ of\ Access}$$

In the case of the Bornholm Island Demo Site, before the implementation of ecoCommunity, no access control was carried out, as there was no ecoCommunity. Once the ecoCommunity has been installed, all accesses have been controlled.

The following table includes this result:

	BAU	RE-EMPOWERED	Change
Data Access Control	N/A	100%	**100% access control**

Table 12 Data access control, for ecoCommunity, for the Bornholm Demo Site.

2.2.9. KPI 9: Personal Data Consent (ecoCommunity)

The KPI evaluates the percentage of engaged customers who have provided explicit consent for data processing in compliance with the GDPR requirements. The tool users, during their first stage of engagement with the tool, are provided with an information sheet and consent form which provide information on the details of processing the personal data.

The GDPR (General Data Protection Regulation) is the Regulation (EU) 2016/679), which regulates the personal data privacy, and the treatment which can be given to these data. It includes the need to ask for specific consent when personal data are asked and treated.

In RE-EMPOWERED, all personal data have been correctly managed.

	BAU	RE-EMPOWERED	Change
Personal Data Consent	N/A	100%	**100% data consent**

Table 13 Personal Data Consent in the Bornholm Demo Site.

2.2.10. KPI 10: Tool Modules Deployed (ecoCommunity)

The KPI evaluates the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project. The tool functionalities or functional modules are developed considering a generic system with the different scenarios associated with all the demo sites. Although only a fraction of these modules will be implemented in the demo site considering the technical and social limitations.

The following table shows the number of modules developed in the project and deployed in the demo site for each tool.

Tool	Modules Developed	Modules Deployed	Percentage Deployed	RE-EMPOWERED
ecoCommunity	10	6	60%	60%

Table 14 Tool modules deployed, for the Bornholm Demo Site.

2.3 Kythnos Power System: Greece

The power system of Kythnos Island is not connected to the mainland electricity grid. This has led to problems coping with the electricity demand in the island, and that all electricity has to be produced in the island.

The power generation infrastructure in the Kythnos Island consists of the following power plants:

- 5.2 MW of fossil fuel generation (diesel generators), in particular:
  - 4 units MWM TBD603V12: 4 x 0.3 MW.
  - 4 units MITSUBISHI S16R-PTA: 4 x 1 MW.
- 908.65 kW of renewable energy generation, including:
  - 3 solar PV power plants, totalizing 238.25 kW (1 x 98,4 kW + 1 x 69.92 kW + 1 x 69.93 kW).
  - 2 solar PV rooftop installations, with a total of 29.535 kW (1x 19.875 kW + 1 x 9.66 kW).
  - 6 wind turbines, totalizing 665 kW: 5 x 33 kW + 1 x 500 kW. However, these wind turbines are out of order and must be repowered.

In 2023, the total electricity production in Kythnos was 11,387.33 MWh, with a yearly peak load of 4.05 MW in 2022.

The electricity generation of the different power plants is as follows (data for 2023):

- Diesel generators: 10,989.93 MWh/year (96.5%).
- Solar PV power plants: 372.64 MWh/year (3.3%).
- Solar PV rooftop installations: 24.76 MWh/year (0.2%).

This means that the use of renewable energies for electricity generation in the Kythnos Island is reduced to about 3-4%, despite the high availability of renewable energy resources in the island, including wind and solar irradiation.

The island faces power outages and energy drops, although there are not energy scarcity problems. Besides, in extreme weather situations, the power system can be affected.

The main energy consumption in the island includes cooling during summertime, and water treatment in the desalination plant. There are three main energy vectors: colling, water, and electricity.

RE-EMPOWERED project in Kythnos Island is focused on the digitalisation and energy transition in the energy system of the island. Besides, one of its objectives is the reduction in the use of fossil fuels, and the increase of the penetration of solar PV plants.

Two business models are proposed for the Kythnos Island: energy communities and demand response mechanisms. Energy communities will involve citizens to develop renewable energy plants (in Kythnos Island, they will be solar PV plants), sharing the investment cost, and operation and maintenance costs, as well as the free renewable energy produced.

On the other hand, demand response mechanisms have been implemented to encourage consumers in Kythnos Island to adapt their electricity consumption to the hours when the electricity production by solar PV plants is higher.

The following table includes a summary of the main results of the evaluation of the KPIs in the Kythnos Island Demo Site:

Kythnos Power System			
KPI #	Name	Value	Description
1	Peak load reduction	ecoEMS 16% ecoPlanning 9.5%	It measures the reduction in the maximum demand or peak load on the electricity grid achieved through various demand-side management strategies or energy efficiency measures.
2	RES curtailment reduction	ecoPlanning 37%	It is the reduction in the amount of renewable energy generation (from sources like wind, solar, hydro, etc.) that is curtailed or wasted due to grid constraints, oversupply, or other operational limitations. RES curtailment is calculated to be: BAU 23.2 MWh, R&I 9 MWh.
3	Hours with non-served load or non-observed reserve	ecoEMS -100% (BaU: 1.5h, R&I: 0h) ecoPlanning -87.7% (BaU: 49h, R&I: 6h)	It measures the total number of hours during which a power grid or energy system experiences either non-served load (when the demand for electricity exceeds the available supply, leading to load shedding or outages) or non-observed reserve (when the system fails to maintain a sufficient reserve capacity to meet unforeseen demand or contingencies).
4	Total non-served load and non-observed reserve (MWh)	ecoEMS -100% (BaU: 0.9 MWh, R&I: 0 MWh) ecoPlanning -90.7% (BaU: 16.3 MWh, R&I: 1.5 MWh)	It measures the total amount of energy, in megawatt-hours (MWh), that represents non-served load and non-observed reserve over a specified period.

Kythnos Power System			
KPI #	Name	Value	Description
5	Hours with underload of conventional units (h)	ecoEMS -75% (BaU: 8h, R&I: 2h) ecoPlanning -39.4% (BaU: 147h, R&I: 89h)	It measures the total number of hours during which conventional power generation units (e.g., coal, gas, nuclear plants) are operating below their optimal or expected output levels,
6	Wind turbine capacity factor (%)	ecoEMS -19% (BaU: 27%, R&I: 22%)	It measures the efficiency with which a wind turbine or a wind farm is producing electricity compared to its maximum possible output.
7	Availability of communication infrastructure	ecoPlatform 99.31%	It measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.
8	Data Reliability	ecoPlatform 99.90%	It measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.
9	Energy data transfer	ecoPlatform 5 MB/hour	It measures the capacity of a data exchange platform to transfer different types of data successfully.

Table 15 List of technical KPIs for the Kythnos Island Demo Site.

2.3.1. KPI 1: Peak load reduction (ecoEMS, ecoPlanning).

This KPI measures the reduction in the maximum demand or peak load on the electricity grid achieved through various demand-side management strategies or energy efficiency measures. The primary goal of reducing peak load is to avoid the need for additional capacity (e.g., power plants, grid infrastructure) during periods of high demand, improve grid stability, and optimize energy consumption.

Peak load typically occurs during times of high energy demand, such as hot summer afternoons (when air conditioning is used extensively) or cold winter mornings (when heating is in demand). These periods are crucial because the grid has to meet the maximum load, and power generation resources must be able to supply this demand. Reducing peak load can result in lower operational costs for utilities, better grid reliability, and a reduction in the environmental impact of generating energy.

- Smart Grid and Demand Response:

Technologies like smart grids, demand response programs, and energy storage systems can be used to reduce peak load. Demand response, for example, involves shifting or curtailing electricity consumption during peak periods by incentivizing consumers (industrial, commercial, or residential) to lower their energy usage.

Key benefits of Peak Load Reduction:

- Cost Savings: Reduces the need for costly peak power plants (which are often inefficient or run on fossil fuels).
- Grid Stability: Prevents the grid from becoming overloaded and potentially experiencing outages or failures.
- Environmental Impact: Lower peak demand can lead to less reliance on carbon-intensive power generation during periods of high load.

The following formula is used to calculate the Peak load reduction:

$$Peak\ Load\ Reduction = \frac{Peak\ Load_b - Peak\ Load_j}{Peak\ Load_b}$$

Where:

- J: Total number of scenarios.
- b: Base scenario.

In order to carry out the calculations, the BAU scenario refer to the actual scheduling from DSO while the RE-EMPOWERED scenario refer to the suggestions provided by the ecoEMS.

The following table includes the results for this KPI:

	BAU	RE-EMPOWERED	**Change**
System peak - ecoEMS	1.35 MW	1.13 MW	**-16%**
System peak -ecoPlanning (annualized)	3.47 MW	3.14 MW	**-9.5%**

Table 16 System peak reduction for the Kythnos Island Demo Site.

Peak load reduction was achieved through various methods such as:

- Demand-side management: Encouraging consumers to use less energy during peak times, often through incentives, rebates, or time-of-use pricing.
- Energy efficiency improvements: Implementing technologies or practices that reduce the overall consumption of energy, thereby lowering peak demand.
- Distributed energy resources: Using decentralized energy sources like solar panels, wind, or local power generation to reduce the demand on the grid during peak times.

2.3.2. KPI 2: RES curtailment reduction (ecoPlanning).

This KPI measures the reduction in the amount of renewable energy generation (from sources like wind, solar, hydro, etc.) that is curtailed or wasted due to grid constraints, oversupply, or other operational limitations. Curtailment occurs when renewable energy is generated but cannot be utilized or transmitted to the grid, usually because the demand is too low or there is insufficient grid capacity to accommodate the renewable power.

The goal of this KPI is to track efforts to reduce curtailment, which can be achieved through better grid management, energy storage systems, or improvements in forecasting and scheduling of renewable energy. Reducing curtailment is important as it maximizes the use of clean energy, minimizes waste, and enhances the overall efficiency of the energy system.

- **RES Curtailment**: It refers to the amount of energy produced by renewable sources that is not used due to limitations in the grid, either because of too much generation compared to demand or due to lack of sufficient transmission capacity.
- **RES Curtailment Reduction**: The reduction in this unused or wasted renewable energy. A reduction can be achieved by optimizing grid operations, enhancing forecasting, improving energy storage capabilities, or increasing grid flexibility.

Tracking this KPI is important to understand how effectively the grid is integrating renewable energy, ensuring that maximum clean energy is used and minimizing reliance on fossil fuels.

$$RES\ Curtailment\ Reduction\ (MWh) = RES\ Curtailment\ Before\ Improvement\ (MWh) - RES\ Curtailment\ After\ Improvement\ (MWh)$$

Where:

- **RES Curtailment Before Improvement (MWh)**: The total amount of renewable energy that was curtailed (wasted) before any measures were taken to reduce curtailment.
- **RES Curtailment After Improvement (MWh)**: The total amount of renewable energy curtailed after implementing strategies to reduce curtailment, such as grid enhancements, energy storage, better demand forecasting, or improved renewable energy integration.

Depending on the value of the KPI, there can be two situations:

- High Reduction in RES Curtailment: A significant reduction in curtailment indicates that the system has successfully integrated renewable energy, improved grid flexibility, and reduced wasted clean energy. This is a positive sign for both environmental sustainability and operational efficiency.
- Low or No Reduction in RES Curtailment: If there is little or no reduction, it may suggest that the grid is not effectively utilizing renewable energy, and improvements are needed in storage, transmission capacity, or demand forecasting to better accommodate fluctuating renewable generation.

This KPI is crucial for assessing the progress of integrating renewable energy into the grid, improving the overall sustainability of energy generation, and ensuring that clean energy is not wasted. It highlights areas where grid infrastructure or operational strategies need to be enhanced to maximize the potential of renewable resources.

The KPI is calculated with data from a week of demonstration round B, during November, which did not have high loads. In addition, the renewable penetration in Kythnos demo site is minimum, so in order to allocate this KPI, some theoretical simulations with much higher penetration were examined, with the use of heuristic methods.

So, the effect of the ecoTool is expected to be much higher under different conditions.

The following table includes the result for the RES curtailment reduction for the Kythnos Power System:

	BAU	RE-EMPOWERED (theoretical)	**Change (at example days**	**Change (annualized)**
RES curtailment reduction	23.2 MWh	9 MWh	**-61%**	**-37%**

Table 17 RES curtailment reduction for the Kythnos Power System.

2.3.3. KPI 3: Hours with non-served load or non-observed reserve (h) (ecoEMS, ecoPlanning).

This indicator measures the total number of hours during which a power grid or energy system experiences either non-served load (when the demand for electricity exceeds the available supply, leading to load shedding or outages) or non-observed reserve (when the system fails to maintain a sufficient reserve capacity to meet unforeseen demand or contingencies). These hours are critical for assessing the reliability and stability of the power system.

- Non-Served Load: It refers to the total energy demand that cannot be met by the system due to insufficient generation or capacity, leading to disruptions in service, such as power cuts or rolling blackouts.
- Non-Observed Reserve: It refers to periods when the system reserve (the backup capacity to handle sudden demand spikes or generation failures) is insufficient or unavailable, putting the grid at risk of instability.

Tracking this KPI is crucial for utilities and grid operators to monitor system performance, identify reliability issues, and take corrective actions to improve the grid reliability and prevent prolonged outages or operational failures.

To calculate Hours with Non-Served Load or Non-Observed Reserve (h), the formula is:

$$\begin{aligned} Hours\ with\ Non - Served\ Load\ or\ Non - Observed\ Reserve\ (h) \\ = \sum(Hours\ where\ load\ is\ not\ fully\ served \\ + Hours\ of\ insufficient\ reserve\ capacity) \end{aligned}$$

Where:

- **Hours where load is not fully served** is the total number of hours when the grid experiences load shedding or cannot meet the full demand.
- **Hours of insufficient reserve capacity** is the total number of hours when the grid fails to maintain adequate reserves for unforeseen contingencies.

Depending on the value of the KPI, there can be two situations:

- High Values: A high number of hours indicates poor grid reliability, highlighting periods of outages or potential system stress due to inadequate reserves.
- Low Values: A low number of hours suggests a more reliable grid, with minimal disruptions and sufficient reserves during peak demand or emergencies.

This KPI is critical for assessing the performance of grid management strategies, forecasting, and planning for improvements in capacity and reserve management to ensure consistent service and reliability.

The following table includes the results for this KPI:

	BAU	RE-EMPOWERED	**Change**
Hours with Non-Served Load or Non-Observed Reserve- ecoEMS	1.5 hours	0 hours	**-100% (at example days)**
Hours with Non-Served Load or Non-Observed Reserve- annualized-ecoPlanning	49 hours	6 hours	**-87.7% (annualized)**

Table 18 Hours with Non-Served Load or Non-Observed Reserve for Kythnos demo site.

2.3.4. KPI 4: Total non-served load and non-observed reserve (MWh) (ecoEMS, ecoPlanning).

This KPI quantifies the total amount of energy, in megawatt-hours (MWh), that represents non-served load and non-observed reserve over a specified period. It measures the total energy demand that could not be met due to capacity issues, leading to load shedding or failures in maintaining an adequate reserve.

- Non-Served Load: This is the total amount of energy that the power grid was unable to provide to consumers because the demand exceeded available supply. This can happen due to generation shortages, transmission constraints, or operational failures.
- Non-Observed Reserve: This refers to the total energy associated with periods when the grid failed to maintain enough reserve capacity. Reserves are backup power resources kept available to address unforeseen spikes in demand or sudden generation failures. When reserves are insufficient, the grid may become unstable or may not be able to respond quickly to emergencies.

Tracking this KPI is important for understanding the total energy shortfall and the system inability to handle peak loads or emergencies, helping to highlight reliability issues and identify where improvements are needed in grid capacity, generation, or reserve management.

$$Total\ Non-Served\ Load\ and\ Non-Observed\ Reserve\ (MWh) = \sum(Non-Served\ Load\ (MWh) + Non-Observed\ Reserve\ (MWh))$$

Where:

- Non-Served Load (MWh): The total energy demand (in MWh) that the system was unable to meet due to insufficient generation or capacity issues.

- Non-Observed Reserve (MWh): The amount of reserve (in MWh) that was unavailable or insufficient during the observation period, impacting the system's ability to handle unexpected demand spikes or generation failures.

High Values: A high total of non-served load and non-observed reserve indicates significant grid reliability problems, where large amounts of energy demand are unmet, and reserve capacity is not available to maintain system stability during high-demand or emergency situations.

Low Values: A low total indicates a stable and reliable system, with adequate supply to meet demand and sufficient reserve capacity to handle unforeseen situations.

The KPI is referring to a week of demonstration round B, which did not have high loads. So, the effect of the ecoTool is expected to be much higher if a different or larger period is examined. Yet, the optimality converges to the ecoTool solution, as it can be shown in the below table.

	BAU	RE-EMPOWERED	**Change**
Total Non-Served Load and non-observed reserve-ecoEMS	0.9 MWh	0 MWh	**-100% (at example days)**
Total Non-Served Load and non-observed reserve-annualized-ecoPlanning	16.3 MWh	1.5 MWh	**-90.7% (annualized)**

Table 19 Total Non-Served Load and non-observed reserve for Kythnos demo site.

2.3.5. KPI 5: Hours with underload of conventional units (h) (ecoEMS, ecoPlanning).

This KPI measures the total number of hours during which conventional power generation units (e.g., coal, gas, nuclear plants) are operating below their optimal or expected output levels, referred to as **underload**. Underloading occurs when these units are producing less power than their maximum capacity, often due to low electricity demand, operational constraints, or grid requirements.

- **Underload**: This refers to situations where a conventional generation unit is generating less power than it can produce. This can be inefficient from both an economic and environmental perspective because the unit might still be running but at suboptimal levels, which could increase operating costs or reduce the cost-effectiveness of the plant.
- Conventional units are typically less efficient when running at low output levels, as their efficiency decreases when they are not running near their full capacity. Additionally, maintaining a plant in underload conditions can result in higher operational costs and wear and tear over time.

This is a very common situation for the thermal units of the Greek islands due to the high seasonality and the unilateral penetration of the solar PV energy as a renewable technology.

Tracking this KPI helps utilities and grid operators understand how often conventional units are underused and provides insights into optimizing generation capacity and operational efficiency.

$$\text{Hours with Underload of Conventional Units } (h) = \sum(\text{Hours when conventional units operate below optimal output})$$

Where:

- Hours when conventional units operate below optimal output is the total number of hours during which the conventional generation units are running at less than their full capacity or below a predefined threshold that represents optimal or efficient generation.

Depending on the value of the KPI, there can be two situations:

- High Values: A high number of hours with underload indicates that conventional units are often running below their optimal efficiency, leading to potential inefficiencies, increased costs, and a possible need to adjust the generation mix to reduce reliance on these units during low-demand periods.
- Low Values: A low number of hours indicates that conventional units are being efficiently utilized and operating near their optimal output levels, minimizing waste and maximizing cost-effectiveness.

This KPI is critical for identifying periods when conventional generation units are being underused and provides an opportunity to assess whether the generation mix, load forecasting, or operational strategies need adjustment to avoid inefficiencies or unnecessary emissions. It can also help in decision-making regarding plant maintenance, decommissioning, or integrating renewable energy sources to better match grid demand.

The KPI is calculated with data from a week of demonstration round B, during November, which did not have high loads. So, the effect of the ecoTool is expected to be much higher if a different or larger period will be examined. Yet, the optimality converges with the ecoTool solution, as it can be shown in the below table.

	BAU	RE-EMPOWERED	**Change**
Hours with underload of conventional units (h)-ecoEMS	8 hours	2 hours	**-75% (at example days)**
Hours with underload of conventional units (h)-annualized-ecoPlanning	147 hours	89 hours	**-39.4% (annualized)**

Table 20 Hours with underload of conventional units for Kythnos demo site.

2.3.6. KPI 6: Wind Turbine Capacity Factor (%) (ecoPlanning).

The Wind Power (WP) Capacity Factor measures the efficiency with which a wind turbine or a wind farm is producing electricity compared to its maximum possible output. It is expressed as a percentage and reflects how effectively the wind turbine or wind farm is converting available wind energy into electrical energy over a specific period, usually on an annual basis.

The capacity factor is an important indicator of the performance of wind energy systems. It helps to evaluate whether wind turbines are operating as expected, considering the variable nature of wind. A higher capacity factor indicates that the wind turbine is operating closer to its maximum potential, while a lower capacity factor may suggest inefficiencies or underperformance. Wind power systems do not operate at full capacity all the time because wind speeds fluctuate. The capacity factor helps account for this variability by comparing the actual output to the theoretical maximum.

$$Capacity\ Factor\ (\%) = \frac{Maximum\ Possible\ Energy\ Production\ (MWh)}{Actual\ Energy\ Production\ (MWh)} \times 100$$

Where:

- Actual Energy Production (MWh) is the actual electricity generated by the wind turbine or wind farm over a given time period (in megawatt-hours).
- Maximum Possible Energy Production (MWh) is the amount of energy that would have been generated if the wind turbine operated at its rated capacity (maximum power output) continuously over the same period.

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
WPs capacity factor (%)	27%	22%	**-19%**

Table 21 WPs capacity factor, for the Kythnos Island Demo Site.

2.3.7. KPI 7: Availability of communication infrastructure (ecoPlatform).

The KPI availability of communication infrastructure measures the reliability of the communication system, in terms of failure frequency and the required time to repair and restore the operation of the communication system.

More specifically, it measures the percentage of time when the communication system (e.g., ecoPlatform, its APIs, and data exchanges) are operational and accessible during the observation period.

It can be calculated with the following formula:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

Where:

- Uptime is the total time when the communication system is operational during the observation period.
- Downtime is the total time when the communication system was not operational (for example, due to failures, maintenance actions, unexpected outages).

In the testing period for ecoPlatform:

- Uptime was 715 hours.
- Downtime was 5 hours.

Therefore, the availability of communication infrastructure was:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{715\ hours}{715\ hours + 5\ hours}\right) \cdot 100 = 99.31\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Availability of communication infrastructure	N/A	99.31%	**N/A**

Table 22 Availability of communication infrastructure, for ecoPlatform for the Kythnos Island Demo Site.

2.3.8. KPI 8: Data reliability (ecoPlatform)

This KPI measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.

It can be calculated using the following formula:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted - Total\ data\ packages\ with\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

This is equivalent to:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted\ without\ mistakes\ or\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

Where:

- Total data packages transmitted are the number of data packages which are transmitted, whether they are received or not.
- Total data packages with losses are the number of data packages which are not transmitted, or which have any kind of mistake.
- Total data packages transmitted without mistakes or losses are the number of data packages which are correctly and completely transmitted without losses or mistakes.

During the testing period, for the Kythnos Island Demo Site:

- Total data packages transmitted: 1,000,000.

- Total data packages with losses: 1,000.

Therefore, the Data reliability KPI for Kythnos Island, and for ecoPlatform is as follows:

$$Data\ reliability\ (\%) = \left(\frac{1{,}000{,}000 - 1{,}000}{1{,}000{,}000}\right) \cdot 100 = \frac{999{,}000}{1{,}000{,}000} = 99.90\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Data reliability	N/A	99.90%	**N/A**

Table 23 Data reliability, for ecoPlatform, for the Kythnos Island Demo Site.

2.3.9. KPI 9: Energy data transfer (ecoPlatform).

Energy data transfer measures the capacity of a data exchange platform to transfer different types of data successfully. It is related to the amount of transmitted data (in MB) within the observation period.

Transmitted data can include logs, real-time monitoring data and other information.

The formula which can be used to estimate this KPI is:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

Where:

- Total transmitted data is the volume of energy-related data which are transferred using the ecoPlatform, in MB.
- Total time is the period when the transmission of data is monitored.

During the testing period, the following results were obtained:

- Total transmitted data: 50 MB.
- Total time: 10 hours.

Using the previously described formula:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{50\ MB}{10\ hours} = 5\ MB/hour$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	Change
Energy data transfer	N/A	5 MB/hour	**N/A**

Table 24 Energy data transfer, for ecoPlatform, for the Kythnos Island Demo Site.

2.4 Gaidouromantra Microgrid: Kythnos Island: Greece

In the RE-EMPOWERED project, the Demo Site of Kythnos Island also includes the specific case of the Gaidouromantra Microgrid.

Gaidouromantra is a small settlement of 14 vacation houses located in a small valley next to the coast, in the southern part of Kythnos Island. While the whole Kythnos power system is isolated from the rest of the Greek mainland system, Gaidouromantra has not any connection with the rest of the Kythnos power system, being a totally islanded microgrid.

Besides, this microgrid operates with 100% renewable energies, what makes it a perfect pilot site for advanced technologies based on renewable energies, batteries, and decentralized technologies for demand-side management (DSM).

The consumption profile is the typical for vacation houses: very high consumption in summer, and very low in non-holidays period (specially in winter).

The electric infrastructure of the Gaidouromantra microgrid includes the following components:

- 6 distributed solar PV plants (rooftop and ground-mounted): 20 kWp.
- A Lead-Acid battery bank, with a nominal capacity of 96 kWh (@20h), 48 V.
- A 3-phase back-up diesel generator of 22 kVA.
- Fiber optic Communication network of 1 Gbps.
- Advanced smart meters and load controllers, Feeder controllers and Real Time Automation Controller.

The total electricity production of the solar PV panels and the diesel generator is around 6.3 MWh/year. Around 97% of the total electricity production is covered with the solar PV plants, although the diesel generator has to be put into operation specially in August (when the electricity demand reaches a peak), and in winter (January, February and December), when the solar PV production is lower.

In the following table, it is possible to find a summary of the main results of the evaluation of the KPIs in the Gaidouromantra Microgrid:

Gaidouromantra Microgrid Demo Site			
KPI #	Name	Value	Description
1	SAIFI	ecoMicrogrid -100% (BaU: 7, R&I: 0)	It measures the average number of failures per customer served per unit time.

2	SAIDI	ecoMicrogrid -100% (BaU: 35 min, R&I: 0 min)	It measures the duration of the outages or power interruptions.
3	RES curtailment reduction	ecoMicrogrid 18.0%	It quantifies the decrease in energy produced by solar PV sources that cannot be injected into the microgrid, even when available, due to the technical and operational limitations of the microgrid. RES curtailment is calculated to be: BAU 11,12 MWh, R&I 9,12 MWh, R&I enhanced 3,20 MWh.
4	RES increase in the energy mix (annual)	ecoMicrogrid 11.07%	It measures the higher penetration of renewable energy sources in the Demo Site, when the solutions proposed in the RE-EMPOWERED project are used. RES in the energy mix is calculated to be: BAU 86.3%, R&I 95.8%, R&I enhanced 97.6%.
5	Solar PV utilization factor	ecoMicrogrid +22.28% (BaU: 38.51%, R&I: 47.10%)	It measures the difference between the used power generation of a solar PV project, and the theoretical maximum power production of that project, in a location and a period of time.
6	Reduction of thermal power production unit operation	ecoMicrogrid 66.40%	It measures the yearly number of hours that the diesel generator has to be operated on to cover the power demand in the Gaidouromantra Microgrid, before and after the implementation of ecoMicrogrid. Thermal unit operation time is calculated to be: BAU 97 h 55 min, R&I 32 h 54 min.
7	Reduction of battery degradation-Mean charging rate	ecoMicrogrid 3.9%	It measures the effect that the use of ecoMicrogrid has on the useful lifetime of the battery system, and on the cost of the system.
8	Wind Turbine Capacity Factor	ecoResilience 23%	It measures the difference between the real power production of a renewable energy project, and the nominal or theoretical maximum power production of that renewable energy project (for example, a wind turbine), in a location and a period of time.
9	Wind Turbine Annual Energy Production	ecoResilience 5,586 kWh/year	It measures the average power generation of the installed wind turbine.
10	Forecasting accuracy	ecoMicrogrid MAPE Solar PV: 18.74% MAPE Load: 30.44% MAE Solar PV: 1.996% MAE Load: 35.76% MAD Solar PV: 54.47 W	They are some indicators which assess the forecasting accuracy of the ecoMicrogrid.

		MAD Load: 369.12 W	
11	Availability of communication infrastructure	ecoPlatform 99.31%	It measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.
12	Digital solutions integrated	3 solutions	It measures the number of digital solutions installed because of the development of the project.
13	Customers engaged with smartphone application	4 customers (50%)	It measures the customer's involvement with the developed tool.
14	Data Access Control	ecoCommunity 100%	It evaluates the level of authorised vs unauthorized access to the tool or tool data.
15	Personal Data Consent	ecoCommunity 100%	It evaluates the percentage of engaged customers who have provided explicit consent for data processing in compliance with the GDPR requirements.
16	Booking Summary Publishing Accuracy	ecoCommunity +15 min	It evaluates the time accuracy of the booking summary published by ecoCommunity tool.
17	Tool Modules Deployed	ecoCommunity 70%	It measures the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project. Modules Developed: 10, Modules Deployed: 7.
18	Data Reliability	ecoPlatform 99.90%	It measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.
19	Energy data transfer	ecoPlatform 5 MB/hour	It measures the capacity of a data exchange platform to transfer different types of data successfully.
20	Increased access to own metering data	ecoCommunity, ecoMicrogrid 8 consumers	It measures the number of new consumers which use a smart meter and can access their electricity meter data through a single access point
21	Automatic metering of consumers	ecoCommunity 8 consumers	It compares the number of consumers which have their smart meter information remotely gathered by the DSO, compared to the number of consumers who had their data collected in the BAU scenario

Table 25 List of technical KPIs for the Gaidouromantra Microgrid Demo Site.

2.4.1. KPI 1: SAIFI (ecoMicrogrid)

The SAIFI (System Average Interruption Frequency Index) is a widely accepted indicator, which measures the average number of failures per customer served per unit time.

In the case of the Gaidouromantra Microgrid, this indicator has been assessed by comparing the baseline scenario without the ecoTools (the BAU situation) to the RE-EMPOWERED scenario, where the ecoMicrogrid and other ecoTools have been deployed.

Although a direct comparison with available historical data is limited by specific hardware upgrades to the critical commercial infrastructure at the demo site, the available data underscores the very positive impact of the ecoMG solution on the reliability index SAIFI.

For the BAU situation, the available information about the SAIFI comes from historical real data of year 2021. The comparison is focused on the period from August 8th to October 22nd, 2021.

On the other hand, for the RE-EMPOWERED situation, the measurements have been carried out during the whole summer period of the year 2024, starting from June 7th, 2024, to November 30th, 2024. This period includes the interest period, the summer, when the power consumption in the Gaidouromantra Microgrid is higher. As can be seen, the period to compare the BAU and the RE-EMPOWERED situations have been chosen to be the same, in order that the comparisons are correct.

According to the existing records Ref. [5], before the development of the RE-EMPOWERED project, during the period from August 8th to October 22nd, 2021, seven (7) interruption events were reported. These events involve total power loss for all users. No individual interruptions for a specific consumer have been reported, as the reason for the interruption has been always in the main system (DG, BESS or Battery Inverter).

In the RE-EMPOWERED situation, that is after the installation of ecoMicrogrid, no power supply interruption events have occurred.

SAIFI is calculated with the following formula:

$$SAIFI = \frac{\sum_{j=1}^{J} N_j}{N_T}$$

Where:

- J: Total number of incidents.
- N_j: Number of customers interrupted per incident.
- N_T: Total number of customers served.

The following table shows the results of the KPI SAIFI for the BAU and the RE-EMPOWERED situations:

	BAU	RE-EMPOWERED	**Change**
SAIFI	7	0	**-100%**

Table 26 SAIFI for the Gaidouromantra Microgrid Demo Site.

2.4.2. KPI 2: SAIDI (ecoMicrogrid)

The SAIDI (System Average Interruption Duration) measures the duration of the outages or power interruptions. As for SAIDI, in Gaidouromantra Microgrid, the following situations are compared:

- BAU: The available data include the period from August 8th to October 22nd, for the year 2021.
- RE-EMPOWERED: There have been measurements during the whole summer period of the year 2024, starting from June 7th, 2024, up to November 30th, 2024.

As has been described before, it is not possible to carry out a direct comparison between the BAU and the RE-EMPOWERED situations because, given the available historical data, a commercial infrastructure update has intervened. However, the available data offers good information to evaluate this KPI.

For the BAU situation, taking year 2021 (period from August 8th to October 22nd, 2021), 7 power supply interruption events were registered, with an average duration of 35 minutes. These power supply interruption events involved total power loss for all users. No individual interruptions for a specific consumer have been reported, as the reason for the interruption has been always the main system (DG, BESS or Battery Inverter).

In the RE-EMPOWERED situation, no power supply interruption events have been registered.

SAIDI is calculated using the following formula:

$$SAIDI = \frac{\sum r_i N_i}{N_T}$$

In the previous formula, the variables are:

- r_i: Restoration time, in minutes, for each interruption.
- N_i is the number of customers interrupted.
- N_T is the total number of customers served.

Considering that all customers were affected in each interruption, then, for all "i", $N_i = N_T$, and then, SAIDI is the average restoration time, 35 min.

The following table shows the results of the SAIDI KPI for Gaidouromantra microgrid.

	BAU	RE-EMPOWERED	**Change**
SAIDI	35 min	0 min	**-100%**

Table 27 SAIDI for the Gaidouromantra Microgrid Demo Site.

2.4.3 KPI 3: RES curtailment reduction (ecoMicrogrid).

The RES curtailment reduction quantifies the decrease in energy produced by solar PV sources that cannot be injected into the microgrid, even when available, due to the technical and operational limitations of the microgrid.

The reduction is calculated using the following formula:

$$RC_{RES} = \frac{C_{RES_{BaU}} - C_{\Re S_{R\&I}}}{C_{RES_{BaU}}} * 100$$

where:

$$C_{RES} = \sum_{i=1}^{I} \sum_{t=1}^{T} (P_{i,t}^{prod} - P_{i,t}^{inj})$$

- $C_{\Re S_{R\&I}}$ is the RES curtailment for the RE-EMPOWERED scenario (kWh or MWh).
- $C_{RES_{BaU}}$ is the RES curtailment for the BAU scenario (kWh or MWh).
- I is the number of facilities under consideration.
- T is the set of time intervals of period under consideration, excluding periods of scheduled maintenance and outages.
- $P_{i,t}^{prod}$ is the available energy production of the i^{th} RES facility at period t (kWh or MWh).
- $P_{i,t}^{inj}$ is the injected energy of the i^{th} RES facility at period t (kWh or MWh).

The Gaidouromantra microgrid operates as an off-grid system. During the summer months, when the microgrid has a lot of production from solar PV, the batteries frequently reach their SoC (State of Charge) upper limit around noon. This results in a restriction on potential power production for the rest of the day. The ecoMicrogrid is capable to utilize this excess power to cool buildings by leveraging the thermal vector, thus reducing RES curtailment.

The evaluation of RES curtailment reduction considers data from two periods: the demonstration round 2 special test on September 28th, 2024, and a period spanning from July 20th, 2024, to September 10th, 2024.

The following scenarios were considered to assess the impact of ecoMicrogrid operation on the demo site:

- **BAU Scenario**: This scenario assumes that ecoMicrogrid is not in operation and thus no thermal vector is considered.
- **RE-EMPOWERED Scenario**: In this scenario, ecoMicrogrid is operating normally with the thermal vector enabled.

- **Expanded RE-EMPOWERED Scenario**: It evaluates the potential impact of expanding HVAC utilization to more buildings.

The results show that under the RE-EMPOWERED scenario, renewable energy curtailment decreased by 18.0%, demonstrating the effectiveness of ecoMicrogrid in reducing energy waste. In the RE-EMPOWERED scenario with expanded HVAC, which assumes the integration of HVAC systems in additional buildings, renewable energy curtailment experienced a dramatic reduction of 71.2%, further highlighting the potential of ecoMicrogrid to enhance renewable energy utilization significantly.

	BAU	RE-EMPOWERED	**Change**	RE-EMPOWERED with expanded HVAC	**Change**
Annual renewable energy produced	6,640.29 kWh	8,120.29 kWh	**+22.3%**	14,038.80 kWh	**+111.4%**
Annual renewable energy curtailment	11,123.8 kWh	9,121.56 kWh	**-18.0%**	3,203.05 kWh	**-71.2%**

Table 28 RES curtailment reduction in Gaidouromantra Microgrid.

A detailed analysis reveals two primary mechanisms through which ecoMicrogrid optimization manages energy operations.

Predictive Optimization of Diesel Generator Operation: The first mechanism involves the ecoMicrogrid ability to manage the operation of the diesel generator in a way that minimizes curtailment and improves the overall energy mix. This can be easily seen in the Figure 8 that demonstrates the results of the demonstration round 2 special test. Figure 8 highlights the impact on curtailment due to diesel generator charging patterns.

In the **BaU scenario** (top graph), the diesel generator rapidly restores storage capacity to 80% before shutting down in the early morning (06:40). This leads to solar PV curtailment during the day as the system reaches its maximum SoC limit before noon.

In the **RE-EMPOWERED scenario** (bottom graph), the system anticipates solar PV generation overtaking system needs during early morning hours. This results in both reduced diesel generator operation and better utilization of solar PV production, consequently reducing curtailment.

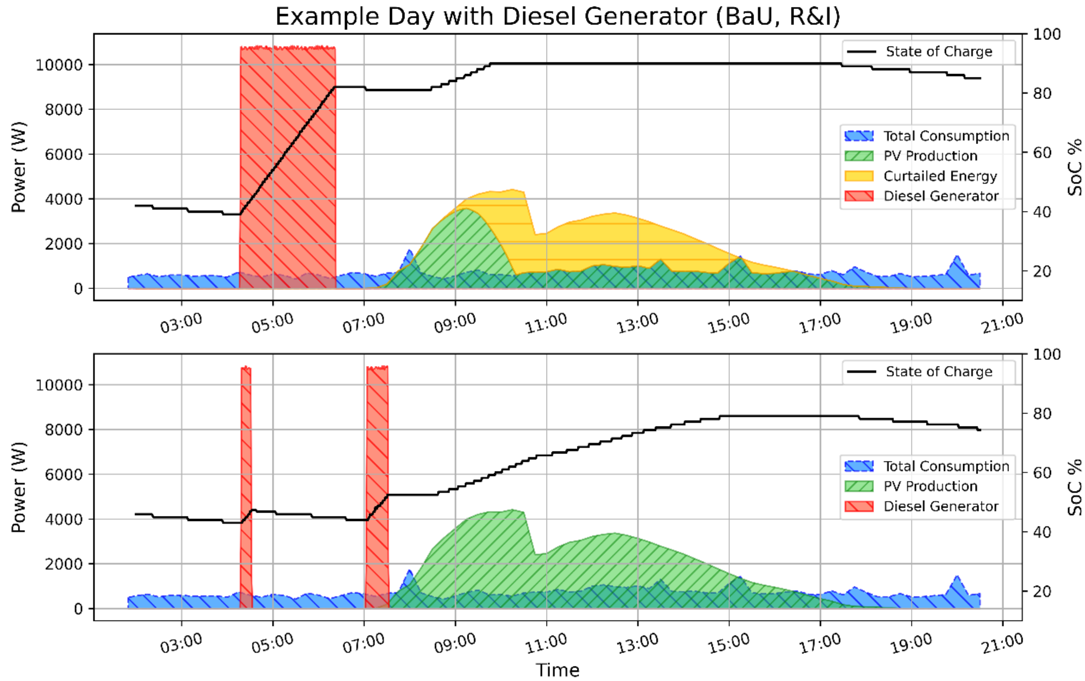

Figure 8: Comparison of the total energy consumption, the solar PV generation, the curtailed energy, and the use of diesel, in the BAU and the RE-EMPOWERED situations.

Utilization of the Thermal Vector: The second mechanism shows more frequent impact, particularly during spring and summer months. The strategic use of HVAC systems helps utilize excess solar PV generation that would otherwise be curtailed. ecoMicrogrid is specifically designed to shift HVAC consumption to periods of peak PV generation, thereby reducing reliance on diesel generators during periods of low solar availability. The system capabilities extend further, implementing precooling strategies for spaces to minimize or eliminate energy requirements during evening and nighttime hours while maintaining temperatures within acceptable limits.

This mechanism is clearly illustrated in the accompanying Figure 9, which demonstrates the effect of expanding HVAC capacity to four units. The upper graph displays the forecast solar PV production and the actual production highlighting curtailed energy (indicated by the yellow dashed area) over four typical summer days. The bottom graph shows the energy utilization achieved through the thermal vector deployment, represented by the green dashed area.

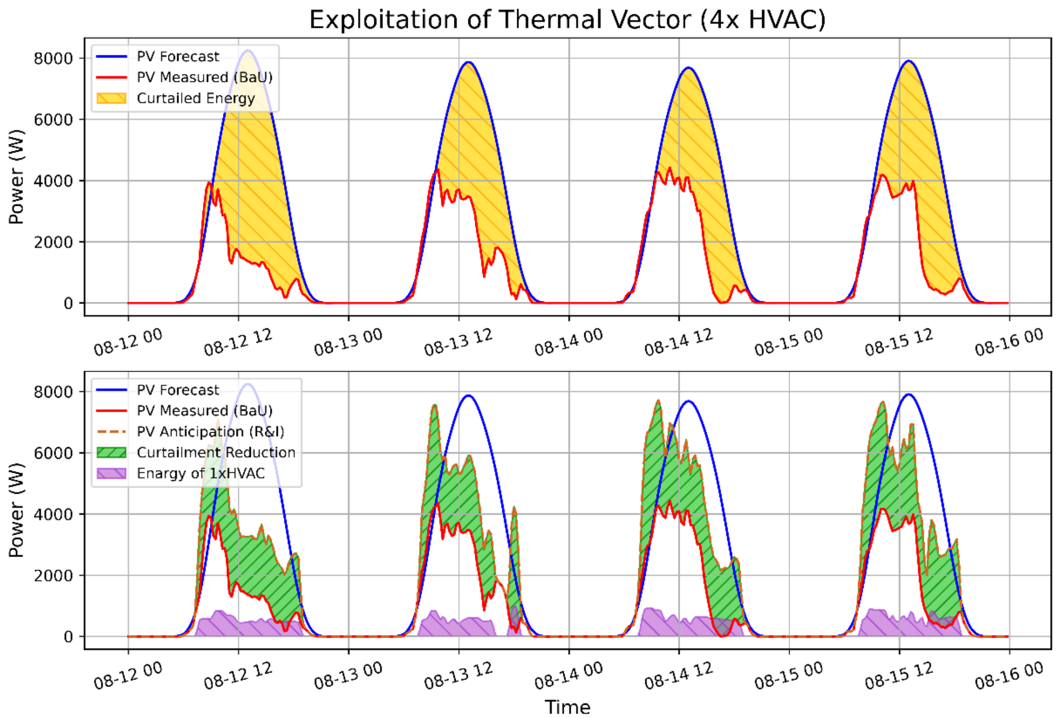

Figure 9: Effect of using 4 HVAC systems in the Gaidouromantra microgrid, in terms of the reduction of power curtailments.

2.4.4 KPI 4: RES increase in the energy mix (annual) (ecoMicrogrid)

The **RES increase in the energy mix** measures the higher penetration of renewable energy sources in the Demo Site, when the solutions proposed in the RE-EMPOWERED project are used.

It is measured in terms of the growth of the penetration of renewable energy sources, this is, an increase in the percentage of used energy which is renewable.

It can be calculated with the following formula:

$$RES\ increase\ in\ the\ energy\ mix = \frac{\%\ of\ renewable\ energy\ in\ the\ energy\ mix\ (RE-EMPOWERED)}{\%\ of\ renewable\ energy\ in\ the\ energy\ mix\ (BAU)} - 1$$

The evaluation of RES increase in the energy mix considers data from two distinct periods: the demonstration round 2 special test conducted on September 28th, 2024, and a longer period spanning from July 20th, 2024, to September 10th, 2024. For the analysis, only three out of the six solar PV systems were included. This selection was made to enable a comparative analysis of the influence of each period on the overall improvement.

The following scenarios were considered to assess the impact of ecoMicrogrid operation on the demo site:

- **BAU Scenario**: This scenario assumes that ecoMicrogrid is not in operation and thus no thermal vector is considered.
- **RE-EMPOWERED Scenario**: In this scenario, ecoMicrogrid is operating normally with the thermal vector enabled.
- **Expanded RE-EMPOWERED Scenario**: It evaluates the potential impact of expanding HVAC utilization to more buildings (4 HVAC).

To annualize the impact, the following assumptions were made:

- Based on historical data, there were 47 days in the year when the diesel generator needed to be activated.
- The results from the period from July 20th, 2024, to September 10th, 2024, were proportionally expanded to cover the rest of the year, incorporating seasonal adaptations by utilizing typical days from the PVGIS tool.

The implementation of RE-EMPOWERED system, along with expanded HVAC capacity, has demonstrated significant improvements in renewable energy utilization at the Gaidouromantra Microgrid. The annualized results are shown in Table 29.

	BAU	RE-EMPOWERED	Change	RE-EMPOWERED with expanded HVAC	Change
Annual fossil fuel energy produced (diesel generator)	1,054.21 kWh/year	352.03 kWh/year	**-66.6%**	352.03 kWh/year	**-66.6%**
Annual renewable energy produced	6,640.66 kWh/year	8,120.29 kWh/year	**22.3%**	14,038.8 kWh/year	**111.4%**
Fossil fuel contribution to the energy mix (%)	13.7%	4.2%	**-69.7%**	2.4%	**-82.1%**
Renewable energy contribution to the energy mix (%)	86.3%	95.8%	**11.1%**	97.6%	**13.0%**

Table 29 RES increase in the energy mix in Gaidouromantra Microgrid. Annualized results

According to the data, the RE-EMPOWERED project allows for an increase in the renewable energy contribution to the energy mix from 86.3% to 95.8%, representing an increase of 11.1%. This contribution can be further increased with the expansion in the use of HVAC systems, reaching 97.6% (a 13.0% increase). These results are also presented in the bar graph of Figure 10.

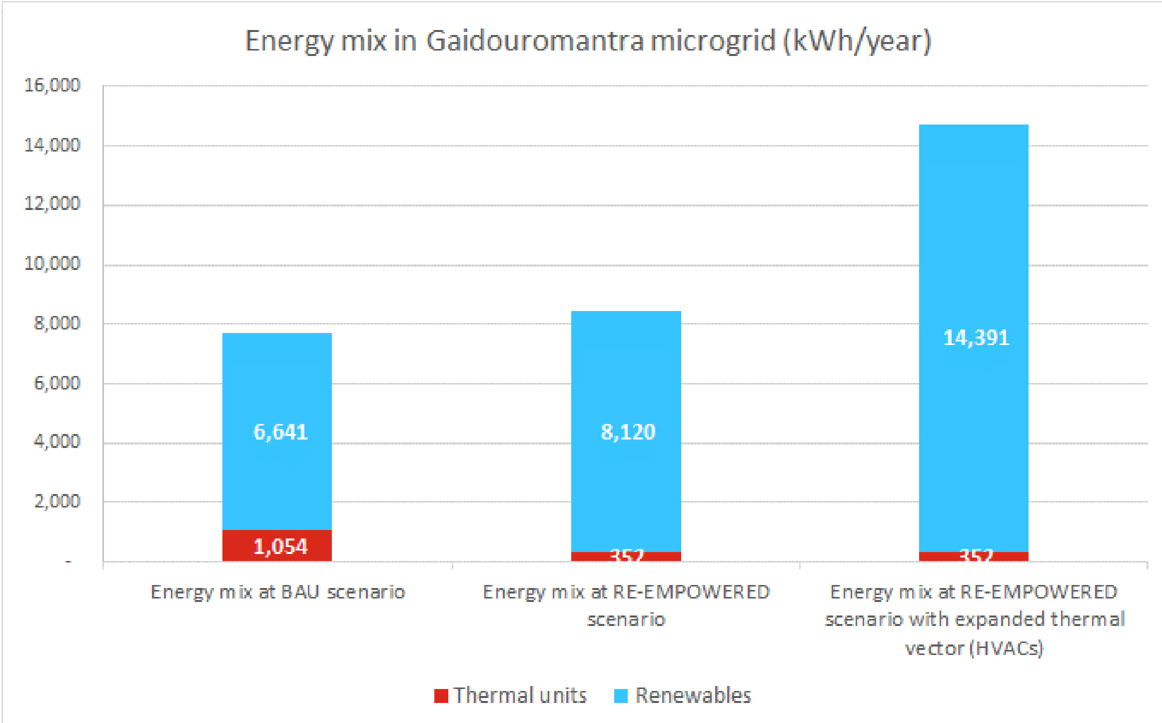

Figure 10: Energy mix in Gaidouromantra microgrid- Annualized results.

2.4.5 KPI 5: Solar PV utilization factor (ecoMicrogrid)

The utilization factor of a solar PV project measures the difference between the used power generation of a solar PV project, and the theoretical maximum power production of that project, in a location and a period of time.

It is measured by dividing the average power generated by the solar PV project into the maximum theoretical electricity that this project can produce:

$$Solar\ PV\ Utilization\ Factor\ (\%) = \frac{Yearly\ used\ power\ generated\ (kWh)}{Maximum\ electricity\ generated\ (kWh)}$$

The evaluation of Solar PV utilization factor considers data from two distinct periods: the demonstration round 2 special test conducted on September 28th, 2024, and a longer period spanning from July 20th, 2024, to September 10th, 2024. For the analysis, only three out of the six PV systems were included. This selection was made to enable a comparative analysis of the influence of each period on the overall improvement.

The following scenarios were considered to assess the impact of ecoMicrogrid operation on the demo site:

- **BAU Scenario**: This scenario assumes that ecoMicrogrid is not in operation and thus no thermal vector is considered.

- **RE-EMPOWERED Scenario**: In this scenario, ecoMicrogrid is operating normally with the thermal vector enabled.
- **Expanded RE-EMPOWERED Scenario**: Evaluates the potential impact of expanding HVAC utilization to more buildings (4 HVAC).

To annualize the impact, the following assumptions were made:

- Based on historical data, there were 47 days in the year when the diesel generator needed to be activated.
- The results from the period from July 20th, 2024, to September 10th, 2024, were proportionally expanded to cover the rest of the year, incorporating seasonal adaptations by utilizing typical days from the PVGIS tool.

The results are shown in Table 30. The total produced energy, calculated based on the forecasting provided by the ecoMicrogrid tool, is 17,241.85 kWh. The RE-EMPOWERED Scenario leads to an increase in the solar PV utilization factor by 22.28%, from 38.51% to 47.10%. Furthermore, if the use of HVAC systems is expanded to more vacation houses, the solar PV utilization factor can reach 81.42%, representing an increase of 111.41% compared to the BAU.

	Annual renewable energy utilized (kWh/year)	Solar PV utilization factor (%)	Increase compared to BAU
BAU	6,640.66	**38.51%**	
RE-EMPOWERED	8,120.29	**47.10%**	**22.28%**
RE-EMPOWERED with expanded HVAC	14,038.80	**81.42%**	**111.41%**

Table 30 Solar PV utilization factor in Gaidouromantra Microgrid.

2.4.6. KPI 6: Reduction of thermal power production unit operation (ecoMicrogrid)

This KPI measures the yearly number of hours that the diesel generator has to be operated on to cover the power demand in the Gaidouromantra Microgrid, before and after the implementation of ecoMicrogrid.

In this case, BAU scenario would be the case when the ecoMicrogrid is not installed, while the RE-EMPOWERED scenario is based on real measurements from the microgrid, once the ecoTool has been installed. To estimate the BAU scenario, a simulation has been made for the hypothetical equivalent situation, if ecoMicrogrid had not been installed.

To make proper and fair comparisons, only one half of the solar PV facility has been considered.

The KPI has been estimated based on real data, extracted from the Demo Site on September 28th, 2024, during a demonstration round with a frequency of measurements of 1 minute.

According to the measurements made during that day:

- Operating time of the diesel generator during a day, BAU: 125 min.
- Operating time of the diesel generator during a day, RE-EMPOWERED: 42 min.
- Reduction in the operating time of the diesel generator during a day: 83 min.

These empirical results have been extrapolated to a complete year, based on historical data. It has been estimated that there are 47 days per year when the diesel generator has to be put into operation.

Considering a reduction in the operating time of the diesel generator due to the use of the ecoMicrogrid of 83 min per day of use, then the total reduction in the operating hours during a year amount to:

$$83\,\frac{\min of\ use}{day}\cdot 47\,\frac{days}{year}\cdot\frac{1}{60}\frac{hours}{min}=65\ hours\ and\ 1\ minute$$

These results are summarized in the following table:

	BAU	RE-EMPOWERED	**Change**
Diesel generator operation time	5,875 min (97 h 55 min)	1,974 min (32 hours 54 min)	**-66,40%**

Table 31 Automatic metering of consumers for the Gaidouromantra Microgrid Demo Site.

2.4.7. KPI 7: Reduction of battery degradation (ecoMicrogrid).

This KPI evaluates the impact of ecoMicrogrid on the useful lifetime of the battery system and its associated costs. The focus is on understanding how optimized control strategies influence battery degradation and overall system efficiency.

A key metric for assessing battery health is the **State-of-Health (SoH)** of the energy storage system. SoH quantifies the difference between a used battery and a new, unused battery, serving as an indicator of cell aging.

The **State-of-Health (SoH)** is calculated as:

$$SoH\ (\%) = 100\cdot\frac{Q_{max}}{C_r}$$

Where:

- SoH (%) is the State-of-Health of the energy storage system.
- Q_{max} is the maximum charge available in the battery.
- C_r is the rated capacity.

The **instantaneous SoH** of a battery is influenced by multiple factors related to the chemical state of its cell components. For the purposes of this analysis, a good indication of the State-of-Health can be inferred by utilizing metrics such as the **charging rate** and **processed capacity**. These metrics provide insights into how different utilization patterns impact critical longevity factors, such as operating temperature, DoD, C-rate, battery cycles performed.

It should be noted that the correlation of these parameters with the State of Health of our batteries has not been quantified as this is a multifactorial subject still under research and not clearly defined. It requires much more complex research work that goes beyond the scope of the current analysis.

The reduction in the use of the diesel generator, facilitated by ecoMicrogrid, significantly reduces the duration for which the batteries are charged at high current (C-rate), thereby mitigating battery deterioration compared to scenarios where solar PV generation is used for charging.

It has been estimated that when the battery is charged with the diesel generator, the current intensity is approximately 2.55 times higher than when charged with solar PV (+155%). This value was calculated by dividing the diesel generator's mean charging power (10.2 kW) by that of the solar PV (4 kW).

For the example day on **September 28, 2024** (see KPI 3 at 2.4.3):

- The mean charging rate, for the whole example day, using the diesel generator (BAU scenario) is 3,484 W, which leads to a current intensity of 0.0747 C.
- The mean charging rate using the solar PV (RE-EMPOWERED scenario) is 2,519 W, which leads to a current intensity of 0.0525 C.

This is a reduction of 29.72% in the current intensity, which can be extrapolated to 3.83% for the whole year.

	BAU	RE-EMPOWERED	Change
Reduction of Mean charging rate (C-rate)	0,0747 C	0,0525 C	**-29.72%**
			-3.83% annualized

Table 32 Reduction of battery degradation- Mean charging rate for the Gaidouromantra Microgrid Demo Site.

In the same example day, the processed capacity, charging and discharging of the battery was:

- The processed capacity using the diesel generator (BAU scenario) is 45,16 kWh.
- The processed capacity using the solar PV (RE-EMPOWERED scenario) is 31,40 kWh.

This involves a reduction of 30.47%, which is extrapolated to -3,92% for the whole year.

	BAU	RE-EMPOWERED	Change
Reduction of Processed capacity (kWh)	45,16 kWh	31,40 kWh	**-30.47%**
			-3.92% annualized

Table 33 Reduction of battery degradation- Mean charging rate for the Gaidouromantra Microgrid Demo Site.

The improvement of the useful lifetime of the batteries would be around **4%** reduction in the replacement cost of the batteries, or in a suspension of their purchase for 5 months, along a decade.

2.4.8. KPI 8: Wind Turbine Capacity Factor (ecoResilience).

The capacity factor of a renewable energy source measures the difference between the real power production of a renewable energy project, and the nominal or theoretical maximum power production of that renewable energy project (for example, a wind turbine), in a location and a period of time.

It is measured by dividing the average power generated by wind turbines into the nominal power capacity:

$$Wind\ Turbine\ Capacity\ Factor\ (\%) = \frac{Yearly\ power\ generated\ (kWh)}{Nominal\ power\ generated\ (kWh)}$$

In the case of the Gaidouromantra microgrid, the wind turbine capacity factor has been estimated to be 23%, for a 5 m/s average wind speed site.

The following table includes this result:

	BAU	RE-EMPOWERED	Change
Wind turbine capacity factor	N/A	23%	**23% capacity factor**

Table 34 Wind Turbine Capacity Factor for the Gaidouromantra Microgrid Demo Site.

2.4.9. KPI 9: Wind Turbine Annual Energy Production (ecoResilience).

This indicator measures the average power generation of the installed wind turbine in the Gaidouromantra Microgrid.

According to the measurements which have been done, the annual energy production of the locally manufactured small wind turbine is 5,586 kWh/year, at a 5 m/s average wind speed.

The following table includes this result:

	BAU	RE-EMPOWERED	Change
Wind turbine annual energy production	N/A	5,586 kWh/year	**+5,586 kWh/year**

Table 35 Wind Turbine Annual Energy Production for the Gaidouromantra Microgrid Demo Site.

2.4.10. KPI 10: Forecasting accuracy (ecoMicrogrid).

To thoroughly assess the forecasting accuracy of the ecoMicrogrid at the Gaidouromantra Demo Site, multiple statistical indicators are employed. Each provides a unique perspective on the model performance, ensuring a comprehensive evaluation:

1. **Normalized Mean Absolute Percentage Error (nMAPE):** This indicator measures the accuracy of the forecast relative to the scale of the observed values, making it particularly useful for comparing errors across datasets with different magnitudes. It highlights percentage-based deviations, offering insight into proportional accuracy.
2. **Normalized Mean Absolute Error (nMAE):** The nMAE evaluates the absolute average error while normalizing it to the range of the observed data. This metric is less sensitive to outliers than nMAPE and provides a straightforward assessment of average forecasting performance.
3. **Median Absolute Deviation (MAD):** MAD focuses on the median error, which is robust to outliers, capturing the central tendency of errors. This makes it particularly useful for understanding the consistency of the forecasting model in scenarios with occasional extreme deviations.

The MAPE (Normalized Mean Absolute Percentage Error) evaluates the accuracy of the developed forecasting algorithms, according to the calculation of the Normalized Mean Absolute Percentage Error of solar PV power generation or load forecasting.

It has been calculated as the deviation between forecasts and actual measurements for production and consumption, in different time intervals. ecoMicrogrid tool has produced forecasts with a projection of up to 72 hours. The following shifting period has been considered: from 0 h (this is, right before the actual event) to 48 h, with steps of 6 hours. The used method has been the shifting window using data with granularity of 15 minutes.

The formula used to calculate the MAPE is:

$$MAPE = \frac{\sum_{t=1}^{N} \left| \frac{E_t}{L_t} \right|}{N} = \frac{\sum_{t=1}^{N} \left| \frac{L_t - F_t}{L_t} \right|}{N}$$

Where:

- E_t is the forecast error in the calculation of the load or generation, at period "t", being $E_t = L_t - F_t$.
- L_t is the actual, real value of load or generation at period "t".

- F_t is the forecast value of load or generation at period “t”.
- N is the number of available data points of generation time series.

For solar PV forecasting, the measurements have been taken during the period from September 25th, 2024 to October 7th, 2024.

For load forecasting, the measurements have been made during the period from June 12th, 2024 to October 21st, 2024.

In the following figure, it is possible to look into the comparison of the forecast and real data for solar PV generation, during the period from September 27th, 2024, to October 7th, 2024:

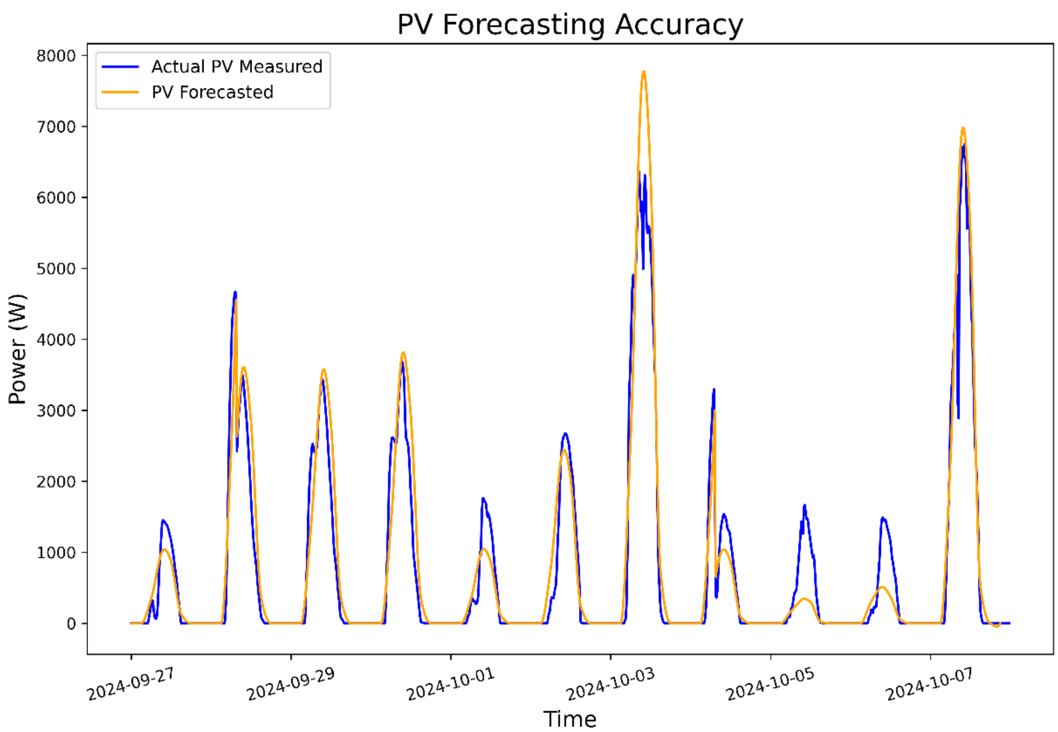

Figure 11: Solar PV generation forecasting data for the Gaidouromantra Microgrid Demo Site, period from September 27th, 2024, to October 7th, 2024.

Similarly, the following figure shows the comparison between the forecast and actual load values, for the period from June 15th, 2024, to September 15th, 2024:

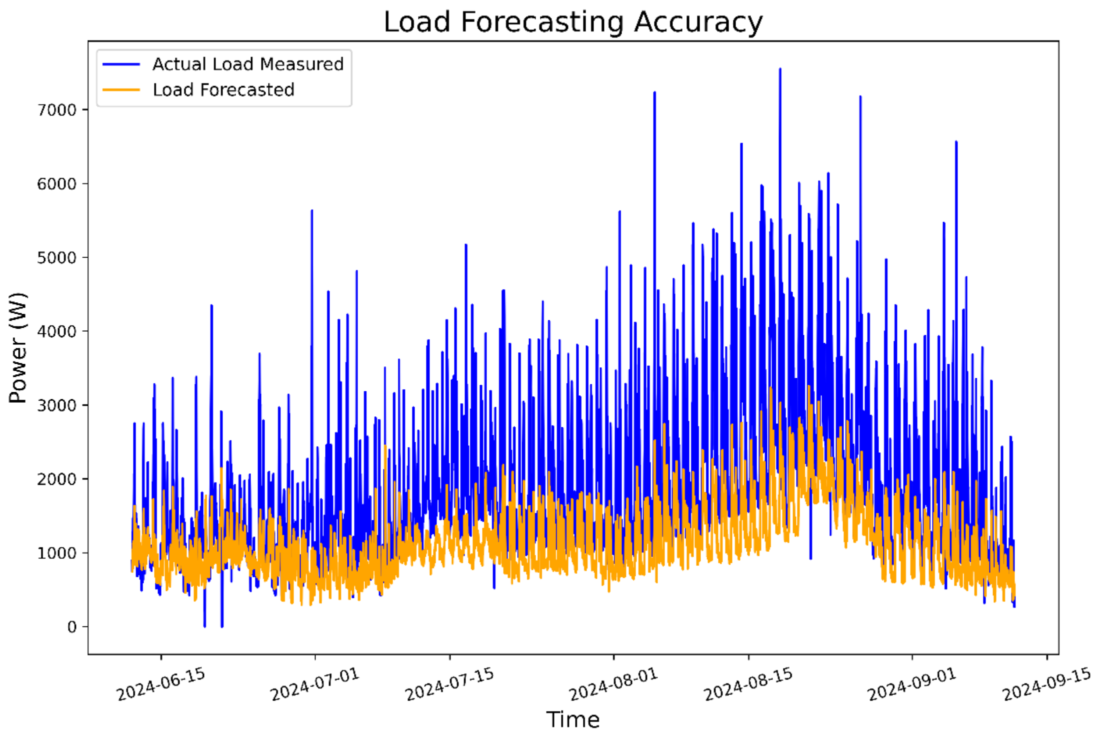

Figure 12: Load forecasting data for the Gaidouromantra Microgrid Demo Site, period from June 15th, 2024 to September 25th, 2024.

The following table shows the results for the MAPE forecasting accuracy:

MAPE forecasting accuracy	PV Forecasting	Load Forecasting
0 hours.	0.18931	0.31126
6 hours.	0.19113	0.30987
12 hours.	0.18952	0.30443
18 hours.	0.19207	0.30837
24 hours.	0.20260	0.31653
30 hours.	0.18764	0.30987
36 hours.	0.18737	0.30443
42 hours.	0.22678	0.30837
48 hours.	0.38222	0.31653

Table 36 MAPE (forecasting accuracy) for the Gaidouromantra Microgrid Demo Site.

As can be seen from Table 36, the accuracy of the solar PV generation forecasts can be classified as marginally good, as it is in the range of 20%.

However, the accuracy of the load forecasts is lower, as MAPE indicator is over 30%. The reason for this is that forecasting the load is more difficult, as this depends on the decisions of a small number of consumers, and the statistical sample is quite limited. For this reason, the result of around 30% for the accuracy index can be considered acceptable. In any case, for the operation of ecoMicrogrid, it is not necessary to reach a higher level of precision, so it is not necessary to optimize better the accuracy of the tool. The general purpose is to show the robustness and validity of the provided control results by ecoMicrogrid tool, by using standard accuracy forecasts as inputs.

The MAE (Normalized Mean Absolute Error) measures the accuracy of the developed forecasting algorithms, according to the calculation of the Normalized Mean Absolute Error (MAE), to forecast the solar PV production or the load.

The formula used to calculate the MAE is as follows:

$$MAE = \frac{\frac{\sum_{t=1}^{N} |E_t|}{N}}{\bar{L}} = \frac{\frac{\sum_{t=1}^{N} |L_t - F_t|}{N}}{\bar{L}}$$

Where:

- E_t is the forecast error in the calculation of the load or generation, at period "t", being $E_t = L_t - F_t$.
- L_t is the actual, real value of load or generation at period "t".
- F_t is the forecast value of load or generation at period "t".
- $\bar{L}$ is the average of the actual values of generation, over the N data points.
- N is the number of available data points of generation time series.

It has been calculated as the deviation between forecasts and actual measurements for production and consumption, in different time intervals. The following shifting period has been considered: from 0 h (right before the actual event) to 48 h, with steps of 6 hours. The method of the shifting window has been used.

For solar PV forecasting, the measurements have been taken during the period from September 25th, 2024 to October 7th, 2024.

For load forecasting, the measurements have been made during the period from June 12th, 2024 to October 21st, 2024. Data with a granularity of 15 minutes have been used.

The following table shows the results for the MAE forecasting accuracy:

MAE forecasting accuracy	PV Forecasting	Load Forecasting
0 hours.	0.02031	0.36034
6 hours.	0.02039	0.36607
12 hours.	0.02016	0.36476
18 hours.	0.01996	0.36459
24 hours.	0.02218	0.35765
30 hours.	0.02082	0.36607
36 hours.	0.02064	0.36476
42 hours.	0.02821	0.36459
48 hours.	0.03353	0.35765

Table 37 MAE (forecasting accuracy) for the Gaidouromantra Microgrid Demo Site.

As commented for the MAPE, the accuracy of the forecasts of solar PV generation is good, around 20%, except for the period of 42 and 48 hours, when they are over 30%. The accuracy of the forecasts is getting worse, as the time period is longer, especially when the time distance is higher than 40 hours. However, this medium accuracy is enough for the objectives of ecoMicrogrid.

On the other hand, load forecast accuracy is lower than solar PV generation accuracy, around 35%. This is due to the difficulty to forecast the behavior of a small number of consumers in the Gaidouromantra microgrid.

The MAD (Median Absolute Deviation) measures the accuracy of the developed forecasting algorithms, according to the calculation of the Median Absolute Deviation (MAD), to forecast the solar PV production, or the load.

This KPI is measured with the following formula:

$$MAD = median(|E_t|_{t=1}^{N})$$

Where:

- E_t is the forecast error in the calculation of the load or generation, at period "t", being $E_t = L_t - F_t$.
- L_t is the actual, real value of load or generation at period "t".
- F_t is the forecast value of load or generation at period "t".
- N is the number of available data points of generation time series.

It has been calculated as the deviation between forecasts and actual measurements for production and consumption, in different time intervals. The following shifting period has been considered: from 0 hours (this is, right before the actual event) to 48 h, with steps of 6 hours.

For solar PV forecasting, the measurements have been taken during the period from September 25th, 2024 to October 7th, 2024.

For load forecasting, the measurements have been made during the period from June 12th, 2024 to October 21st, 2024. A data granularity of 15 minutes has been always used in the measurements.

The following table shows the results for the MAD forecasting accuracy:

MAD forecasting accuracy	PV Forecasting	Load Forecasting
0 hours.	54.692	427.726
6 hours.	55.665	405.737
12 hours.	54.467	369.1186
18 hours.	62.031	392.5653
24 hours.	58.179	426.1878
30 hours.	60.243	405.737

MAD forecasting accuracy	PV Forecasting	Load Forecasting
36 hours.	51.468	369.1186
42 hours.	100.128	392.5653
48 hours.	89.415	426.1878

Table 38 MAD (forecasting accuracy) for the Gaidouromantra Microgrid Demo Site

2.4.11. KPI 11: Availability of communication infrastructure (ecoPlatform).

The KPI availability of communication infrastructure measures the reliability of the communication system, in terms of failure frequency and the required time to repair and restore the operation of the communication system.

It can be calculated with the following formula:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

Where:

- Uptime is the total time when the communication system is operational during the observation period.
- Downtime is the total time when the communication system was not operational (for example, due to failures, maintenance actions, unexpected outages).

In the testing period for ecoPlatform, in the Gaidouromantra Microgrid:

- Uptime was 715 hours.
- Downtime was 5 hours.

Therefore, the availability of communication infrastructure was:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{715\ hours}{715\ hours + 5\ hours}\right) \cdot 100 = 99.31\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	Change
Availability of communication infrastructure	N/A	99.31%	**N/A**

Table 39 Availability of communication infrastructure, for ecoPlatform, for the Gaidouromantra Microgrid Demo Site.

2.4.12. KPI 12: Digital solutions integrated (ecoCommunity, ecoPlatform, ecoMicrogrid).

The KPI measures the number of digital solutions installed because of the development of the project. The list of digital solutions installed is given in the following table.

Sl. No.	Tool	Digital Platform
1	ecoCommunity	Android Mobile
2	ecoPlatform	Interoperable ICT tool
3	ecoMicrogrid	Energy Management System

Table 40 List of digital solutions integrated in the Gaidouromantra Microgrid Demo Site.

Therefore, the following table includes the total number of digital solutions integrated in the Gaidouromantra Microgrid Demo Site:

	BAU	RE-EMPOWERED	Change
Digital Solutions Integrated	0	3	**+3 solutions**

Table 41 Number of digital solutions integrated in the Gaidouromantra Microgrid Demo Site.

2.4.13. KPI 13: Customers engaged with smartphone application (ecoCommunity).

This KPI measures the customer's involvement with the developed tool. The introduction of a new solution and its features can attract consumers to register for their use.

It is important to note that all registered consumers of the tool might not be actively engaging with the tool after the registration. This might be due to various reasons like customer lost interest to functionalities, tool failing to meet the customer expectations, customer might not have the time/patience for an active engagement etc.

The following table provides the number of customers registered as well as engaged with the tools during the demonstration activities.

		Registered	Engaged	Percentage Engaged
ecoCommunity	Administrator	2	1	50 %
	Consumer	4	2	50 %

Table 42 Number of customers registered and engaged with smartphone application in the Gaidouromantra Microgrid Demo Site.

The following table evaluates the KPI for customer registered and engaged in the digital solutions developed for the demo site.

	BAU	RE-EMPOWERED	Change
Customer Registration	0	4	**+4 customers**
Customer Percentage Engaged	0	50%	**+50%**

Table 43 Percentage of customers registered and engaged with smartphone application in the Gaidouromantra Microgrid Demo Site.

2.4.14. KPI 14: Data Access Control (smartphone application) (ecoCommunity)

The KPI evaluates the level of authorised vs unauthorized access to the tool or tool data. In the case of ecoCommunity the access to the tool and the data is restricted using username-password based authentication.

The KPI is evaluated using the formula:

$$Access\ Control\ Ratio\ = \frac{No\ of\ Authorised\ Access}{Total\ Number\ of\ Access}$$

In the Gaidouromantra Microgrid, all accesses which have been monitored have been controlled, as can be seen in the following table:

	BAU	RE-EMPOWERED	Change
Data Access Control	N/A	100%	**100% access control**

Table 44 Data Access Control in the Gaidouromantra Microgrid Demo Site.

2.4.15. KPI 15: Personal Data Consent (ecoCommunity)

The KPI evaluates the percentage of engaged customers who have provided explicit consent for data processing in compliance with the GDPR requirements. The tool users, during their first stage of engagement with the tool, are provided with an information sheet and consent form which provide information on the details of processing the personal data.

The GDPR (General Data Protection Regulation) is the Regulation (EU) 2016/679), which regulates the personal data privacy, and the treatment which can be given to these data. It includes the need to ask for specific consent when personal data are asked and treated.

In RE-EMPOWERED, all personal data have been correctly managed.

	BAU	RE-EMPOWERED	Change
Personal Data Consent	N/A	100%	**100% consent**

Table 45 Personal Data Consent in the Gaidouromantra Microgrid Demo Site.

2.4.16. KPI 16: Booking Summary Publishing Accuracy (ecoCommunity)

One of the functionalities of the ecoCommunity tool is to provide the day-ahead estimate of flexible load that would be connected to the system. This is utilized in the load forecasting algorithm implemented in ecoMicrogrid. Based on user inputs from the tool users, ecoCommunity summarizes the total load booked for each hour of the day and is sent to ecoMicrogrid.

The KPI evaluates the time accuracy of the booking summary published by ecoCommunity tool. The booking summary is expected to be published by the administrative instance of the tool daily at 12:00 am. However, due to various system constants of the android device which runs the administrative instance, it can be delayed or offset by certain minutes.

The KPI is evaluated by computing the average delay (minutes) during a month, for publishing the booking summary.

	BAU	RE-EMPOWERED	Change
Average Publishing Time Offset	N/A	15 min	**+15min**

Table 46 Average Publishing Time Offset in the Gaidouromantra Microgrid Demo Site.

It is expected that the booking summary will be received with a minimum delay so that the load estimation and associated algorithms can run accurately.

2.4.17. KPI 17: Tool Modules Deployed (ecoCommunity)

The KPI evaluates the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project. The tool functionalities or functional modules are developed considering a generic system with the different scenarios associated with all the demo sites. Although only a fraction of these modules will be implemented in the demo site considering the technical and social limitations.

The following table shows the number of modules developed in the project and deployed in the demo site for each tool.

Tool	Modules Developed	Modules Deployed	Percentage Deployed	RE-EMPOWERED
ecoCommunity	10	7	70%	70%

Table 47 Tool modules deployed, for the Gaidouromantra Microgrid Demo Site.

2.4.18. KPI 18: Data reliability (ecoPlatform).

This KPI measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.

It can be calculated using the following formula:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted - Total\ data\ packages\ with\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

This is equivalent to:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted\ without\ mistakes\ or\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

Where:

- Total data packages transmitted are the number of data packages which are transmitted, whether they are received or not.
- Total data packages with losses are the number of data packages which are not transmitted, or which have any kind of mistake.
- Total data packages transmitted without mistakes or losses are the number of data packages which are correctly and completely transmitted without losses or mistakes.

During the testing period, for the Gaidouromantra Microgrid:

- Total data packages transmitted: 1,000,000.
- Total data packages with losses: 1,000.

Therefore, the Data reliability KPI for the Gaidouromantra Microgrid is as follows:

$$Data\ reliability\ (\%) = \left(\frac{1{,}000{,}000 - 1{,}000}{1{,}000{,}000}\right) \cdot 100 = \frac{999{,}000}{1{,}000{,}000} = 99.90\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Data reliability	N/A	99.90%	**N/A**

Table 48 Data reliability, for ecoPlatform for the Gaidouromantra Microgrid Demo Site.

2.4.19. KPI 19: Energy data transfer (ecoPlatform).

Energy data transfer measures the capacity of a data exchange platform to transfer different types of data successfully. It is related to the amount of transmitted data (in MB) within the observation period.

Transmitted data can include logs, real-time monitoring data and other information.

The formula which can be used to estimate this KPI is:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

Where:

- Total transmitted data is the volume of energy-related data which are transferred using the ecoPlatform, in MB.
- Total time is the period of time when the transmission of data is monitored.

During the testing period, the following results were obtained:

- Total transmitted data: 50 MB.
- Total time: 10 hours.

Using the previously described formula:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{50\ MB}{10\ hours} = 5\ MB/hour$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Energy data transfer	N/A	5 MB/hour	**N/A**

Table 49 Energy data transfer, for ecoPlatform for the Gaidouromantra Demo Site.

2.4.20. KPI 20: Increased access to own metering data (ecoCommunity, ecoMicrogrid).

This KPI is related to the number of consumers which use a smart meter and can access their electricity meter data through a single access point. It measures the new consumers (including both households and organizations) that can access these data, because of the implementation of ecoMicrogrid and ecoCommunity.

The KPI is compared between the BAU and the RE-EMPOWERED scenario. The following table shows the number of consumers which can access these data:

	BAU	RE-EMPOWERED
Number of consumers which can access own metering data	0	8

Table 50 Increased access to own metering data for the Gaidouromantra Microgrid Demo Site.

2.4.21. KPI 21: Automatic metering of consumers (ecoCommunity).

This KPI is very related to the increased access to own metering data. It compares the number of consumers which have their smart meter information remotely gathered by the DSO, compared to the number of consumers who had their data collected in the BAU scenario.

In the case of the Gaidouromantra Microgrid, the result of the evaluation of the KPI is the same as for the Increased access to own metering data. Before the implementation of ecoDR and ecoCommunity, none of the consumers had their electricity consumption measured, while after the development of the RE-EMPOWERED project, the consumption of 8 consumers is monitored.

	BAU	RE-EMPOWERED
Number of consumers which have their energy consumption measured	0	8

Table 51 Automatic metering of consumers for the Gaidouromantra Microgrid Demo Site.

2.5 Ghoramara Island Microgrid: West Bengal, India

Ghoramara Island is located approximately 92 km south of Kolkata, in the Sundarban Delta complex of the Bay of Bengal in India.

The island has several villages. The nearest mainland is Kakdwip, located 5 km away. It takes around 1 hour to reach Kakdwip, using diesel operated boats and paddle boats.

There are 1,100 houses, mainly single-family dwellings, and mud houses or huts. There are also four primary schools (around 500 students), one higher secondary school (420 students), and a primary health care centre in the island.

Residents live in poor conditions, and also the island is affected by severe cyclonic storms, which happen every 5-10 years. Each cyclone affects the power supply, due to damages in solar PV panels.

The main characteristics of the energy system in the Ghoramara Island are:

- There is not any connection between the Ghoramara Island and the mainland, and there is not an electricity grid. For this reason, each house and shop have its own power supply. A reduced number of solar PV panels is installed in the rooftop of individual houses and businesses, which are used for mobile charging, or for LED lamps. However, the total power demand cannot be covered with the solar PV panels. On the other hand, residents do not have to pay for the electricity supply.
- In the streets, there are around 100 streetlights, powered with solar PV panels, but they are inoperative.
- There are two rice-cum-hauler mills in the island, powered with a diesel engine.

- Four e-rickshaws are used to move in the island, which are charged with a diesel generator.
- There is a 3-kW wind turbine near the school, but it is not operative.
- During the RE-EMPOWERED project, the following new facilities have been developed:
    - A 160 kW off-grid system, consisting of 150 kW solar PV + 10 kW wind + 720 kWh BESS.
    - 2 5-kW wind turbines, connected to the microgrid.
    - A 10-kW advanced microgrid, including 7.5 kW solar PV + 2.5 kW wind + 50 kWh BESS, with RE-EMPOWERED developed technologies.
    - 2 electric three wheelers, and a charging station with 15-kW, 15 kW solar PV panels and 72 kWh BESS.
    - 80 streetlights, out of which 20 are energy efficient dimmable.
    - Wind resilient structures for 2 kW solar PV and two 5 kW wind installations.
    - 3 kW locally made wind turbine system.
    - An electric boat, with a 3-kW on-board solar panel, 2x6 kW electric outboard motor and 2x12 kWh Li-ion battery.
    - A high mast light installed in the market area of the Ghoramara Island, with 4 LED lamps of 40 kW each. The LED lamps are powered with 4 solar PV panels with 200 Wp capacity, a battery with 12.8 V and 120 Ah.

The proposed business model for the Ghoramara Island involves the development of a safe electricity supply for the households and businesses, improving their welfare and quality of live, which also obtains incomes from different sources. Electricity is provided for 650 households, with 100 W per house.

Incomes will be obtained from the sale of electricity to domestic users at a reduced price, and the investment and management of transport system, such as the electric boat, the electric 3-wheelers, and the electric loads, which are used by citizens for a limited fee.

The microgrid will be operated by an energy services company (ESCO) or a company in charge of all the assets, which will charge a fee for their use to the users, or by a user cooperative.

The following table includes a summary of the technical KPIs described for the Ghoramara Island Microgrid:

Ghoramara Island Demo Site			
KPI #	Name	Value	Description
1	SAIDI	BAU: N/A R&I: 2 days	It measures the duration of the outages or power interruptions.
2	Factor of safety for Solar PV	BAU: 24,000 R&I: 133,333	It measures the ratio of a material strength to the working stress it experiences, for solar PV.

Ghoramara Island Demo Site			
KPI #	**Name**	**Value**	**Description**
3	Factor of safety for the wind turbine structure	50 times higher than the BAU	It measures the ratio of a material strength to the working stress it experiences, for wind.
4	Wind load reduction potential for solar PV	R&I: 82%	It measures the potential of the designed ecoResilience support structure, for the solar PV, to reduce wind load effects or mitigation risks of installed systems.
5	Wind load reduction potential for wind	-1.51% (BAU: 99.5% R&I: 98%)	It measures the potential of the designed ecoResilience support structures, for the wind turbine, to reduce the wind load effects or mitigation risks of installed systems.
6	Functional downtime for solar PV	BAU: N/A R&I: 0 days	It measures the ability of a structure to recover after suffering extreme events, such as earthquakes, windstorms or impacts, for solar PV.
7	Functional downtime for wind	BAU: 4-8 hours R&I: 4-6 hours	It measures the ability of a structure to recover after suffering extreme events, such as earthquakes, windstorms or impacts.
8	Operational downtime index (ODI) during overload cut-off	Scenario 1: 1.67% Scenario 2: 5.00% Scenario 3: 20.00%	It measures the percentage of time the ecoDR remains operational and resumes normal functioning during and after overload cutoff scenarios, compared to the total monitored time period.
9	Number of electric three wheelers operating in the island	BAU: 4 R&I: 4 + 2	It measures the number of electric three wheelers which are available for mobility.
10	Availability of communication infrastructure	99.31%	It measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.
11	Data Reliability	99.90%	It measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.
12	Energy data transfer	5 MB/hour	It measures the capacity of a data exchange platform to transfer different types of data successfully.
13	Increased access to own metering data	BAU: 4-5 smart meters R&I: 6 smart meters, including	It measures the number of new consumers which use a smart meter and can access their electricity meter data through a single access point.

Ghoramara Island Demo Site			
KPI #	Name	Value	Description
		1 new smart meter designed in RE-EMPOWERED	
14	Average Percentage Error (APE)	For voltage: -0,0097% For current: -0.089%	It defines the deviation between the measured values recorded by the ecoDR and the actual values, expressed as a percentage or within a specified tolerance range

Table 52 List of technical KPIs for the Ghoramara Island Microgrid Demo Site.

2.5.1. KPI 1: SAIDI

The SAIDI (System Average Interruption Duration) measures the duration of the outages or power interruptions.

In the Ghoramara Island Microgrid, the BAU situation was a total lack of power supply, so the KPI SAIDI could not be measured before the RE-EMPOWERED project.

Once the RE-EMPOWERED microgrid was implemented, the power supply was stopped for a period of 2 days, during the cyclone. Besides, there have been supply scarcity situations when the weather is cloudy.

This indicative result can be summarized in the following table, as follows:

	BAU	RE-EMPOWERED	**Change**
SAIDI	N/A	2 days	**N/A**

Table 53 SAIDI for the Ghoramara Island Microgrid.

2.5.2. KPI 2: Factor of safety for Solar PV (ecoResilience).

The safety of the mechanical systems is defined using factor of safety (FOS) which is a nondimensional quantity that measures the ratio of a material strength to the working stress it experiences. FOS formula varies for different materials. For the ductile materials which were used in the design of resilient ground-mounted solar PV and wind turbine support structures, it is defined as the ratio of yield strength to applied load.

$$Factor\ of\ safety\ (FOS) = \frac{(Yield\ strength \cdot Cross\ section\ area)}{Maximum\ applied\ load}$$

In this case, the yield strength of the support structure is 250 MPa.

A minimum FOS for conventional fixed PV system is 2.5 and it is increased to multifold based on the requirements to handle local cyclonic or seismic effects.

The maximum load experienced by the conventional fixed ground-mounted PV system is calculated based on the following formula,

$$Maximum\ load = C_X \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot S$$

Where:

- C_x is the force coefficient, in this case, 0.85 for the proposed inclined plate.
- ρ is the air density, this is, 1.225 kg/m^3.
- v is the air velocity, estimated to be 60 m/s.
- S is the solar panel area, 4 m^2.

Applying these values to the formula:

$$Maximum\ load = C_X \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot S = 0.85 \cdot \frac{1}{2} \cdot 1.225\ \frac{kg}{m^3} \cdot \left(60\,\frac{m}{s}\right)^2 \cdot 4\ m^2 = 7{,}500\ N$$

Hence, Force or load = 7,500 N.

Whereas the maximum load experienced by the resilient ground-mounted solar PV system is 1,351 N as the inclination angle is reduced from 23° to 0° and the Cx becomes 0.15 ~0.2.

Using the formula which is applied to the Factor of Safety:

$$Factor\ of\ safety\ (FOS) = \frac{(Yield\ strength \cdot Cross\ section\ area)}{Maximum\ applied\ load}$$

$$Factor\ of\ safety\ (FOS) = \frac{(250\ MPa \cdot 10^6 Pa/MPa \cdot 4\ m^2)}{7{,}500\ N} = 133{,}333$$

The designed movable ground-mounted PV system has a FOS around 5.5 times better the FOS of the conventional solar PV systems.

This increased FOS helps in improving the life of the complete systems including the PV panels as they were subjected to less loads.

This result can be found in the following table:

	BAU	RE-EMPOWERED	**Change**
Factor of safety for solar PV	24,000	133,333	**+550%**

Table 54 Safety for Solar PV, for ecoResilience, in Ghoramara island Microgrid

2.5.3. KPI 3: Factor of safety for the wind turbine structure (ecoResilience).

The safety of the mechanical systems is defined using factor of safety (FOS) which is a nondimensional quantity that measures the ratio of a material strength to the working stress it experiences. FOS formula varies for different materials. For the ductile materials which was used in the design of resilient ground-mounted and solar PV wind turbine support structures, it is defined as the ratio of yield strength to applied load.

$$Factor\ of\ safety\ (FOS) = \frac{(Yield\ strength \cdot Cross\ section\ area)}{Maximum\ applied\ load}$$

With the ecoResilience tool, the blades of the wind turbine are removed from the generator during cyclones in the designed hybrid structure. Hence, the exposed area of the blades of the wind turbine is reduced.

The aerodynamic axial load on the conventional wind turbine (blades are intact) with an axial coefficient (Cx) of 1 = 32 kN.

The aerodynamic axial load on the wind turbine with resilient structure (blades removed) with an axial coefficient (C_x) of 1 = 624 N.

The wind load on the generator and support structure is reduced more than 50 times in designed wind turbine support structure at the wind velocity of 60 m/s compared to conventional wind turbine installations.

Thus, the following table includes the result for this indicator:

	BAU	RE-EMPOWERED	**Change**
Factor of safety for the wind turbine structure	X	50 X	**+500%**

Table 55 Factor of safety for the wind turbine structure,for ecoResilience, in Ghoramara Microgrid

The 3-kW small wind turbine manufactured with locally available materials will be installed on a monopole which has much higher stability due to incorporation of guywires at three stages. Further, it has a provision to get removed by tilting down the monopole with required tools and training to the locals. Hence it is highly safe compared to the removed damaged wind turbine system.

The designed resilient structures are highly safe compared to the conventional ground-mounted PV and wind turbine installations.

2.5.4. KPI 4: Wind load reduction potential for solar PV (ecoResilience).

This KPI measures the potential of the designed ecoResilience support structures to reduce wind load effects or mitigation risk of installed systems, for the solar PV design.

The wind load reduction potential (WRP) at the designed wind speed (216 km/h) is defined as follows:

$$Wind\ Load\ Reduction\ Potential\ (WRP) = \frac{Reduced\ wind\ load}{Reference\ wind\ load\ of\ a\ conventional\ system} \cdot 100$$

Where the reduced wind load is the difference between the reference wind load and the actual load on the designed system.

In this case, the reference wind load of a conventional system is 7,500 MPa, while the reduction in the load for the designed system is estimated to be 1,351 MPa.

For a ground-mounted solar PV system with the ecoResilience tool, the Wind Load Reduction Potential is:

$$Wind\ Load\ Reduction\ Potential\ (WRP) = \frac{(7{,}500 - 1{,}351)\ MPa}{7{,}500\ MPa} \cdot 100 = 82\%$$

Therefore, the installed resilient ground-mounted solar PV system has a wind load reduction potential of 82%.

The following table shows the result for this indicator:

	BAU	RE-EMPOWERED	**Change**
Wind load reduction potential	N/A	82%	**N/A**

Table 56 Wind load reduction potential for solar PV, for ecoResilience, in Ghoramara island Microgrid

2.5.5. KPI 5: Wind load reduction potential for wind turbine (ecoResilience).

This KPI measures the potential of the designed ecoResilience support structures, for the wind turbine, to reduce the wind load effects or mitigation risk of installed systems.

The wind load reduction potential (WRP) is measured with the following formula:

$$Wind\ Load\ Reduction\ Potential\ (WRP) = \frac{Reduced\ wind\ load}{Reference\ wind\ load\ of\ a\ conventional\ system} \cdot 100$$

Compared to a commercial wind turbine, with a rotor diameter of 5.25 meters, the locally manufactured wind turbine with a rotor diameter of 4.3 meters has a substantially larger wind load reduction potential.

- The WRP of a commercial wind turbine, with hybrid support structure is 99.5%.
- The WRP of a locally made small wind turbine with tilt-up monopole structure is 98%.

Considering that the reference wind load for a conventional wind turbine is 32,021 MPa, and that the reduction due to the designed system is of 624 MPa.

The WRP of a locally made small wind turbine with tilt-up monopole structure can be calculated as:

$$Wind\ Load\ Reduction\ Potential\ (WRP) = \frac{(32{,}021 - 624)}{32{,}021} \cdot 100 = 98\%$$

The following table includes these results:

	BAU	RE-EMPOWERED	Change
Wind load reduction potential for wind	99.5%	98%	**-1.51%**

Table 57 Wind load reduction potential for wind, for ecoResilience, in Ghoramara island Microgrid

2.5.6. KPI 6: Functional downtime for solar PV (ecoResilience).

Functional downtime measures the ability of a structure to recover after suffering extreme events, such as earthquakes, windstorms, or impacts, for the solar PV.

Functional downtime (FD) is defined as the time that the system is out of operation, after it has suffered an event such as a cyclone.

In the case of ground-mounted solar PV structures with the ecoResilience tool, they can adjust themselves to the environmental effects, and so they do not need for any manual interventions. This involves that the functional downtime is zero. The system is immediately ready for operation after the event.

The following table includes these results:

	BAU	RE-EMPOWERED	Change
Functional downtime for solar PV	N/A	0	**N/A**

Table 58 Functional downtime for Solar PV, for ecoResilience, in Ghoramara island Microgrid

2.5.7. KPI 7: Functional downtime for wind (ecoResilience).

Functional downtime measures the ability of a structure to recover after suffering extreme events, such as earthquakes, windstorms, or impacts, for the wind structure.

In the case of a tilt-up monopole tower with a wind turbine, it needs some manual interventions to be put into operation again. The functional downtime for these systems varies from 4 to 8 hours, depending on the available manpower, and the conditions at the demo site (floods, water logging, etc.).

For a hybrid tower, the functional downtime varies, similarly, from 4 to 6 hours. The system is not affected by the conditions at the demo site, as only the top part of the monopole is brought down vertically over the truss structure platform.

The following table includes a summary of these results:

	Tilt-up monopole tower	RE-EMPOWERED hybrid tower	Change
Functional downtime for wind	4-8 hours	4-6 hours	**N/A**

Table 59 Functional downtime for Wind, for ecoResilience, in Ghoramara island Microgrid

2.5.8. KPI 8: Operational downtime index (ODI) during overload cut-off (ecoDR).

This KPI defines the percentage of time the ecoDR remains operational and resumes normal functioning during and after overload cutoff scenarios, relative to the total monitored time period.

It can be calculated with the following formula:

$$ODI\ (\%) = \left(\frac{Total\ Operational\ Downtime\ during\ Overload\ Cutoff}{Total\ monitored\ time\ period}\right) \cdot 100$$

Where:

- Total Downtime during Overload Cutoff is the cumulative time (in hours or minutes) when the ecoDR is non-operational due to overload cutoff events.
- Total Monitored Time Period is the total observation period over which the performance is assessed (e.g., a day, month, or year).

During the testing period of ecoDR at Ghoramara, the total operation time is 300 mins (5 hours), and the following three different scenarios were performed:

- Scenario 1: In 3 min after cut-off, the excess load was withdrawn and the ecoDR reconnects the load at 5 min after cut-off; hence total operation downtime due to ecoDR is 2 min.
- Scenario 2: In 15 min after cut-off, the excess load was withdrawn and the ecoDR reconnects the load at 30 min after cut-off; hence total operation downtime due to ecoDR is 15 min.
- Scenario 3: In 60 min after cut-off, the excess load was withdrawn and the ecoDR reconnects the load at 120 min after cut-off; hence total operation downtime due to ecoDR is 60 min.

Therefore, Operational downtime indexes (ODI) were, in these three scenarios:

$$Scenario\ 1\ (\%) = \left(\frac{5}{300}\right) \cdot 100 = 1.67\%$$

$$Scenario\ 2\ (\%) = \left(\frac{15}{300}\right) \cdot 100 = 5\%$$

$$Scenario\ 3\ (\%) = \left(\frac{60}{300}\right) \cdot 100 = 20\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Operational downtime index (ODI) during overload cut-off	N/A	1.67% (Scenario 1) 5.00% (Scenario 2) 20.00% (Scenario 3)	**N/A**

Table 60 Operational downtime due to overload cutoff, for ecoDR for the Ghoramara Island Demo Site.

2.5.9. KPI 9: Number of electric three wheelers operating in the island (ecoVehicle)

This KPI measures the number of electric three wheelers which are available for mobility in the Ghoramara Island.

In the BAU scenario, there were 4 e-rickshaws, which were charged with a diesel generator. Additionally, pedal rickshaws were also used to carry loads.

The RE-EMPOWERED project has involved the deployment of 2 new electric rickshaws or three-wheelers, with the following technical features:

- Pay-load: 800 kg.
- Motor rating: 1.2 kW BLDC.
- 48 V, 100 Ah Lithium-Ion battery.
- Millage: 60-70 km per charge.
- Speed: 25 km/h.

Therefore, in the BAU scenario, there were 4 e-rickshaws, and after the RE-EMPOWERED project, there are 6 e-rickshaws.

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Number of electric three wheelers	4, charged with a diesel generator	6, charged with solar PV	**150%**

Table 61 Number of electric three wheelers operating in the island, for the Ghoramara Island Demo Site.

2.5.10. KPI 10: Availability of communication infrastructure (ecoPlatform).

The KPI availability of communication infrastructure measures the reliability of the communication system, in terms of failure frequency and the required time to repair and restore the operation of the communication system.

It can be calculated with the following formula:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

Where:

- Uptime is the total time when the communication system is operational during the observation period.
- Downtime is the total time when the communication system was not operational (for example, due to failures, maintenance actions, unexpected outages).

For ecoPlatform, the results in the Ghoramara Island are the same that were obtained for the Kythnos Island Demo Site and the Gaidouromantra Microgrid:

- Uptime was 715 hours.
- Downtime was 5 hours.

Therefore, the availability of communication infrastructure was:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{715\ hours}{715\ hours + 5\ hours}\right) \cdot 100 = 99.31\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Availability of communication infrastructure	N/A	99.31%	**N/A**

Table 62 Availability of communication infrastructure, for ecoPlatform for the Ghoramara Island Demo Site.

2.5.11. KPI 11: Data reliability (ecoPlatform).

This KPI measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.

It can be calculated using the following formula:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted - Total\ data\ packages\ with\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

This is equivalent to:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted\ without\ mistakes\ or\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

Where:

- Total data packages transmitted are the number of data packages which are transmitted, whether they are received or not.

- Total data packages with losses are the number of data packages which are not transmitted, or which have any kind of mistake.
- Total data packages transmitted without mistakes or losses are the number of data packages which are correctly and completely transmitted without losses or mistakes.

The results in the Ghoramara Island Microgrid are the same that were obtained for the Kythnos Island and the Gaidouromantra Microgrid:

- Total data packages transmitted: 1,000,000.
- Total data packages with losses: 1,000.

Therefore, the Data reliability KPI for Ghoramara Island is as follows:

$$Data\ reliability\ (\%) = \left(\frac{1{,}000{,}000 - 1{,}000}{1{,}000{,}000}\right) \cdot 100 = \frac{999{,}000}{1{,}000{,}000} = 99.90\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Data reliability	N/A	99.90%	**N/A**

Table 63 Data reliability, for ecoPlatform for the Ghoramara Island Demo Site.

2.5.12. KPI 12: Energy data transfer (ecoPlatform).

Energy data transfer measures the capacity of a data exchange platform to transfer different types of data successfully. It is related to the amount of transmitted data (in MB) within the observation period.

Transmitted data can include logs, real-time monitoring data and other information.

The formula which can be used to estimate this KPI is:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

Where:

- Total transmitted data is the volume of energy-related data which are transferred using the ecoPlatform, in MB.
- Total time is the period of time when the transmission of data is monitored.

The obtained results for these variables in the Ghoramara Island are the same that were obtained for the Kythnos Island and the Gaidouromantra Microgrid:

- Total transmitted data: 50 MB.
- Total time: 10 hours.

Using the previously described formula:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{50\ MB}{10\ hours} = 5\ MB/hour$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Energy data transfer	N/A	5 MB/hour	**N/A**

Table 64 Energy data transfer, for ecoPlatform for the Ghoramara Island Demo Site.

2.5.13. KPI 13: Increased access to own metering data (ecoDR).

This KPI measures the increase in the number of consumers (including both households and organizations), that have their electricity consumption monitored with an electricity smart meter, through a single access point.

Before the RE-EMPOWERED project (BAU scenario), there were around 4 or 5 smart meters.

In the RE-EMPOWERED project, a new smart meter, specially designed by CSIR-CMERI in the project, has been installed. These smart meters were integrated along with other components, inside the enclosure.

Smart meters were connected to the feeders like school and four houses and were installed in September 2024.

This can be summarized in the following table, as follows:

	BAU	RE-EMPOWERED	**Change**
Access to own metering data	4-5 smart metes	6 smart meters, including a new smart meter designed in RE-EMPOWERED	**+20%**

Table 65 Increased access to own metering data, in Ghoramara Island Microgrid.

ecoMicrogrid is expected to be integrated with the smart meters by January 2025.

2.5.14. KPI 14: Average Percentage Error (APE) (ecoDR).

This KPI defines the deviation between the measured values recorded by the ecoDR and the actual values, expressed as a percentage or within a specified tolerance range.

It can be calculated with the following formula:

$$APE\ (\%) = \frac{\sum\left(\frac{Actual\ Value - Measured\ Value}{Actual\ Value}\right)}{Total\ measurements} \cdot 100$$

Where:

- Measured value: The readings provided by the smart meter.
- Actual value: The reference readings obtained from a highly accurate and calibrated device or standard.

During the testing period of ecoDR, the following six (6) voltage and current measurement events were performed, and the readings were compared with a calibrated portable single phase energy meter (Model: Genus Achook-1080).

The following table compares the readings:

Sl. No	Calibrated meter readings		ecoDR readings		Actual Value - Measured Value	
	Voltage (a)	Current (b)	Voltage (c)	Current (d)	Voltage (a-c)	Current (b-d)
1	150.2	3.29	150.15	3.29	0.05	0
2	149.92	4.381	150.03	4.39	-0.11	-0.009
3	190.34	4.153	190.19	4.15	0.15	0.003
4	190.24	5.5	190.2	5.51	0.04	-0.01
5	220.62	4.797	220.59	4.8	0.03	-0.003
6	220.11	6.32	220.4	6.33	-0.29	-0.01

Table 66 Comparative voltage and current readings of ecoDR and commercial single-phase meter, in the Ghoramara Island Microgrid.

Therefore, Average Percentage Error (APE) for voltage of ecoDR was calculated as:

$$APE_V\ (\%) = \frac{\sum\left(\frac{Actual\ Value - Measured\ Value}{Actual\ Value}\right)}{Total\ measurements} \cdot 100$$

$$= \frac{\left(\frac{0.05}{150.2} + \frac{-0.11}{149.92} + \frac{0.15}{190.34} + \frac{0.04}{190.24} + \frac{0.03}{220.62} + \frac{-0.29}{220.11}\right)}{6}.100$$

$$= -\frac{0.00058}{6} * 100 = -0.0097\%$$

Therefore, Average Percentage Error (APE) for current of ecoDR was calculated as:

$$APE_I\ (\%) = \frac{\sum\left(\frac{Actual\ Value - Measured\ Value}{Actual\ Value}\right)}{Total\ measurements} \cdot 100$$

$$= \frac{\left(\frac{0}{3.29} + \frac{-0.009}{4.381} + \frac{0.003}{4.153} + \frac{-0.01}{5.5} + \frac{-0.003}{4.794} + \frac{-0.01}{6.32}\right)}{6}.100 = -\frac{0.00536}{6} * 100$$

$$= -0.089\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Average Percentage Error (APE) for voltage	N/A	-0.0097%	**N/A**
Average Percentage Error (APE) for current	N/A	-0.089%	**N/A**

Table 67 Average percentage error (APE) for ecoDR, in the Ghoramara island Microgrid

2.6 Keonjhar Microgrid: Odisha, India

Kanheigola, Nola and Ranipada are small villages/hamlets in Harichadanpur-Tehsil reserve forest in Keonjhar District of Odisha State, India.

These villages are not connected to the main utility grid, and the area of the Demo Site is 2.02 km^2. There are around 1,000 inhabitants, and the main infrastructure is a high school, a primary school, and a sub centre of primary health care.

The power system has a total of 77 kWp (Kanheigola-30 kWp, Nola- 25 kWp and Ranipada-22 kWp) solar PV installations, which supply 306 households. From them, only 75 households live in the Demo Site.

Each household is provided with 100 W, which only allows basic facilities, like 2 LED lights and a fan. Houses only have 4 hours of light during nighttime, approximately from 18:00 to 22:00.

There are also three rice-cum-hauler meals, run by a diesel engine. During the RE-EMPOWERED project, 2 electric vehicle chargers, with 1.5 kW, have been installed.

The before described solar PV installations are totally isolated. Besides, there is a battery backup, but there is not a purified water drinking facility. Solid biomass from the forest is also an energy source.

In the Keonjhar demo, the main power generation units are:

- 52 kWp of solar PV panels, from which 30 kWp were installed during the RE-EMPOWERED project. They can produce 185 kWh/day.
- A battery bank with an energy storage capacity of 340 kWh, from which, a battery of 180 kWh has been installed during the RE-EMPOWERED project, while there was a 160-kWh battery before the project.
- A biomass system with 10 kW, able to generate around 20 kWh/day.
- A biogas system, with 10 kW, which generates 40 kWh/day.

After the development of the RE-EMPOWERED facilities, a maximum energy demand of 120 kWh/day and a minimum energy generation of 150 kWh/day is estimated, so the whole energy consumption demand of the Demo Site would be covered.

Before the development of the RE-EMPOWERED project, the electricity supply was not reliable, and electricity cost was very high. However, electricity was being provided to the clients for free. The objective of RE-EMPOWERED in the Demo Site is to test the integration of the existing solar PV system, with various energy vectors, such as biomass and energy storage solutions.

The proposed business model for Keonjhar is the development of an energy community, the Ranipada Gram Shakti Samooh. This energy community will be in charge of the operation of the microgrid, and the supply of clean electricity to the inhabitants of the Kanheigola, Nola and Ranipada villages. Each household and electric rice huller machine user will pay a monthly fee for receiving the electricity, what will make the business model economically profitable.

The following table includes a summary of the technical KPIs described for the Ghoramara Island Microgrid:

Keonjhar Microgrid			
KPI #	Name	Value	Description
1	Peak Load Reduction	ecoPlanning 13%	It measures the reduction in the maximum demand or peak load on the electricity grid achieved through various demand-side management strategies or energy efficiency measures. Peak load is calculated to be: BAU 16.9 kW, R&I 14.7 kW.
2	RES curtailment	EcoMicrogrid 54.13%	It measures the reduction in the amount of energy produced from solar PV sources which cannot be injected in the microgrid, even if it is available, due to technical and operational limits in the grid.
3	RES penetration percentage (annual)	ecoPlanning +13.6% (BaU: 88%, R&I: 100%)	It measures the proportion of total annual energy consumption that is supplied by Renewable Energy Sources (RES).
4	RES increase in the energy mix	ecoPlanning 44.9%	It measures the growth or change in the share of RES within the total energy mix over a given period. RES in the energy mix is calculated to be: BAU: 11.6 MWh/year, R&I: 16,8 MWh/year.
5	Hours with non-served load or non-observed reserve (h)	ecoPlanning -93% (BaU: 369 h, R&I: 23 h)	It measures the total number of hours during which a power grid or energy system experiences either non-served load (when the demand for electricity exceeds the available supply, leading to load shedding or outages) or non-observed reserve (when the system fails to maintain a sufficient reserve capacity to meet unforeseen demand or contingencies).
6	Total non-served load and non-observed reserve (MWh)	ecoPlanning -91.7% (BaU: 84 MWh, R&I: 7 MWh)	It quantifies the total amount of energy, in megawatt-hours (MWh), that represents non-served load and non-observed reserve over a specified period.

Keonjhar Microgrid			
KPI #	Name	Value	Description
7	Hours with underload of conventional units (h)	ecoPlanning -100% (BaU: 42 h, R&I: 0 h)	It measures the total number of hours during which conventional power generation units (e.g., coal, gas, nuclear plants) are operating below their optimal or expected output levels, referring to as overload
8	Forecasting accuracy	ecoMicrogrid MAPE Solar PV: 16,81% MAPE Load: 34,387%	It evaluates the accuracy of the developed forecasting algorithms, according to the calculation of the Normalized Mean Absolute Percentage Error of solar PV power generation or load forecasting.
9	Number of electric three wheelers operating in the island	ecoVehicle 2 electric three-wheelers	It measures the number of electric three wheelers which are available for mobility.
10	Availability of communication infrastructure	ecoPlatform 99.31%	It measures the reliability of the communication system, focusing on the frequency of failures and the time required to repair and restore operations.
11	Digital solutions integrated	ecoCommunity 3 solutions	It measures the number of digital solutions installed because of the development of the project.
12	Customers engaged with smartphone application	ecoCommunity 41 customers	It measures the customer's involvement with the developed tool.
13	Data Access Control	ecoCommunity 100%	It evaluates the level of authorised vs unauthorized access to the tool or tool data.
14	Tool Modules Deployed	ecoCommunity 90%	It measures the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project. Modules Developed: 10, Modules Deployed: 9.
15	Data Reliability	ecoPlatform 99.90%	It measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.
16	Energy data transfer	ecoPlatform 5 MB/hour	It measures the capacity of a data exchange platform to transfer different types of data successfully.

Keonjhar Microgrid			
KPI #	Name	Value	Description
17	Increased access to own metering data	ecoCommunity, ecoMicrogrid 9 clusters of houses + 1 rice hull miller	It measures the number of new consumers which use a smart meter and can access their electricity meter data through a single access point
18	Automatic metering of consumers	ecoCommunity 10 consumers	It compares the number of consumers which have their smart meter information remotely gathered by the DSO, compared to the number of consumers who had their data collected in the BAU scenario

Table 68 List of technical KPIs for the Keonjhar Microgrid Microgrid Demo Site.

2.6.1. KPI 1: Peak load reduction (ecoPlanning)

The Peak Load Reduction KPI measures the reduction in the maximum demand or peak load on the electricity grid achieved through various demand-side management strategies or energy efficiency measures. The primary goal of reducing peak load is to avoid the need for additional capacity (e.g., power plants, grid infrastructure) during periods of high demand, improve grid stability, and optimize energy consumption.

Peak load typically occurs during times of high energy demand, such as hot summer afternoons (when air conditioning is used extensively) or cold winter mornings (when heating is in demand). These periods are crucial because the grid has to meet the maximum load, and power generation resources must be able to supply this demand. Reducing peak load can result in lower operational costs for utilities, better grid reliability, and a reduction in the environmental impact of generating energy.

- Smart Grid and Demand Response:

Technologies like smart grids, demand response programs, and energy storage systems can be used to reduce peak load. Demand response, for example, involves shifting or curtailing electricity consumption during peak periods by incentivizing consumers (industrial, commercial, or residential) to lower their energy usage.

Key benefits of Peak Load Reduction:

- Cost Savings: Reduces the need for costly peak power plants (which are often inefficient or run on fossil fuels).
- Grid Stability: Prevents the grid from becoming overloaded and potentially experiencing outages or failures.
- Environmental Impact: Lower peak demand can lead to less reliance on carbon-intensive power generation during periods of high load.

The following formula is used to calculate the Peak load reduction:

$$Peak\ Load\ Reduction = \frac{Peak\ Load_b - Peak\ Load_j}{Peak\ Load_b}$$

Where:

- J: Total number of scenarios.
- b: Base scenario.

The following table includes the results for this KPI:

	BAU	RE-EMPOWERED	**Change**
System peak - ecoPlanning (annualized)	16.9 kW	14.7 kW	**-13%**

Table 69 System peak reduction for the Keonjhar Microgrid.

Peak load reduction was achieved through various methods such as:

- Demand-side management: Encouraging consumers to use less energy during peak times, often through incentives, rebates, or time-of-use pricing.
- Energy efficiency improvements: Implementing technologies or practices that reduce the overall consumption of energy, thereby lowering peak demand.

2.6.2. KPI 2: RES curtailment (ecoMicrogrid)

The RES curtailment reduction measures the reduction in the amount of energy produced from solar PV sources which cannot be injected in the microgrid, even if it is available, due to technical and operational limits in the grid.

In the case of Keonjhar microgrid, there is no other vector in order to contribute in the excessive RES energy exploitation. The only way to reduce the curtailment of the photovoltaics is by optimally operating the biomass and biogas generators. This is an operation that ecoMicrogrid offers by means of suggestion provided to the system administrator. Up until now, there were no such incidents to be used for evaluation. Also, as already stated, the previous situation for the demo site was the non-existence of the microgrid, thus, there is no BAU scenario in order to calculate the reduction of RES curtailment. Thereafter, only the current situation of the RES curtailment is imprinted for the RE-EMPOWERED scenario from the following calculation.

$$C_{\mathfrak{R}S_{R\&I}} = \sum_{i=1}^{I}\sum_{t=1}^{T}(P_{i,t}^{prod} - P_{i,t}^{inj})$$

- $C_{\mathfrak{R}S_{R\&I}}$ is the RES curtailment for the RE-EMPOWERED scenario (kWh or MWh).
- I is the number of facilities under consideration.

- T is the set of time intervals of period under consideration, excluding periods of scheduled maintenance and outages.
- $P_{i,t}^{prod}$ is the available energy production of the i^{th} RES facility at period t (kWh or MWh).
- $P_{i,t}^{inj}$ is the injected energy of the i^{th} RES facility at period t (kWh or MWh).

The results of the calculation of the RES curtailment reduction for the Keonjhar Demo Site is as follows:

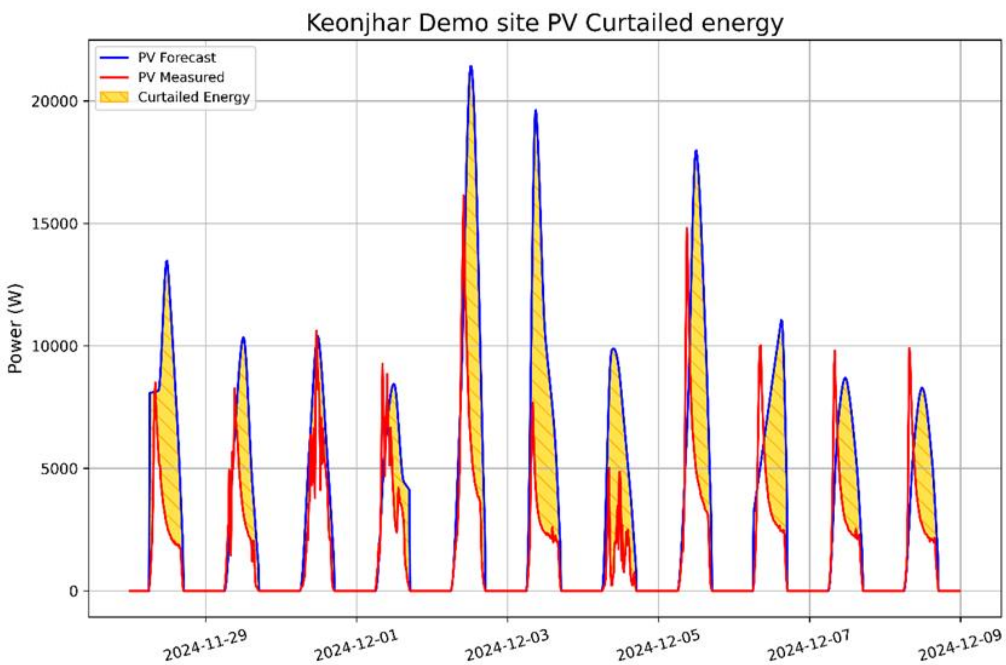

Figure 13: Comparison of the solar PV generation, which is forecast, the actual measured solar PV generation, and the curtailed energy, in the Keonjhar Demo Site.

The evaluation of the RES curtailment in the Keonjhar Microgrid has been carried out for the pilot site with data extracted for November 28th to December 8th 2024, with granularity of 15 minutes. In this microgrid case, the curtailment is occurring due to fully charged batteries.

The results are as follows:

	RE-EMPOWERED
Renewable energy produced during the selected available period	415.72 kWh
Renewable energy curtailed during the selected available period	490.57 kWh
Percentage of Curtailed Energy (%)	54.13 %

Table 70 RES curtailment reduction (annual) in Keonjhar Microgrid.

2.6.3. KPI 3: RES penetration percentage (annual) (ecoPlanning)

The RES penetration percentage in the energy mix (annual) measures the proportion of total annual energy consumption that is supplied by Renewable Energy Sources (RES). It provides an insight into how much of the energy consumed by the grid is generated from renewable resources such as solar, wind, hydro, geothermal, and other renewable sources. This KPI is crucial for tracking the progress of the energy transition toward more sustainable and environmentally friendly energy sources.

- Renewable Energy Sources (RES) include energy generated from solar, wind, hydroelectric power, geothermal energy, and other forms of clean energy.
- Annual Energy Consumption refers to the total amount of electricity consumed across all sectors (residential, commercial, industrial, etc.) within a year.

This KPI is a key indicator for assessing the success of energy policies and strategies that aim to increase the share of renewables in the energy mix.

$$RES\ Penetration\ Percentage = \frac{Annual\ Renewable\ Energy\ Generation\ (MWh)}{Total\ Annual\ Energy\ Consumption\ (MWh)} \times 100$$

Where:

- Annual Renewable Energy Generation (MWh) is the total amount of electricity generated from renewable sources (in MWh) during the year.
- Total Annual Energy Consumption (MWh) is the total amount of electricity consumed by all sectors (in MWh) during the year.

Depending on the value of the KPI, there can be two situations:

- High-RES Penetration Percentage: A high percentage indicates that a significant portion of the total energy consumption is being met by renewable energy sources. This reflects a strong commitment to sustainable energy production and consumption, and it may signal a country, region, or utility progress toward meeting climate goals and decarbonizing the energy grid.
- Low-RES Penetration Percentage: A low percentage suggests that the share of renewable energy in the overall energy mix is still limited, and more efforts are needed to transition to sustainable energy sources. This might indicate the continued reliance on fossil fuels or other non-renewable sources to meet energy demand.

The following table includes the RES penetration percentage (annual), for the Keonjhar Microgrid:

	BAU	RE-EMPOWERED	**Change**
RES penetration percentage (annual)	88%	100%	**+13.6%**

Table 71 RES penetration percentage (annual), for ecoPlanning, in the Keonjhar Microgrid.

2.6.4. KPI 4: RES increase in the energy mix (ecoPlanning)

The RES Increase in the Energy Mix KPI measures the growth or change in the share of RES within the total energy mix over a given period. This metric helps to track the progress of the energy system toward increasing the contribution of renewable energy (such as solar, wind, hydro, geothermal, etc.) compared to fossil fuels (coal, gas, oil) and nuclear energy.

As the global focus shifts toward sustainability, this KPI is vital for assessing how well a country, region, or utility is transitioning to a cleaner, more sustainable energy mix. The increase in RES demonstrates the success of renewable energy policies, investments in clean technologies, and efforts to reduce greenhouse gas emissions and dependence on non-renewable resources.

The RES increase in the energy mix is measured with the following formula:

$$\begin{aligned} RES\ Increase\ (MWh) &= Annual\ RES\ Generation\ After\ Period\ (MWh) \\ &- Annual\ RES\ Generation\ Before\ Period\ (MWh) \end{aligned}$$

The following table includes the results for the RES increase in the energy mix in the Keonjhar Microgrid:

	BAU	RE-EMPOWERED	**Change**
RES increase in the energy mix (kWh/year)	11,567 kWh/year	16,764 kWh/year	**+44.9%**

Table 72 RES increase in the energy mix, for ecoPlanning, in the Keonjhar microgrid.

2.6.5. KPI 5: Hours with non-served load or non-observed reserve (h) (ecoPlanning).

This indicator measures the total number of hours during which a power grid or energy system experiences either non-served load (when the demand for electricity exceeds the available supply, leading to load shedding or outages) or non-observed reserve (when the system fails to maintain a sufficient reserve capacity to meet unforeseen demand or contingencies). These hours are critical for assessing the reliability and stability of the power system.

- Non-Served Load: Refers to the total energy demand that cannot be met by the system due to insufficient generation or capacity, leading to disruptions in service, such as power cuts or rolling blackouts.
- Non-Observed Reserve: Refers to periods when the system reserve (the backup capacity to handle sudden demand spikes or generation failures) is insufficient or unavailable, putting the grid at risk of instability.

Tracking this KPI is crucial for utilities and grid operators to monitor system performance, identify reliability issues, and take corrective actions to improve the grid reliability and prevent prolonged outages or operational failures.

To calculate Hours with Non-Served Load or Non-Observed Reserve (h), the formula is:

$$Hours\ with\ Non-Served\ Load\ or\ Non-Observed\ Reserve\ (h) = \sum(Hours\ where\ load\ is\ not\ fully\ served + Hours\ of\ insufficient\ reserve\ capacity)$$

Where:

- Hours where load is not fully served is the total number of hours in which the grid experiences load shedding or cannot meet the full demand.
- Hours of insufficient reserve capacity is the total number of hours when the grid fails to maintain adequate reserves for unforeseen contingencies.

Depending on the value of the KPI, there can be two situations:

- High Values: A high number of hours indicates poor grid reliability, highlighting periods of outages or potential system stress due to inadequate reserves.
- Low Values: A low number of hours suggests a more reliable grid, with minimal disruptions and sufficient reserves during peak demand or emergencies.

This KPI is critical for assessing the performance of grid management strategies, forecasting, and planning for improvements in capacity and reserve management to ensure consistent service and reliability.

The following table includes the results for this KPI:

	BAU	RE-EMPOWERED	Change
Hours with Non-Served Load or Non-Observed Reserve- annualized-ecoPlanning	369 hours	23 hours	**-93%**

Table 73 Hours with Non-Served Load or Non-Observed Reserve for ecoPlanning, for Keonjhar Microgrid.

2.6.6. KPI 6: Total non-served load and non-observed reserve (MWh) (ecoPlanning).

This KPI quantifies the total amount of energy, in megawatt-hours (MWh), that represents non-served load and non-observed reserve over a specified period. It measures the total energy demand that could not be met due to capacity issues, leading to load shedding or failures in maintaining an adequate reserve.

- Non-Served Load: This is the total amount of energy that the power grid was unable to provide to consumers because the demand exceeded available supply. This can happen due to generation shortages, transmission constraints, or operational failures.
- Non-Observed Reserve: This refers to the total energy associated with periods when the grid failed to maintain enough reserve capacity. Reserves are backup power resources kept available to address unforeseen spikes in demand or sudden generation

failures. When reserves are insufficient, the grid may become unstable or may not be able to respond quickly to emergencies.

Tracking this KPI is important for understanding the total energy shortfall and the system inability to handle peak loads or emergencies, helping to highlight reliability issues and identify where improvements are needed in grid capacity, generation, or reserve management.

$$Total\ Non-Served\ Load\ and\ Non-Observed\ Reserve\ (MWh) = \sum(Non-Served\ Load\ (MWh) + Non-Observed\ Reserve\ (MWh))$$

Where:

- Non-Served Load (MWh): The total energy demand (in MWh) that the system was unable to meet due to insufficient generation or capacity issues.
- Non-Observed Reserve (MWh): The amount of reserve (in MWh) that was unavailable or insufficient during the observation period, impacting the system's ability to handle unexpected demand spikes or generation failures.

Depending on the value of the KPI, there can be two situations:

- High Values: A high total of non-served load and non-observed reserve indicates significant grid reliability problems, where large amounts of energy demand are unmet, and reserve capacity is not available to maintain system stability during high-demand or emergency situations.
- Low Values: A low total indicates a stable and reliable system, with adequate supply to meet demand and sufficient reserve capacity to handle unforeseen situations.

The following table includes the results of the Total non-served load and non-observed reserve for the Keonjhar Microgrid:

	BAU	RE-EMPOWERED	**Change**
Total Non-Served Load and non-observed reserve-annualized-ecoPlanning	84 MWh	7 MWh	**-91.7%**

Table 74 Total Non-Served Load and non-observed reserve for Keonjhar Microgrid

2.6.7. KPI 7: Hours with underload of conventional units (h) (ecoPlanning).

This KPI measures the total number of hours during which conventional power generation units (e.g., coal, gas, nuclear plants) are operating below their optimal or expected output levels, referred to as underload. Underloading occurs when these units are producing less power than their maximum capacity, often due to low electricity demand, operational constraints, or grid requirements.

- Underload: This refers to situations where a conventional generation unit is generating less power than it is capable of producing. This can be inefficient from both an economic and environmental perspective because the unit might still be running but at suboptimal levels, which could increase operating costs or reduce the cost-effectiveness of the plant.

- Conventional units are typically less efficient when running at low output levels, as their efficiency decreases when they are not running near their full capacity. Additionally, maintaining a plant in underload conditions can result in higher operational costs and wear and tear over time.

This is a very common situation for the thermal units of the Greek islands due to the high seasonality and the unilateral penetration of the PVs as a renewable technology.

Tracking this KPI helps utilities and grid operators understand how often conventional units are underused and provides insights into optimizing generation capacity and operational efficiency.

$$Hours\ with\ Underload\ of\ Conventional\ Units\ (h) = \sum(Hours\ when\ conventional\ units\ operate\ below\ optimal\ output)$$

Where:

- Hours when conventional units operate below optimal output is the total number of hours during which the conventional generation units are running at less than their full capacity or below a predefined threshold that represents optimal or efficient generation.

Depending on the value of the KPI, there can be two situations:

- High Values: A high number of hours with underload indicates that conventional units are often running below their optimal efficiency, leading to potential inefficiencies, increased costs, and a possible need to adjust the generation mix to reduce reliance on these units during low-demand periods.
- Low Values: A low number of hours indicates that conventional units are being efficiently utilized and operating near their optimal output levels, minimizing waste, and maximizing cost-effectiveness.

This KPI is critical for identifying periods when conventional generation units are being underused and provides an opportunity to assess whether the generation mix, load forecasting, or operational strategies need adjustment to avoid inefficiencies or unnecessary emissions. It can also help in decision-making regarding plant maintenance, decommissioning, or integrating renewable energy sources to better match grid demand.

The following table includes the results of the Hours with underload of conventional units, for the Keonjhar Demo Site:

	BAU	RE-EMPOWERED	Change
Hours with underload of conventional units	42 hours	0 hours	**-100%**

Table 75 Hours with underload of conventional units for ecoPlanning, for Keonjhar Microgrid.

2.6.8. KPI 8: Forecasting accuracy (ecoMicrogrid).

The forecasting accuracy at the Keonjhar pilot is assessed using the Normalized Mean Absolute Percentage Error (MAPE), which measures the performance of the developed forecasting algorithms. The evaluation is based on the calculated MAPE for solar PV power generation or load forecasting, providing a standardized metric for accuracy.

It has been calculated as the deviation between forecasts and actual measurements for production and consumption, in different time intervals. ecoMicrogrid tool has produced forecasts with a projection of up to 72 hours. The following shifting period has been considered: from 0 h (this is, right before the actual event) to 48 h, with steps of 6 hours. The used method has been the shifting window using data with granularity of 15 minutes.

The formula used to calculate the MAPE is:

$$MAPE = \frac{\sum_{t=1}^{N} \left|\frac{E_t}{L_t}\right|}{N} = \frac{\sum_{t=1}^{N} \left|\frac{L_t - F_t}{L_t}\right|}{N}$$

Where:

- E_t is the forecast error in the calculation of the load or generation, at period "t", being $E_t = L_t - F_t$.
- L_t is the actual, real value of load or generation at period "t".
- F_t is the forecast value of load or generation at period "t".
- N is the number of available data points of generation time series.

For solar PV forecasting, the measurements have been taken during the period from November 28th, 2024 to December 8th, 2024, as shown in Figure 14. Unfortunately, during this period, the solar PV was subject to curtailment, making the comparison with the forecast curves impossible. It is only possible to find one whole day with no curtailment traces, November 30th, 2024, and this day is used for calculations.

Forecast accuracy assessment derived from the data from only one day cannot be considered reliable and concrete, but they can offer some useful information.

For load forecasting, the period with clear data used for the forecast accuracy calculations is from November 28th, 2024 to December 17th, 2024. EcoMicrogrid tool is constantly producing forecasts with a projection of up to 72 hours. The indicator is calculated for the forecasts generated from 48 h up to right before the actual event (0 h) with intervals of 6 hours with the method of the shifting window using data with granularity of 15 min.

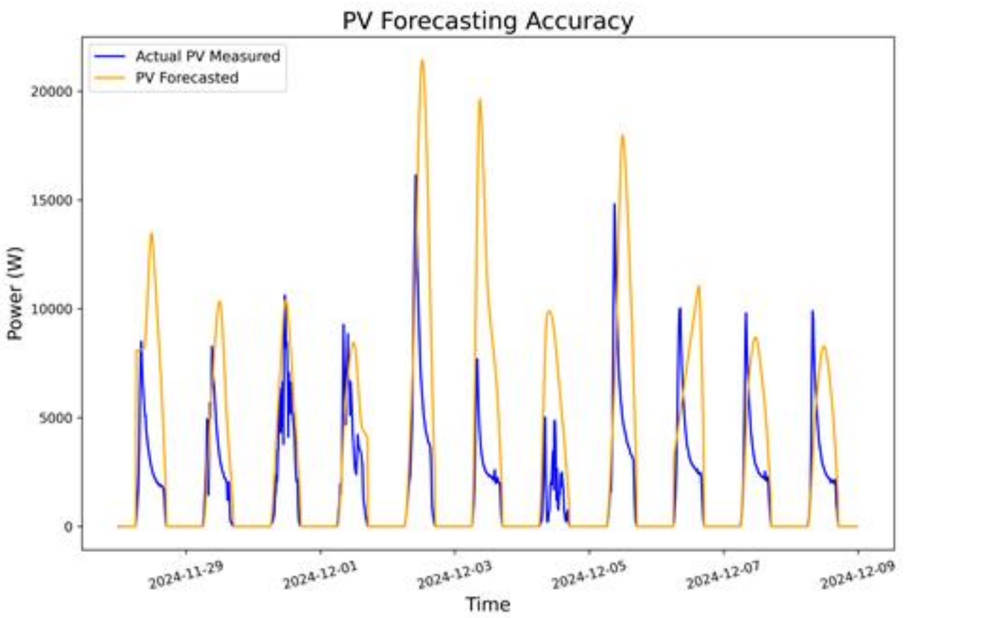

Figure 14: Solar PV generation forecasting data for the Keonjhar Microgrid, period from November 28th, 2024 to December 8th, 2024.

The following table shows the results for the MAPE forecasting accuracy:

MAPE forecasting accuracy	PV Forecasting	Load Forecasting
0 hours.	19.695%	34.387%
6 hours.	16.811%	36.026%
12 hours.	16.808%	38.559%
18 hours.	16.808%	42.511%
24 hours.	17.488%	47.181%
30 hours.	16.871%	44.275%
36 hours.	27.312%	44.995%
42 hours.	31.694%	46.309%
48 hours.	32.419%	49.473%

Table 76 MAPE (forecasting accuracy) for the Keonjhar Microgrid Demo Site.

As can be seen from Table 76, the accuracy of the solar PV generation forecasts can be classified as good enough as it is within the range of 15-20% and always having in mind the data shortage.

Regarding load forecasting, it has a greater degree of difficulty, particularly when it concerns a small number of consumers, and the statistical sample becomes limited. However, the approximately 35% for the latest forecasts is considered a marginally acceptable result. High level of precision in general was not the scope or a necessity for ecoMicrogrid smooth operation, so it was not fully optimized in this regard. The general purpose is to exhibit the robustness and validity of the provided control results by ecoMicrogrid tool by using standard accuracy forecasts as inputs.

2.6.9. KPI 9: Number of electric three wheelers operating in the island (ecoVehicle)

This KPI measures the number of electric three wheelers which are available for mobility in the Keonjhar Microgrid

In the BAU scenario, there were no e-rickshaws in the Keonjhar Microgrid.

The RE-EMPOWERED project has involved the deployment of 2 new electric rickshaws or three-wheelers.

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Number of electric three wheelers	0 electric three-wheelers	2 electric three-wheelers	**N/A**

Table 77 Number of electric three wheelers operating in the island, for the Keonjhar Microgrid Demo Site.

2.6.10. KPI 10: Availability of communication infrastructure (ecoPlatform).

The KPI availability of communication infrastructure measures the reliability of the communication system, in terms of failure frequency and the required time to repair and restore the operation of the communication system.

It can be calculated with the following formula:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

Where:

- Uptime is the total time when the communication system is operational during the observation period.
- Downtime is the total time when the communication system was not operational (for example, due to failures, maintenance actions, unexpected outages).

For ecoPlatform, the results in all the Demo Sites are the same:

- Uptime was 715 hours.
- Downtime was 5 hours.

Therefore, the availability of communication infrastructure was:

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{Uptime}{Uptime + Downtime}\right) \cdot 100$$

$$Availability\ of\ communication\ infrastructure\ (\%) = \left(\frac{715\ hours}{715\ hours + 5\ hours}\right) \cdot 100 = 99.31\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	Change
Availability of communication infrastructure	N/A	99.31%	**N/A**

Table 78 Availability of communication infrastructure, for ecoPlatform, for the Keonjhar Microgrid Demo Site.

2.6.11. KPI 11. Digital solutions integrated (ecoCommunity).

The KPI measures the number of digital solutions installed because of the development of the project. The list of digital solutions installed is given in the following table.

Sl. No.	Tool	Digital Platform
1	ecoCommunity	Android Mobile
2	ecoPlatform	Interoperable ICT tool
3	ecoMicrogrid	Energy Management System

Table 79 Digital solutions deployed in Keonjhar

The following formula is used to calculate the KPI:

$$Digital\ Solutions\ Integrated\ Ratio = \frac{Solutions\ Integrated\ as\ part\ of\ RE - EMPOWERED}{Total\ Solutions\ Integrated}$$

	BAU	RE-EMPOWERED	Change
Digital Solutions Integrated	0	3	**+3 solutions**

Table 80 Number of Digital Solutions Integrated in Keonjhar

2.6.12. KPI 12: Customers engaged with smartphone application (ecoCommunity).

This KPI measures the customer involvement with the developed tool. The introduction of a new solution and its features can attract consumers to register for their use.

It is important to note that all registered consumers of the tool might not be actively engaging with the tool after the registration. This might be due to various reasons like customer lost interest to functionalities, tool failing to meet the customer expectations, customer might not have the time/patience for an active engagement, etc.

The following table provides the number of customers registered as well as engaged with the tools during the demonstration activities.

		Registered
ecoCommunity	Administrator	1
	Manager	10
	Consumer	41

Table 81 Users engaged with ecoCommunity in Keonjhar

The following table evaluates the KPI for customer registered and engaged in the digital solutions developed for the demo site:

	BAU	RE-EMPOWERED	Change
Customer Registration	0	41	**+41 customers**

Table 82 Users registered in ecoCommunity in Keonjhar

2.6.13. KPI 13: Data Access Control (ecoCommunity)

The KPI evaluates the level of authorised vs unauthorized access to the tool or tool data. In the case of ecoCommunity the access to the tool and the data is restricted using username-password based authentication.

The KPI is evaluated using the formula:

$$Access\ Control\ Ratio\ = \frac{No\ of\ Authorised\ Access}{Total\ Number\ of\ Access}$$

In the Gaidouromantra Microgrid, all accesses which have been monitored have been controlled, as can be seen in the following table:

	BAU	RE-EMPOWERED	Change
Data Access Control	N/A	100%	**100% access control**

Table 83 Data Access Control in the Keonjhar Microgrid Demo Site

2.6.14. KPI 14: Tool Modules Deployed (ecoCommunity)

The KPI evaluates the number of functional modules of a tool implemented in the demo site to the total modules developed as part of the project. The tool functionalities or functional modules are developed considering a generic system with the different scenarios associated with all the demo sites. Although only a fraction of these modules will be implemented in the demo site considering the technical and social limitations.

The following table shows the number of modules developed in the project and deployed in the demo site for each tool.

Tool	Modules Developed	Modules Deployed	Percentage Deployed	RE-EMPOWERED
ecoCommunity	10	9	90%	90%

Table 84 Tool modules deployed, for the Keonjhar Microgrid Demo Site.

2.6.15. KPI 15: Data reliability (ecoPlatform).

This KPI measures the percentage of data packages which are successfully transmitted without mistakes or losses during the observation period, compared to the total amount of data packages or data which are transmitted.

It can be calculated using the following formula:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted - Total\ data\ packages\ with\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

This is equivalent to:

$$Data\ reliability\ (\%) = \left(\frac{Total\ data\ packages\ transmitted\ without\ mistakes\ or\ losses}{Total\ data\ packages\ transmitted}\right) \cdot 100$$

Where:

- Total data packages transmitted are the number of data packages which are transmitted, whether they are received or not.
- Total data packages with losses are the number of data packages which are not transmitted, or which have any kind of mistake.
- Total data packages transmitted without mistakes or losses are the number of data packages which are correctly and completely transmitted without losses or mistakes.

The results in the Keonjhar Microgrid are the same that were obtained in the other Demo Sites:

- Total data packages transmitted: 1,000,000.
- Total data packages with losses: 1,000.

Therefore, the Data reliability KPI for Keonjhar Microgrid is as follows:

$$Data\ reliability\ (\%) = \left(\frac{1{,}000{,}000 - 1{,}000}{1{,}000{,}000}\right) \cdot 100 = \frac{999{,}000}{1{,}000{,}000} = 99.90\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Data reliability	N/A	99.90%	**N/A**

Table 85 Data reliability, for ecoPlatform, for the Keonjhar Microgrid Demo Site.

2.6.16. KPI 16: Energy data transfer (ecoPlatform).

Energy data transfer measures the capacity of a data exchange platform to transfer different types of data successfully. It is related to the amount of transmitted data (in MB) within the observation period.

Transmitted data can include logs, real-time monitoring data and other information.

The formula which can be used to estimate this KPI is:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

Where:

- Total transmitted data is the volume of energy-related data which are transferred using the ecoPlatform, in MB.
- Total time is the period of time when the transmission of data is monitored.

The obtained results for these variables in the Ghoramara Island are the same that were obtained for the other Demo Sites:

- Total transmitted data: 50 MB.
- Total time: 10 hours.

Using the previously described formula:

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{Total\ transmitted\ data\ (MB)}{Total\ time\ (hours)}$$

$$Energy\ data\ transfer\ \left(\frac{MB}{hour}\right) = \frac{50\ MB}{10\ hours} = 5\ MB/hour$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Energy data transfer	N/A	5 MB/hour	**N/A**

Table 86 Energy data transfer, for ecoPlatform for the Keonjhar Microgrid Demo Site.

2.6.17. KPI 17: Increased access to own metering data (ecoCommunity, ecoMicrogrid).

This KPI is related to the number of consumers which use a smart meter and can access their electricity meter data through a single access point. It measures the new consumers (including both households and organizations) that can access these data, because of the implementation of ecoMicrogrid and ecoCommunity.

In Keonjhar demo site each meter refers to a cluster of around 10 houses. There are 9 meters placed for 9 different clusters of houses and one meter for the rice hull miller of the village.

The KPI is compared between the BAU and the RE-EMPOWERED scenario. The following table shows the number of consumers which can access these data:

	BAU	RE-EMPOWERED

Number of consumers which can access own metering data	0	9 + 1

Table 29 Increased access to own metering data for the Keonjhar Microgrid Demo Site

2.6.18. KPI 18: Automatic metering of consumers (ecoCommunity).

This KPI is very related to the increased access to own metering data. It compares the number of consumers which have their smart meter information remotely gathered by the DSO, compared to the number of consumers who had their data collected in the BAU scenario.

In the case of the Keonjhar Microgrid, the result of the evaluation of the KPI is the same as for the increased access to own metering data. Before the implementation of ecoDR and ecoCommunity, none of the consumers had their electricity consumption measured, while after the development of the RE-EMPOWERED project, the consumption of 10 consumers is monitored.

	BAU	RE-EMPOWERED
Number of consumers which have their energy consumption measured	0	10

Table 30 Automatic metering of consumers for the Keonjhar Microgrid Demo Site.

3. Economic assessment of demos and tools

This chapter focuses on the results which are obtained from the economic assessment of the use of the ecoTools in the Demo Sites. The structure of the chapter is the same that was used for the technical assessment. Firstly, the methodology which is used to calculate the different KPIs is described, as well as the collection of information to calculate them. Afterwards, the detailed calculation of each KPI, for each Demo Site, is presented.

For several KPIs, an evaluation has been carried out in the cash flow models which were defined in the Deliverable 8.2 "Report on the business models and financing tools (V2)". More detailed information can be found in this document, and will not be repeated here.

3.1 Methodology to carry out the economic impact assessment of demos and tools

The calculation of the economic impact has been carried out considering a reference scenario, or BAU (Business-as-usual), which is the situation before the implementation of the technologies and ecoTools in the Demo Site, and a RE-EMPOWERED scenario, after their implementation.

The following input variables have been used:

- Total investment cost in the Demo Site and/or the ecoTool: This includes the cost of developing the Demo Site, such as the equipment cost, cost of carrying out the technical and economic feasibility analyses, environmental impact evaluation if needed, as well as the cost of installing the ecoToolset.
- Operation and maintenance cost in the Demo Site: This cost includes the recurring and non-recurring costs derived from the operation of the demo sites, for example fuel cost, maintenance costs (corrective, preventive, predictive), labour cost, electricity supply cost, and so on.
- Revenues or incomes: The expected incomes, or positive flows that will be received by the project. Incomes can be received from the sale of energy (heat, electricity) to the final consumers, from the provision of ancillary services, from the provision of other services, such as the loan of electric vehicles, or, simply, due to a reduction in costs. For example, the implemented technologies can have a lower operation and maintenance cost, or expensive fuel oil can be replaced for renewable energy.
- Yearly energy consumption (kWh), for electricity, fuel, biomass, biogas and so on. In some cases, energy consumption can be measured in tons/year, for example, for biomass, or litres/year, for diesel.
- Energy price (€/kWh, €/ton, €/litre), for electricity, fuel, biomass, biogas and so on.
- Expected lifetime of the system.
- Applicable taxes.
- Discount rate.

Most of the information used in this chapter comes from the assessment carried out in Report on the business models and financing tools (V2).

Finally, as some of the Demo Sites are based on countries which do not use the Euro as currency, it has been necessary to also use the Danish Krone (DKK) and the Indian Rupee (₹). The main currency used in the Deliverable is, however, the Euro (€)

To transform Danish Krones and Indian Rupees into Euros, the following exchange rates have been used:

- 1 € = 7.463 DKK, or 1 DKK = 0.134 €.
- 1 € = 90.09 INR, or 1 ₹ = 0.0111 €.

These exchange rates are the average values for the last years.

3.1.1 Selection of economic KPIs

Some of the most relevant economic KPIs, such as the investment cost in each Demo Site, the operation and maintenance costs, the incomes, or the parameters which measure the economic profitability of business models, such as the net present value, the internal rate of return, or the payback, are calculated, for each Demo Site, in the Deliverable 8.2 Report on the business models and financing tools (V2), and will not be repeated in this chapter.

Instead, the chapter will focus on some new KPIs, which have been calculated during the last three months of the RE-EMPOWERED project.

- **Reduced overall cost:** This KPI measures the reduction in the cost, due to the use of the ecoTools or the renewable energy and demand response solutions in the Demo Site, compared to the BAU situation.
- **Revenues from the project to the project developer:** This KPI measures the expected revenues which will be obtained by the project developer, as it develops the business model defined for each Demo Site.

3.2 Bornholm Island: Denmark

The model for Bornholm is based on the economic sustainability analysis carried out for Bornholm in Deliverable 8.2 Report on the business models and financing tools (V2).

In this assessment, the overall cost of the Demo Site is considered, as well as the economic savings and expenses that are derived from the implementation of the proposed business model.

The following price assumptions have been taken for the calculation of the economic indicators of the model:

Variable	Value
Cost of the straw (€/ton)	75 €/ton
Electricity tariff (€/kWh)	0.12 €/kWh

Variable	Value
Average salary cost in Denmark (€/year)	50,000 €/year
Up-front fee for customers to be integrated in the Bornholm district heating plant	22,400 DKK[1] per household or customer + 5,600 DKK for each installation
Yearly fixed tariff for customers to be integrated in the Bornholm district heating plant	2,140 DKK + 23 DKK per m^2 of the household or building
Variable cost for customers to be integrated in the Bornholm district heating plant	570 DKK per MWh
Revenue for participating in the electricity flexibility market	440 DKK/MWp/hour
Lifetime of the district heating	20 years

Table 87 *Economic assumptions-Bornholm Island.*

3.2.1. KPI 1: Reduced overall cost (ecoEMS)

This KPI measures the reduction in total operational costs due to various efficiency improvements, cost-saving initiatives, or process optimizations. It is crucial for assessing the effectiveness of efforts to reduce expenditures across an organization, particularly in energy production, maintenance, and operational management.

In the context of power generation, the overall cost reduction can come from several sources, including but not limited to:

- Fuel cost reduction: Using more cost-effective or alternative fuels or switching to renewable energy sources that are less expensive or have lower operational costs.
- Operational efficiency improvements: Enhancing the efficiency of power plants, equipment, and personnel, which can reduce costs associated with maintenance, energy losses, or overproduction.
- Demand-side management: Implementing strategies that reduce peak demand or optimize energy use, leading to lower operational costs or avoided capital expenditures (e.g., new power plants or grid infrastructure).

Tracking this KPI helps organizations understand how well they are controlling their costs, optimizing resources, and improving overall financial performance, often in relation to sustainability and energy usage.

[1] An exchange rate of 1 DKK=0.134 € has been used to transform values in DKK into €.

$$Reduced\ Overall\ Cost = Total\ Cost\ Before\ Reduction - Total\ Cost\ After\ Reduction$$

Where:

- Total Cost Before Reduction is the total operational cost of the organization or system before implementing cost-saving initiatives.
- Total Cost After Reduction is the total operational cost after applying cost-saving strategies, energy efficiency improvements, or other optimization measures.

Depending on the value of the KPI, there can be two situations:

- High Reduction in Cost: A significant reduction in overall costs indicates that the organization has effectively implemented cost-saving measures or improved efficiency, leading to enhanced profitability and financial sustainability.
- Low or No Reduction in Cost: If there is little or no reduction, it may suggest that the cost-saving measures were ineffective, or the strategies need to be reevaluated. It could also indicate that rising external costs (e.g., fuel prices) offset any internal savings.

This KPI is vital for monitoring the financial health of an organization, particularly in industries with high operational costs, such as energy production, manufacturing, and transportation. It highlights the efficiency of resource use, the success of cost-reduction efforts, and provides insight into the organization's ability to stay competitive while maintaining quality and service standards.

The KPI is calculated with data from a specific range of days during December 2024 that the second round of demonstration took place. To be in line with the previous KPIs, a theoretical RE-EMPOWERED KPI was calculated, based on the same conditions.

As shown in the next table, the effect of the ecoTool is expected to be much higher under conditions of high-RES penetration.

Regarding the cost of fuels in Østerlars production prices for straw boiler is fixed (negotiated every fifth year) and now is at 219 DKK/MWh ~ 29,2 EUR/MWh (exchange rate 7.5), and the average Day Ahead Price from Denmark for importing energy during the week of the demonstration was 162 €/MWh. For the scopes of the KPI, the cost of RES production is considered zero, and only the alternative sources of energy are calculated.

The following table includes a summary of the main results which have been obtained for this KPI:

	BAU (day with high RES)	RE-EMPOWERED (day with high RES)	**Change**	BAU (day with low RES)	RE-EMPOWERED (day with low RES)	**Change**
Overall fuel cost (€)	26,446 €	23,340 €	**-11.7%**	62,010 €	53,088 €	**-14.4%**

Table 88 Reduced overall costs in the Bornholm Demo Site.

3.3 Kythnos Power System: Greece

3.3.1. KPI 1: Reduced overall cost (ecoEMS).

This KPI measures the reduction in total operational costs due to various efficiency improvements, cost-saving initiatives, or process optimizations. It is crucial for assessing the effectiveness of efforts to reduce expenditures across an organization, particularly in energy production, maintenance, and operational management.

In the context of power generation, the overall cost reduction can come from several sources, including but not limited to:

- Fuel cost reduction: Using more cost-effective or alternative fuels or switching to renewable energy sources that are less expensive or have lower operational costs.
- Operational efficiency improvements: Enhancing the efficiency of power plants, equipment, and personnel, which can reduce costs associated with maintenance, energy losses, or overproduction.
- Demand-side management: Implementing strategies that reduce peak demand or optimize energy use, leading to lower operational costs or avoided capital expenditures (e.g., new power plants or grid infrastructure).

Tracking this KPI helps organizations understand how well they are controlling their costs, optimizing resources, and improving overall financial performance, often in relation to sustainability and energy usage.

$$Reduced\ Overall\ Cost = Total\ Cost\ Before\ Reduction - Total\ Cost\ After\ Reduction$$

Where:

- **Total Cost Before Reduction** is the total operational cost of the organization or system before implementing cost-saving initiatives.
- **Total Cost After Reduction** is the total operational cost after applying cost-saving strategies, energy efficiency improvements, or other optimization measures.

Depending on the value of the KPI, there can be two situations:

- High Reduction in Cost: A significant reduction in overall costs indicates that the organization has effectively implemented cost-saving measures or improved efficiency, leading to enhanced profitability and financial sustainability.
- Low or No Reduction in Cost: If there is little or no reduction, it may suggest that the cost-saving measures were ineffective, or the strategies need to be reevaluated. It could also indicate that rising external costs (e.g., fuel prices) offset any internal savings.

This KPI is vital for monitoring the financial health of an organization, particularly in industries with high operational costs, such as energy production, manufacturing, and transportation. It highlights the efficiency of resource use, the success of cost-reduction efforts, and provides insight into the organization's ability to stay competitive while maintaining quality and service standards.

The KPI is calculated with data from a week of demonstration round B, during November 2024, which did not have high loads. Therefore, the effect of the ecoTool is expected to be much higher if a different or larger period will be examined. Yet, the optimality converges with the ecoTool solution.

To be in line with the previous two KPIs, a theoretical RE-EMPOWERED KPI was calculated, based on the same theoretical simulations, with much higher RES penetration examination, with the use of heuristic methods.

The following table includes a summary of the main results which have been obtained for this KPI:

	BAU	RE-EMPOWERED	**Change**	**Theoretical RE-EMPOWERED**	**Change**
Overall cost, for the demonstration week (€)	102,478.50 €	96,841.50 €	**-5.5%**	71,745.50 €	**-29%**
Overall cost, annualized (€)	5,328,856 €	5,035,732 €	**-9%**	3,730,740 €	**-23%**

Table 89 Reduced overall costs, for ecoEMS, in the Kythnos Power System.

3.4 Gaidouromantra Microgrid: Kythnos island. Greece

In Deliverable 8.2 “Report on the business models and financing tools (V2)”, a business model was defined for the Gaidouromantra Microgrid, in Kythnos Island (Greece). The proposed business model considered a citizen community, with a pay-as-you-go model to obtain revenues for the operation and maintenance of the microgrid.

In this report, a separate study was conducted based on experimental data where the focus is the measurement and calculation of the economic impact that the RE-EMPOWERED project had on the microgrid.

3.4.1. KPI 1: Reduced overall cost (ecoMicrogrid, ecoDR).

Gaidouromantra microgrid supply is based on three main elements. For each of these assets namely Batteries, Photovoltaics and Diesel Generator, the marginal cost derived from their operational and maintenance costs has been calculated in €/kWh as 0.052€/kWh, 0.01€/kWh and 0.315€/kWh respectively. ecoMicrogrid can affect their utilization thus the overall cost of the microgrid. The impact of ecoTools in microgrid overall cost is following assessed considering the bellow two scenarios:

- **BAU Scenario:** This scenario assumes that ecoMicrogrid is not in operation and no thermal vector is considered. Diesel generation is controlled by batteries inverter based on their SoC with fixed factors.
- **RE-EMPOWERED Scenario:** In this scenario, ecoMicrogrid is operating normally applying optimization algorithms with predictive control for the generator and with the thermal vector enabled.

The evaluation of RES curtailment reduction considers data from two periods: the demonstration round 2 special test on September 28th, 2024, when the effect of the diesel generation can be analysed, and a longer period spanning from July 20th, 2024, to September 10th, 2024 which allow us to expand the results to a whole year. For the analysis, only three out of the six PV systems were included. This selection was made to enable a comparative analysis of the influence of each period on the overall improvement and at the same time allow us to use the necessary available historical data from previous years.

To annualize the impact, the following assumptions were made:

- Based on historical data obtained from Ref.[5] there were 47 days in the year when the diesel generator needed to be activated.
- The results from the period from July 20th, 2024, to September 10th, 2024, were proportionally expanded to cover the rest of the year, incorporating seasonal adaptations by utilizing typical days from the PVGIS tool.

The implementation of RE-EMPOWERED solutions has demonstrated significant improvements in overall cost reduction at the Gaidouromantra Microgrid. The annualized results are shown in Table 90.

	BAU	RE-EMPOWERED	Change
Cost related to diesel generator	€332.05/year	€110.93/year	-66.59%
Cost related to batteries	€505.68/year	€472.91/year	-6.48%
Cost related to solar PV panels	€81.41/year	€86.58/year	+24.09%
Total overall cost	**919.13 €/year**	**670.42 €/year**	**-26.12%**

Table 90 Reduced overall costs in the Gaidouromantra Microgrid.

For this cost analysis, also primary ecoMicrogrid optimization mechanisms for energy operations were taken into consideration. These are, the Predictive Optimization of Diesel Generator Operation and the Utilization of the Thermal Vector. While the first is evident, the later can be observed in Table 90 by the fact of the PV cost rise at RE-EMPOWERED scenario where more energy from photovoltaics is produced thanks to the thermal vector exploitation.

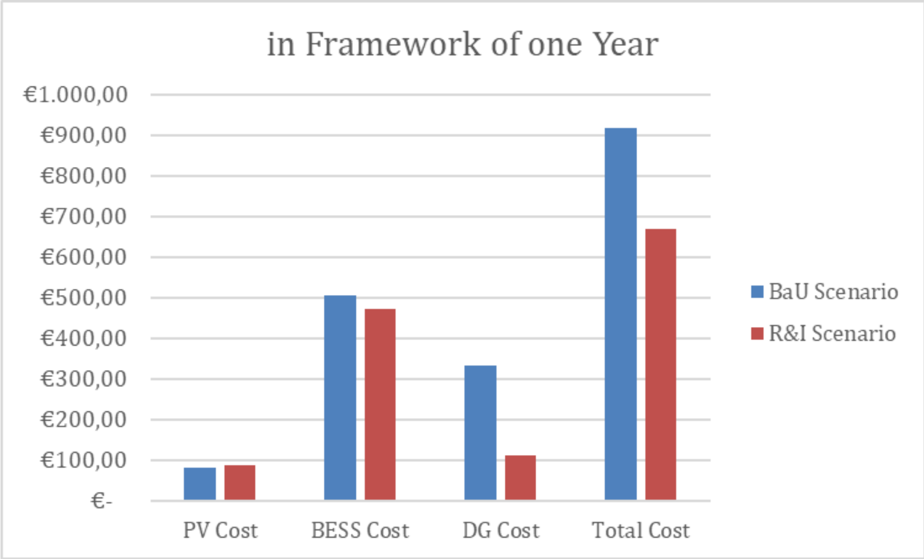

Figure 15: Comparison of the overall annually cost in the BAU and the RE-EMPOWERED situations.

As can be seen clearly in bar chart in Figure 15, even though battery related cost is the highest, the one most affected is diesel generator related cost.

Thus, following it is worth taking a closer look in the example day of diesel generator (DG) operation and the results emerging. In the BAU scenario in Figure 17 (top graph), it is illustrated a usual mode of operation for microgrids where the diesel generator is energized with a hysteresis loop with fixed thresholds. In the RE-EMPOWERED scenario (bottom graph), the system anticipates solar PV generation overtaking system needs during early morning hours. This results in both reduced diesel generator operation and better utilization of solar PV production.

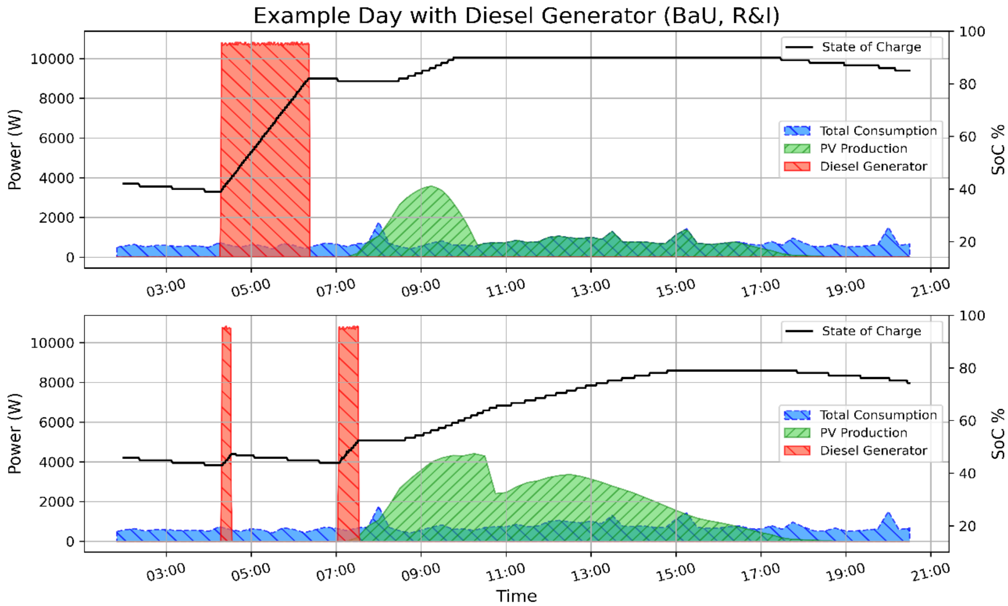

Figure 16: Comparison of the solar PV generation, the use of diesel generator and BESS State of Charge in the BAU and the RE-EMPOWERED situations.

The overall cost for this example day at BAU scenario is 9.54 € while overall cost for the R&I scenario is 4.25 €. The percentage of this reduction is calculated at **55.45%.**

3.5 Ghoramara Island Microgrid: West Bengal, India

To develop the business model for the Ghoramara Island Microgrid, it is necessary to consider the following details of the Demo Site:

Variable	Value
Number of households	650 households
Number of house lighting systems (HLS)	490 house lighting systems
Number of travels in the e-boat	2 round trips/day
Number of passengers travelling by e-boat	15 passengers per trip
Number of electric three wheelers	6 electric three wheelers
Number of travels in the electric three wheelers	30 travels per day
Number of charging facilities	2 charging points for the electric three wheelers

Table 91 Facts- Ghoramara Island Microgrid.

3.5.1. KPI 1: Reduction of diesel consumption (ecoVehicle)

In the Ghoramara Island microgrid, all electricity is produced with renewable energies and does not use diesel.

However, the electric three wheelers which were used before the project needed some diesel as fuel.

It has been estimated that each electric three-wheeler used 60 liters of diesel per month. Considering that there were four e-three wheelers, the total diesel consumption per month would be 240 liters. Per year, the total diesel consumption would be 2,880 liters of diesel per year. If also the two new electric three wheelers which are going to be installed are considered, then the total diesel consumption would be 4,320 liters of diesel per year.

The use of two new electric three wheelers, and the option to charge them using renewable energies (solar PV and wind energy) can lead to a reduction of diesel consumption by 300 liters per month, this is, 3,600 liters of diesel per year (due to the use of five electric three wheelers which are charged with renewable energies). Therefore, the total diesel consumption would be 720 liters per year.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED	**Change**
Reduction of diesel consumption	4,320 litres per year	720 litres per year	**-83.3%**

Table 92 Reduction of diesel consumption in the Ghoramara Island Microgrid

3.5.2. KPI 2: Revenues from the project to the project developer.

The business model which has been designed for the Ghoramara Island Microgrid involves that the project developer obtains different revenues from a variety of sources: sale of electricity to domestic consumers, both for domestic use and for lighting systems, loan of the electric three wheelers, the lease of the two charging facilities, and the use of the electric boat.

Going more into the detail of each source of revenue:

- Incomes from domestic power supply: 650 households are considered, which pay ₹70/month (€0.777) for the use of electricity each. Therefore, the total income from domestic power supply will amount to ₹45,500 per month (€505.05), and ₹546,000 per year (€6,060.60).
- Incomes from house lighting systems: 490 households will also have a house lighting system (HLS). Each house is charged ₹70/month (€0.777/house/month).

  With 650 households, the total incomes will amount to ₹411,600 per year, and €4,568.76/year.
- Incomes from the use of the electric boat: The electric boat is supposed to make 2 round trips per day. In each travel, it can transport 15 passengers on average.

  The tariff for using the electric boat will be ₹25 (€0.278) for each passenger. Then, the total incomes per day will be ₹750 (€8,33). Considering that the boat is used 300 days per year, the total incomes would be ₹273,750/year (€3,038.63/year).
- Renting and charging of e-3 wheelers: The e-3 wheelers are used 30 times per day. The tariff to be paid will be ₹25/trip (€0.278), and each e-3 wheeler is used 300 days per year.

  Therefore, the total incomes from the e-3 wheelers will amount to ₹225,000/year, or €2,497.50/year.
- Lease of the two loaders: Each loader is expected to produce incomes of ₹100 per day (€1.11/day). As there are 2 loaders, the total incomes will be ₹200 per day (€2.22/day).

The use of the loaders will not be constant, and an average of 300 days of use per year are considered. Thus, the total incomes will amount to ₹60,000 per year, or €666.00/year.

The total revenues from the business model will be ₹1,516,350, or €16,831.49/year.

The following table includes a summary of this KPI:

	RE-EMPOWERED	Change
Incomes from domestic power supply	₹546,000year (€6,060.60/year).	N/A
Incomes from house lighting systems	₹411,600/year (€4,568.76/year).	N/A
Incomes from the use of the electric boat	₹273,750/year (€3,038.63/year).	N/A
Renting and charging of e-3 wheelers	₹225,000/year (€2,497.50/year).	N/A
Lease of the two loaders	₹60,000/year (€666.00/year).	N/A
Total revenue	**₹1,516,350/year (€16,831,49/year)**	**N/A**

Table 93 Revenues for the Ghoramara Island Microgrid.

3.6 Keonjhar Microgrid: Odisha, India

The economic assessment of the business model for the Keonjhar Microgrid has been based on the following facts:

Variable	Value
Number of households	75 households
Available power per household	100 W
Number of microenterprises which are developed	25
Number of electrical 3 wheelers	At the beginning of the project: 2 e-3 wheelers Every 5 years, 3 new e-3 wheelers will be purchased
Number of charging facilities	1 charging facility, with 2 ports, and 1.5 kW
Number of mini rice huller mills	3 mini rice huller mills, with a power of 1 HP
Solar power dimmable lights	10 units

Smart meter with fuse and MCCB/MCB	10 units
Solar pumps	2 solar pumps

Table 94 Facts-Keonjhar Microgrid.

3.6.1. KPI 1: Reduced overall fuel cost.

The deployment of two electric three wheelers for transport of passengers and load under RE-EMPOWERED project provided additional income generation streams. However, the two solar pumps for irrigation reduced the cost of fossil fuel for diesel run 3-4 pumps seasonally in addition to the three mini rice huller mills.

The following is a summary of the diesel consumption of the mini rice hullers, and the reduction of diesel consumption derived from the two solar pumps:

- 4-5 litres of diesel consumption per rice huller mill per day. On an average 150 litres of diesel consumption per rice huller mill per month. Therefore, three mini rice huller mills consume a total of 450 litres of diesel per month.
- ₹500 (€5.55) incurred for diesel consumption per day per mini rice huller mill. On an average total of ₹15,000 (€166.50) incurred for diesel per month per mini rice huller mill, thus total of ₹45,000 (€499.50) approximately incurred for all three mini rice huller mill per month.
- Two solar pumps reduced the cost of fuel consumption. 3-4 Pumps operated on diesel for 2 hours per day on an average, consuming 2-3 litres of diesel per day. On an average per pump the cost incurred on diesel was ₹9,000 (€99.90) for approximately 90 litres per month. For two pumps, the cost comes to be ₹18,000 (€199.80) per month, which is saved by operation of two solar pumps in the demonstration site.

The following table includes the result of the reduced overall costs, focusing on the reduction of fossil fuel cost:

	BAY	RE-EMPOWERED	**Change**
Reduced overall fuel cost	N/A	₹63,000/month (€699.30/month)	**₹63,000/month (€699.30/month (37% reduction)**

Table 95 Reduced overall fuel cost, for Keonjhar Microgrid

3.6.2 KPI 2: Revenues from the project to the project developer.

The business model defined for the Keonjhar microgrid considers a wide source of incomes to make the project economically sustainable. These incomes include the sale of electricity to domestic and industrial clients, and tariffs for the use of the e-3 wheelers, the solar pumps, the mini rice hullers and other incomes.

The detail of revenues for the Keonjhar microgrid is as follows:

- Incomes from household clients: There are 75 households, and each one will be charged ₹ 80/month (€0.888) for the use of electricity. Along a complete year, the total revenues will be ₹ 72,000 (€799.20/year).
- Incomes from commercial clients: There are 25 microenterprises. The total income from these users will be ₹ 144,000 per year (€1,598.40/year).
- Incomes from the renting of e-3 wheelers: The payments received for two e-3 wheelers are estimated to be ₹ 2,705,000 per year, equivalent to €2,997.00/year-
- Incomes from the use of the solar pumps: It is estimated that these payments will amount to ₹ 35,000 per year, or €388.50/year.
- Incomes from the use of the mini rice huller mills: For the use of the mini rice huller mills, a fee of ₹ 50 per hour will be charged. Additionally, the use of the mini rice huller mills will be approximately 4 or 5 hours per day. This involves a total monthly use of 120 hours, and incomes amounting to ₹ 6,000 per month, and ₹ 72,000 per year (€799.20).
- Other incomes (e-Vehicle renting): Other incomes, amounting to ₹ 164,000/year will be obtained (€1,820.40/year).

Therefore, the total incomes for the business model of the Keonjhar microgrid will be ₹ 757,000/year, or €8,402.70/year.

These results are summarized in the following table:

	RE-EMPOWERED	Change
Incomes from household clients	₹ 72,000/year (€799.20/year).	N/A
Incomes from commercial clients	₹ 144,000/year (€1,598.40/year).	N/A
Incomes from the renting of e-3 wheelers	₹ 270,000/year (€2,997.00/year).	N/A
Incomes from the use of the solar pumps	₹ 35,000/year (€388.50/year).	N/A
Incomes from the use of the mini rice huller mills	₹ 72,000/year (€799.20/year).	N/A
Other incomes (e-Vehicle renting)	₹ 164,000/year (€1,820.40/year).	N/A
Total revenue	**₹ 757,000/year (€8,402.70/year)**	**N/A**

Table 96 Revenues for the Keonjhar microgrid.

4. Social assessment of demos and tools

4.1 Methodology to carry out the social impact assessment of demos and tools

The social impact assessment of the four RE-EMPOWERED demonstration sites has been conducted based on the rigorous analysis of the identification, relevance, description and measurement of critical KPIs in the social context. For conducting this analysis, firstly the information and data from the demo site leaders and the ecoTool leaders have been collected based on a preliminary questionnaire.

Moreover, several discussions had been conducted with the WP2 leaders as well to extract some of the key KPIs from the corresponding deliverables. Next, some of the most relevant information has been collected from the community as well, to understand the level of change in terms of social capital, income generation, employment, satisfaction level, wellbeing, education and healthcare improvements, community cohesiveness, capacity building, etc. This exercise involved the community representatives, local governance members and few sample households. Based on this an exhaustive list of KPIs was generated and the data was collected via a full-length questionnaire. The aim of this whole analysis is to clearly understand the social impact of the RE-EMPOWERED project in the demo sites in terms of pre- and post- level of changes observed on ground. Some KPIs were directly deduced from the data, while others more subjective in nature have been induced and quantified to measure the change.

4.1.1 Selection of social KPIs

25 critical social KPIs have been identified with significant impact in bringing change through RE-EMPOWERED. Few of these KPIs are generic in nature while others are specific in view of the specific features and characterization of the different demo sites. All the KPIs lead to a good understanding of the impact created in four demo sites, maybe with a varying degree of change. This exploration of the deployment and demonstration of the microgrid clearly shows that access to clean energy has multipronged effects.

A detailed list of the social KPIs which have been selected to measure the social impact of the use of ecoTools in the Demo Sites is included in the following table:

Social KPIS						
#	Name	BO	KY	GA	GH	KE
1	Employment			X	X	X
2	Participant recruitment	X		X		X
3	Active participation	X		X		
4	Customer acceptance	X		X		X
5	EnC participation/adoption		X	X		X
6	User satisfaction contributing to aggregated flexibility	X	X	X		
7	Skill/Knowledge acquirement	X	X	X		X

Social KPIS						
#	**Name**	**BO**	**KY**	**GA**	**GH**	**KE**
8	Social compatibility		X	X		
9	Consumers' engagement	X		X	X	X
10	New customers connected			X	X	X
11	Level of user satisfaction and expectation				X	X
12	Ease of use for end-users of the solution			X		
13	Advantages for end-users		X	X		
14	Knowledge about district heating systems	X				
15	Energy Poverty				X	X
16	Power provided per household and day				X	X
17	Average electricity supply at night (hours/day)				X	X
18	Opening of bank account for tariff collection				X	
19	Increase in income generation				X	X
20	Average nighttime electricity for school studies				X	X
21	Increased access to healthcare services				X	
22	Number of training workshops in pilot cases	X				
23	Uses for education purposes through workshops		X	X		
24	Wind Turbine Manufacturing Course Attendance			X	X	
25	Energy community					X

Table 97. List of detailed KPIs used for the evaluation of the social impact.

4.2 Bornholm Island: Denmark

4.2.1. KPI 1: Participant recruitment (ecoPlatform).

This KPI measures the number of consumers that have been included in the demonstration activities of ecoPlatform, in the Bornholm Demo Site, in terms of the number of participants who have decided to take part in the Demo Site, compared to the number of planned participants.

KPI is measured by the formula:

$$Requitment\ rate\ (\%) = \frac{No. of\ requited\ participants}{No. of\ planned\ participants} * 100$$

The table below displays a list of project participants in the project, divided into subgroups.

	Planned	Recruited
Private households	4	4

	Planned	Recruited
School	1	1
Swimming pool	1	1
Church	1	1
Total	**7**	**7**

Table 98 Participants involved in the project in the Bornholm Demo Site

The requitement process was successful as the planned number of 7 participants were met resulting a KPI score of 100%.

4.2.2. KPI 2: Active participation (ecoCommunity)

This KPI measures the number of consumers that actively participate in the different demos. It is compared to the total number of consumers that had accepted, in principle, to participate in the RE-EMPOWERED project.

According to the results of the tests of the ecoCommunity in Bornholm, ecoCommunity has been installed in 3 android devices.

	Possible	Active	**Result**
Active participation	**7 consumers**	**3 consumers**	**43%**

Table 99 Active participation in the Bornholm Island Demo Site.

4.2.3. KPI 3: Customer acceptance (ecoCommunity).

Customer acceptance measures the level of satisfaction and acceptance of ecoCommunity among users at the Bornholm demo site, ensuring their needs are being met.

It is measured using a Likert scale, with a 5-level scale.

According to the results of the RE-EMPOWERED project, customers were not interested at all before the development of the project, and the result in the Likert scale was 1. After the project, the level of interest has grown to 2 - Uninterested.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Customer acceptance	1 Strongly uninterested	2 Uninterested

Table 100 Customer acceptance in the Bornholm Island Demo Site.

4.2.4. KPI 4: User satisfaction contributing to aggregated flexibility.

This KPI measures the satisfaction and acceptance among private consumers with the development of participation in the flexible energy consumption on Bornholm Island.

As with the previous KPIs, it is measured with a Likert scale (satisfaction), with 5 different steps.

The satisfaction of users remains neutral and has not changed during the project.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
User satisfaction contributing to aggregated flexibility	3 Neutral	3 Neutral

Table 101 User satisfaction among consumers who participate with flexible consumption in Bornholm.

4.2.5. KPI 5: Skill/Knowledge acquirement (ecoCommunity).

Skill/knowledge acquirement measures how effectively ecoCommunity tool enhance the skills and knowledge of private project participants in the Bornholm demo site, particularly in sustainable practices and tool use.

It is measured with a Likert scale, with 5 different steps (level of skill/knowledge). The use of ecoCommunity was limited due to accumulating delays narrowing down the window for usage. This, however, did not stop the skill and knowledge acquisition which was given through events and meetings.

In relation to ecoCommunity, most project participants did not own an android phone which unfortunately limited the engagement through the application.

The following table includes these results and clarifies if the users were satisfied with the skill/knowledge acquirement:

	BAU	RE-EMPOWERED
Skill/ knowledge acquirement	N/A	3 Neutral

Table 102 Skill/Knowledge acquirement in the demonstration site on Bornholm.

4.2.6. KPI 6: Consumers' engagement (ecoCommunity).

This KPI measures the overall level of consumer engagement and satisfaction with ecoTools, reflecting how deeply they interact with, and can integrate the tools into daily life, in the Bornholm Demo Site.

It is measured with a 5-step Likert scale.

According to the analyses carried out, before the RE-EMPOWERED project, customers showed a low interest (2 in the Likert scale), while, after the development of the project, the interest level has grown to Interested (4 in the Likert scale).

These results can be found in the following table:

	BAU	RE-EMPOWERED
Consumers' engagement	2 Unsatisfied	4 Satisfied

Table 103 Consumers engagement in the Bornholm Demo Site.

4.2.7. KPI 7: Knowledge about district heating systems (ecoCommunity).

This KPI measures the level of knowledge of the consumers in the Bornholm Demo Site about the district heating systems.

It is measured with a 5-step Likert scale, where 1 means "No knowledge at all", and 5 means "Very high knowledge". According to the measurements carried out, firstly the consumers had a low level of knowledge about district heating systems, measured with a 2 "Low knowledge". After the development of the RE-EMPOWERED project, the level of knowledge about district heating systems went up to "Medium knowledge", with a 3.

These results can be found in the following table:

	BAU	RE-EMPOWERED
Knowledge about district heating systems	2 Low knowledge	3 Medium knowledge

Table 104 Knowledge about district heating systems in the Bornholm Demo Site.

4.2.8. KPI 8: Number of training workshops in pilot cases

This KPI measures the number of workshops which have been organized in the Bornholm Demo Site, and the attendance at these workshops.

The number of workshops which have been organized has been 1, with an attendance of 4 householders. It was later followed by individual training.

The following table includes a summary of the attendance to this course:

	BAU	RE-EMPOWERED
Attendance to workshops for private customers (4 households)	N/A	4
Attendance to individual training and guidance (of 7 participants)	N/A	7

Table 105 Number of training workshops in the Bornholm Demo Site

4.3. Kythnos Power System: Greece

4.3.1. KPI 1: EnC participation/adoption.

The Energy Community participation/adoption KPI measures the increase in the adoption rates and active participation in energy communities. In this case, it measures the attitude of the residents of Kythnos island towards the possibility of establishing an energy community.

This KPI is also measured with a Likert scale, with 5 different levels.

The RE-EMPOWERED project has obtained quite satisfactory results: before the development of the project, customers were not interested in participating in energy communities, and the level in the scale was 1- No participation.

However, the RE-EMPOWERED project has achieved to increase the level of interest to 4- High participation.

The following table shows these results:

	BAU	RE-EMPOWERED
EnC participation/adoption	1 No interest	4 High interest

Table 106 EnC participation/adoption in the Kythnos Power System.

4.3.2. KPI 2: User satisfaction contributing to aggregated flexibility.

This KPI measures the satisfaction and acceptance of small consumers and producers with the development of the aggregated flexibility in the Kythnos Power System, and how their needs are being met, and energy demands are managed.

As with the previous KPIs, it is measured with a Likert scale, with 5 different steps.

The satisfaction of users has been increased from 2 (Unsatisfied) to 3 (Neither unsatisfied nor satisfied), as a result of the RE-EMPOWERED project.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
User satisfaction contributing to aggregated flexibility	2 Unsatisfied	3 Neither unsatisfied nor satisfied

Table 107 User satisfaction contributing to aggregated flexibility in the Kythnos Power System.

4.3.3. KPI 3: Skill/Knowledge acquirement.

Skill/knowledge acquirement measures how effectively ecoTools enhance the skills and knowledge of residents at the Kythnos Power System demo site, particularly in sustainable practices and tool use.

It is also measured with a Likert scale, with 5 different steps. In this case, the development of the RE-EMPOWERED project has improved skill acquirement from 2 Unsatisfied, to 4 Satisfied.

The following table includes these results:

	BAU	RE-EMPOWERED
Skill/ knowledge acquirement	2 Unsatisfied	4 Satisfied

Table 108 Skill/Knowledge acquirement in the Kythnos Power System.

4.3.4. KPI 4: Social compatibility.

This KPI measures how well ecoTools align with the social dynamic, values, and relationships within the Kythnos Power System.

It is measured with a 5-step Likert scale, and the results show that the interest of citizens in using these solutions has grown importantly, from 3 (Neither compatible nor incompatible) to 4 (Compatible), as a consequence of the development of the solutions proposed in RE-EMPOWERED.

These results can be found in the following table:

	BAU	RE-EMPOWERED
Social compatibility	3 Neither incompatible nor compatible	4 Compatible

Table 109 Social compatibility in the Kythnos Power System.

4.3.5. KPI 5: Advantages for end-users.

This KPI measures the tangible benefits experienced by end-users at the Kythnos Power System, such as increased energy efficiency, cost savings, or improved quality of life due to ecoTools.

It is evaluated with a 5-step Likert scale. In the case of the Kythnos Power System, the situation before the development of the RE-EMPOWERED solutions was bad, and end-users have ranked it with a 1 (a lot of disadvantages have been found by end-users). The RE-EMPOWERED solutions have led to an increase of the score to 2 (many disadvantages have been found by the end-users).

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Advantages for end users	1 A lot of disadvantages have been found	2 Many disadvantages have been found

Table 110 Advantages for end-users of the solution in the Kythnos Power System.

4.3.6: KPI 6: Uses for education purposes through workshops (ecoCommunity).

This KPI measures the extent to which ecoTools can be integrated into educational workshops, fostering awareness and knowledge transfer about sustainable living practices at the Kythnos Power System.

It is measured with a 5-step Likert scale. In the case of the Kythnos Power System, the results of measuring this KPI show that, before the development of the RE-EMPOWERED solutions, there were reduced possibilities to use the Demo Site in a workshop, for educational purpose (Low possibilities, 2). With the ecoCommunity and other ecoTools, there are many more options to use the Kythnos Power Demo Site in educational purposes, so the interest of the Demo Site to be used in workshop grew to High (4).

These results can be found in the following table:

	BAU	RE-EMPOWERED
Uses for education purposes through workshops	2 Low	4 High

Table 111 Uses for education purposes through workshops in the Kythnos Power System.

4.4. Gaidouromantra Microgrid: Kythnos Island: Greece

4.4.1. KPI 1: Employment.

This KPI measures the overall employment opportunities created by implementing ecoTools, including jobs related to the development and maintenance of equipment.

Due to the limited size of the Gaidouromantra Microgrid, there is not any professional continuously working in the Demo Site.

It is estimated that there is a need for 1-2 visits per year to carry out the maintenance of the diesel generator, taking each visit some days (approximately, 0.2 jobs). For maintenance actions in the wind turbine and the solar PV panels, it is estimated that there is need for 1 working day for 1 person, per year.

Therefore, no employment will be created in the Gaidouromantra Microgrid.

The following table summarizes the employment created in the Gaidouromantra Microgrid:

	BAU	RE-EMPOWERED
Employment	0 posts	0.2 posts

Table 112 Employment created in the Gaidouromantra microgrid.

4.4.2. KPI 2: Participant recruitment (ecoCommunity).

This KPI measures the success in recruiting participants for the ecoCommunity, in the Gaidouromantra microgrid Demo Site, in terms of the number of customers who accepted to participate in the Gaidouromantra microgrid Demo Site, compared to the total number of customers who were initially contacted. It measures the community willingness to engage with the ecoTool at the Gaidouromantra Demo Site.

It has been measured using a Likert scale, which is commonly used in research questionnaires, for sociological surveys (specially, to know the opinion of a population about something).

Using a scale of 5 levels, this is: 1. Strongly uninterested, 2. Uninterested, 3. Neither interested nor uninterested, 4. Interested and 5. Strongly interested, before the project, the willingness of citizens to participate in the Demo Site was very low, at 1.

After the project, the interest has grown to 3. Neither interested, nor uninterested.

This is shown in the following table:

	BAU	RE-EMPOWERED
Participant recruitment	1 Strongly uninterested	3 Neither interested, nor uninterested

Table 113 Participant recruitment in the Gaidouromantra microgrid.

4.4.3. KPI 3: Active participation (ecoCommunity).

Active participation is a KPI which measures the level of consistent and meaningful engagement from community members in activities and programs facilitated by ecoTools at the Gaidouromantra demo site.

Similarly to Participant recruitment, it is measured with a Likert scale, with a 5-level scale.

According to the results of the project, before the development of the RE-EMPOWERED project, customers were strongly uninterested in participating actively in the project (1). However, after the development of the project, they have become interested in participating (4).

This can be seen in the following table:

	BAU	RE-EMPOWERED
Active participation	1 Strongly uninterested	4 Interested

Table 114 Active participation in the Gaidouromantra microgrid.

4.4.4. KPI 4: Customer acceptance (ecoCommunity).

Customer acceptance measures the level of satisfaction and acceptance of ecoCommunity among users at the Gaidouromantra demo site, ensuring their needs are being met.

It is measured using a Likert scale, with a 5-level scale.

According to the results of the RE-EMPOWERED project, customers were not interested at all before the development of the project, and the result in the Likert scale was 1. After the project, the level of interest has grown to 2, Uninterested.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Customer acceptance	1 Strongly uninterested	2 Uninterested

Table 115 Customer acceptance in the Gaidouromantra microgrid.

4.4.5. KPI 5: EnC participation/adoption.

The Energy Community participation/adoption KPI measures the increase in the adoption rates and active participation in energy communities. In this case, it measures the attitude of the residents of Gaidouromantra towards the possibility of establishing an energy community.

This KPI is also measured with a Likert scale, with 5 different levels.

The RE-EMPOWERED project has obtained quite satisfactory results: before the development of the project, customers were not interested in participating in energy communities, and the level in the scale was 1- No participation at all.

However, the RE-EMPOWERED project has achieved to increase the level of interest to 4- High participation.

The following table shows these results:

	BAU	RE-EMPOWERED
EnC participation/adoption	1 No interest	4 High interest

Table 116 EnC participation/adoption in the Gaidouromantra microgrid.

4.4.6. KPI 6: User satisfaction contributing to aggregated flexibility (ecoCommunity).

This KPI measures the satisfaction of small consumers and producers with the development of the aggregated flexibility in the Gaidouromantra microgrid, and how energy demands are managed.

As with the previous KPIs, it is measured with a Likert scale, with 5 different steps.

The satisfaction of users has been increased from 2 (Unsatisfied) to 3 (Neither unsatisfied nor satisfied), as a result of the RE-EMPOWERED project.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
User satisfaction contributing to aggregated flexibility	2 Unsatisfied	3 Neither unsatisfied nor satisfied

Table 117 User satisfaction contributing to aggregated flexibility in the Gaidouromantra microgrid.

4.4.7. KPI 7: Skill/Knowledge acquirement (ecoCommunity).

Skill/knowledge acquirement measures how effectively ecoCommunity tool enhance the skills and knowledge of residents at the Gaidouromantra demo site, particularly in sustainable practices and tool use.

It is also measured with a Likert scale, with 5 different steps. In this case, the development of the RE-EMPOWERED project has improved skill acquirement from 2 Unsatisfied, to 4 Satisfied.

The following table includes these results:

	BAU	RE-EMPOWERED
Skill/ knowledge acquirement	2 Unsatisfied	4 Satisfied

Table 118 Skill/Knowledge acquirement in the Gaidouromantra microgrid.

4.4.8. KPI 8: Social compatibility (ecoCommunity).

This KPI measures how well ecoTools align with the social dynamic, values, and relationships within the Gaidouromantra Demo Site.

It is measured with a 5-step Likert scale, and the results show that the interest of citizens in using these solutions has grown importantly, from 3 (Neither compatible nor incompatible) to 4 (Compatible), because of the development of the solutions proposed in RE-EMPOWERED.

These results can be found in the following table:

	BAU	RE-EMPOWERED
Social compatibility	3 Neither compatible nor incompatible	4 Compatible

Table 119 Social compatibility in the Gaidouromantra microgrid.

4.4.9. KPI 9: Consumers' engagement (ecoCommunity).

This KPI measures the overall level of consumer engagement and satisfaction with ecoTools, reflecting how deeply they interact with, and can integrate the tools into daily life, in the Gaidouromantra microgrid.

It is measured with a 5-step Likert scale.

According to the analyses carried out, before the RE-EMPOWERED project, customers showed a reduced interest (2 in the Likert scale), while, after the development of the project, the interest level has grown to Interested (4 in the Likert scale).

These results can be found in the following table:

	BAU	RE-EMPOWERED
Consumers' engagement	2 Unsatisfied	4 Satisfied

Table 120 Consumers engagement in the Gaidouromantra microgrid.

4.4.10. KPI 10: New customers connected (ecoCommunity).

The number of customers connected to the Gaidouromantra Microgrid ranges from zero in low season, to 25 in high season. These customers live in 14 vacation houses, and there are no businesses.

The RE-EMPOWERED project is not expected to lead to an increase in the number of customers connected in the Gaidouromantra Microgrid.

	BAU	RE-EMPOWERED
Customers connected to the Microgrid	25 customers in high season	25 customers in high season

Table 121 Customers connected in the Ghoramara Island Microgrid.

4.4.11. KPI 11: Ease of use for end-users of the solution (ecoCommunity)

This KPI measures how easily the customers can use the ecoCommunity tool: how intuitive and user-friendly this ecoTool is, ensuring accessibility for individuals with varying technical expertise. It is important to ensure a positive user experience.

It is measured with a 5-step Likert scale. The solutions developed in the RE-EMPOWERED project have managed to reach a 5 (Very easy to use), compared to the BAU score of 2 (Difficult to use).

These results are included in the following table:

	BAU	RE-EMPOWERED
Ease of use for end users of the solution	2 Difficult to use	5 Very easy to use

Table 122 Ease of use for end users of the solution in the Gaidouromantra microgrid.

4.4.12. KPI 12: Advantages for end-users (ecoCommunity).

This KPI measures the tangible benefits experienced by end-users at the Gaidouromantra Demo Site, such as increased energy efficiency, cost savings, or improved quality of life, due to ecoTools.

It is measured with a 5-step Likert scale. In this case, there has not been a relevant improvement of the situation, as before the RE-EMPOWERED project, users scored the advantages with a 3 (normal advantages for the end user), and after the implementation of RE-EMPOWERED, the results are 4 (some advantages for the end-user).

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Advantages for end users	3: Normal advantages for the end user	4: Some advantages for the end user

Table 123 Advantages for end-users of the solution in the Gaidouromantra microgrid.

4.4.13. KPI 13: Uses for education purposes through workshops (ecoCommunity

This KPI measures the extent to which ecoTools can be integrated into educational workshops, fostering awareness and knowledge transfer about sustainable living practices at the Gaidouromantra Demo Site.

It is measured with a 5-step Likert scale. The results of measuring this KPI show that, before the development of the RE-EMPOWERED solutions, the options to use the Demo Site in a workshop, for educational purposes, were Low (2). However, once the ecoCommunity and other ecoTools were developed, the interest of the Demo Site to be used in workshop grew to High (4).

These results can be found in the following table:

	BAU	RE-EMPOWERED
Uses for education purposes through workshops	2 Low	4 High

Table 124 Uses for education purposes through workshops in the Gaidouromantra microgrid.

4.4.14. KPI 14: Wind Turbine Manufacturing Course Attendance (ecoResilience).

A workshop was organized by ICCS-NTUA, at the NTUA premises where students were engaged in the construction of a small wind turbine. The constructed wind turbine was then installed, with the help of the students, at the Gaidouromantra microgrid.

The total attendance to the course amounted to 25 students, who learnt about the local manufacturing of small wind turbines at the ICCS-NTUA.

The following table summarizes the attendance to the Wind Turbine Manufacturing Course:

	BAU	RE-EMPOWERED
Wind Turbine Manufacturing Course Attendance	N/A	35 students

Table 125 Wind Turbine Manufacturing Course Attendance to Gaidouromantra Microgrid.

4.5. Ghoramara Island Microgrid: West Bengal, India

4.5.1. KPI 1: Employment.

The community in Ghoramara island is extremely poor with very limited employment and income generation opportunities. The island experiences difficult weather conditions on account of frequent cyclones, hence farming and agricultural production are also very limited. However, the RE-EMPOWERED project has helped in the creation of some self-employment activities for the community. Due to electricity access during night hours (4-4.5 hours) the number of shops in the market has increased along with the extended time of operation till 9:00 PM at night. The fish and vegetable markets are developed with semi-permanent structures like sheds etc. for local farmers and growers. Deployment of more electric three wheelers also added to income generation activities for the owners with significant cost reduction in terms of fossil fuel consumption. The dispensary in the market area has become operational as 2-3 doctors have started visiting the island.

Before the development of the solutions offered by the RE-EMPOWERED project, there were very few opportunities to create new jobs on Ghoramara Island.

Once the solutions developed in the RE-EMPOWERED project have been implemented, it has been estimated that self-employment has grown by 15-20%.

Besides, 2 new employments have been created for the maintenance and operation of the microgrid. Two diploma holders of residents have been employed by the contractor, one as Supervisor, and the other as a Technical Person. They are paid around ₹5,000 per month. These operators have received training from field engineers. These two operators will supervise various assets of the project and will be collecting the fees from individuals.

Additionally, they can contact these engineers to receive very efficient instructions from remote video calls, phone calls and social media messages.

The following table summarizes the employment created in the Gaidouromantra Microgrid:

	BAU	RE-EMPOWERED
Employment	Few opportunities	Increase by 15%-20% of self-employment

Table 126 Employment created in the Ghoramara Island Microgrid.

4.5.2. KPI 2: Consumers' engagement.

The level of community engagement has been observed during the RE-EMPOWERED project for development and installation of the Ghoramara island microgrid. The local governance i.e., gram panchayat members showed considerable interest and participation. Often the field visits during the project had been conducted at the island with DST committee members, partnering institutions and involved vendors. The cooperation and enthusiasm of the local community has been significant. Community representatives were open to discussions and placed their concerns and expectations from time to time during such interactions. Community also supported during infrastructure development, installation and household surveys for various requirements. The land for microgrid development was provided by the school with due approvals and permissions.

The local governance i.e. Gram Panchayat conducts Gram Sabha once a month or as per the agenda to discuss for decision making. The decision passed in Gram Sabha is binding on all the community members. Capacity building of an operator has been done for operation and maintenance of the microgrid. The operator can follow the instructions remotely and perform efficiently.

	Before	RE-EMPOWERED
Land for microgrid development	N/A	Provided by the School with active participation of Gram Pradhan and members
Community participation during the Field visits	N/A	Approx. 20 field visits were conducted having DST members & additional 10-15 field visits by the partnering institutions Gram Pradhan with Gram Panchayat members and Community representatives' participation very high during such visits
Willingness for ownership of the microgrid	N/A	Gram Panchayat willing to take the ownership through an agreement and will set up a village electricity committee to monitor

Table 127 Level of community engagement in Ghoramara Island Microgrid.

4.5.3. KPI 3: New customers connected.

The KPI "New customers connected" measures the increase in the number of customers which are connected to the grid.

Before the RE-EMPOWERED project, virtually no customer was connected to the grid, as there was no connection between Ghoramara Island and the mainland. The total number of households is 1,140. **After the implementation of the RE-EMPOWERED project, 650 households are connected to the RE-EMPOWERED microgrid (out of 1,140 households).** The remaining 490 households will be connected in Phase II, with a house lighting system. Furthermore, some 10-12 shops in the market area along with the school have also been provided with electricity. In addition, one Primary Healthcare Centre (PHC) along with a dispensary also got connected.

	BAU	RE-EMPOWERED
Number of households connected to the microgrid	0 (out of 1,140)	650 households (out of 1,140)

	BAU	RE-EMPOWERED
Number of house lighting systems (HLS)	0	490 households
Number of shops	0	10-12
Number of schools	0	1
Number of primary healthcare centres and dispensary	0	1

Table 128 New customers connected to the grid.

4.5.4. KPI 4: Level of user satisfaction and expectation.

The community representatives, Gram Panchayat members and few householders have been interviewed and based on their opinion the level of satisfaction has been attempted to capture after two-three months' operation of the Ghoramara island microgrid. The members have expressed their expectations also during the focused group discussions.

	Before	RE-EMPOWERED	Satisfaction level	Expectations
Level of Satisfaction for:				
a. No. of hours of electricity access during night	N/A	Currently 4-4.5 hours per day	**Medium 60%**	**Increase to at least 6 hours per day**
b. No. of appliances to use	N/A	Currently one electric fan, two LED bulbs and mobile charging	**Medium 60%**	**Increase in usage of appliances by 20-30%**
c. Fixed monthly tariff	N/A	At present householders pay @ ₹50 per month	**Low 30%**	**Further decrease the tariff or free**
d. High Mast	N/A	Deployed in the market area	**Very High 100%**	**N/A**
e. Operator satisfaction	N/A	Trained and paid by vendor. Very efficient. Can operate from remote and follows instructions over video calls WhatsApp messages/ calls	**Very High 100%**	**N/A**

Table 129 Level of user satisfaction and expectation in Ghoramara Island Microgrid.

4.5.5. KPI 5: Energy Poverty.

Energy poverty is a situation where a household cannot meet its domestic energy needs. The KPI energy poverty measures the percentage of households in the Demo Site which cannot afford to cover their energy needs, using renewable energy.

In Ghoramara Island, there was no access to electricity since grid extension was not feasible, hence the community was experiencing a very high energy poverty. The RE-EMPOWERED project significantly reduced the energy poverty by access to clean energy which significantly improved the wellbeing and living conditions of the community as well.

The use of ecoTools has allowed to improve the energy poverty in the Ghoramara Island Microgrid from 100% to 59.10%.

	BAU	RE-EMPOWERED
Energy poverty	100%	59.10%

Table 130 Energy poverty in the Ghoramara Island Microgrid.

The tools and solutions developed by the RE-EMPOWERED project, have allowed to access electricity supply to:

- 650 households.
- 10-12 shops.
- One school.
- One primary healthcare doctor and a dispensary.

4.5.6. KPI 6: Power provided per household and day.

This KPI measures the electricity supply which can be used by each household and day, due to the solutions implemented along the RE-EMPOWERED project.

Before the development of the RE-EMPOWERED project, users did not have good access to electricity supply. Only a few solar PV panels were mounted on the rooftop of some individual houses, to provide power to one or two LED lamps and mobile charging. The total available power was 30-70 W.

The RE-EMPOWERED project offers an additional 100 W to every house, what allows to use basic facilities, such as 2 LED lights and a fan.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED	Change
Power provided per household and day	30-70	130-170	**+243%-+433%**

Table 131 New customers connected to the grid in Ghoramara Island Microgrid.

4.5.7. KPI 7: Average electricity supply at night (hours/day).

This KPI measures the additional light time that householders can have each day due to the availability of power to light the LED lamps. The increase in the number of hours per night is essential to improve success at school, and to increase the available useful time.

It has been estimated that the use of the proposed solutions can increase the nighttime electricity by around 4 or 4.5 hours per night, compared to 0 hours before the development of the project.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Average electricity supply at night	0 hours per night	4-4.5 hours per night

Table 132 Average electricity supply at night in Ghoramara Island Microgrid.

4.5.8. KPI 8: Opening of bank account for tariff collection.

This KPI measures the effect that the RE-EMPOWERED project has made on the use of bank accounts to collect the fees paid by the inhabitants and the businesses of the Ghoramara Island Microgrid for the use of the electricity.

Before the development of the RE-EMPOWERED project, no bank account had been opened to collect the payments for the use of electricity, as electricity was provided for free, although with limited availability.

As a result of the investments carried out in the RE-EMPOWERED project, as well as the development of a business model where householders have to pay for a reliable electricity supply and for the use of house lighting systems, a bank account to collect these payments was opened in October 2024. The holder of the bank account is the Ghoramara Gram Panchayat.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Opening of bank account for tariff collection	No bank account	1 bank account for tariff collection

Table 133 Opening of bank account for tariff collection in Ghoramara Island Microgrid.

4.5.9. KPI 9: Market area development due to High Mast.

This KPI measures the existence of a continuous market area in the Ghoramara Island, and the commercial activity, in terms of number of clients and duration of the commercial activity.

The deployment of standalone solar powered High Mast in the Market area under RE-EMPOWERED project has led to significant development with lot of socializing of people, particularly during evening after sunset. This has led to increased social gatherings; meetings of people; increased footfall and cohesiveness among the community people. new fish & vegetable market with semi-permanent structures like sheds, etc. for local farmers and growers. The market area is well lit, which increased the security among people to come out after sunset for their day-to-day transactions and requirements.

One dispensary in the market area also became operative with 2-3 doctors visiting leading to increased healthcare services to the community.

Before the development of the RE-EMPOWERED project, there was not a suitable fish and vegetable market. The market was temporary and used modular non-permanent structures. There were 6 or 7 shops, which were closed when it got dark.

After the development of the RE-EMPOWERED project, a good fish and vegetable market was developed, with sheds and temporary structures, for between 8 and 10 local growers and vendors.

Besides, the number of shops grew to 10-12, and they can now operate until 21:00, due to the availability of a high mast, which has been installed in the market area, with 4 LED lamps of 40 W each.

Therefore, the development of the RE-EMPOWERED project has led to an improvement of the business activity in Ghoramara Island. The following table includes a summary of these results:

	BAU	RE-EMPOWERED	Change
Fish and vegetable market	Temporary market, with modular non-permanent structures	Good fish and vegetable market, for between 8 and 10 local growers and vendors	**N/A**
Number of shops	6-7 shops, closed early	10-12 shops, operating until 9:00 PM	**+70%**

	BAU	RE-EMPOWERED	Change
Closing time	After sunset, no activities	21:00, even if it is dark	**The number of transactions increased by 30-40%**
Social activity	Social activity ended after sunset	Community gathering and socializing after sunset. Increased footfall.	

Table 134 Opening of bank account for tariff collection in Ghoramara Island Microgrid.

4.5.9. KPI 9: Increase in income generation.

Incremental streams of income generation have been observed after the electricity access to the community. More shops and local markets started operating; electric charging port drastically reduced the cost of fossil fuel consumption leading to cost savings and enhancing the income flow to the operators; one diploma holder local resident was also trained and paid monthly salary of approximately ₹15,000 by the vendors for the maintenance and operation of the Ghoramara island microgrid.

The following table includes the new incomes which can be obtained with the additional electricity supply:

	BAU	RE-EMPOWERED	Change
Income generation and increments:	₹90,000	Electric Charging @ ₹60 per day per electric three wheelers	**₹79,200 (80% reduction)**
a. Deployment of two electric three wheelers	₹600 per day on an average	₹800 per day on an average	**₹6,000 per month on an average Increased by 33%**
b. New Shops	N/A	₹500 per day on an average	**₹15,000 per month on an average**
c. From cost saving due to electric charging ports	₹90,000 per month on diesel consumption	₹79,200 cost saved due to electric charging	**₹10,800 per month on an average Cost saving by 80%**
d. One operator	N/A	₹15,000 per month approx.	**₹15000 per month on an average**

Table 135 Increase in the income generation in the Ghoramara Island microgrid.

$$Total\ Incremental\ Income\ Generation\ per\ month = ₹6{,}000 + ₹15{,}000 + ₹15{,}000 + (₹90{,}000 - ₹79{,}200) = ₹46{,}800$$

4.5.10. KPI 10: Average nighttime electricity for school studies.

There are around 850 students enrolled in the primary and secondary schools in Ghoramara island. Access to electricity during night has increased the study hours per student per day by approximately two hours, which was not available to them prior to the RE-EMPOWERED project.

The following table includes a summary of these results:

	Before	RE-EMPOWERED
Additional hours for study during night	N/A	2-3 hours per day approx.

Table 136 Average nighttime electricity for school studies in Ghoramara Island Microgrid.

4.5.11. KPI 11: Increased access to healthcare services.

Due to clean energy access during night the Primary Healthcare Centre (PHC) is able to attend patients with first aid requirements and non-critical emergencies. There is also more medicine stock available in the Primary Healthcare Centre and the dispensary in the market area. 2/3 doctors have also started visiting the dispensary to provide healthcare services. This has improved the access to primary healthcare services to the community.

	Before	RE-EMPOWERED
Access to increased primary healthcare services	N/A	2 -3 doctors visit in dispensary approx. per week

Table 137 Increased access to healthcare services in Ghoramara Island Microgrid.

4.5.12. KPI 12: Wind Turbine Manufacturing Course Attendance (ecoResilience).

The Knowledge Exchange Activity 11 was organized by Institute of Communication and Computer Systems- National Technical University of Athens (ICCS-NTUA) and Central Mechanical Engineering Research Institute (CSIR-CMERI)

This activity had two different parts:

- Part 1: A half-day online workshop, conducted in February 2023, focusing on theoretical and design tools for Locally Manufactured Small Wind Turbines (LMSWTs).
- Part 2: A one-week practical workshop, scheduled for September 2024, with ICCS-NTUA researchers visiting CSIR-CMERI in India.

The total attendance to the course amounted to 35 students, who learnt about the local manufacturing of small wind turbines at CSIR-CMERI. The wind turbine is being installed at Ghoramara island.

The following table summarizes the attendance to the Wind Turbine Manufacturing Course:

	BAU	RE-EMPOWERED
Wind Turbine Manufacturing Course Attendance	N/A	35 students

Table 138 Wind Turbine Manufacturing Course Attendance at CSIR-CMERI.

4.6 Keonjhar Microgrid: Odisha, India

4.6.1. KPI 1: Employment.

During the RE-EMPOWERED project, clean energy access has been provided to 75 households in the Keonjhar Demo Site, which are benefitting from a 24-hours electricity supply. This has led to a great improvement in the living standard of people.

Besides, three mini rice huller mills with a power of 4 kW each (12 kW) have been installed, with an electricity consumption of around 50 kWh/day. Two new electric three wheelers have been purchased, along with an electric charging facility with two ports and 1.5 kW. Two solar pumps for irrigation purposes and 10 solar powered dimmable streetlights have been also installed.

4-5 microenterprises have been developed in the Keonjhar Demo Site.

It can be mentioned that, in the Keonjhar Microgrid, the main source of income is agriculture, mostly rice. Around 80%-90% of the people in the village work in this sector. The RE-EMPOWERED project has led to the development of an ecosystem, which fosters not only agricultural activities, but also the setting up of 4-5 new microenterprises. This has inspired many other microenterprises to explore similar opportunities.

	Before	RE-EMPOWERED	**Change**
Employment generation	Very little possibilities	4-5 new microenterprises 7-10 new commercial customers	Self-employment generation of 20 - 25%

Table 139 Employment created in the Keonjhar Microgrid.

4.6.2. KPI 2: Participant recruitment (ecoCommunity).

This KPI measures the success in recruiting participants for the ecoCommunity, in the Keonjhar microgrid Demo Site, in terms of the number of customers who accept to participate in the Demo Site, compared to the total number of customers who were initially contacted.

It has been measured using a Likert scale, which is commonly used in research questionnaires, for sociological surveys (specially, to know the opinion of a population about something).

Using a scale of 5 levels, this is: 1. Strongly uninterested, 2. Uninterested, 3. Neither interested nor uninterested, 4. Interested and 5. Strongly interested, before the project, there was not any willingness between the inhabitants to participate in the testing of the ecoTools.

After the project, the interest has grown to 4. Interested.

This is shown in the following table:

	BAU	RE-EMPOWERED
Participant recruitment	1 Strongly uninterested	4 Interested

Table 140 Participant recruitment in the Keonjhar Microgrid.

4.6.3. KPI 3: Customer acceptance (ecoCommunity).

Customer acceptance measures the level of satisfaction and acceptance of ecoCommunity among users at the Keonjhar Microgrid, ensuring their needs are being met.

It is measured using a Likert scale, with a 5-level scale.

According to the results of the RE-EMPOWERED project, customers were not interested at all before the development of the project, and the result in the Likert scale was 1. After the project, the level of interest has grown to 3, Neither interested, nor uninterested.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Customer acceptance	1 Strongly uninterested	3 Neither interested, nor uninterested

Table 141 Customer acceptance in the Keonjhar Microgrid.

4.6.4. KPI 4: EnC participation/adoption (ecoCommunity).

Energy Community participation/adoption measures the increase in the adoption rates and active participation in energy communities, and, specifically, in the use of ecoCommunity.

This KPI is also measured with a Likert scale, with 5 different levels.

In the Keonjhar Microgrid, the RE-EMPOWERED project has achieved to improve the results from 1- No participation at all, to 3- Neither interested, nor uninterested.

The following table shows these results:

	BAU	RE-EMPOWERED
EnC participation/adoption	1 No participation	3 Neither interested, no uninterested

Table 142 EnC participation/adoption in the Keonjhar microgrid.

4.6.5. KPI 5: Skill/Knowledge acquirement (ecoCommunity).

Skill/knowledge acquirement measures how effectively ecoCommunity tool enhance the skills and knowledge of residents at the Keonjhar Demo Site, particularly in sustainable practices and tool use.

As other social indicators, it can only be measured with a Likert scale, with 5 different steps. In this case, the development of the RE-EMPOWERED project has improved skill acquirement from 2 Unsatisfied, to 3 Moderately satisfied. Villagers have been trained to take care of the microgrid.

The following table includes these results:

	BAU	RE-EMPOWERED
Skill/ knowledge acquirement	2 Unsatisfied	3 Moderately satisfied

Table 143 Skill/Knowledge acquirement in the Keonjhar Microgrid.

4.6.6. KPI 6: Consumers' engagement.

High level of community engagement has been observed during the RE-EMPOWERED project for development and installation of the microgrid in Keonjhar demo site. The local governance i.e., gram panchayat members showed high interest and participation rate. Often the field visits during the project had been conducted with DST committee members, partnering institutions, and involved vendors. The cooperation and enthusiasm of the local community has been significant. Community representatives were open for discussions and placed their concerns and expectations from time to time during such interactions. The community also supported during installation and commissioning of microgrid along with householders surveys for various requirements. The land for microgrid development was provided with due approvals and permissions. Regular meetings were conducted among the community members including the local governance body i.e. Gram Panchayat. The formation of Cooperative society was also done for ownership, operation, maintenance, and regular monitoring of the microgrid. Capacity building of an operator has been done for operation and maintenance of the microgrid. The operator can follow the instructions remotely and perform efficiently.

	Before	RE-EMPOWERED
Land for microgrid development	N/A	Provided by the community members with active participation of Gram Pradhan and members
Community participation during the Field visits	N/A	Approx. 30 field visits were conducted having DST members & additional 10-15 field visits by the partnering institutions Gram Pradhan with Gram Panchayat members and Community representatives participation very high during such visits
Willingness for ownership of the microgrid	N/A	Co-operative society formation done for ownership, regular monitoring, maintenance and operation of microgrid

Table 144 Level of consumers' engagement in Keonjhar Microgrid.

4.6.7. KPI 7: New customers connected.

The number of new household customers connected to the Keonjhar Microgrid was zero, as all the 75 households located in the area had already electricity. However, newly developed 25 microenterprises have been added for electricity access. In addition, few more commercial entities were provided with enhanced electricity access. The RE-EMPOWERED project has led to a significant increase in the number of commercial customers connected in the Keonjhar Microgrid.

The following table includes a summary of the results:

	Before	RE-EMPOWERED
Residential Customers connected to the Microgrid	100% (75 households)	100% (75 households)
Capacity (Watt per HH)	100 W	Unlimited
Newly developed Commercial Customers connected to the Microgrid	N/A	100% (25 microenterprises)

Table 145 New customers connected in the Keonjhar Microgrid.

4.6.8. KPI 8: Level of user satisfaction and expectation.

The community representatives, gram panchayat members and few householders have been interviewed and based on their opinion the level of satisfaction has been attempted to capture after few months' of operation of the Keonjhar microgrid. The members have expressed their expectations also during the focused group discussions.

The following table includes a summary of the satisfaction level of the users in the Keonjhar Microgrid:

	Before	RE-EMPOWERED	Expectations	Level of satisfaction
Level of Satisfaction for:				
a. No. of hours of electricity access during night	N/A	6 hours per day	24 hours	**Very High 100%**
b. No. of appliances to use	N/A	Electric fan, LED bulbs	Electric fan, LED bulbs, TV, Fridge and mobile charging, 20%-30% increase in the use of appliances	**Medium 60%**
c. Fixed monthly tariff	N/A	N/A	At present households pay ₹80 (€0.88) per month Commercial tariff ₹10 (€0.11) per unit	**Medium 60%**
d. Operator satisfaction	N/A	N/A	Trained and paid by vendor. Very efficient. Can operate from remote and follows instructions over video calls WhatsApp messages/ calls	**Very High 100%**

Table 146 Level of user satisfaction and expectation in Keonjhar Microgrid

4.6.9. KPI 9: Energy poverty.

Energy poverty is a situation where a household cannot meet its domestic energy needs. The KPI energy poverty measures the percentage of households in the Demo Site which cannot afford to cover their energy needs, using renewable energy.

In Keonjhar, there was already access to electricity to 75 households, yet the community was experiencing a significant energy poverty due to access of electricity for limited duration and capacity. The access to electricity was limited to 4 hours per day.

The RE-EMPOWERED project eliminated the energy poverty by access to clean energy which significantly improved the wellbeing and living conditions of the community as well. All households can access a good electricity supply, for 24 hours.

	BAU	RE-EMPOWERED	Change
Energy poverty	**75%**	**0%**	**-75.0%**
	Although the 75 households could access electricity, electricity supply was limited to 4 hours a day	**All households have unlimited electricity access**	

Table 147 Energy poverty in the Keonjhar Microgrid.

4.6.10. KPI 10: Power provided per household and day.

This KPI measures the electricity supply which can be used by each household and day, due to the solutions implemented along the RE-EMPOWERED project.

Before the development of the RE-EMPOWERED project, users did not have a good access to electricity supply. Only a few solar PV panels were mounted on the rooftop of some individual houses, to provide power to one or two LED lamps and mobile charging. The total available power was 30-70 W.

The RE-EMPOWERED project offers an additional 100 W to every house, what allows to use basic facilities, such as 2 LED lights and a fan.

	BAU	RE-EMPOWERED	Change
Power provided per household and day	**30-70**	**130-170**	**+243%-+433%**

Table 148 Power provided per household and day in Keonjhar Microgrid.

4.6.11. KPI 11: Average electricity supply at night (hours/day)

This KPI measures the additional light time that householders, can have each day due to the availability of power to light the LED lamps. The increase in the number of hours per night is essential to improve success at school, and to increase the available useful time.

It has been estimated that the use of the proposed solutions can increase the nighttime by around 4 or 4.5 hours per night, compared to 0 hours before the development of the project.

The following table includes a summary of these results:

	BAU	RE-EMPOWERED
Average electricity supply at night	**0 hours per night**	**4-4.5 hours per night**

Table 149 Average electricity supply at night in Keonjhar Microgrid.

4.6.12. KPI 12: Increase in income generation.

Incremental streams of income generation have been observed after the electricity access to the community. As more microenterprises have started operating; electric charging has reduced the cost of fossil fuel consumption leading to cost savings and enhancing the income flow to the mill operators and farmers; electric three-wheeler charging will also be cost effective in comparison to diesel fuel consumption; one diploma holder local resident was also trained and paid monthly salary of approximately ₹15,000 (€166.50) by the vendors for the maintenance and operation of the Keonjhar microgrid.

- Each mini rice huller mill consumes approximately 4-5 liters of diesel per day. They are using 3.7 kW motor for 3-4 hours daily on average. Per rice huller mill consumes diesel cost ₹500 (€5.55) per day i.e., ₹15,000 per month (€166.50/month) on an average. Therefore, total cost incurred for diesel for three mini rice huller mill is ₹45,000 (499.50).
- Each electric three-wheeler consumes approximately 2-3 liters of diesel incurring a cost of around ₹6,000 per month on an average (€66.60/month). So, total cost incurred for diesel for two electric three wheelers is ₹12,000 (€133.20/month).
- Each three wheelers may use 4-5 units for electric charging per day. Each mini rice huller mill may use 12-15 units for electric charging per day. Cost of electric charging is ₹10 (€0.11) per unit for commercial uses.

The following table includes a summary of the incomes which are expected in the Keonjhar Microgrid:

	BAU	RE-EMPOWERED	**Change**
Income generation and increments:			
Deployment of two electric three wheelers	N/A	₹150 per day on an average (€1.67)	**₹4,500 per month on an average (€49.95)**
4-5 new microenterprises created	N/A	₹300-500 per day per enterprise on an average (€3.33-€5.55)	**₹60,000 per month on an average (€66.60)**
3 mini rice huller mills	₹45,000 (€499.50) per month on an average on diesel consumption	₹13,500 (€149.85) per month on an average on electric charging.	**₹31,500 per month (€349.65) on average. Cost saving Reduced by 70%**
From fuel cost saving due to electric charging ports for two electric three wheelers	₹12,000 (€133.20) per month on an average on diesel consumption	Cost incurred due to electric charging is ₹3,000 (€33.3) per month	**₹5,000 (€55.55) per month on average. Cost saving Reduced by 75%**

	BAU	RE-EMPOWERED	Change
One operator	N/A	₹15,000 (€166.50) per month approx.	**₹15,000 (€166.50) per month on an average**

Table 150 Increase in income generation in the Keonjhar Microgrid.

4.6.13. KPI 13: Average nighttime electricity for school studies.

There are around 50-60 students enrolled in the primary/ secondary schools in Keonjhar. Access to electricity during the night has increased the study hours per student per day by approximately two hours, which were not available to them prior to the RE-EMPOWERED project.

The following table includes this result:

	Before	RE-EMPOWERED	Change
Additional hours for study during night	1-2 hours	3-4 hours per day approx.	**Increased by 50%**

Table 151 Average nighttime electricity for schools in the Keonjhar Microgrid.

4.6.14. KPI 14: Energy community.

The energy community viz., the Ranipada Gram Shakti Samooh has been developed in the Keonjhar demonstration site under RE-EMPOWERED. This energy community oversees the operation of the microgrid, and the supply of clean electricity to the inhabitants of the Kanheigola, Nola and Ranipada villages under the Keonjhar microgrid. There is a fixed monthly tariff for residential consumption while a commercial rate per unit for business related activities.

	BAU	RE-EMPOWERED
Development of Energy Community	N/A	**1**

Table 152 Development of energy communities in Keonjhar Microgrid.

5. Environmental assessment of demos and tools

5.1 Methodology to carry out the environmental impact assessment of demos and tools

The environmental impact assessment of the RE-EMPOWERED Demo Sites has been conducted based on the rigorous analysis of the identification, relevance, description and measurement of critical environmental KPIs.

Firstly, the information and data from the Demo Site leaders and the ecoTool leaders have been collected based on the preliminary questionnaire shared with them. In some cases, the evaluation of the environmental impact has been carried out using carbon dioxide emission factors and performance indexes obtained from reputed sources. Finally, in other cases, the information for the definition of KPIs comes directly from the measurements of the ecoMonitor tool.

5.1.1 Selection of environmental KPIs

Critical environmental KPIs have been identified with significant impact measuring the impact on environment of the RE-EMPOWERED solutions. These KPIs are centered on the reduction of emissions of carbon dioxide and polluting gases, as well as in the increase of the environmental awareness in the citizens. This exploration of the deployment and demonstration of microgrid clearly shows that the access to clean energy has multipronged effects and not merely limited to electricity self-consumption.

The selected aggregate indicators are:

- Reduction in CO_2 emissions.
- Increase environmental awareness.
- Air Quality Measurement Reliability Index.

The following table includes a summary of the environmental KPIs which have been measured for each Demo Site:

Environmental KPIs						
#	**Name**	**BO**	**KY**	**GA**	**GH**	**KE**
1	Reduction in CO_2 emissions	X	X	X	X	X
2	Increase of environmental awareness	X			X	X
3	Air Quality Measurement Reliability Index				X	

Table 153. List of detailed KPIs used for the evaluation of the environmental impact.

5.2 Bornholm Island: Denmark

5.2.1. KPI 1: Reduction in CO_2 emissions (ecoEMS).

This KPI tracks the reduction in carbon dioxide (CO_2) emissions over a specific period. CO_2 is one of the primary greenhouse gases contributing to climate change, and reducing its emissions is a key objective for organizations, governments, and industries aiming to mitigate environmental impact.

In the context of energy production, CO_2 emissions are typically generated from the burning of fossil fuels (such as coal, natural gas, and oil). The reduction in CO_2 emissions was achieved by:

- Switching to cleaner energy sources like renewable energy (solar, wind, hydro) instead of fossil fuels.
- Improving energy efficiency in industrial processes, that are used for generating energy from fossil fuels.

The CO_2 reduction KPI helps measure the success of sustainability efforts, track the impact of decarbonization strategies, and demonstrate environmental responsibility.

$$Reduction\ in\ CO_2\ (tons) = CO_2\ Emissions\ Before\ Reduction\ (tons) - CO_2\ Emissions\ After\ Reduction\ (tons)$$

Where:

- CO_2 Emissions Before Reduction (tons): The total amount of CO_2 emissions produced from energy generation or operations before implementing any CO_2 reduction measures.
- CO_2 Emissions After Reduction (tons): The total amount of CO_2 emissions produced after implementing strategies to reduce emissions, such as transitioning to renewable energy, improving efficiency, or adopting emission reduction technologies.

Depending on the value of the KPI, there can be two situations:

- High Reduction in CO_2: A significant reduction in CO_2 emissions indicates the successful implementation of decarbonization strategies, such as the shift to renewable energy, energy efficiency improvements, or the adoption of carbon capture technologies. This is a positive sign for both environmental sustainability and regulatory compliance.
- Low or No Reduction in CO_2: If there is little or no reduction in CO_2 emissions, it may indicate that the efforts to transition to cleaner energy or implement efficiency measures have not been as effective as planned, requiring a re-evaluation of strategies or technologies used to reduce emissions.

This KPI is crucial for organizations aiming to meet environmental targets, improve their carbon footprint, and contribute to global efforts to fight climate change. It can also be important for regulatory compliance, as many regions have set CO_2 emission reduction goals for industries and power plants.

The KPI is calculated with data from a specific range of days during December that the second round of demonstration took place (see Section 2). So as before, to prove the impact of ecoEMS on the CO_2 emissions, a parallel theoretical demonstration was considered, with much higher RES penetration, with the use of heuristic methods.

As shown in the next table, the effect of the ecoTool is expected to be much higher under conditions of high-RES penetration.

	BAU	RE-EMPOWERED	**Change**	**Theoretical RE-EMPOWERED**	**Change**
CO_2 emissions	9.6 g CO_2/kWh	8.8 g CO_2/kWh	**-8.3%**	**7.01 g CO_2/kWh**	**-26.9%**

Table 154 Reduction in CO_2 emissions in Bornholm Demo Site.

5.2.2. KPI 2: Increase of environmental awareness.

This KPI measures the increase or decrease of environmental awareness among project participants and workforce which has been involved in the project. Participants are asked about their interest in environmental awareness before and after the project.

The measurements are captured using a Likert scale that ranges from 1 (Very low awareness) to 5 (High awareness). According to the measurements carried out during the project, environmental awareness has grown from Low to Moderate, during the development of the RE-EMPOWERED project, in the Bornholm Demo Site.

This result can be found in the following table:

	BAU	RE-EMPOWERED
Increase in environmental awareness	2-Low awareness	3-Moderate awareness

Table 155 Increase of environmental awareness in Bornholm Demo Site.

5.3 Kythnos Power System: Greece

5.3.1. KPI 1: Reduction in CO_2 emissions (ecoEMS, ecoPlanning).

This KPI tracks the reduction in carbon dioxide (CO_2) emissions over a specific period. CO_2 is one of the primary greenhouse gases contributing to climate change, and reducing its emissions is a key objective for organizations, governments, and industries aiming to mitigate environmental impact.

In the context of energy production, CO_2 emissions are typically generated from the burning of fossil fuels (such as coal, natural gas, and oil). The reduction in CO_2 emissions was achieved by:

- Switching to cleaner energy sources like renewable energy (solar, wind, hydro) instead of fossil fuels.

- Improving energy efficiency in industrial processes, that are used for generating energy from fossil fuels.

The CO_2 reduction KPI helps measure the success of sustainability efforts, track the impact of decarbonization strategies, and demonstrate environmental responsibility.

$$Reduction\ in\ CO_2\ (tons) = CO_2\ Emissions\ Before\ Reduction\ (tons) - CO_2\ Emissions\ After\ Reduction\ (tons)$$

Where:

- **CO_2 Emissions Before Reduction (tons)**: The total amount of CO_2 emissions produced from energy generation or operations before implementing any CO_2 reduction measures.
- **CO_2 Emissions After Reduction (tons)**: The total amount of CO_2 emissions produced after implementing strategies to reduce emissions, such as transitioning to renewable energy, improving efficiency, or adopting emission reduction technologies.

Depending on the value of the KPI, there can be two situations:

- High Reduction in CO_2: A significant reduction in CO_2 emissions indicates the successful implementation of decarbonization strategies, such as the shift to renewable energy, energy efficiency improvements, or the adoption of carbon capture technologies. This is a positive sign for both environmental sustainability and regulatory compliance.
- Low or No Reduction in CO_2: If there is little or no reduction in CO_2 emissions, it may indicate that the efforts to transition to cleaner energy or implement efficiency measures have not been as effective as planned, requiring a re-evaluation of strategies or technologies used to reduce emissions.

This KPI is crucial for organizations aiming to meet environmental targets, improve their carbon footprint, and contribute to global efforts to combat climate change. It can also be important for regulatory compliance, as many regions have set CO_2 emission reduction goals for industries and power plants.

The KPI is calculated with data from a week of demonstration round B, during November 2024, which did not have high loads due to seasonality (see Section 2). Thus, the renewable penetration in Kythnos Demo Site is minimum, so to allocate this KPI, some theoretical simulations with much higher penetration were examined, with the use of heuristic methods. So, the effect of the ecoTool is expected to be much higher under different conditions.

	BAU	RE-EMPOWERED	**Change**
Reduction in CO_2 emissions (actual loads/RES)	637.6 ton CO_2/year	429.6 ton CO_2/year	**-29%**
Reduction in CO_2 emissions (assuming higher loads/RES)	637.6 ton CO_2/year	401.7 ton CO_2/year	**-37%**

Table 156 Reduction in CO_2 emissions in the Kythnos Power System.

5.4 Gaidouromantra Microgrid: Kythnos Island: Greece

5.4.1. KPI 1: Reduction in CO_2 emissions (ecoMicrogrid).

The calculation of the CO_2 emissions reduction in the Gaidouromantra Microgrid will be based on the results for the RES increase in the energy mix, which were described in 2.4.4 KPI 4: RES increase in the energy mix (annual) (ecoMicrogrid) and emission factors will be used to transform electricity generation into CO_2 emissions.

The following emission factors for diesel and solar PV generation are considered:

- Diesel emission factor: 95.1 g CO_2/MJ[2]= 342.36[3] g CO_2/kWh.
- Performance diesel generator:

  Considering that in 2022, a total electricity production of 212.8 kWh was obtained, and an average of 155 liters of diesel are used, then the performance is 1.37 kWh/liter of diesel.

  Using a lower heating value of 43.1 MJ/kg[2] for the diesel, then, the total diesel energy used to produce electricity was 6,680.5 MJ/year, equivalent to 1,855.6 kWh/year.

  Thus, the performance of the diesel generator would be:

$$Performance\ diesel\ generator = \frac{Electricity\ produced\ (\frac{kWh}{year})}{Diesel\ used\ (\frac{kWh}{year})} = \frac{212.8\ kWh}{1{,}855.6\ kWh} = 11.5\%$$

- Solar PV emission factor: 0 g CO_2/kWh.

According to the before described data, the CO_2 emissions produced when electricity is obtained from the diesel generator can be calculated as follows:

$$CO2\ emissions, electricity, diesel\ gen. (g\ CO_2) = \frac{Electricity\ generated\ (kWh)}{Performance} \cdot Emission\ factor(g\ \frac{CO_2}{kWh})$$

This is,

$$CO2\ emissions, electricity, diesel\ gen. (g\ CO_2) = \frac{Electricity\ generated\ (kWh)}{11.5\%} \cdot 342.36\ g\ \frac{CO_2}{kWh}$$

Using the previously described formula, the annual electricity produced with diesel can be easily transformed into CO_2 emissions:

[2] Source: European Commission. Commission implementing regulation (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria. Official Journal of the European Union June 27th, 2022. Page L 168/1 to L 168/62.
[3] Change of units using the equivalent 1 MWh = 3,600 MJ.

	BAU	RE-EMPOWERED	Change	RE-EMPOWERED with expanded HVAC	Change
Annual electricity produced with fossil fuel (diesel generator)	1,054.21 kWh/year	352.03 kWh/year	**-66.6%**	352.03 kWh/year	**-66.6%**
Annual CO_2 emissions produced with diesel	360.92 kg CO_2/year	120.52 kg CO_2/year	**-66.6%**	120.52 kg CO_2/year	**-66.6%**
Annual renewable energy produced	6,640.66 kWh/year	8,120.29 kWh/year	**22.3%**	14,038.8 kWh/year	**111.4%**
Annual CO_2 emissions produced with renewable energy	0 g CO_2/kWh	0 g CO_2/kWh	**N/A**	0 g CO_2/kWh	**N/A**
Total energy produced	7,694.87 kWh/year	8,472.32 kWh/year	**10.1%**	14,390.83 kWh/year	**87.0%**
Total CO2 emissions produced	360.92 kg CO_2/year	120.52 kg CO_2/year	**-66.6%**	120.52 kg CO_2/year	**-66.6%**

Table 157 Reduction in CO_2 emissions in Gaidouromantra Microgrid.

As can be seen, the use of the ecoTools Gaidouromantra Microgrid allows to reduce CO_2 emissions by 66.6%.

5.5 Ghoramara Island Microgrid: West Bengal, India

5.5.1. KPI 1: Reduction in CO_2 emissions (ecoVehicle).

Based on the reduction of the diesel consumption by the electric three wheelers used in the Ghoramara Island Microgrid, it is possible to calculate the reduction of carbon dioxide emissions in the Microgrid.

The carbon dioxide emission factor of diesel is 832 kg CO_2/m^3 [4]= 0,832 kg CO_2/liter.

Applying this factor to the diesel consumption of the electric three wheelers, which is shown in Table 92, the CO_2 emissions in the BAU and the RE-EMPOWERED scenarios can be obtained:

[4] Source: European Commission. Commission implementing regulation (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria. Official Journal of the European Union June 27th, 2022. Page L 168/1 to L 168/62.

	BAU	RE-EMPOWERED	Change
Reduction in CO_2 emissions	3,594 kg CO_2/year	599 kg CO_2/year	**-83.3%**

Table 158 Reduction in CO_2 emissions in the Ghoramara Island Microgrid.

5.5.2. KPI 2: Increase of environmental awareness (ecoCommunity).

This KPI measures the increase in the environmental awareness of the people which live in an area. It is referred to the people who participate or are engaged in activities related to environment, such as the climate change, or the use of renewable energies, and the willingness to have renewable energy projects developed in their areas.

The measurements are captured using a Likert scale that range from 1 (Very low awareness) to 5 (High awareness).

According to the surveys carried out, the awareness and interest of citizens of Ghoramara Island were low (2) before the RE-EMPOWERED project, while they have grown until moderate (3) after the development of the project.

	BAU	RE-EMPOWERED
Increase in environmental awareness	2-Low awareness	3-Moderate awareness

Table 159 Increase of environmental awareness in the Ghoramara Island Microgrid.

5.5.3. KPI 3: Air Quality Measurement Reliability Index (AMRI) (ecoMonitor).

This KPI defines the degree of reliability, accuracy, and consistency in measuring and reporting Air Quality Index (AQI) parameters (e.g., PM2.5, PM10, NO_2, CO, O_3, SO_2) by the ecoMonitor, relative to validated reference instruments or standards.

It can be calculated with the following formula:

$$AMRI\ (\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations}{Sum\ of\ Reference\ Values}\right) \cdot 100$$

Where:

- Absolute Measurement Deviation: $|Measured\ Value - \ Reference\ Value|$
- Sum of Reference Values: The total of validated reference instrument readings during the monitoring period.

During the testing period of ecoMonitor at Ghoramara, the following six (06) AQI parameters were monitored, and the readings were compared with the real time AQI data available in the pollution control board (PCB) website (https://www.aqi.in/in/dashboard).

The following table compares the readings:

AQI Parameter	Measured value (a)	Reference Value (b)	Absolute Measurement Deviation (a-b)
Ozone (O_3)	0.02 ppm	0.021 ppm	**0.001**
Sulphur Dioxide (SO_2)	0.01 ppm	0.009 ppm	**0.001**
Nitrogen Dioxide (NO_2)	0.02 ppm	0.019 ppm	**0.001**
Carbon Monoxide (CO)	0.10 ppm	0.099 ppm	**0.001**
Particulate Matter (PM2.5)	154 $\mu g/m^3$	121$\mu g/m^3$	**33**
Particulate Matter (PM10)	167 $\mu g/m^3$	172 $\mu g/m^3$	**5**

Table 160 Comparative AQI parameters of ecoMonitor and pollution control board data.

Therefore, AQI Measurement Reliability Index (AMRI) for Ozone (O_3) was calculated as:

$$AMRI_{O_3}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ Ozone}{Sum\ of\ Reference\ Values\ of\ Ozone}\right) \cdot 100$$
$$= \left(1 - \frac{0.001}{0.021}\right) * 100 = 95.24\%$$

Therefore, AQI Measurement Reliability Index (AMRI) for Sulphur Dioxide (SO_2) was calculated as:

$$AMRI_{SO_2}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ SO2}{Sum\ of\ Reference\ Values\ of\ SO2}\right) \cdot 100$$
$$= \left(1 - \frac{0.001}{0.009}\right) * 100 = 88.88\%$$

Therefore, AQI Measurement Reliability Index (AMRI) for Nitrogen Dioxide (NO_2) was calculated as:

$$AMRI_{NO_2}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ NO2}{Sum\ of\ Reference\ Values\ of\ NO2}\right) \cdot 100$$
$$= \left(1 - \frac{0.001}{0.019}\right) * 100 = 94.74\%$$

Therefore, AQI Measurement Reliability Index (AMRI) for Carbon Monoxide (CO) was calculated as:

$$AMRI_{CO}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ CO}{Sum\ of\ Reference\ Values\ of\ CO}\right) \cdot 100$$
$$= \left(1 - \frac{0.001}{0.099}\right) * 100 = 98.99\%$$

Therefore, AQI Measurement Reliability Index (AMRI) for Particulate Matter (PM2.5) was calculated as:

$$AMRI_{PM_{2.5}}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ PM2.5}{Sum\ of\ Reference\ Values\ of\ PM2.5}\right) \cdot 100$$
$$= \left(1 - \frac{33}{121}\right) * 100 = 72.72\%$$

Therefore, AQI Measurement Reliability Index (AMRI) for Particulate Matter (PM10) was calculated as:

$$AMRI_{PM_{10}}\,(\%) = \left(1 - \frac{Sum\ of\ Absolute\ Measurement\ Deviations\ for\ PM10}{Sum\ of\ Reference\ Values\ of\ PM10}\right) \cdot 100$$
$$= \left(1 - \frac{5}{172}\right) * 100 = 97.09\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	Change
AQI Measurement Reliability Index (AMRI) for Ozone (O_3)	N/A	95.24%	**N/A**
AQI Measurement Reliability Index (AMRI) for Sulphur Dioxide (SO_2)		88.88%	**N/A**
AQI Measurement Reliability Index (AMRI) for Nitrogen Dioxide (NO_2)		94.74%	**N/A**
AQI Measurement Reliability Index (AMRI) for Carbon Monoxide (CO)		98.99%	**N/A**
AQI Measurement Reliability Index (AMRI) for Particulate Matter (PM2.5)		72.72%	**N/A**
AQI Measurement Reliability Index (AMRI) for Particulate Matter (PM10)		97.09%	**N/A**

Table 161 Average AQI Measurement Reliability Index (AMRI) for ecoMonitor, for Ghoramara Island

5.6. Keonjhar Microgrid: Odisha, India

5.6.1. KPI 1: Reduction in CO_2 emissions (ecoPlanning)

This KPI tracks the reduction in carbon dioxide (CO_2) emissions over a specific period. CO_2 is one of the primary greenhouse gases contributing to climate change, and reducing its emissions is a key objective for organizations, governments, and industries aiming to mitigate environmental impact.

In the context of energy production, CO_2 emissions are typically generated from the burning of fossil fuels (such as coal, natural gas, and oil). The reduction in CO_2 emissions was achieved by:

- Switching to cleaner energy sources like renewable energy (solar, wind, hydro) instead of fossil fuels.
- Improving energy efficiency in industrial processes, that are used for generating energy from fossil fuels.

The CO_2 reduction KPI helps measure the success of sustainability efforts, track the impact of decarbonization strategies, and demonstrate environmental responsibility.

$$\begin{aligned} Reduction\ in\ CO_2\ (tons) \\ &= CO_2\ Emissions\ Before\ Reduction\ (tons) \\ &- CO_2\ Emissions\ After\ Reduction\ (tons) \end{aligned}$$

Where:

- CO_2 Emissions Before Reduction (tons): The total amount of CO_2 emissions produced from energy generation or operations before implementing any CO_2 reduction measures.
- CO_2 Emissions After Reduction (tons): The total amount of CO_2 emissions produced after implementing strategies to reduce emissions, such as transitioning to renewable energy, improving efficiency, or adopting emission reduction technologies.

Depending on the value of the KPI, there can be two situations:

- High Reduction in CO_2: A significant reduction in CO_2 emissions indicates the successful implementation of decarbonization strategies, such as the shift to renewable energy, energy efficiency improvements, or the adoption of carbon capture technologies. This is a positive sign for both environmental sustainability and regulatory compliance.
- Low or No Reduction in CO_2: If there is little or no reduction in CO_2 emissions, it may indicate that the efforts to transition to cleaner energy or implement efficiency measures have not been as effective as planned, requiring a re-evaluation of strategies or technologies used to reduce emissions.

This KPI is crucial for organizations aiming to meet environmental targets, improve their carbon footprint, and contribute to global efforts to combat climate change. It can also be important for regulatory compliance, as many regions have set CO_2 emission reduction goals for industries and power plants.

The following table includes a summary of the results for the KPI Reduction in CO_2 emissions of the Keonjhar microgrid:

	BAU	RE-EMPOWERED	**Change**
Reduction in CO_2 emissions	7.6 ton CO_2/year	2 ton CO_2/year	**-73%**

Table 162 Reduction in CO_2 emissions, for ecoPlanning in the Keonjhar Microgrid.

5.6.2. KPI 2: Increase of environmental awareness (ecoCommunity)

This KPI measures the increase in the environmental awareness of the people which live in an area. It refers to the people who participate or are engaged in activities related to the environment, such as the climate change, or the use of renewable energies, and the willingness to have renewable energy projects developed in their areas.

The measurements are captured using a Likert scale that range from 1 (Very low awareness) to 5 (High awareness).

In the case of the Keonjhar Microgrid, and according to the surveys which have been carried out, before the project, the awareness and interest of citizens of Keonjhar Microgrid was low before the RE-EMPOWERED project, and after it, it has grown to moderate.

	BAU	RE-EMPOWERED
Increase in environmental awareness	2-Low awareness	3- Moderate awareness

Table 163 Increase of environmental awareness in the Keonjhar Microgrid.

6. Potential for replication in EU and India

6.1 Methodology to carry out the replication analysis of demos and tools

The objective of replication analysis of demo sites and tools in both EU and India is to guide the project developers, policy makers, stakeholders engaged to design and formulate similar projects with replicable deliverables and outcomes. The resource planning and acquisition for delivering research and innovation for such deployment and demonstration projects will provide clear and precise information with minimum risks involved, particularly in difficult terrains like islands, etc. Hence, the level of investment, payback period, along with sustainability of the microgrid itself will be designed better in view of informed decisions. The beneficiaries can also be sensitized and provided training in advance pertaining to their active roles and engagement for timely commissioning of such projects on account of the cost-benefit insights from a collective community perspective. The lessons learned, knowledge sharing, and information dissemination are some of the intangible valuable offerings for the potential stakeholders.

The replicability analysis is focused on the measurement of selected KPIs related to the use of standard protocols in the design of ecoTools, to make sure that they can be easily used in other islands or cases. Additionally, the use of webinars to engage professionals and islands is valuable to make sure that the solutions are worldwide known, and that they can be used in other cases, and business models can be replicated.

Moreover, four events focused on replication have been organized. Two of them were focused on the European Union, and have been organized by the RE-EMPOWERED consortium, one of them along with the Clean Energy for EU Islands Initiative (CE4EU Islands).

In India, there has been a Joint EU-India Workshop organized in Bombay, by the RE-EMPOWERED Consortium in collaboration with the sister H2020 project, SUSTENANCE. Another workshop was focused on the fabrication of a 2.5 kW wind turbine at CSIR-CMERI, aiming to foster the development of locally manufactured small wind turbines in India.

6.1.1 Selection of replication KPIs

The proposed KPIs can be divided into two groups. Some of them are focused on the replicability of the developed ecoTools, such as:

- Use of protocol standards.
- Use of equipment standards.
- Interoperability.
- System replication potential.
- Open source.

Other KPIs are focused on the engaged countries and professionals in the webinars which have been organized to disseminate the solutions developed in the RE-EMPOWERED project, such as:

- Countries engaged through webinars.
- Islands engaged through webinars.
- People engaged through webinars.

The following table includes a summary of the replicability KPIs which have been measured for each Demo Site:

Replication KPIs						
#	Name	BO	KY	GA	GH	KE
1	Use of protocol standards	X	X	X	X	X
2	Use of equipment standards	X				
3	Interoperability	X				
4	System replication potential	X				
5	Open Source	X				
6	Islands engaged through webinars		X	X		
7	Countries engaged through webinars		X	X		
8	People engaged through webinars		X	X		

Table 164. List of detailed KPIs used for the evaluation of the potential for replication.

6.2. Bornholm Island: Denmark

Bornholm Island in Denmark, a grid-connected energy hub, presents a different replication scenario. Its energy ecosystem benefits from an established infrastructure but still encounters technical obstacles. The integration of district heating systems with demand management frameworks is complex, while cybersecurity vulnerabilities arise from using advanced digital energy management systems. Managing the disposal and recycling of outdated components further complicates the technical landscape.

Financial sustainability in Bornholm depends heavily on state subsidies and grants. Limited participation from private investors and fluctuating market dynamics raises long-term viability concerns. Innovative financial models and public-private partnerships could help alleviate these issues.

Administratively, the island energy projects find delays due to multi-agency environmental approvals and permitting processes. Establishing a streamlined regulatory framework specifically supporting renewable expansion would accelerate implementation timelines.

Bornholm Island offers a strong case for replication due to its well-developed energy infrastructure. The island has successfully integrated renewable energy sources into both its electrical grid and district heating systems. Its experience demonstrates that similar island-based or isolated regions could adopt comparable renewable energy models if the right administrative and technical frameworks are in place. Bornholm serves as a scalable model for European regions aiming to become carbon-neutral through energy management and multi-source integration.

6.2.1. KPI 1: Use of protocol standards (ecoPlatform).

This KPI evaluates whether the required communication protocols are utilized to ensure secure and efficient data exchanges. The assessment is conducted qualitatively as either compliant or non-compliant.

To measure this KPI, a binary scoring system is applied:

- **1**: Compliant — If the ecoPlatform uses one of the standard communication protocols such as MQTT, HTTP/HTTPS, or Modbus with TLS for secure, encrypted communication.
- **0**: Non-compliant — If none of these protocols are used, or if non-standard or insecure protocols are implemented.

Since the ecoPlatform uses MQTT for data exchange and HTTP for other functionalities, while also ensuring secure communication through TLS encryption, it is assigned a score of **1**, signifying compliance.

The following table includes a summary of this KPI:

	BAU	RE-EMPOWERED	**Change**
Use of protocol standards	0- Non compliant	1- Compliant	**100%**

Table 165 Use of protocol standards in the Bornholm Demo Site.

6.2.2. KPI 2: Use of equipment standards

This KPI measures the use of equipment standard during deployment. In this case, IoT devices were used for large scale customers in the district heating network. A total of 3 customers were controlled, and some interaction between the district heating production and the control of the consumption of the customers has been produced.

Additionally, the installed IoT devices have provided additional options for control and can be adjusted individually.

As all standards were followed, this KPI because of 100% use.

	BAU	RE-EMPOWERED
Use of equipment standards	N/A	100%

Table 166 Use of equipment standards in the Bornholm Demo Site.

6.2.3. KPI 3: Interoperability (ecoPlatform).

This KPI measures interoperability with the ability of integrating different ecoTools and devices, or applications without requiring customization and having any issue.

It is measured with the following formula:

$$Interoperability = \frac{Number\ of\ integrated\ tools}{Total\ targeted\ tools\ for\ integration} x100$$

Where:

- Number of integrated tools: ecoTools/devices/applications that can exchange data without having any issue and exchange data with the rest.
- Total targeted tools for integration: All ecoTools/devices/applications planned for integration with the platform in the Bornholm demo site.

The following table includes a summary of the integrated tools in the ecoPlatform tool, as well as the tools which are planned to be integrated:

	Name of the tools
Integrated tools in ecoPlatform	ecoEMS, ecoCommunity, ecoDR, ecoMonitor, Forecasting Services, Neogrid edge devices
Total targeted integrated tools	ecoEMS, ecoCommunity, ecoDR, ecoMonitor, Forecasting Services, Neogrid edge devices

Table 167 The summary of integrated and planned to be integrated and operational tools on ecoPlatform regarding the Bornholm demo site.

A total of 32 datasets have been created by these tools to publish data for use by others. Each dataset contains a varying number of data streams, collectively amounting to over 1,000 data streams. Based on this information, it can be concluded that all planned tools have been successfully integrated into the Bornholm demo site, achieving 100% interoperability.

This result can be found in the following table:

	BAU	RE-EMPOWERED
Interoperability	N/A	100%

Table 168 Interoperability in the Bornholm Demo Site.

6.2.4. KPI 4: System replication potential (ecoCommunity).

This KPI measures the replicability potential of the system as a whole. This is done using an System Replication Index (SRI) score:

$SRI =$ (Operational Efficiency Score + Customer Satisfaction Score + Resource Availability Score + Market Demand Score + Risk Mitigation Score) / 5

The resulting variables included in the SRI score is displayed below:

Subject	Score (Maximum 100)
Operational efficiency	80
Customer satisfaction	80
Resource availability	60
Market demand	70
Risk mitigation	50
Total	**68**

Table 169 Summary of scores used to calculate the SRI score which serve as the KPI score as well

This results in an SRI score of 68. The following table includes a summary of this KPI:

	BAU	RE-EMPOWERED	Change
EnC replication potential	N/A	68%	**100%**

Table 170 EnC replication potential in the Bornholm Demo Site.

6.2.5. KPI 5: Open Source (ecoPlatform).

This KPI assesses whether the ecoPlatform relies on open-source technologies to ensure transparency and accessibility for external users.

The documentation and installation guidelines for the ecoPlatform—a cloud-based platform offering a secure and reliable interface for distributed energy infrastructures—are open source and accessible. The platform source code and supporting materials are publicly available at https://gitlab.com/re-empowered/ecoplatform. The ecoPlatform is designed to manage, process, and handle heterogeneous data streams and command flows from various RE-EMPOWERED tools, metering infrastructures, SCADA systems, MGCC, and selected controllable assets, thereby enabling seamless integration and advanced data utilization.

Given that the documentation and development details are openly available and licensed under open-source agreements, it can be concluded that the ecoPlatform fully meets the criteria for open-source compliance, achieving a 100% score.

The following table offers the result for this KPI:

	BAU	RE-EMPOWERED
Open Source	N/A	100%

Table 171 Open Source in the Bornholm Demo Site.

6.3. Kythnos Power System: Greece

Kythnos Island, a non-interconnected island in Greece, faces significant hurdles due to its geographical isolation and environmental conditions. Technically, its energy infrastructure struggles with frequent component failures caused by high salinity and humidity, limited energy storage capacity, and dependency on intermittent renewable energy sources like solar and wind. Integration with the existing grid infrastructure is also problematic, compounded by a lack of specialized local workforce capable of managing system maintenance and operations.

Financially, the island's energy projects are hampered by high transportation and installation costs, reflecting the logistical complexities of operating in a remote area. Business models and revenue mechanisms remain underdeveloped, causing customer dissatisfaction and reduced payment reliability. The island relies heavily on grants, with insufficient investment incentives to attract private capital.

From an administrative perspective, Kythnos Island energy projects face challenges due to environmental licensing complexities stemming from its proximity to the shoreline. Land and infrastructure ownership disputes further complicate deployments. Additionally, the lack of a regulatory framework for demand-side management and complex, multi-level regulatory processes creates persistent delays.

The case of Kythnos can become a prototype to be replicable in non-interconnected islands of Greece, Europe and beyond. The potential replication cases within the scope of the RE-EMPOWERED project exhibit a promising landscape for future adoption and expansion. Greece has more than 6,000 islands, of which 227 are inhabited. Greek islands are both electrically interconnected and non-interconnected to the mainland. The non-interconnected islands consist of 29 autonomous systems and some of them consist of several islands (island complexes). If the 2 larger autonomous systems with a peak demand of more than 100 MW (Crete and Rhodes) are excluded, then there are 19 “small” stand-alone systems with a peak demand of up to 10 MW and 8 “medium-sized” stand-alone systems with peak demand from 10 MW to 100 MW.

Overall, the EU has more than 100 islands which have non-interconnected island electricity systems. These non-interconnected islands are mainly part of six EU Member States: Greece, Italy, Spain, Portugal, France, and the Netherlands. Gran Canaria, Tenerife, La Gomera, La Palma, Fuerteventura, El Hierro and Lanzarote Islands (Canary Islands, Spain, Atlantic Ocean). Besides, EU outermost regions, which include the Azores archipelago (Portugal), Madeira and Porto Santo, Portugal, Réunion (France), Aruba (Netherlands), Bonaire (Netherlands), French Polynesia archipelago (France).

6.3.1. KPI 1: Use of protocol standards (ecoPlatform, ecoEMS).

This KPI measures the compliance and implementation of standardized communication protocols, such as MQTT, RESTful APIs, within the system to ensure interoperability and consistency.

It is calculated as the percentage of communication interactions which comply with the defined standards, compared to the total communication interactions (complying or not with standards).

The formula to calculate the Use of protocol standards is as follows:

$$Use\ of\ protocol\ standards\ (\%) = \frac{Compliant\ interactions}{Total\ interactions} \cdot 100$$

Where:

- Compliant interactions are the number of interactions which follow protocol standards.
- Total interactions are the total number of interactions which are carried out.

During the testing period, in the Kythnos Demo Site, the following information was gathered:

- Compliant interactions: 950.
- Total interactions: 1,000.

Thus, the use of protocol standards can be calculated as:

$$Use\ of\ protocol\ standards\ (\%) = \frac{950}{1{,}000} \cdot 100 = 95\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED
Use of protocol standards	N/A	95%

Table 172 Use of protocol standards in the Kythnos Island Demo Site

6.3.2. KPI 2: Islands engaged through webinars

This KPI measures the number of islands which have sent any representative to participate in the webinars and workshops developed for replicability during the RE-EMPOWERED project.

A total of 13 islands have been represented during the workshops organized in the project.

	BAU	RE-EMPOWERED
Islands engaged through webinars	N/A	13 islands

Table 173 Islands engaged through webinars in the Kythnos Power System Demo Site

6.3.3. KPI 3: Countries engaged through webinars.

This KPI measures the number of countries which have been represented by any attendant to the webinars and workshops developed for replicability during the RE-EMPOWERED project.

A total of 8 countries have been represented during the workshops organized in the project.

	BAU	RE-EMPOWERED
Countries engaged through webinars	N/A	8 countries

Table 174 Countries engaged through webinars in the Kythnos Power System Demo Site

6.3.4. KPI 4: People engaged through webinars.

This KPI measures the attendance at the webinars and workshops about replicability organized during the RE-EMPOWERED project.

An attendance of 21 professionals has been measured during the replicability workshops organized in the project.

	BAU	RE-EMPOWERED
People engaged through webinars	N/A	21 professionals

Table 175 People engaged through replicability webinars in the Kythnos Power System Demo Site

6.4. Gaidouromantra Microgrid: Kythnos Island: Greece

6.4.1. KPI 1: Use of protocol standards (ecoPlatform, ecoMicrogrid, ecoDR, ecoCommunity).

This KPI measures the compliance and implementation of standardized communication protocols, such as MQTT, RESTful APIs, within the system to ensure interoperability and consistency.

It is calculated as the percentage of communication interactions which comply with the defined standards, compared to the total communication interactions (complying or not with standards).

The formula to calculate the Use of protocol standards is as follows:

$$Use\ of\ protocol\ standards\ (\%) = \frac{Compliant\ interactions}{Total\ interactions} \cdot 100$$

Where:

- Compliant interactions are the number of interactions which follow protocol standards.
- Total interactions are the total number of interactions which are carried out.

During the testing period, in the Gaidouromantra Microgrid, as well as in the whole Kythnos Island Demo Site, the following information was gathered:

- Compliant interactions: 950.
- Total interactions: 1,000.

Thus, the use of protocol standards can be calculated as:

$$Use\ of\ protocol\ standards\ (\%) = \frac{950}{1{,}000} \cdot 100 = 95\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Use of protocol standards	N/A	95%	**N/A**

Table 176 Use of protocol standards in the Gaidouromantra Microgrid Demo Site

6.4.2. KPI 2: Islands engaged through webinars

This KPI measures the number of islands which have sent any representative to participate in the webinars and workshops developed for replicability during the RE-EMPOWERED project.

A total of 13 islands have been represented during the workshops organized in the project.

	BAU	RE-EMPOWERED
Islands engaged through webinars	N/A	13 islands

Table 177 Islands engaged through webinars in the Gaidouromantra Microgrid Demo Site

6.4.3. KPI 3: Countries engaged through webinars

This KPI measures the number of countries which have been represented by any attendant to the webinars and workshops developed for replicability during the RE-EMPOWERED project.

A total of 8 countries have been represented during the workshops organized in the project.

	BAU	RE-EMPOWERED
Countries engaged through webinars	N/A	8 countries

Table 178 Countries engaged through webinars in the Gaidouromantra Microgrid Demo Site

6.4.4. KPI 4: People engaged through webinars

This KPI measures the attendance to the webinars and workshops about replicability organized during the RE-EMPOWERED project.

An attendance of 32 professionals has been measured during the workshops organized in the project.

	BAU	RE-EMPOWERED
People engaged through webinars	N/A	32 professionals

Table 179 People engaged through webinars in the Gaidouromantra Microgrid Demo Site

6.5. Ghoramara Island Microgrid: West Bengal, India

Ghoramara Island in India, an off-grid, geographically remote location, presents unique replication challenges. Technically, the absence of pre-existing transmission and distribution lines, coupled with integration difficulties involving industrial-grade components, creates system vulnerabilities. Frequent power disruptions occur due to backup generation issues, while the uneven distribution of households requires the establishment of two microgrids. The lack of a specialized local workforce exacerbates these problems.

Financial viability is undermined by high transportation and installation costs, reliance on external grants, and the absence of a sustainable business model. The community socioeconomic vulnerability leads to unreliable payments, adding another layer of financial uncertainty.

On the administrative front, Ghoramara Island remoteness complicates logistics and deployment. Real-time system monitoring is challenged by insufficient Internet infrastructure, while adverse weather conditions put system durability at risk. A clear regulatory framework is essential for managing these complexities.

Ghoramara Island (India), despite being geographically remote and off-grid, highlights potential replication opportunities in similar isolated or disaster-prone locations. Its decentralized microgrid approach, supported by solar photovoltaic systems and battery storage, demonstrates how localized, community-driven models can provide energy security in regions with minimal infrastructure. Expanding this model to other vulnerable islands or remote districts with challenging environmental conditions could ensure wider energy access and climate resilience.

6.5.1. KPI 1: Use of protocol standards (ecoPlatform, ecoMicrogrid).

This KPI measures the compliance and implementation of standardized communication protocols, such as MQTT, RESTful APIs, within the system to ensure interoperability and consistency.

It is calculated as the percentage of communication interactions which comply with the defined standards, compared to the total communication interactions (complying or not with standards).

The formula to calculate the Use of protocol standards is as follows:

$$Use\ of\ protocol\ standards\ (\%) = \frac{Compliant\ interactions}{Total\ interactions} \cdot 100$$

Where:

- Compliant interactions are the number of interactions which follow protocol standards.
- Total interactions are the total number of interactions which are carried out.

During the testing period, the same results were obtained in all the Demo Sites, the following information was gathered:

- Compliant interactions: 950.
- Total interactions: 1,000.

Thus, the use of protocol standards can be calculated as:

$$Use\ of\ protocol\ standards\ (\%) = \frac{950}{1{,}000} \cdot 100 = 95\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Use of protocol standards	N/A	95%	**N/A**

Table 180 Use of protocol standards in the Ghoramara Island Microgrid Demo Site

6.6. Keonjhar Microgrid: Odisha, India

Keonjhar in India, characterized by scattered rural populations, confronts significant replication barriers. Technically, a lack of local technical manpower affects maintenance and operations. Integration issues with renewable energy sources (RES) and compatibility challenges with national standard codes hinder system scalability. Additionally, environmental concerns related to component disposal and recycling present long-term risks.

Financial challenges in Keonjhar stem from high transportation, installation, and operational costs. Low returns on investment due to limited population density and minimal willingness to pay, except for commercial activities, constrain financial viability. Furthermore, a lack of targeted subsidies and financial opportunities deters potential investors.

Administratively, complex regulatory frameworks with extensive bureaucratic procedures slow project implementation. National environmental clearances cause further delays, while institutional support for community-driven projects remains insufficient. Ownership disputes and unclear operational responsibilities add to these administrative difficulties.

The demonstrated solutions, tools, strategies and business models in Keonjhar will enable to develop a socio-economically sustainable model which can be easily replicated in other remote villages in India.

Keonjhar District represents another critical replication environment due to its scattered rural populations and limited energy access. Its lessons suggest that scaling microgrid installations, supported by hybrid solar and storage systems, could address electricity shortages in other rural districts. The deployment of similar energy systems across remote areas in India and other developing countries could improve socioeconomic conditions through enhanced energy availability and increased support for commercial and agricultural productivity.

6.6.1. KPI 1: Use of protocol standards (ecoPlatform, ecoMicrogrid).

This KPI measures the compliance and implementation of standardized communication protocols, such as MQTT, RESTful APIs, within the system to ensure interoperability and consistency.

It is calculated as the percentage of communication interactions which comply with the defined standards, compared to the total communication interactions (complying or not with standards).

The formula to calculate the Use of protocol standards is as follows:

$$Use\ of\ protocol\ standards\ (\%) = \frac{Compliant\ interactions}{Total\ interactions} \cdot 100$$

Where:

- Compliant interactions are the number of interactions which follow protocol standards.
- Total interactions are the total number of interactions which are carried out.

During the testing period, the same results were obtained in all the Demo Sites, the following information was gathered:

- Compliant interactions: 950.
- Total interactions: 1,000.

Thus, the use of protocol standards can be calculated as:

$$Use\ of\ protocol\ standards\ (\%) = \frac{950}{1{,}000} \cdot 100 = 95\%$$

The following table summarizes this result:

	BAU	RE-EMPOWERED	**Change**
Use of protocol standards	N/A	95%	**N/A**

Table 181 Use of protocol standards in the Keonjhar Microgrid Demo Site

6.7. Replication workshops in EU

Two replication webinars were carried out in the European Union, which delt with the replication of the solutions and technologies tested during the RE-EMPOWERED project.

The following is a description of these two replication webinars:

6.7.1. Workshop 1: Exploitation II- Replication Workshop

This webinar was carried out in combination with the RE-EMPOWERED 2nd Exploitation Workshop. **CPMR (Conference of Peripheral Maritime Regions)** and **Greening the Islands** were invited by DAFNI to deliver presentations and discuss the replicability of the RE-EMPOWERED tools.

- **Participants**: EU partners, Indian Partners and 11 external stakeholders.
- **Venue:** Online webinar.

- **Date**: December 4th, 2024.
- **Hour**: From 11:00 to 13:00 EET (Greece).
- **Agenda**:

Hour	Content
11:00-11:05 EET 14:30-14:35 IST	Welcome (5 min) Bikash Pal, Imperial College London, ICL Moderated by Sai Pavan Polissety, ICL
11:05-11:10 EET 14:35-14:40 IST	Introduction to RE-EMPOWERED (5 min) Panos Kotsampopoulos, ICCS-NTUA Moderated by Sai Pavan Polissety, ICL
11:10-12:00 EET 14:40-15:30 IST	Presentation of ecoTools (50 min) ecoPlatform- Aysegül Kahraman, DTU ecoMicrogrid- Nasos Vasilakis, ICCS-NTUA ecoEMS- George Milionis, ICCS-NTUA ecoPlanning- George Milionis, ICCS-NTUA ecoDR- Santu Giri, CSIR-CMERI ecoResilience- Murugan Thangadurai, CSIR-CMERI ecoCommunity Moderated by Sai Pavan Polissety, ICL
12:00-12:10 EET 15:30-15:40 IST	Business model analysis of ecoTool set (10 min) ecoCommunity- Jesús Rubio Conde ecoEMS- Jesús Rubio Conde Moderated by Sai Pavan Polissety, ICL
12:10-12:35 EET 15:40-16:05 IST	Replicability Session: potential synergy with other island projects (25 min) Claire Helly- CPMR Gianni Chianetta- Greening the Islands Foundation Moderated by Ismini Moustafelou- DAFNI
12:35-12:55 EET 16:05-16:25 IST	Panel discussion and feedback (20 min) Konstantinos Kyparissis, Panagiota Statha- PPC Claire Helly- CPMR Gianni Chianetta- Greening the Islands Foundation Moderated by Ismini Moustafelou- DAFNI

Hour	Content
12:55-13:00 EET 16:25-16:30 IST	Conclusion (5 min) Moderated by Panos Kotsampopoulos- ICCS-NTUA

Table 182. Agenda of the 1st Replication Webinar

- **Attendants**: 11 stakeholders from the CPMR (Conference of Peripheral Maritime Regions), Greening the Islands, IPTO (Independent Power Transmission Operator), HEDNO (Hellenic Electricity Distribution Network Operator), PPC Group, Centre for Research and Technology, Hellas (CERTH).

The main outcomes of the webinar were the awareness creation about the significant potential for replicability in non-interconnected and underserved energy markets, stressing the need for robust user engagement strategies and data security measures.

The following photo was taken during this webinar:

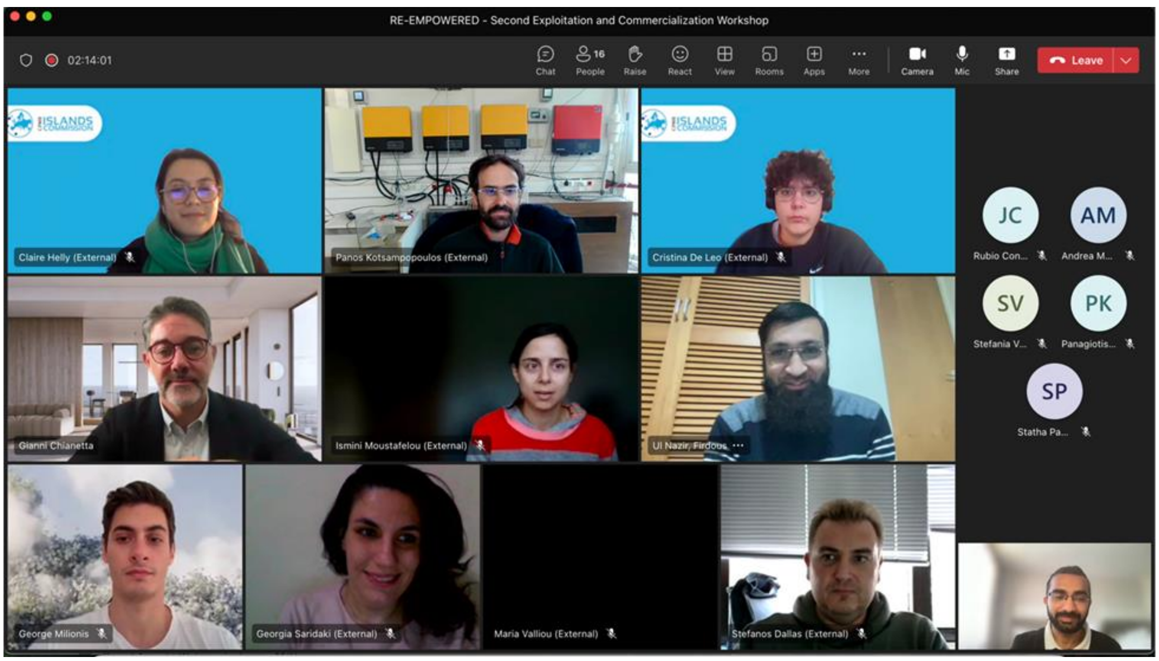

Figure 17: 1st Replication Workshop.

6.7.2. Workshop 2: Replication Webinar Dedicated to the Selected 30 Renewable Islands for 2030

This webinar was carried out along with the **Clean Energy for EU Islands Initiative (CE4EUI)**.

- **Organizer**: RE-EMPOWERED Consortium and Clean Energy for EU Islands Initiative (CE4EUI).
- **Participants**: EU partners, Indian Partners and **21 stakeholders from EU islands**

- **Venue:** Online webinar.
- **Date**: December 16th, 2024
- **Hour**: From 11:00 to 12:20 CET.
- **Agenda**:

Hour	Content
11:00-11:05	Welcome (5 min)
11:05-11:10	Salutation from Clean Energy for EU Islands Secretariat (5 min) Martina Cannata, 3E
11:10-11:20	Brief overview of the four demosites and ecoTools (10 min) Panos Kotsampopoulos, ICCS-NTUA
11:20-11:35	Demonstration of ecoPlanning to a selected CE4EU island (15 min) George Milionis, ICCS-NTUA
11:35-11:45	Live demonstration of ecoEMS in Kythnos demosite (10 min) George Milionis, ICCS-NTUA
11:45-11:50	ecoMicrogrid (5 min) Nasos Vasilakis, ICCS-NTUA
11:50-11:55	ecoCommunity (5 min) Aysegül Kahraman, DTU
11:55-12:05	Replicability and potential synergies of RE-EMPOWERED solutions and beyond (10 min) Petros Markopoulos, DAFNI
12:05-12:20	Discussion and Feedback (15 min)

Table 183. Agenda of the Replication Webinar Dedicated to the Selected 30 Renewable Islands for 2030.

- **Attendants**: **21 stakeholders from EU islands**, from different countries: Greece, Portugal, Denmark, Ireland, Spain, Sweden, Estonia, and Norway.

During the webinar, the representatives showed interest about the presented ecoTools. Specifically, they asked for access to ecoPlanning and ecoMicrogrid.

RE-EMPOWERED partners showed willingness to discuss potential collaborations for the replicability of the RE-EMPOWERED ecoTools.

After the webinar, the slides were distributed to the participants.

The following photo was taken during this webinar:

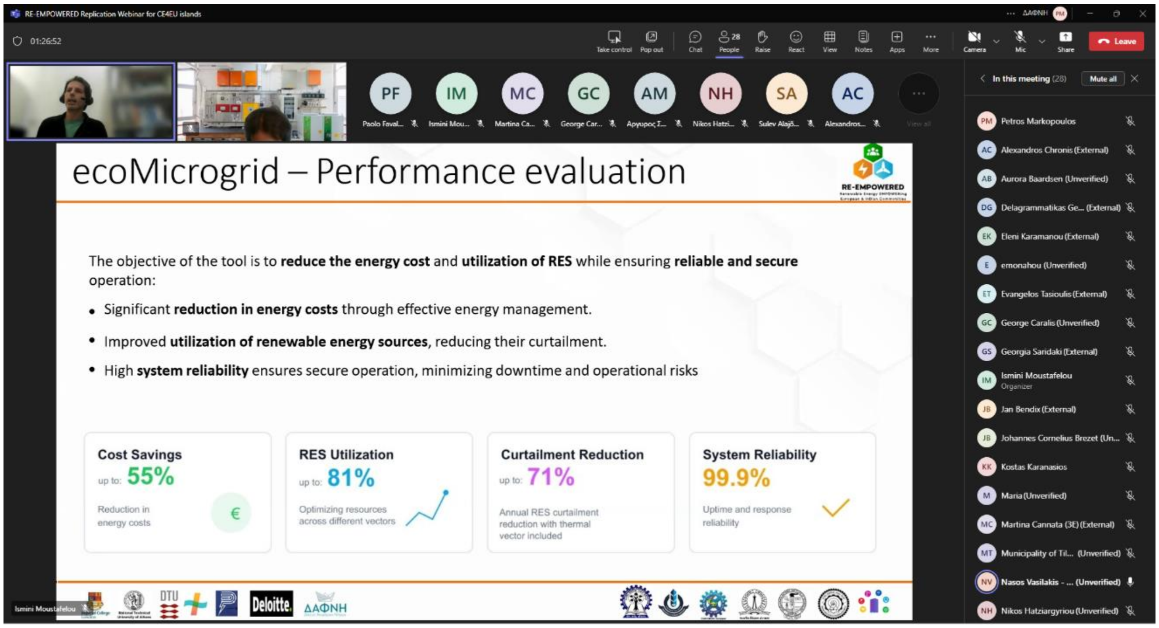

Figure 18: The Replication Webinar Dedicated to the Selected 30 Renewable Islands for 2030 of CE4EUI

6.8. Replication workshops in India

Similarly to the European Union, two replication webinars have been organized for India.

These webinars revolved around the demonstration of the solutions developed in RE-EMPOWERED, and their replicability.

A description of these two replication webinars follows:

6.8.1. Workshop 1: Joint EU-India workshop on RE-EMPOWERED project

- **Participants:** EU partners, Indian partners, and external attendees.
- **Venue:** Bombay, India.
- **Date:** February 6th, 2024.
- **Agenda:**

Joint meeting at IIT Bombay with partners from EU and India for both RE-EMPOWERED and SUSTENANCE projects.

On behalf of RE-EMPOWERED, there were 7 participants from EU partners (ICCS-NTUA, ICL, DAFNI) and 5 participants from Indian partners (IIT KGP, IIT BBS, CMERI, IITD, VNIT). On behalf of SUSTENANCE, its coordinator and many Indian and European partners attended.

During the joint meeting, plenty of experiences and lessons learnt from the two projects were exchanged, and potential joint actions for future cooperation were discussed. The event finished with a poster session and networking time among the partners of the 2 sister projects.

Figure 19: Meeting at IIT Bombay with RE-EMPOWERED and SUSTENANCE partners

6.8.2. Workshop 2: Fabrication of 2.5 kW wind turbine at CSIR-CMERI

- **Participants:** EU partners and Indian partners.
- **Venue:** CMERI Durgapur.
- **Agenda:**

A team from ICCS-NTUA visited CMERI in September, 2024 when a 2.5 kW wind turbine was jointly developed by CMERI and NTUA. The design of the technology was shared by ICCS-NTUA to CMERI and interested parties. The components of the wind turbine were procured locally from the Indian market to promote local market creation. A goal of the workshop was to share the knowledge and promote small wind turbine local manufacturing in India.

Figure 20: Workshop organized about the Fabrication of 2.5 kW wind turbine at CSIR-CMERI

7. Conclusions

Deliverable 8.4 presents the results of the impact assessment within the RE-EMPOWERED project. It evaluates the technical, economic, social, environmental, and replicability aspects of the all Demo Sites while highlighting the benefits achieved through the application of the ecoTools.

The technical assessment demonstrates significant improvements in energy management across the Demo Sites due to the use of the ecoTools. RES utilization was improved overall in all the demos, either by integrating more assets or management tools, reducing curtailment and improving the utilization. Significant digitalization was also achieved in most of the cases, integrating digital tools with reliable data management. In this analysis, 10 KPIs were calculated for Bornholm Island, 9 for the Kythnos Power System, 21 for the Gaidouromantra microgrid (in Kythnos Island), 14 for the Ghoramara Island Microgrid in West Bengal, India, and 18 for the Keonjhar Microgrid in Odisha, India.

The economic impact assessment of the Demo Sites mainly highlighted the reduction in the overall operational costs for the systems across the different demo sites. The reductions in some cases, such as the Gaidouromantra microgrid, **were up to 55%,** resulting from the reduced operation of the diesel generator. Similar cost reductions are observed in the other demos as well.

The social impact assessment highlights the effects of energy management and locally generated renewable energy on citizen engagement. This evaluation has demonstrated that, in most cases, the RE-EMPOWERED project significantly enhanced citizens' knowledge of renewable energy and innovative technologies, such as the ecoTools. Moreover, the project has had notable positive effects on economic growth and welfare across the Demo Sites, particularly in India. Improved electricity supply—whether through increased availability or enhanced reliability—has benefited both residents and businesses. This progress has, in turn, stimulated economic activity, creating employment opportunities and enabling nighttime access to electricity for activities such as studying.

For instance, in the Keonjhar Microgrid, clean energy is now provided to **75 households**, ensuring a **24-hour electricity supply,** compared to the previous limitation of just 4 hours per day. This improved access has facilitated the creation of 4-5 new microenterprises and attracted 7-10 new commercial customers. Additionally, with approximately 4-4.5 extra hours of nighttime lighting, commercial and social activities have increased, and students now have better opportunities to study during the evening.

On Ghoramara Island, the microgrid has achieved a significant milestone by **electrifying 650 households**. This development also ensures between 4 and 4.5 hours of lighting each evening, significantly improving the quality of life for residents. Additionally, the project is set to connect 490 more households with dedicated lighting systems in the coming months. Beyond residential electrification, the project has fostered economic growth by enabling a permanent market with 8-10 local growers and vendors and 10-12 shops, supported by a high light mast. This infrastructure has allowed shops to extend their operating hours until 9:00 PM, irrespective of nightfall, further enhancing the island's economic activity and community well-being.

Considering the environmental impact, the implemented solutions have shown a reduction of CO_2 emissions by 8.3% in the case of Bornholm Demo Site, by 37% in the Kythnos Power System, by 66.6% in the Gaidouromantra Microgrid. At a smaller scale, the replacement of the five electric three wheelers at Ghoramara have resulted in 83.3% reduction of CO2 emissions.

Finally, an assessment of the replicability of the proposed ecoTools has been conducted, focusing on their potential implementation in other islands and remote areas through the use of standardized protocols. This analysis highlights how the ecoTools can be adapted and applied in diverse contexts to maximize their impact. The replicability potential was highlighted and communicated through dedicated replication workshops, in EU and India. Most notably replication events were organized with important organizations such as the Clean Energy for EU Islands Initiative (CE4EUI), the Conference of Peripheral Maritime Regions (CPMR) and Greening the Islands, while a dedicated replication plan was created for selected islands.

In conclusion, the RE-EMPOWERED project has successfully developed and tested a suite of developed tools in real-world scenarios. These tools have proven highly effective in optimizing energy management and significantly increasing the penetration of renewable energy in islands and microgrids with limited or no connection to the mainland. Additionally, they have played a key role in fostering citizen engagement and raising awareness about renewable energy, energy communities, and smart energy management systems. In the Indian demo sites, the impact has been particularly transformative. The enhanced electricity supply has not only improved the reliability of supply but also contributed to increased economic activity and improved well-being for residents. Reliable nighttime electricity has enabled citizens to extend their activities into the evening, further supporting both economic and social development.

8. References

[1] WP1, RE-EMPOWERED, "Deliverable 1.7 International cooperation activities", 2024.

[2] WP2, RE-EMPOWERED, "Deliverable 2.1 Report on requirements for each demo", use cases and KPIs definition", 2021.

[3] WP7, RE-EMPOWERED, "Deliverable 7.5 Report demonstration round 2 (final demo)", 2024

[4] WP8, RE-EMPOWERED, "Deliverable 8.2 Report on the business models and financing tools (V2)", 2024.

[5] WP3, Kythnos Smart Island, "Deliverable 3.7.2 "Report on full scale smart microgrids testing results", March 2023

[6] European Commission. Commission implementing regulation (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria. Official Journal of the European Union June 27th, 2022. Page L 168/1 to L 168/62.

Appendix A- Replication Plan for the Clean Energy for EU Islands

A.1. EcoTools

The following is a summary of the ecoTools that have been developed in RE-EMPOWERED:

- ecoEMS: Improvement of the efficiency of weakly interconnected energy systems by integrating renewable energy sources (RES) and storage.
- ecoMicrogrid: Optimization of microgrids through advanced algorithms managing RES, loads, and storage.
- ecoPlanning: A decision-support tool for mid-term energy planning in Non-Interconnected Islands, assessing new conventional and RES integration, and interconnection benefits.
- ecoDR: A smart metering and load control system enabling dynamic pricing, demand-side management, and remote load control in residential settings.
- ecoPlatform: A cloud-based platform providing secure management of energy infrastructure, integrating RE-EMPOWERED tools and handling data streams.
- ecoMonitor: Monitors air quality.
- ecoCommunity: A digital platform fostering citizen engagement and participation, featuring dynamic pricing, load management, billing, and community feedback mechanisms.
- ecoResilience: Focuses on developing cyclone-resilient structures for solar PV and wind systems, using local resources for improved maintenance and resilience.
- ecoConverter: Develops power converters for microgrids, optimizing energy extraction from PV systems under partial shading and providing ancillary grid services.
- ecoVehicle: Establishes charging stations and deploys electric vehicles to support green transportation on remote areas.

The following table is a summary of the application of the different ecoTools to a range of islands:

ecoTool	Type of sites for replication
ecoEMS	Medium to large islands with energy market operating
ecoMicrogrid	Small non-interconnected islands / Remote off-grid areas on islands
ecoPlanning	Non-interconnected islands
ecoDR	Small communities on islands
ecoPlatform	All energy systems of islands
ecoMonitor	Areas with air pollution (industries/ports)
ecoCommunity	Remote off-grid or weakly interconnected areas on islands / Islands with dynamic pricing for electricity
ecoResilience	Areas with extreme weather conditions (cyclones, strong winds)

ecoConverter	Remote off-grid or weakly interconnected areas on islands
ecoVehicle	Islands with wide adoption of electromobility

Table 184. Replicability of ecoTools in Island Areas.

A.2. Clean Energy for EU Islands – 30 for 30 islands[5]

In 2023 The Clean energy for EU islands initiated a call for 30 islands by 2030, to offer technical support to 30 islands and island groups over the next three years (2024-2027), propelling them towards complete energy independence through 100% renewable sources by 2030. The selection consisted of 30 islands and island groups across 10 European countries. This selection marked a significant step for the 30 finalists towards achieving complete energy independence through 100% renewable sources.

The description of each island can be seen below:

St. Eustatius

The islands' electricity use is 16.5 GWh. Still, the demand is growing fast (2% per year) and depends on investments in new grand resorts on the island, such as the envisaged Golden Rock Resort, with an expected installed 700 kWp solar park with battery storage/BESS. Statia Utility Company (STUCO) supplies electricity and drinking water. The energy system is transitioning to renewables. Until 2016, power was solely diesel-generated. In March 2016, the inaugural phase of a solar park with a 1.89 MWp capacity began, catering to 23% of the total power needed.

Sherkin

Sherkin Island, Ireland, is located southwest of County Cork - together with the islands of Roaringwater Bay. The island is interconnected to the neighboring island of Cape Clear.

São Jorge

São Jorge is located in the Azores archipelago. Situated between Pico and Faial islands, it is separated by the 15-kilometre Pico-São Jorge Channel. Referred to as part of the Triângulo group, São Jorge is a relatively long and narrow island with towering cliffs. Home to 8,373 inhabitants, the population is concentrated in geological debris fields (fajãs) along the north and south coasts.

Pico

Pico is the second largest island of the Azores. The energy demand in Pico was 48 GWh on each island (2022). The peak of these systems reached 8.3 MW and 9.2 MW, respectively (2022). Pico has renewable energy sources (RES) production plants like wind farms. RES penetration on Pico was 10% and 11.5% in the energy mix (2022)..The aim is to prepare the islands of Faial, Pico

[5] Source: Clean Energy for EU Islands. 30 for 2030. European Commission. Retrieved on: https://clean-energy-islands.ec.europa.eu/taxonomy/term/754.

and São Jorge for the impact on the electricity system resulting from charging the new electric passenger and vehicle ferries project.

Faial

The energy demand of Faial was at 48 GWh in 2022. The peak of these systems reached 8.3 MW and 9.2 MW, respectively (2022). Both islands have renewable energy sources (RES) production plants. RES penetration on Faial was 10% and 11.5%, respectively, in the energy mix (2022). In Faial, there is a hydro plant and a wind farm. The aim is to prepare the islands of Faial, Pico, and São Jorge for the impact on the electricity system resulting from charging the new electric passenger and vehicle ferries project.

Giannutri

Giannutri is a small Italian island located in the Tyrrhenian Sea off the coast of Tuscany. It is the southernmost island of this archipelago. The island and its nearby marine areas fall under the Arcipelago Toscano National Park and Marine Sanctuary. Predominantly privately owned, certain sections belong to Italy's Ministry of the Environment, participating in the Coastal Area Management Programme authorized by the Ministry. Assessing renewable energy is a fundamental step towards the energy transition, as the island is heavily dependent on fossil fuels.

Visingsö

Visingsö's residents, businesses and visitors consume energy for their households, business premises, agriculture, forestry and fishing as well as for land transport, sea transport, municipal buildings, engineering and other public services (preschool, school and retirement home, water, sewage, street lighting, construction etc.).After a CETA-survey of energy flows and consumption on Visingsö, we will strive to locally produce renewable energy needed to continue developing a vibrant countryside on Visingsö.

Giglio Island

The island is one of seven that form the Tuscan Archipelago, lying within the Arcipelago Toscano National Park. Giglio means "lily" in Italian, and though the name would appear consistent with the insignia of Medici Florence, it originally derives from the Latin name of the island, Igilium. The island is separated by a 16 km stretch of sea from the nearest point of the mainland, the promontory of Monte Argentario. Mainly mountainous, it consists almost entirely of granite, culminating in the Poggio della Pagana, which rises to 496 m.

Ruhnu

According to the DSO, in 2022, renewable electricity generation on Ruhnu accounted for 108% of the total consumption, with the small island annually consuming 450 MWh.

Saaremaa

Transfers to and from Estonian islands rely on fossil fuels. Current projects explore the possibility of hydrogen or electric-driven ferries and buses operating on green fuels. However, the slow deployment of electric vehicles is due to their high cost, and the number of charging points remains limited. CO_2 emissions on the islands also stem from industry and agriculture. In Estonia, specific support systems for renewable energy or energy efficiency on islands are lacking, as are island-specific permitting procedures.

Tory Island

Lying 12 km off north Donegal, Toraigh (Tory Island) is the most remote of Ireland's inhabited islands, with enduring local traditions, unique historical sites, and rare bird life. Tory Island has 105 houses. 55 of which are occupied all year round and the remaining 50 are holiday homes, which are used on average about six months of the year. Toraigh aims to achieve sustainability and energy conservation as a result of our participation in the 30 for 2023 call by the Clean energy for EU islands secretariat.

Vinön

At 4.5 km², Vinön is the largest island in Hjälmaren in the east of Närke in Sweden and part of the east-west oriented archipelago that separates southern Hjälmaren from Storhjälmaren. Vinön is located in Lännäs in the municipality of Örebro. The island has around 100 inhabitants in the two villages of Norra and Södra Vinön.

Bonaire

Bonaire, a Caribbean Island grappling with distinctive energy challenges stemming from its geography, population growth, and socio-economic disparities, has exhibited notable progress in transitioning from fossil fuels to renewable energy sources. Despite heavily relying on non-renewable energy, Bonaire is committed to enhancing sustainability. This proposal introduces Technical Assistance for an action plan that builds upon the Sustainable Energy Roadmap.

Saba

Saba has continued to transition its fossil fuel electricity production to more renewable energy production since 2018. The island currently has 36-40% of solar PV energy and battery in its energy production mix. Saba has proposed an expansion of its renewable energy production and penetration to 90% by 2025.

Holmön

Holmön has an electrical power supply by cables from the mainland. Holmön has no fuel supply station on the island. It is up to the inhabitants to transport fuel from the mainland, either with ferry or by boat.

Astypalea

Based on 2022 data, the annual power demand of Astypalea amounts to about 7GWh. Currently, only about 8% of the demand is covered by RES (solar energy) with the main load being served by diesel units.

Inishbofin

Inishbofin has prepared an Energy Transition Plan in 2022 and the support from CE4EUI will help to put this plan into action regarding renewable energy.

[Arcipelago di Lipari]

The Aeolian Archipelago is in the southern Tyrrhenian Sea. It comprises seven islands, six under the Municipality of Lipari (Lipari itself, Vulcano, Panarea, Stromboli, Alicudi and Filicudi). The differences between the islands and the distance between them and from the mainland determine a mosaic of issues: complexity in energy supply, high costs and fossil-based transports. The whole archipelago is non-interconnected between the mainland and among him. The management of the electric grid and the energy production are handled by private actors (S.E.L. srl in Lipari) and ENEL S.p.A.

[Arranmore]

Arranmore (Árainn Mhór) aims to achieve sustainability and energy conservation as a result of our participation in the 30 for 2023 call by the Clean energy for EU islands secretariat.

[Hven]

The current grid is under-dimensioned and outdated, with no local energy production because of that, and the landscape preservation regulation. Hven's vision is to mitigate those obstacles, refurbish our grid and produce enough power on the island without altering the landscape.

[Pašman]

The Island of Pašman is located in the Zadar County, it is 21.3 km long, 4.3 km wide at its widest, 63 km2 in surface and is located directly along the mainland, from which it is separated by a channel, 2-5 km wide. Characteristics of the climate are hot and dry summers and mild and wet winters. The island belongs to the Mediterranean climate type. In January/February, the average temperature is 6.5-7 °C, while in July /August the average is 24-24.5 °C. Average insolation is 2,490 hours (county average), annual average precipitation is 800-900 mm.

[Lesvos]

Lesvos has an autonomous electrical system. It is not interconnected with the mainland and its annual peak demand has been on a slight increase over the last four years reaching 63,25 MW in 2022. The island is connected to Megalonisi with a power transmission capacity of 11,5 MVA through various types of conductors. In terms of installed capacity, Lesvos showcases a diverse portfolio, of five wind farms with a total capacity of 13,95 MW, 133 photovoltaic stations, with a total capacity of 8,838 MW and 102.6 MW of thermal units in the local power station.

[Megisti (Kastellorizo)]

Megisti is the easternmost and most isolated region of Greece, located 520 km from the mainland. The island is neither electrically interconnected, nor are there any relevant national plans for the future. With no RES installed as of today, all electricity is currently generated by a diesel thermal power station. Despite Megisti's small size, electricity demand shows very high seasonality, mostly due to the large diaspora.

[Psara]

The electrical system of Psara has for a long time been a wind energy net exporter through its interconnection to the island of Chios. However, the installed intermittent wind capacity can neither cover the island's electricity needs on a 24/7 basis, nor provide resilience to the local grid or security of supply, in case of interconnection interruption. In such an event, critical infrastructure (water production and distribution systems, telecommunications, Rural Clinic, etc.) could remain out of service.

Öland

The total energy use in Öland was approximately 350 GWh for 2020. Almost 60 % of the energy comes from renewable sources. Private housing is the sector that uses the most energy, with transport as the second largest. Wind power has been established for a long time on the island and many are soon facing the end of their technical lifespan and are to be replaced by new more efficient ones.

Fejø

Fejø is integrated into the Danish electrical grid but lacks connectivity to the natural gas network. Energy consumption predominantly relies on gasoline, fuel oil, and wood. The island's vision is twofold: achieving a complete shift to renewable energy sources for all energy needs and establishing the island as a self-sufficient energy producer. As part of the 30 for 2030 call the following activities are planned: The first activity involves conducting a feasibility study for upgrading or replacing two old windmills.

La Graciosa

The Island of La Graciosa has, for 50 years and until today, an energy and water supply completely dependent on the island of Lanzarote, located 1.5 km away. All the energy and drinking water supplied to La Graciosa is channelled through underwater cables and pipes and comes from processes that, approximately 90%, are derived from the burning of fossil fuels.

Venø

Venø is a Danish Island and the only island in the municipality of Struer (Central Denmark Region). Distance to the mainland is 256 m. The island is served by municipality owned ferry-service with 44 daily departures. Venø has 80 resident houses and 60 holiday cottages. The main economic activities are a boarding school, farming, seafood production facility, few active craftsmen and tourism. In mid-2022, the local citizen association began an energy transition project sponsored by the NESOI, Struer Municipality and the energy supplier.

Tilos

Tilos is a Greek island located in the South Aegean Sea. It belongs to the complex of the Dodecanese Islands. There are around 500 permanent residents on Tilos, which is increased by 4 to 5 times during the summer. The island's main economic field is tourism. How does the island cover its need for energy? The island covers large shares of its electricity needs through local renewable energy systems power generation, a hybrid wind-PV battery station of 1 MW. It is interconnected with the island systems of Kos and Kalymnos.

San Pietro

The Island of San Pietro is located in the southwest of Sardinia, and about 5,950 inhabitants live on 51 square kilometers, characterized by pristine beaches and breathtaking scenery. In August 2019, up to 50,000 tourists reached this ‘paradise’. A relevant economic part rests on the sustainable fishing of bluefin tuna, unique for its culinary and healthy properties. On the island, the tuna is also processed and prepared for shipments around the world.

Bere Island

Bere Island is on the Southwest coast of Ireland in Bantry Bay. It has a population of 190 people and in the summertime, it reaches over 2,000. The main economic activities are farming, fishing, tourism, and the commercial marine industry. Is Bere Island interconnected to the mainland? Bere Island receives most of its energy from the national grid through a subsea cable from the mainland. Some houses already use renewable energy like windmills and solar PV panels to generate electricity.

Ameland

Under the 30 for 2030 call the following activities are planned: Ownership Models for District Heating Company. Ownership models and organization for a heating company that is scenario-free and independent from the heat source. Ownership models to operate the network and retain revenues on the island, considering existing examples and requiring legal expertise. Development of a business case and risk management plan. Feasibility Study for District Heating Network Thermal resources assessment and business models, including geothermal and other resources.

Madeira

As part of the 30 for 2030 call the following activities are planned. A technical and financial review of the plans for four micro-hydro plants will encompass an evaluation of energy assessments, technical solutions, the preparation of technical tenders, and their compatibility with the water supply system.

Cres & Lošinj

The Cres & Losinj archipelago, situated in the Kvarner Gulf in Croatia, is the largest in the Adriatic Sea. In ancient times, the islands of Cres and Lošinj were one big island. But as the small strip of land between the two islands was the fastest way to cross this region by ship, the channel of Osor was excavated during the Roman period to shorten the path to the open sea.

Pantelleria

Pantelleria is the largest "small island" in the Sicily Region. It is located in the Strait of Sicily, Mediterranian Sea, between Sicily and Tunisia. Its area measures 83 square kilometers and counts about 7,800 inhabitants in winter and about 30,000 in the summertime. The first evidence of human activity dates back to the Neolithic period by "sesioti". Afterwards, it was occupied by Carthaginians, Romans, Arabs, Aragoneses, Spaniards and Italians. In the past, the main economic activity was agriculture.

Korčula

The island of Korčula is located in Dubrovnik-Neretva County, which is the southernmost county in Croatia. It stretches in the east-west direction, with its length of 46.8 km, a width of 5.3 to 7.8 km has an area of 279.03 km^2 and is the sixth-largest island in Croatia. The island was once a Greek colony called Korkyra Melaina or Black Korcula because of the lush vegetation which adorns the island. The island population is turning to a new future, bright and green.

[Gotland](#)

Gotland, the largest island in the Baltic Sea has set ambitious goals to become carbon neutral by 2040. To achieve these goals, the island plans to address all aspects of the energy transition. The Clean energy for EU islands secretariat has provided a grant to support these ambitions.

[Menorca](#)

As part of the 30 for 2030 call the following activities are planned:

- "Legal and regulatory support to enhance the energy transition".
- "Energy storage and demand flexibility".
- "Land and marine mobility".
- "Energy storage and demand flexibility".

[Mallorca](#)

Organizations that are involved in the energy transition of Mallorca are: Balearic Islands Government, IBE, Balearic Cluster for Ecological Transition (Cluster TEIB) and the Balearic Islands University. As part of the 30 for 2030 call the following activities are planned: The activity "Legal and regulatory support to enhance the energy transition" involves an analysis of the current energy sector-related regulatory framework concerning environmental constraints on the development of renewable energies.

[Ibiza](#)

As part of the 30 for 2030 call the following activities are planned: The activity "Legal and regulatory support to enhance the energy transition" involves an analysis of the current energy sector-related regulatory framework concerning environmental constraints on the development of renewable energy systems and electricity grid development and management. This includes identifying additional key barriers for the Balearic Islands compared to those discussed in the Secretariat's study published in early 2023.

[Cape Clear](#)

Oileán Chléíre, also known in English as Cape Clear, is the home of the southernmost community in Ireland. A North Atlantic island located 12 kilometers by sea from the mainland port of Baltimore, Cape Clear is very exposed to the wild Atlantic wind and rain. The island population is very cosmopolitan, with island residents from every part of Ireland and many different parts of the world. The islanders cultivate a welcoming community where everyone is respected and equally important.

[La Palma](#)

Commonly known as "La Isla Bonita" (the beautiful island), La Palma is the greenest of the eight Canary Islands. Located in the Atlantic Ocean with a population of close to 82,000, the island captures its visitors with stunning hiking trails and natural phenomena and provides pleasant temperatures for its inhabitants all year round. La Palma's economy relies mainly on the island's banana production and tourism.

Salina

A volcanic island in the Mediterranean Sea with an abundance of olive trees and bushes of capers, Salina is part of the Aeolian islands North of Sicily. With its three cities Santa Marina, Malfa and Leni - home to around 2,500 inhabitants spread across 26km² - Salina is the second-largest island in the archipelago.

Aran Islands

Remoteness, idyllic lifestyle, and unique natural landscapes are some of the common characteristics of islands. The Aran Islands, located on the West coast of Ireland just off Galway, are no exception. Majestic cliffs, Celtic medieval churches and lush green fields crossed by ancient stone walls form part of the rich local culture that makes the Aran Islands an unforgettable experience for anyone who visits them. The three islands that make up the Aran Islands are Árainn (Big Island), Inishmaan (Middle Island) and Inisheer (East Island).

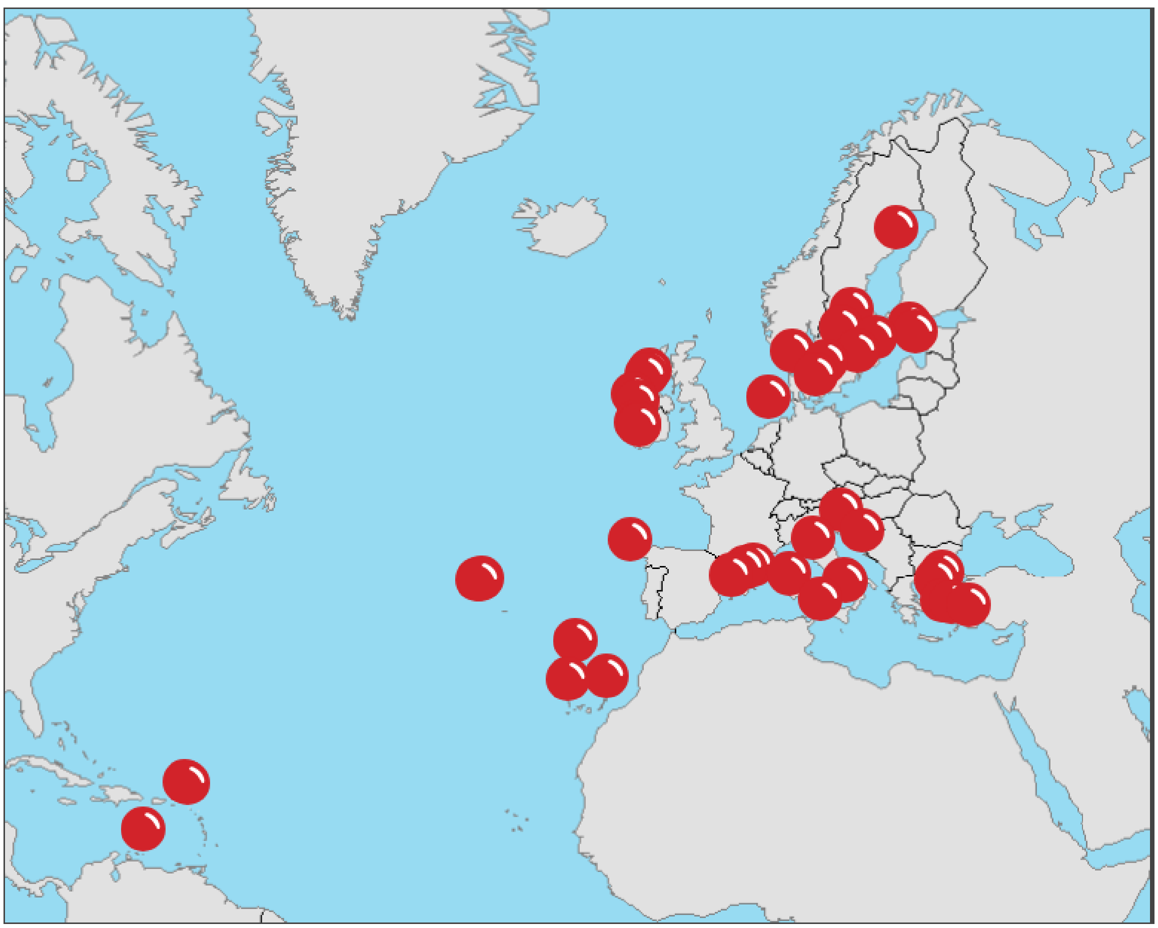

Figure 21: Map with the islands receiving technical assistance from CE4EUI

Based on the information about an indicative list of proposed islands to reach out for replication could be the following for each ecoTool:

- ecoEMS: Lesvos, Mallorca, Gotland, Ameland.
- ecoMicrogrid: Fejø, Venø, Megisti, Salina, Diapontia.
- ecoPlanning: Inishbofin, Aran Islands, Azores, Ruhnu.
- ecoVehicle: Astypalea, Menorca, Inishbofin, Hven, Madeira.
- ecoResilience: Bonaire, St Eustatius.
- ecoMonitor: Pantelleria.
- ecoCommunity: Aran islands, Cres Losinj.
- ecoDR: Cape Clear.

A.3. Action plan

The island that will show an interest for replicating ecoTools solutions will be provided with the indicative action plan.

<u>1. Site Assessment</u>

- Energy Demand Analysis: Conduct surveys to identify current energy consumption and peak demand patterns.
- Renewable Resource Mapping: Evaluate solar, wind, hydro, and biomass potential using GIS and climate data.
- Infrastructure Review: Analyze the current grid, storage solutions, and connectivity challenges. Identify technical and logistical gaps.

<u>2. Stakeholder Engagement</u>

- Local Authorities: Align with policies and regulations to ensure government support.
- Community Engagement: Include residents, businesses, and community leaders to address their priorities and gain support.
- Partnerships: Secure collaborations with energy companies, NGOs, and funding agencies for technical and financial backing.

<u>3. Energy Community Formation</u>

- Community Workshops: Raise awareness about energy independence and benefits of cooperatives.
- Legal Structure: Create a governance framework for cooperative or community-owned energy projects.
- Social Equity: Ensure representation of marginalized groups in decision-making and ownership.

- Revenue Sharing: Design equitable profit-sharing models to incentivize participation.

4. Develop an EcoTool Deployment Plan

- EcoTool Selection: Identify and customize the specific ecoTools needed for the island, such as microgrid design tools, renewable energy forecasting, and storage optimization tools.
- Deployment Phases: Create a roadmap for sequential implementation—starting with core tools and scaling to advanced features.
- Integration Strategy: Plan how ecoTools will interface with existing infrastructure and support future expansion.
- Risk Management: Develop mitigation strategies for deployment challenges, such as technological compatibility or data availability.
- KPIs: Define success metrics, such as energy savings, renewable integration, and cost reductions.

5. Pilot Project Implementation

- Site Selection: Choose a representative area for testing ecoTools and renewable technologies.
- Installation: Deploy renewable systems (solar, wind, etc.) and integrate them with the selected EcoTools.
- Performance Evaluation: Monitor system performance and user satisfaction, using feedback for adjustments.

6. Training and Capacity Building

- Operator Training: Train local technicians to manage and maintain EcoTools.
- Community Programs: Educate residents on using renewable technologies and participating in energy communities.
- Knowledge Hubs: Collaborate with educational institutions to build long-term capacity in renewable energy management.

7. Scaling and Long-Term Planning

- Island-Wide Scaling: Expand the pilot to other regions on the island, customizing solutions for varying conditions.
- Financial Models: Establish long-term revenue streams through energy sales, feed-in tariffs, or community energy funds.
- Policy Advocacy: Work with governments to implement supportive policies for renewable energy and community energy projects.
- Continuous Improvement: Periodically assess and upgrade EcoTools and renewable systems based on performance data and community feedback.