RE-EMPOWERED

Renewable Energy EMPOWERing
European & InDian Communities

Deliverable D8.3: Report on TRL monitoring and planning

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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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EXECUTIVE SUMMARY

The RE-EMPOWERED project focuses on developing and advancing a set of solutions (ecoToolset) namely ecoMicrogrid, ecoEMS, ecoPlanning, ecoDR, ecoPlatform, ecoConverter, ecoMonitor, ecoCommunity, ecoVehicle and ecoResilience aimed at enhancing renewable energy systems and sustainable resource management. This report assesses each tool's readiness, scalability, and integration potential across various technological and operational contexts, using the Technology Readiness Level (TRL) framework. to ensure the tools are evaluated consistently with regard to their maturity levels.

The primary objective of this TRL monitoring and planning is to determine the current developmental stages of each of the ecoTools within the RE-EMPOWERED project. This evaluation provides insight into the tools' technical and commercial readiness and identifies gaps or next steps to promote further development toward market deployment and scalability.

Each ecoTool was assessed using the TRL framework, which ranks from TRL 1 (Basic principles observed) to TRL 9 (Actual system proven in operational environment). The assessment involved laboratory level prototype testing and pilot implementations.

Within the framework of this document, the **self-assessment questionnaire based TRL evaluation process** has been adopted. In this process, the ecoTool developers were provided with a set of questions comprising of the following four (4) parts:

- **Part A: General questionnaire** covers basic questions about each ecoTool such as ecoTool name, developer's details, starting TRL and anticipated TRL, and current status of development
- **Part B: ecoTool specific questionnaire** specifically covering technology description, various constituent parts of the technology, envisioned deployment of this technology, testing and validation information etc
- **Part C: Top level questionnaire** following the TRL levels for determining anticipated TRL
- **Part D:** A set of **Detailed questionnaires** corresponding to each TRL for a comprehensive assessment

The questionnaire was distributed to the ecoTool developers for completion, and the filled-in responses were obtained for evaluation.

The key findings are that the ecoConverter and ecoVehicle have reached TRL 5, where technology validation has been successfully done in relevant operational environments. These tools are progressing toward field demonstration but need further refinement in robustness. The mechanical structures of ecoResilience have reached TRL 6. Most of the ecoTools namely ecoMicrogrid, ecoEMS, ecoDR, ecoMonitor, ecoCommunity and the small wind turbine (part of ecoResilience) have reached TRL 7, indicating high operational readiness. ecoPlatform and ecoPlanning have reached higher levels of TRL i.e. 8–9.

KEYWORDS:

Technology Readiness Level (TRL), Technology Readiness Assessment (TRA), Technology Readiness Level Framework, Technology Roadmap, TRL Milestones, Laboratory Testing, Operational Environment, Technology Validation, Technology Demonstration, ecoTools

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Acronyms

Acronym	Description
IEEE	Institute of Electrical and Electronics Engineers
RES	Renewable Energy Sources
TRL	Technology Readiness Level
TRA	Technology Readiness Assessment
DSM	Demand Side Management
RES	Renewable Energy Resources
EMS	Energy Management System
CTE	Critical Technology Elements
LMSWT	Locally Manufactured Small Wind Turbine
NASA	National Aeronautics and Space Administration
DoD	U.S. Department of Defense
DoE	U.S. Department of Energy
ESA	European Space Agency
FAA	U.S. Federal Aviation Administration
CTE	Critical Technology Elements
CDP	Communication Data Processor
SQL	Structured Query Language
NII	Non-Interconnected Islands
DAS	Day Ahead Scheduling
ED	Economic Dispatch
SCADA	Supervisory Control and Data Acquisition
EPS	Electrical Power System
EV	Electric Vehicle
MGCC	microgrid central controllers
MQTT	Message Queuing Telemetry Transport
STATCOM	Static Compensator
LFC	Load Flow Controller
PPC	Partial Power Converter
FPGA	Field Programmable Gate Array
BESS	Battery Energy Storage System
PSO	Particle Swarm Optimization
IPM	Intelligent Power Module
AQI	Air Quality Index
AFPMG	Axial Flux Permanent Magnet Generator
DSM	Demand-Side Management
HIL	Hardware-in-the-Loop
THD	Total Harmonic Distortion

1 Introduction

1.1 Purpose and scope of the document

The RE-EMPOWERED project has established the overarching goal of developing technical solutions to address the challenges towards efficient, decarbonized, and renewable energy source (RES)-intensive multi-energy local systems. In this direction, the project aims to achieve high Technology Readiness Level (TRL) solutions that are robust and capable of being demonstrated and tested in operational environments.

The RE-EMPOWERED project follows a systematic and rigorous methodology for the development of high TRL solutions. This methodology encompasses key stages, including requirements analysis, technology assessment, conceptual design, prototyping and testing, iterative refinement, and demonstration and validation.

The purpose of this document is to systematically assess and document the maturity of the ten (10) developed technologies (ecoTools). Withing the scope of this document, an explanation of TRL and their relevance to the project outcomes is provided. A detailed description of the evaluation process is provided, including the chosen approach and criteria for assessing TRL within the context of the ecoTools. Comprehensive details for each one of the 10 developed ecoTools, including components and key innovations and applications, are also included in this document. This document analyzes the current maturity levels of the technologies based on the development status, testing, validation results, and supporting data as was reported in deliverable D7.4 “Report demonstration round 1 (testing)”.

This evaluation provides a clear understanding of their readiness for deployment, identifies gaps in development, and guides the next steps towards achieving full market readiness. It also ensures that the technologies align with the project's objectives of fostering sustainability, replicability of the solutions and innovation in the energy sector.

This deliverable also aims to showcase the **whole process** of TRL development of each ecoTool, starting from the design, development, and leading to field demonstration in order to provide the whole picture in a single document. Consequently, information from other project deliverables (i.e. D4.1 [7], D4.2 [8], D4.3 [9], D3.4 [10], D5.2 [11], D5.3 [12], D7.4 [13]) has been summarized where needed.

1.2 Structure of the document

The document is structured as follows. Chapter 2 provides a comprehensive idea about TRL, its definitions and explanations corresponding to each TRL level. It also describes various methodologies available for TRL assessment and the suitable methodology adopted within the framework of this project. A description of each of the developed technologies (ecoTool) is provided in Chapter 3, including potential applications. Chapter 4 assesses the TRL of each ecoTool. Specifically, the TRL of each ecoTool is evaluated, considering factors such as the current development stage, laboratory and field testing, validation results, and supporting data. Chapter 5 summarizes the findings and outcomes presented in the document. A comparison of the projected TRL and the achieved TRL is also provided in this Chapter.

2 TRL Criteria, Definitions and Methodology Adopted for Assessment

2.1 TRL Framework: explanation of the TRL scale being used and definitions

The Technology Readiness Level (TRL) is a framework used to evaluate the maturity of emerging technologies—such as devices, materials, components, software, and processes—throughout their development and, in some cases, early operational use. When a new technology is initially conceived or invented, it is often not ready for immediate application. Instead, it undergoes stages of experimentation, refinement, and progressively realistic testing. Once sufficiently validated, the technology can be integrated into a production system or subsystem.

Various organizations require the use of TRLs, and while the concept remains broadly similar, there are notable differences in the interpretation of maturity at each technology readiness level. The following TRLs are publicly documented [1]:

- U.S. Department of Defense (DoD). Besides Software TRL is included
- U.S. Department of Energy (DoE)
- National Aeronautics and Space Administration (NASA)
- European Space Agency (ESA)
- U.S. Federal Aviation Administration (FAA)

The TRL scale is a widely used framework to assess and track the maturity of a technology from its initial concept to full deployment. The scale typically consists of nine levels, each representing a stage in the technology development lifecycle. Initially defined by NASA, there are nine technology readiness levels, from TRL 1 being the lowest to TRL 9 that is the highest, as represented in Table 1 [2].

Table 1: NASA Technology Readiness Levels

Technology Readiness Levels	Description
TRL 9	Actual system "Flight proven" through successful mission operations
TRL8	Actual system completed and "Flight qualified" through test and demonstration (ground or space)
TRL7	System prototype demonstration in a space environment
TRL6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL5	Component and/or breadboard validation in relevant environment
TRL4	Component and/or breadboard validation in laboratory environment
TRL3	Analytical & experimental critical function and/or characteristic proof-of-concept
TRL2	Technology concept and/or application formulated

TRL1	Basic principles observed and reported

Using the NASA definition as a starting point, the European Commission (in the H2020 general annexes G11) provides the description of the TRL that applies for EC projects.

TRL 1 – Basic principles observed and reported

- Earliest stage of technology development.
- Focus is on scientific research to observe fundamental principles.

TRL 2 – Technology concept formulated

- Initial concept or application of the technology is identified.
- Theoretical studies begin to define the technology's potential.

TRL 3 – Experimental proof of concept

- Active research and experimentation are conducted.
- Proof-of-concept demonstrations in a controlled environment.

TRL 4 – Technology validated in a lab

- Components or systems are integrated and tested in a laboratory environment.
- Demonstrates that the technology works in principle.

TRL 5 – Technology validated in a relevant environment

- More realistic conditions are used for validation.
- Early prototypes or pilot systems are tested in relevant environments.

TRL 6 – Technology demonstrated in a relevant environment

- A fully functional prototype or model is demonstrated in a relevant environment.
- Moves closer to realistic operational settings.

TRL 7 – System prototype demonstrated in an operational environment

- The prototype is demonstrated in an actual operational environment.
- Tests involve real-world systems, conditions, and performance metrics.

TRL 8 – System complete and qualified

- Technology is fully developed and tested.
- Ready for integration into a production system.

TRL 9 – Actual system proven in operational environment

- Technology is successfully deployed and operating in its intended environment.
- Represents full commercial readiness.

A more detailed explanation of TRL scale is provided in the following Table 2 (example for specific application is included) [3].

Table 2: Technology Readiness Levels descriptions

Relative Level of Technology Development	Technology Readiness Levels	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions	The technology is in its final form and operated under the full range of operating conditions. Examples include using the actual system with the full range of wastes in hot operations.

System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An ORR has been successfully completed prior to the start of hot testing.
	TRL7	Full-scale, similar (prototypical) system demonstrated in relevant environment.	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete
Technology Demonstration	**TRL6**	Engineering /pilot scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering scale prototypical system with a range of simulants. Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is

			the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment
	TRL5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants and actual waste. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/ environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.
	TRL4	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small scale tests on actual waste. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-

			6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.
Research to Prove Feasibility	**TRL3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants. Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
	TRL2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support

			the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work
Basic Technology Research	**TRL1**	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology

In Table 3 an additional category, "Phase," has been introduced that clearly differentiates between Research (TRL 1–3) and Innovation (TRL 4–5); and field validation (TRL 6–7) and the industry's need for mature technologies that are easier and faster to develop for market entry [4].

Table 3: Technology Readiness Levels

Technology Readiness Levels	Description	Phase
TRL 1	**Basic Research.** Principles postulated and observed but no experimental proof available	Idea
TRL2	**Technology formulation.** Concept and application have been formulated	
TRL3	**Applied research.** First laboratory test completed; proof of concept.	
TRL4	**Small scale prototype.** Built in a laboratory environment (early prototype).	Prototype
TRL5	**Large scale prototype.** Tested in intended environment.	
TRL6	**Prototype system.**	Validation

	Tested in intended environment close to expected performance.	
TRL7	**Demonstration system.** Operating in operation environment at pre-commercial scale.	
TRL8	**First of a kind commercial system.** Manufacturing issues solved.	Production
TRL9	**Full commercial application.** Technology generally available for all consumers	

Table 4 below provides additional descriptive terms within the context of TRL.

Table 4: Additional TRL descriptive terms

Term	Description
Breadboard	Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.
High Fidelity	Addresses form, fit, and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting)
Low Fidelity	A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low-fidelity assessments are used to provide trend analysis
Model	A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system
Operational Environment	Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging
Prototype	A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item, or system
Relevant Environment	Testing environment that simulates both the most important and most stressing aspects of the operational environment.
Simulated Operational Environment	Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system

2.2 TRL Assessment Criteria and Methodology Adopted

An important part of a TRL specification, besides defining the actual technology readiness levels for the target area, is the process and methodology which describes how the TRL is determined for a specific component or piece of technology. Different TRL specifications differ in how formal and precise the processes are defined. They range from informal, general descriptions, well-defined questionnaires, to partially or fully-automated procedures.

A Technology Readiness Assessment (TRA) examines program concepts, technology requirements, and demonstrated technology capabilities to determine technological maturity. The TRA determines the readiness level (i.e., TRL) for the Critical Technology Elements (CTEs) being evaluated. It is not a pass/fail exercise and is not intended to provide a value judgment of the technology developers or the technology development program. A TRA can:

- Identify the gaps in testing, demonstration and knowledge of a technology's current readiness level and the information and steps needed to reach the readiness level required for successful inclusion in the project;
- Identify at-risk technologies that need increased management attention or additional resources for technology development; and
- Increase the transparency of management decisions by identifying key technologies that have been demonstrated to work or by highlighting immature or unproven technologies that might result in increased project risk.

Several methodologies are commonly used to evaluate the Technology Readiness Level (TRL) of a technology [5]. Each methodology offers different approaches to assess the maturity, operational readiness, and scalability potential of a technology, helping organizations understand how close it is to real-world deployment. Here are some of the key methodologies available [6].

2.2.1 Self-Assessment Questionnaires

- Description: A structured questionnaire guides stakeholders through each TRL stage with specific questions about technical achievements, prototype development, testing, and operational deployment.
- Process: Respondents answer questions on each TRL criterion, with answers scored to determine an aggregate TRL level.
- Strengths: Straightforward, flexible, and cost-effective. Allows the team to conduct regular assessments.
- Limitations: Relies on the accuracy and honesty of self-reported data. Less objective without external validation

2.2.2 Expert Panel Review

- Description: A panel of industry and technical experts assesses the technology's development and assigns a TRL level based on consensus.
- Process: The panel reviews relevant documentation, technical reports, and test results, and interviews key project members before assigning a TRL.

- Strengths: Provides an objective evaluation from multiple perspectives; experts can validate claims with technical scrutiny.
- Limitations: Time-intensive and costly. Subjectivity may arise if experts interpret criteria differently.

2.2.3 Document Based Review

- Description: TRL evaluation based on reviewing specific technical documents, reports, test results, and project deliverables to assess the technology's progress.
- Process: Reviewers compare documentation against TRL criteria, such as proof of concept, test results, and deployment evidence, to assess readiness.
- Strengths: Provides an evidence-based evaluation using project data. It's reliable when documentation is comprehensive.
- Limitations: Limited if documentation is incomplete or poorly organized. This method may miss insights from hands-on testing or operational experience.

2.2.4 Technology Readiness Assessment (TRA) Framework

- Description: A standardized framework for evaluating TRL, often used by government agencies (e.g., NASA, DoD).
- Process: A TRA framework assesses readiness by examining specific performance benchmarks and metrics, following a detailed checklist.
- Strengths: Comprehensive and widely recognized. Sets clear expectations at each TRL level.
- Limitations: May be too rigid or complex for non-governmental projects. Requires in-depth technical knowledge and strict adherence to criteria.

2.2.5 GAP Analysis

- Description: Identifies gaps between the current technology state and the requirements of the target TRL level.
- Process: Evaluators determine the current TRL level and use gap analysis to outline the specific steps and resources needed to reach the next TRL.
- Strengths: Helps create a roadmap for advancing to the next TRL by identifying actionable steps.
- Limitations: Doesn't directly assign TRL levels. More suitable for strategic planning rather than initial evaluation.

2.2.6 Stage-Gate Assessment

- Description: Uses "gates" or decision points where the technology must meet specific criteria to advance to the next TRL stage.
- Process: At each gate, evaluators assess whether criteria for that stage have been met. Gates can include prototype completion, successful tests, or field trials.
- Strengths: Provides a structured, phased approach that aligns well with project management. Allows ongoing monitoring at each project stage.

- Limitations: Time-consuming and resource-intensive. Requires careful planning and defined success metrics at each gate.

2.2.7 Independent Testing and Validation

- Description: Technology is tested and validated independently, often by a third-party laboratory or organization, to verify maturity.
- Process: Independent labs or organizations conduct testing and provide reports on performance, reliability, and robustness. These results are matched to TRL levels.
- Strengths: Objective and trustworthy. Provides evidence of performance in real-world or relevant conditions.
- Limitations: Expensive and may not be feasible for early-stage technologies.

2.2.8 Use of Technology Readiness Assessment Tools/Software

- Description: Software solutions provide automated TRL assessment tools, using predefined criteria to rate each TRL stage.
- Process: Teams input data about the technology's development, testing, and performance. The software assesses readiness and generates a TRL rating.
- Strengths: Streamlines data input, documentation, and scoring. Useful for large projects with multiple technologies.
- Limitations: Depends on software limitations and requires accurate data input. Limited customization in some tools.

2.2.9 Case Studies and Benchmarking

- Description: Compares the technology to similar, mature technologies that have reached commercialization.
- Process: Evaluators study case studies or benchmarks to see if the current technology matches performance, scalability, and reliability at similar TRLs.
- Strengths: Provides real-world context and practical insights. Helpful in industries with established TRL precedents.
- Limitations: Not applicable for highly novel technologies without precedent. Requires relevant, high-quality benchmarks for comparison.

2.2.10 Combined Approach

- Description: Uses a combination of two or more of the above methods to obtain a comprehensive evaluation.
- Process: For instance, a project might combine self-assessment, expert panel review, and independent testing.
- Strengths: Provides a balanced assessment by leveraging different perspectives and data sources.
- Limitations: Resource-intensive and complex. Requires coordination between various evaluators.

2.3 Selection of appropriate methodology

Choosing the right methodology depends on factors such as the complexity of the technology, available resources, desired level of objectivity, and the need for detailed versus rapid assessments.

Within the framework of this project, the **self-assessment questionnaire based TRL evaluation process** has been adopted due to its simple and quick, yet effective evaluation process, compared to other TRL assessment approaches. In this process, the ecoTool developers were provided with a set of questions comprising of the following four (4) parts:

- **Part A: General questionnaire** covers basic questions about each ecoTool such as ecoTool name, principal investigator (ecoTool developers) details, starting TRL and anticipated TRL, and current status of development
- **Part B: ecoTool specific questionnaire** specifically covering technology description, various constituent parts of the technology, envisioned deployment of this technology, testing and validation information etc
- **Part C: Top level questionnaire** following the TRL levels mentioned in Table 3 for determining anticipated TRL
- **Part D:** A set of **Detailed questionnaire** corresponding to each TRL for a comprehensive assessment

The questionnaires were distributed to ecoTool developers for completion, and the filled-in responses are attached in the Annex.

3 Key aspects and application of the ecoTools

In this Chapter, an overview of each of the developed technologies (ecoTools) including its key functionalities, technology architecture and components, and potential application of the technologies are provided.

A detailed description of each of the technologies are available in the deliverable D4.1– "*Development of the ecoEMS, ecoMicrogrid and ecoDR" [7]*, D4.2 – "*Development of the ecoConverter and ecoVehicle*" [8] and D4.3 – "*Development of the ecoMonitor and ecoResilience*" [9], D3.4 – "*ecoPlanning Tool*" [10], D5.2 –"*ecoPlatform Tool*" [11] and D5.3 – "*ecoCommunity Tool*" [12].

3.1 ecoMicrogrid

3.1.1 Technology overview

The ecoMicrogrid tool is an Energy Management System (EMS) for microgrids where advanced management algorithms are deployed to optimize the performance, taking into consideration synergies with different energy vectors like water management and cooling systems. ecoMicrogrid monitors the state of microgrid components, such as RES production, flexible load consumption, and battery storage charge level, while predicting its short-term development. An optimization procedure defines the required actions like load shedding, diesel generator start-up/shutdown and RES power curtailment according to the desired optimization goals.

ecoMicrogrid is offered as an all-in-one solution with low hardware requirements. By integrating multiple functionalities into a single hardware device. With its scalable and flexible design, the ecoMicrogrid tool is well-equipped to adapt to changing energy needs and future expansion, while its interoperability facilitates seamless communication and coordination within the microgrid ecosystem.

The control system architecture of ecoMicrogrid follows the guidelines of IEEE2030 standards for its implementation. More specifically, a four-layer, modular control architecture has been designed and implemented to enable effective supervisory control.

The control architecture is illustrated in Figure 1, where each layer builds upon the functionalities of the layers beneath it. The layers are structured hierarchically, allowing for a systematic approach to control system design and operation.

EcoMicrogrid is composed of two main components the **Data Concentrator** and the **High level Functions**. The diagram in Figure 2 shows the key system components of the tool.

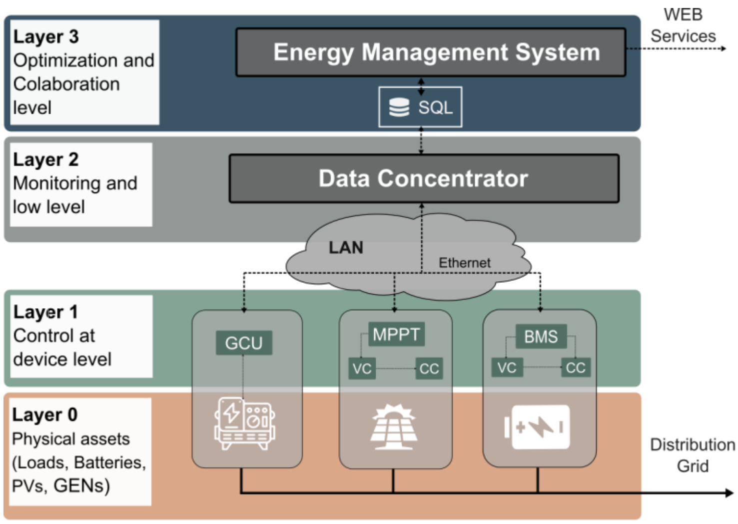


Figure 1 Control Hierarchy of the ecoMicrogrid

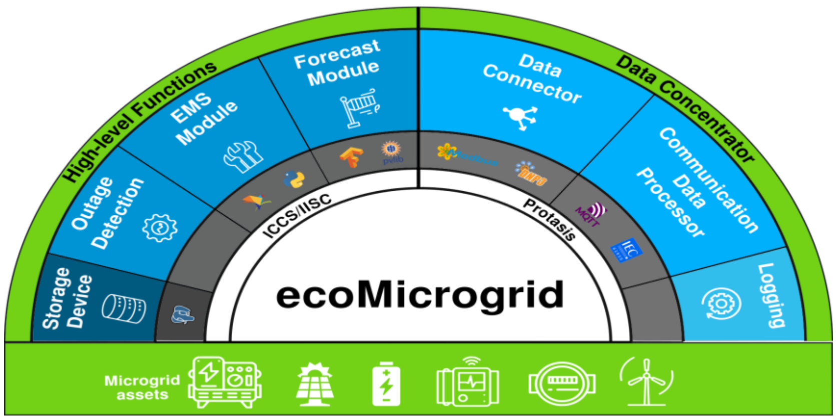


Figure 2: Key system components of the ecoMicrogrid tool

A detailed description of ecoMicrogrid tool is available in deliverable D4.1 – "*Development of the ecoEMS, ecoMicrogrid and ecoDR" [7]*.

3.1.2 Technology applications

Within the scope of RE-EMPOWERED project, the ecoMicrogrid has been deployed and demonstrated in Gaidouromantra microgrid (Kythnos, Greece) and Keonjhar (India). It has also been deployed and partly demonstrated in Ghoramara, India.

3.2 ecoEMS

3.2.1 Technology overview

The ecoEMS tool is developed as an Energy Management System designed to optimize the operation of power systems of Non-Interconnected Islands (NIIs). It includes various optimization algorithms, demand response techniques, and a suitable communication framework.

The tool features a user-friendly interface, database with power station information, and reporting capabilities. It aims to provide 24x7 power supply at low cost, utilizing resources from multiple energy vectors. The system utilizes energy storage, RES and demand forecasting to achieve optimal performance.

ecoEMS, is an internet-based tool that supports multiple users with different permissions. It has the capacity to generate reports in .csv format and utilize HighCharts, HTML5, and Javascript for visualization. The main objectives of the EMS software are to ensure optimal Day Ahead Scheduling (DAS), Economic Dispatch (ED) and support intraday energy market processes for Non-Interconnected Isolated Island Power Systems (NIIPSs). The system aims to minimize operational costs, maximize Renewable Energy Sources (RES) penetration, while adhering to safety regulations and considering technical limitations

The structure of the modules in ecoEMS tool is shown in the following Figure 3, where it can be noted that the core of the module is the database where all the necessary data are stored, e.g., the technical data from the thermal units' datasheets, the real time streamed data through the SCADA system, and the results of the various algorithms that are working as unique modules that cooperate all together and are orchestrated by the Module and Data Managers.

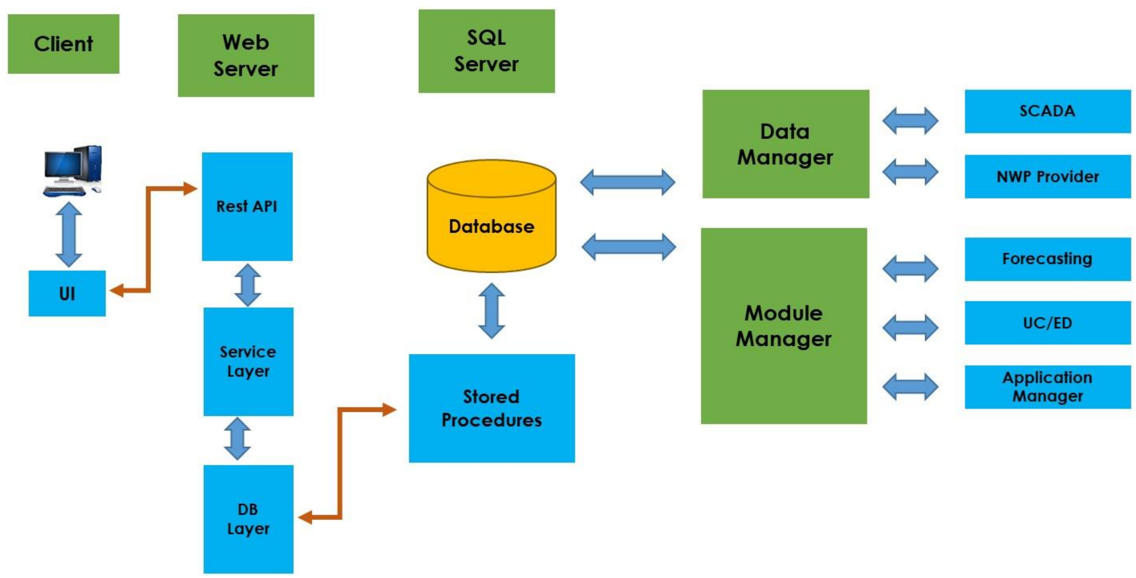


Figure 3: ecoEMS tool architecture

Table 5 presents a concise overview of the ecoEMS tool's features.

Table 5: Features of the ecoEMS Tool

Feature	Description and Objective
Real-time Monitoring	The EMS provides real-time monitoring of generation sources.
Energy Optimization	The core of the EMS consists of a sophisticated optimization algorithm to maximize energy efficiency and minimize operating costs.
Energy Forecasting	The EMS utilizes forecasting models to predict electrical demand and renewables generation of the assets, which are crucial for the best energy scheduling of the power system.

DSM coordination	One of the main mechanisms to achieve these goals is to schedule the different energy vectors by tapping into their flexibility
Control	It offers control capabilities to manage the operation of the power system. The output of the tool could send orders to assets for commit/decommit generating units.

The core of EMS tool is based on the Day Ahead Scheduling (DAS) that consists of the pillar of the energy market framework, (Energy and Ancillary Services Market), aiming for the maximization of the social welfare, respecting the technical and safe operation constraints of the Power System (PS) and the production units.

A detailed description of ecoEMS tool is available in deliverable D4.1 – "*Development of the ecoEMS, ecoMicrogrid and ecoDR*" *[7]*.

3.2.2 Technology applications

Within the scope of RE-EMPOWERED project, the ecoEMS has been deployed and demonstrated in Kythnos Power System and Bornholm demo sites, that have major differences in their generation mix, network and structure. Kythnos on the one hand has only the Electrical Power System (EPS) vector, and Bornholm on the other hand, consists of both an electrical network and district heating system.

3.3 ecoPlanning

3.3.1 Technology overview

ecoPlanning is a tool to support the decision-making process for the deployment of new electricity generation units (conventional and renewable) in the electric systems of non-interconnected islands (NIIs) in a mid-term horizon. ecoPlanning carries out the following studies: 7-Year energy planning for assessing the deployment plan of new conventional production units; analysis of the renewable energy hosting capacity in the power system, and interconnection assessment by performing steady state simulations of the electric system to evaluate the interconnection advantages and reports. ecoPlanning allows defining different scenarios, considering the electricity demand forecast and the composition of the electric system (types of production units, technical and economic characteristics, operation rules, etc.). The tool reports the operation of the generation units and several results about the energy production in terms of quality, fuel consumption and cost, CO_2 emissions, etc. It makes it possible to design and develop high-RES energy systems, taking into account the flexibility offered by demand response mechanisms and other energy carriers, such as cooling.

The key innovative features of ecoPlanning tool are presented in Table 6.

Table 6: Innovative Features of the ecoPlanning Tool

Features	Description and Objective
Generation Adequacy	ecoPlanning offers this study to examine the necessity of deployment of new electricity generation units (conventional and

	renewable) on the Electric Systems (ES) of Non-Interconnected Islands (NIIs)
RES hosting capacity	ecoPlanning examines if available electrical "bandwith" that permits new Renewable assets to be deployed on the Electric System under examination
Interconnection of NIIs with the mainland power system	Through the Interconnections feature, ecoPlanning enables to examine the linked operation of two different islanded power systems as a unique power system.
Peak Shaving	ecoPlanning offers the option to reduce the peak demand by a certain percentage (e.g. 15%). The total demand for the examined island is not modified (i.e. the demand during the peak-hours is transferred to timeslots that a decreased demand is noted)
Increasing the RES penetration	ecoPlanning allows the exploitation of RES synergies with demand response schemes. More specifically, ecoPlanning offers the option of transferring part of the system's
Exploiting the flexibility of EV charging	ecoPlanning allows the selection of the total capacity of the EVs' batteries that can be considered in demand response schemes (e.g. 10 MWh). The user also selects the RES capacity – and the type of RES – that is associated with the particular management schemes.
Application of a demand response scheme according to the user's preferences	ecoPlanning offers the user the choice of applying a specific time-series in ecoPlanning, in order to view the results of their developed management scheme.
Combining the operation of electricity and water networks through desalination units and electrical distribution pumps	ecoPlanning allows the definition of the amount of the desalination loads that can be served and it further outputs the results. This functionality enables the synergy between the electricity and water energy vectors, eliminates the RES curtailment, contributes to the peak shaving and provides to the community a vital resource as the pure water supply
Adding flexibility to the system with hydrogen storage	ecoPlanning enables the user to apply a hydrogen storage unit to the system, in order to investigate the exploitation of the flexibility offered and the benefits to the grid's operation. EcoPlanning provides the results for the optimal storage capacity, the increase of RES penetration and the limitation of thermal power units' production.

3.3.2 Technology applications

Within the scope of RE-EMPOWERED project, the ecoPlanning tool has been deployed and demonstrated in Kythnos Power System and Keonjhar demo sites, that have major differences in their generation mix, network and structure. Kythnos power system consists of transmission lines of some kilometers, with conventional units using heavy fuel to ensure stability to the system and constant supply, while Keonjhar on the other hand does not use any kind of fossil fuel generators, but only RES and batteries.

3.4 ecoDR

3.4.1 Technology overview

ecoDR is the tool focused on the development of advanced metering infrastructure (AMI) with inbuilt load controller and protection functionalities. Additionally, to measurement and billing of household energy consumption, ecoDR facilitates remote monitoring and control of non-critical loads based on user preference. Over-current protection functionalities are included in the smart meter to make it work as an over-current relay.

This tool is available to communicate with ecoMicrogrid to access services such as demand-side management and implement scheduling of critical/non-critical loads via load shedding. If the renewable energy generation is not enough to cover the demand, the tool can create limits to the power and energy demand of all non-critical consumptions. It limits fairly the consumption of all consumers, avoiding situations of overload or blackouts.

Advanced functionalities integrated into the developed meters include an inbuilt programmable load and energy limiter, load-shedding controller, and two output ports for critical and non-critical loads. Additionally, the meters offer management of non-critical loads through scheduling and control based on commands from the ecoMicrogrid.

The standard features of ecoDR include a static single-phase, two-wire energy meter with various parameters available for measurement, such as Irms, Vrms, active energy, power factor, apparent power, and load. The smart meters also come equipped with a visible indicator for poor power factor, an LCD for display, and support for MODBUS communication protocol.

As illustrated in Figure 4, the ecoDR consists of hardware modules such as AC-DC converter to fulfil power requirements various electronic modules, voltage and current sensing units, switching modules consisting of 2 relays, transistors and other required circuit which provides the opportunity to turn on/off power derived from critical and non-critical port whenever needed, real time clock module to create timestamped data packets and a ethernet based communication module to communicate with ecoMicrogrid.

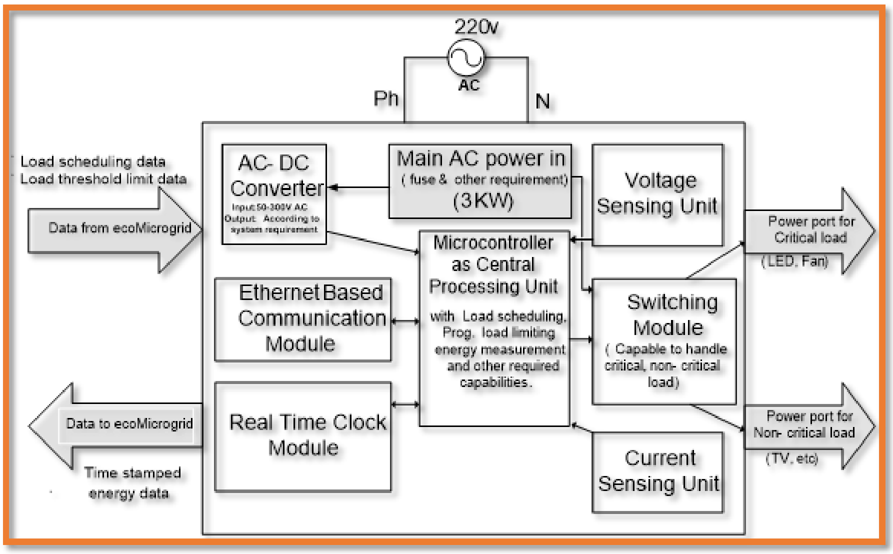


Figure 4: Key system components of the ecoDR tool

ecoDR offers advanced functionalities that provide enhanced control and management of electricity consumption.

A detailed description of ecoDR tool is available in deliverable D4.1 – “*Development of the ecoEMS, ecoMicrogrid and ecoDR” [7]*.

3.4.2 Technology applications

This technology can find applications in microgrid and home residents. Within the scope of RE-EMPOWERED project, the ecoDR tool is being deployed and demonstrated in all the four demo sites in India and EU.

3.5 ecoPlatform

3.5.1 Technology overview

The ecoPlatform tool is a lightweight, cloud-based platform with the primary objective of providing the RE-EMPOWERED tools with a secure and reliable interface to the deployed distributed energy infrastructure. In addition, ecoPlatform is capable of managing, processing, and handling the heterogeneous data and command stream from the RE-EMPOWERED tools, metering infrastructure, supervisory control, and data acquisition (SCADA) systems, microgrid central controllers (MGCCs), and selected controllable assets.

ecoPlatform ensures that all the rest of ecoTools are interconnected and integrated, and is provided as a Platform-as-a-Service (PaaS). Besides, it enables final customers or operators to freely customize the applications and acquire the data streams needed for operation.

ecoPlatform is a software tool which enables final customers or operators to freely customize the applications and acquire necessary data streams for operations. It addresses:

- Communication and data exchange between different tools.
- Data storage.
- Data governance.
- User interface.
- Communication and asset status monitoring.
- Interface for data pre-processing algorithms.

ecoPlatform’s basic functionalities include effective and reliable communication with other tools. The architecture of ecoPlatform is illustrated in Figure 5.

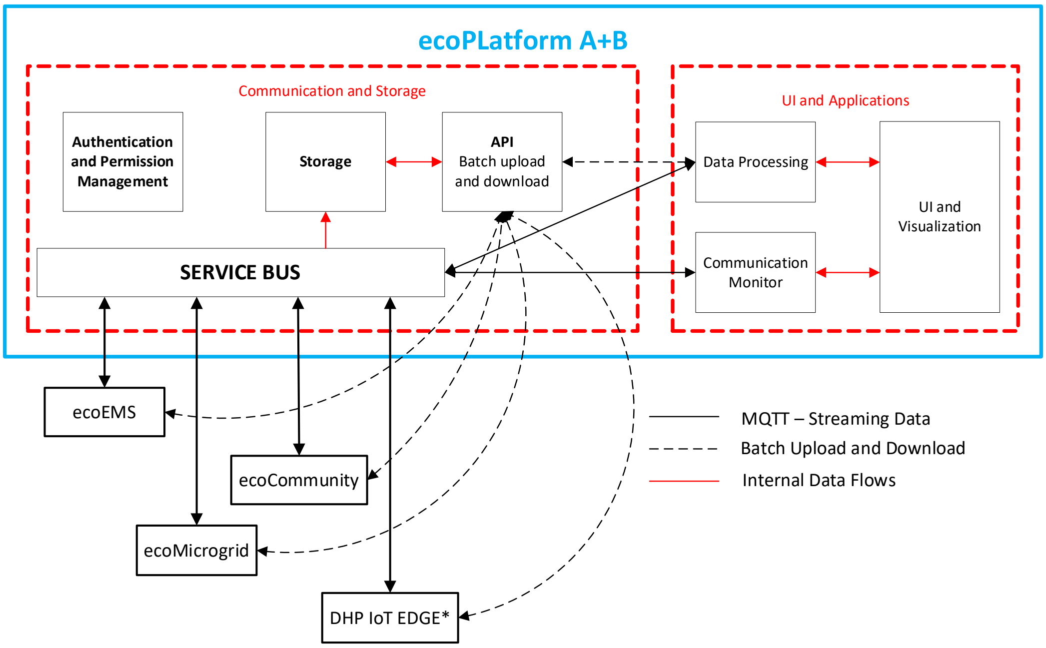


Figure 5 Architecture of the ecoPlatform

Here, communication monitoring is conducted through logs for tracking message delivery and alarm notifications for missing messages and connection losses. The platform also offers data storage, allowing received data from other tools across demo sites to be stored up to a specified limit. Access to the platform is based on the assigned permissions, enabling operators to visualize site specific data and send alarms and notifications related to system operations. The service bus facilitates communication between tools, supporting two data flow options: streaming and batch. In the streaming option, messages are formatted in JSON with parameters such as ID and value (integer, float, or string). In the batch option, data from other tools is sent to the ecoPlatform in CSV format (timestamped integer, float, or string). Data can be stored, or tools can request data via API using parameter identifiers. Relevant ecoTools within a specific demo site can publish, store, and retrieve data only within that group or demo site environment.

A more detailed description of ecoPlatform tool is available in deliverable D5.2 "*ecoPlatform Tool*" [11].

3.5.2 Technology applications

End users of this tool include operators, data providers, consumers, and tool leaders who will interact with the platform. Within the scope of RE-EMPOWERED project, the ecoPlatform tool has been deployed and demonstrated in Bornholm, Kythnos, Keonjhar and Ghoramara.

3.6 ecoConverter

3.6.1 Technology overview

ecoConverter deals with the development of a power electronic converter and its control, for DC/AC microgrids. A 10 kW power converter which has two input ports -to interface PC and Wind – has been developed. The purpose of this converter is to form a local AC grid providing ancillary services and extracting the maximum power from PV panels under partial shading conditions. The converter is a modular, plug-and-play, reliable and compact with functions like built-in communication, protection, remote control, and display option.

Under ecoConverter tool, various converter/inverter systems are being developed which are suitable for an islanded local energy system. As a part of the ecoConverter tool, a 10 kW microgrid is developed. The 10kW microgrid specifically includes a DC/DC partial power converter (PPC) for multi-string PV architecture, an Intelligent Power Module (IPM) based inverter, a SiC based DC/DC converter and an FPGA (Field Programmable Gate Array) based digital control platform. The 10 kW microgrid integrates 7.5 kW PV, 2.5 kW locally manufactured wind turbine, and 50 kWh Battery Energy Storage System (BESS). Various ecoTools (such as ecoMicrogrid, ecoCommunity, ecoDR etc.) are being field tested in the framework of this microgrid.

Specifically, a 10 kW microgrid system was fabricated in the laboratory, in the framework of RE-EMPOWERED project, which was then transferred to Ghoramara island for deployment. The use of PPC and plug-and-play type converters in the microgrid makes it more efficient and flexible. A few important features of this microgrid are mentioned as follows.

Salient Features/Advantages:

- 3 input and 1 output ports
- Lower losses
- High power capture during partial shading
- No shut down at low voltage MPP
- Particle Swarm Optimization (PSO) algorithm for global peak search
- Fast MPPT tracking
- Islanded operation

The configuration of the 10 kW ecoConverter system is shown in Figure 6.

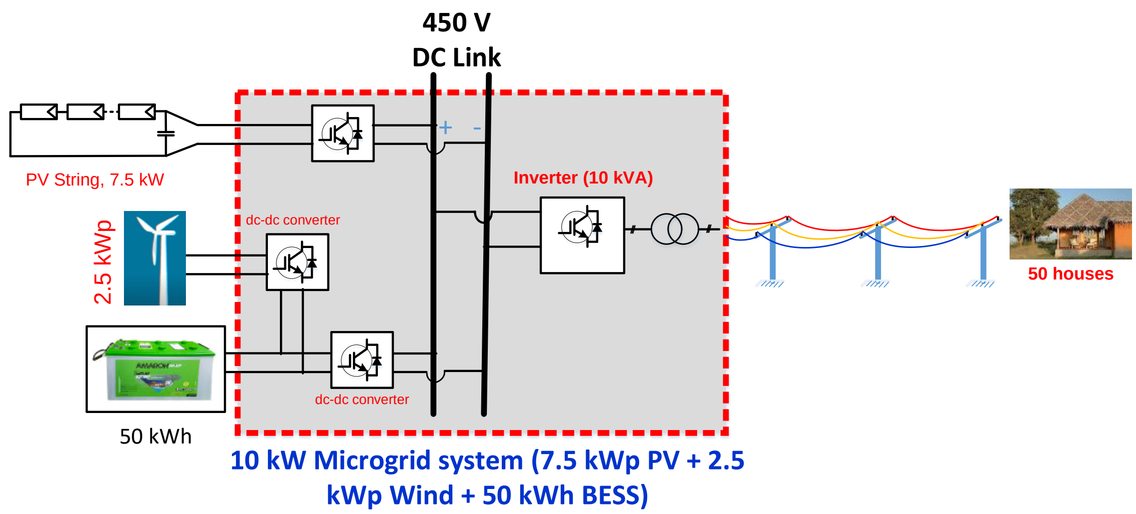


Figure 6 Configuration of 10 kW ecoConverter system

A more detailed description of ecoConverter tool is available in D4.2 – "*Development of the ecoConverter and ecoVehicle*" [8].

3.6.2 Technology applications

The developed ecoConverter tool can be applied in hybrid solar PV and wind based microgrid applications. Withing the scope of RE-EMPOWERED project, this technology is being demonstrated in Ghoramara demonstration site.

3.7 ecoMonitor

3.7.1 Technology overview

ecoMonitor is a tool to develop a portable digital control platform, with multiple sensors and a microcontroller-based processing unit to monitor real-time different ambient air quality parameters, such as the concentration of CO, NO_2, SO_2, O_3, PM2.5 and PM10 microparticles, as well as ambient temperature and relative humidity. The sensor readings are submitted to other ecoTools such as ecoMicrogrid and ecoPlatform, for their processing and analysis.

It is battery-powered with solar panel-based charger units, and it is aimed to be used in remote environmental monitoring. The sensor readings are processed in real time in the control platform and the data are transmitted by suitable communication protocols to a data platform for remote monitoring, display and analysis.

In addition to remote monitoring, the tool features a local display unit with color indication, which alerts the local community once any of the air quality parameters exceed the maximum allowable limit. The inbuilt battery system provides 2 days autonomy when there is no PV production.

Figure 7 illustrates the major constituent parts of ecoMonitor.

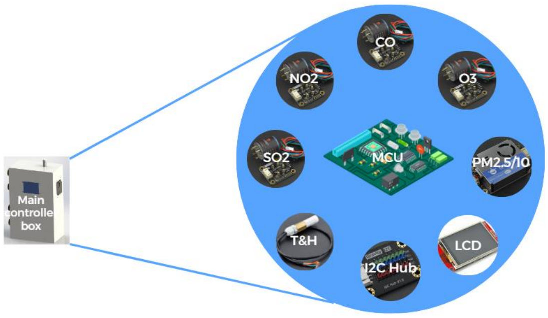


Figure 7 Major Components of ecoMonitor

In the core, there is a MCU which is interfaced with a number of sensors. All the sensors are obtained from commercial sources suitable for outdoor applications.

A digital control platform is responsible for collecting real-time data from the ambient air quality monitoring sensors. The platform gathers data from sensors and other sources for further processing. A robust communication network enables seamless data transmission between ecoMonitor and central control station via Ethernet unit using MODBUS protocol. Figure 8 shows the digital control platform block (shaded region) depicting major components.

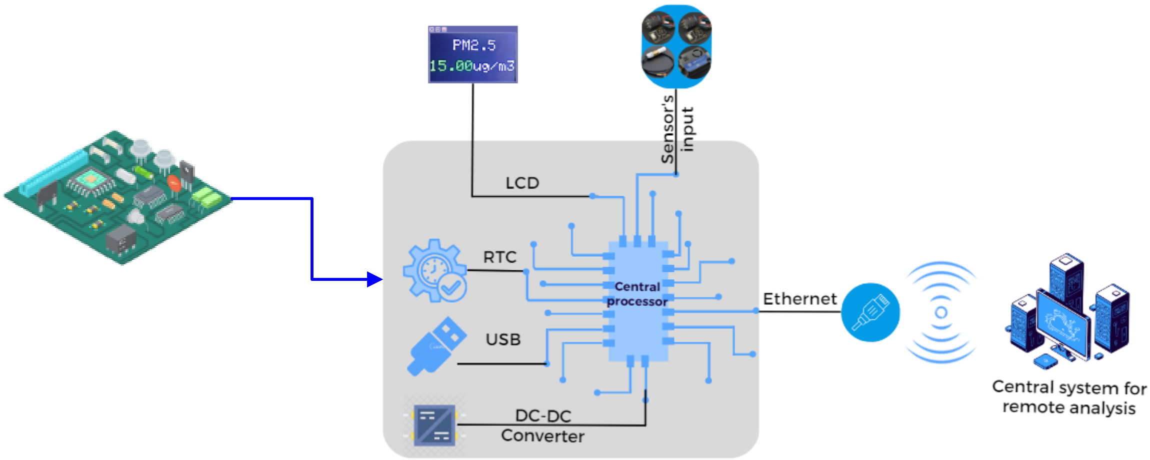


Figure 8 Digital control platform block of ecoMonitor

A more detailed description of ecoMonitor tool is available in D4.3 – "*Development of the ecoMonitor and ecoResilience*" [9].

3.7.2 Technology applications

The end users of the ecoMonitor tool are different pollution control boards and smart cities for ambient air quality monitoring. Within the scope of RE-EMPOWERED project, the ecoMonitor tool has been deployed and field tested at Ghoramara, Bornholm and Kythnos demo sites.

3.8 ecoCommunity

3.8.1 Technology overview

ecoCommunity is a digital platform, designed to improve the engagement of citizens, energy communities and demand aggregators, their active participation, and the technology acceptance in the four Demo Sites. ecoCommunity can be used to coordinate energy users of an energy system, as members of a local energy community. The main functionalities of ecoCommunity are the display of dynamic prices for the residential loads, the demand-side management of non-critical loads, electronic billing, payment, and a feedback portal.

With ecoCommunity, users can monitor their energy data (i.e., energy generation and consumption), and have access to different services with the objective of helping them to define their energy profile. It also offers useful information about billing information, and allows users to use digital platforms through payment gateway interfaces.

ecoCommunity is essentially a software tool which includes the following subsystems:

- Mobile Application
- Cloud Database

Figure 9 illustrates the block level diagram of ecoCommunity tool.

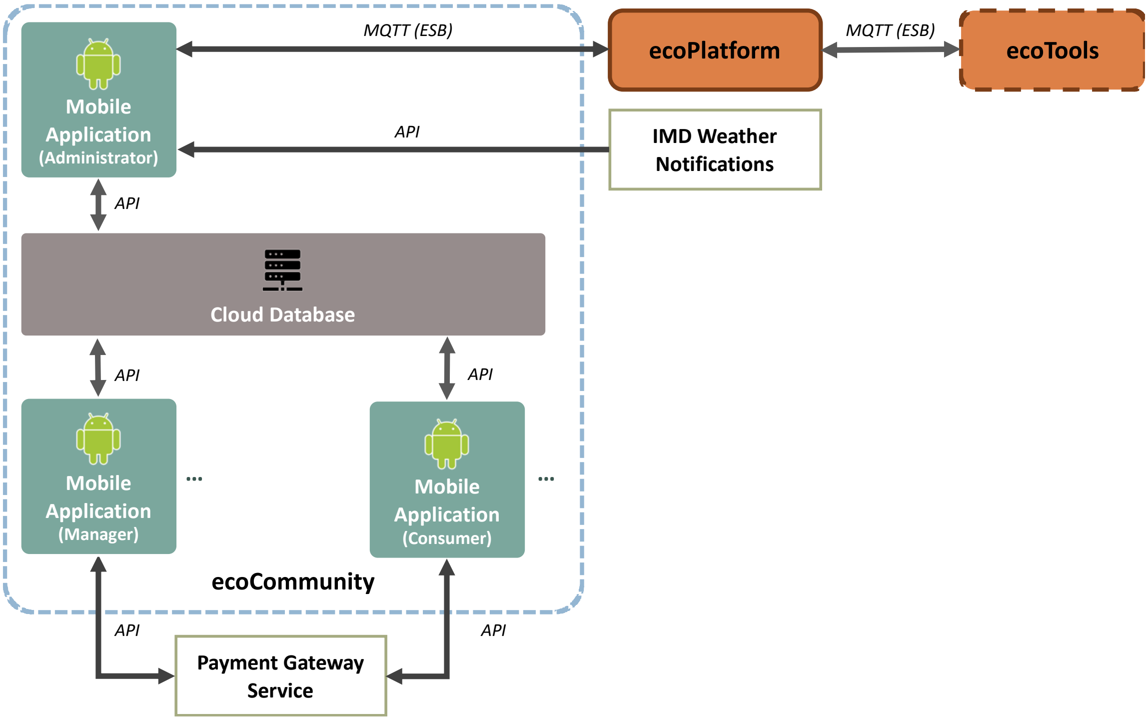


Figure 9 Block level diagram of ecoCommunity depicting two main subsystems and interoperability

The mobile application is the key component of the ecoCommunity tool which acts as the interface to the users of the energy community. The modules and tasks performed by the application depend on the type of users. Communication with other ecoTools is facilitated through ecoPlatform tool using MQTT. The communication with external services and the cloud database utilizes API.

The advanced features of ecoCommunity is presented in Table 7.

Table 7: Key functionalities of ecoCommunity Tool

Features	Description and Objective
Pricing/Status Indication	The tool displays a red-green signal indicating the forecasted energy prices/ system status for the upcoming hours. The red indicates a higher energy price/ low energy availability, and the green indicates a low energy price/ high energy availability. Users can utilize this indication to decide whether to connect their loads. In the case of users who are billed using the dynamic pricing plan, the information will be utilized while generating their bills.
DSM communal load time slot booking	The usage of the communal loads in the demo site is coordinated among the users. The tool displays a set of time slots for using the communal load which can be booked by users. This avoids conflicts in usage and better utilization of the load.
DSM flexible private load time slot booking	Based on the available energy in the system, the user can book the time slots for using their large private non-critical or flexible loads.
DSM thermal load control	Based on the available renewable resources, the ecoEMS tool controls the heating demand of the users. Using ecoCommunity tool, the user can accept or reject this control for various time slots.

Manager	In the case of users who do not have access to digital devices, the users can approach the assigned demo site manager who will be able to access the ecoCommunity tool and the features on their behalf. The manager access level of the tool displays the list of assigned users and can interact with the tool as the selected consumer.
Offline access	The tool stores the data and various input from the users during the offline state and synchronizes the same when the internet is available.
Weather Notifications	Based on the notifications from Indian Meteorological Department, the tool generates weather notifications under extreme weather events

A more detailed description of ecoCommunity tool is available in deliverable D5.3 "*ecoCommunity Tool*" [12].

3.8.2 Technology applications

The end users of this technology includes energy system consumers, RES administrators etc. Within the scope of RE-EMPOWERED project, this ecoCommunity tool is being deployed and field tested at Bornholm, Kythnos and Ghoramara demo sites.

3.9 ecoVehicle

3.9.1 Technology overview

Under ecoVehicle tool, a temperature regulated conductive charger of rating 1.5 kW for electric vehicle has been developed and an electric boat has been customized.

The main key components in this ecoVehicle technology are power factor correction circuit to improve the power factor and buck converter to inject the current of magnitude 30A in continuous mode at 48V. Both the circuits are cascaded and connected by a DC bus 400V. The EV battery pack to be charged is of 48V, 100Ah (4.8kWh Li-ion /Lead acid battery). Charging time is 3.5hrs (up to 0.3C). Battery Temperature will be estimated during Charging process.

Temperature Regulation:

- The challenge faced by charging the vehicle (battery) are the proper regulation of the battery Temperature, Life and Charging time. Hence it controls the temperature of the battery.
- Battery Temperature is estimated during Charging process.
- The key components in this technology are power factor correction circuits to improve the power factor.
- Capability of buck converter to inject the current of magnitude 30A in continuous mode at 48V.

Fast Charging time:

- Charging time is 3.5hrs (up to 0.3C).
- Charger provides fast charging rate which reduces the costs.

Figure 10 shows the constituents parts of the 1.5 kW charger unit with pre-charging arrangements.

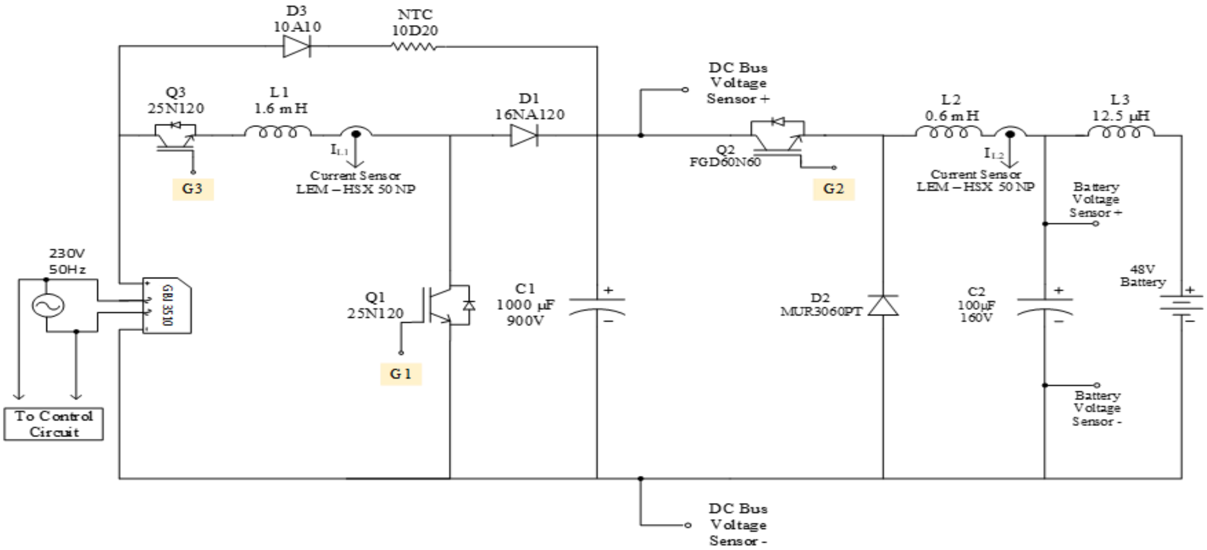


Figure 10 1.5kW Charger power circuit with pre-charging arrangement

A more detailed description of ecoConverter tool is available in D4.2 "*Development of the ecoConverter and ecoVehicle*" [8].

3.9.2 Technology applications

The temperature controller charger unit (under ecoVehicle) can be used in charging the small electric vehicle such as electric three wheelers, electric two wheelers etc. Within the scope of RE-EMPOWERED project, the developed charging unit was expected to be deployed and demonstrated for charging of e-Loaders at Ghoramara and Keonjhar demo sites.

3.10 ecoResilience

3.10.1 Technology overview

ecoResilience is a tool designed to develop cyclone resilient support structures for both ground-mounted solar photovoltaic (PV) arrays and wind turbines, for their use in tropical Indian regions. In these regions, severe cyclones are common, with maximum wind speeds of more than 240 km/h. The tool optimized the design of solar PV facilities to minimize the aerodynamic wind loads through numerical simulations, scale-down wind tunnel testing, and field tests. To do this, the designed solar PV structures are aerodynamic, and have curved plates with concave and convex surfaces.

In the case of wind turbines, hybrid structures resistant to cyclones have been designed to withstand extreme weather conditions, where the designed tower facilitates the removal and reinstallation of wind turbine blades during normal operating conditions. Different turbine heights have been tested using numerical simulations and field tests.

Under the ecoResilience tool, there are essentially three systems as described below.

Ground mounted support structure for solar PV

Eco-resilient support structure is designed for ground mounted PV system through analytical methods and numerical simulations. Its intended functions are validated through a scale down model testing. Two passive aerodynamic components are incorporated with the support frame structure to reduce wind loads by changing the orientation of PV module according to wind flow. Two stoppers are attached with each vertical column. Front stopper helps to maintain the required tilt angle of PV panels and back stopper is attached at a position as PV mounting structure will not go beyond that position to avoid the toppling of structure.
The designed and developed PV support structure (Figure 11) will be installed with a required tilt angle at the demo site for obtaining optimum generation from the PV power plant as per site condition.

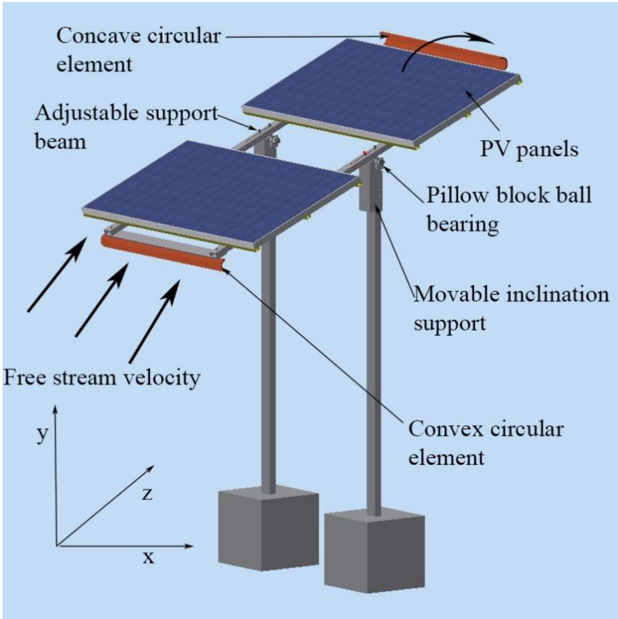


Figure 11 Ground mounted solar PV support structure

The details of the developed support structure follow.

- The developed structure can withstand wind loads up to a maximum velocity of 215 km/hr.
- The resilient structure is designed for 2 solar PV panels of 1956 mm x 992 mm x 36 mm dimension. PV Module will be fixed with the frame through MS bolts. The bolts should be tightened at the required angle.
- It is a two-column base mechanical structure mounted on concrete base 6 feet above ground level. All structural members will be as per latest IS2062:1992.

Rigid ground mounted PV support structures might experience huge wind loads during storms which can cause severe bending moment at the foundation. Here, the panels are kept on a frame which is movable and it is aligned to wind direction using passive aerodynamic surfaces when the wind speed increases beyond a chosen critical speed.

- Passive aerodynamic control surfaces are attached at the edge of the movable PV frame so that their shadow does not fall over the PV panel.
- Net aerodynamic loads are **reduced ~ 1/3** at the cyclonic velocity of 215 kmph

- The solar PV panels are attached at 6 ft. from the ground (This height is chosen for Ghoramora demo site)

Hybrid support structure for wind turbine

The hybrid support structure for wind turbine has a provision to move a part of the tower (monopole) up and down during severe weather condition. The height of the truss structure is 12 m from the ground level. The total structure is made of different types of structural members (basically angles and hollow square bars). The structure consists of 4 vertical members (angles) and each member is divided into two parts and connected with the help of rectangular plates by bolts. The other all cross components are connected with the vertical members by simple bolt joints. *Figure 12* and *Figure 13* show the wind turbine system attached with the support structure at operating altitude and its lower position during the removal of blades.
The main features are summarized below.

- The hybrid structure has a maximum dead load carrying capacity of 150 kg at top of the tower.
- Total height of the designed hybrid support structure is 17m (frame with monopole structure).
- All structural members will be as per latest IS2062:1992 and galvanized (galvanizing thickness will be according to IS4759).

Though many variants of support structures are available based on the operational height, monopole structures are widely used for small wind turbines. However, the whole tower needs to be brought down during maintenance which is impossible in certain locations. The proposed tower does not need to be brought down and the vertical movement allows easy access to the turbine. It has the following innovative features.

- The hybrid support tower has a truss and a movable monopole structure.
- The monopole structure can be brought down for removing the wind turbine system and blades for maintenance & repair.
- The truss structure is fabricated with nuts and bolts for easy transport and installation.
- A removable chain pulley drive is used for lowering/uplifting the monopole structure.

Locally manufactured wind turbine system

The Locally Manufactured Small Wind Turbines (LMSWTs) developed in this project (Figure 14) are grid connected and have a rotor diameter of 4.3 m and rated power of 3 kW, at a rated wind speed of 10 m/s, with annual energy production of 4450 kWh/year, if installed at a hub height of 12 m and at a location with mean wind speed 4.5 m/s, which is a typical mean wind speed for a small wind turbine site.

Figure 12 Wind turbine hybrid support structure during normal operating condition

Figure 13 Wind turbine hybrid support structure during contingencies

Figure 14: LMSWT manufactured at ICCS-NTUA in the framework of RE-EMPOWERED

A more detailed description of ecoResilience tool is available in D4.3 – "*Development of the ecoMonitor and ecoResilience*" [9].

3.10.2 Technology applications

The cyclone resilient support structures for PV and wind can be deployed in locations such as coastal regions having high cyclonic velocities as the free movement of solar panels frame in PV system and lowering of monopole (to remove or lock wind turbine blades) reduce wind loads on structures which increase the life span of these systems. It can also be installed at locations having moderate and low wind profiles with lesser capital cost by reducing the size of the support structures. Within the scope of RE-EMPOWERED project, these are being deployed in Ghoramara demo site.

The LMSWT can be deployed for power generation in remote areas for battery charging and home lighting applications, either in standalone mode or in hybridization with PV. Within the scope of RE-EMPOWERED project, the 1st LMSWT has been deployed and demonstrated in Kythnos (Gaidouromandra). The 2nd LMSWT has been transferred to Ghoramara for deployment.

4 Current TRL Assessment

This section evaluates the TRL of each ecoTool by analyzing results from laboratory prototype experiments as well as performance data collected during field trials.

4.1 ecoMicrogrid

4.1.1 Current stage of development

The performance of developed ecoMicrogrid tool has been initially tested in the ICCS-NTUA laboratory and then deployed for field validation in the following demo sites: Gaidouromandra Microgrid of Kythnos, Greece, Keonjhar and Ghoramara demo sites in India.

4.1.2 Test results, analysis and validation data

The ecoMicrogrid tool has undergone a rigorous evaluation and laboratory testing process to assess its capabilities and functionality. During laboratory testing, a Hardware-in-the-loop (HIL) test bed which utilizes a digital twin model of the microgrid network, that simulated in real-time using a Real-Time Digital Simulator (RTDS) was employed.

During testing, four (4) different operational scenarios have been considered to evaluate EMS's performance to ensure optimal energy management and efficiency within the ecoMicrogrid system.

- Scenario 1 - Normal Operation on 13/07/2023, starting from 20:00 with batteries charged > 80%: The initial room temperature at 20:00 was 29.5°C. The load in this scenario replicates the measured conditions from the Gaidouromadra MG. The objective of this test is to simulate a day when the room begins the night with a high temperature, and minimal precooling of the system house room has occurred during the day. Under these conditions, the EMS should strive to minimize HVAC usage while maintaining the temperature within acceptable levels. This approach is aimed at preventing further reduction in SoC during the night due to HVAC operations.
- Scenario 2 - Normal Operation on 16/07/2023, starting from 10:00 am with batteries fully charged > 90%. At 10:00 am, the initial room temperature was 28°C, and the load conditions resembled those observed in the Gaidouromadra MG. This scenario represents a typical summer day with PV power curtailment, resulting in increased room temperature during the night due to thermal load introduced by the inverters. The EMS's desired performance in this test is to utilize the HVAC system during periods of RES curtailment to proactively cool the room before nightfall. By doing so, it aims to minimize HVAC usage during the night and reduce RES power curtailment.
- Scenario 3 – High Load Operation on 19/07/2023, starting from 19:00 at 19/07 the load measured from Gaidouromadra is doubled before applying it to the digital twin. This scenario represents a high loading condition that has been observed in the microgrid that can lead to a diesel start up by the conventional control. The ecoMicrogrid EMS desired performance will use forecasts of PV and Load to use the diesel generator less amount of time compared to the existing control scheme.
- Scenario 4 – Fault occurrence in a household and in a feeder of the MG to evaluate outage detection algorithm.

The following figures Figure 15, Figure 16 and Figure 17 illustrates the performance of EMS module of ecoMicrogrid under different scenarios.

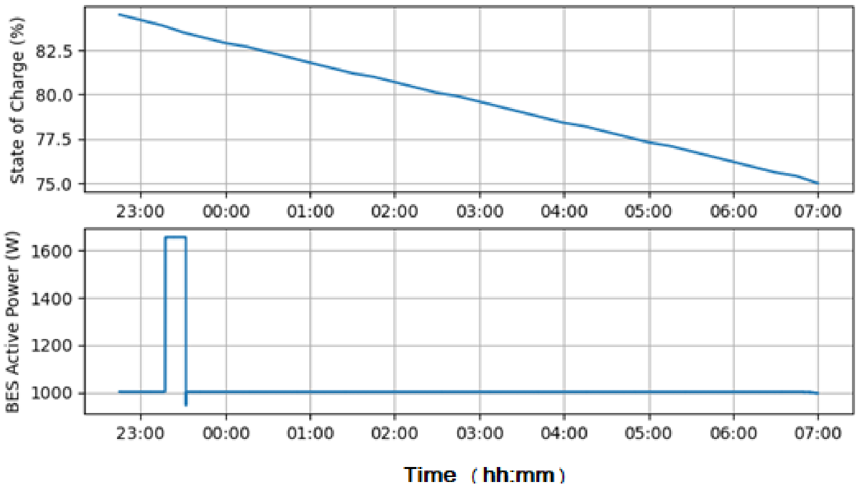


Figure 15: BES Active Power and SoC measured at 13/07/2023 (scenario 1).

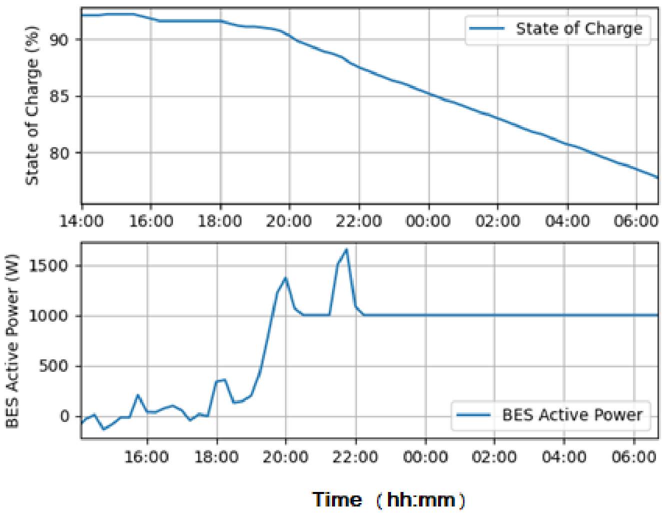


Figure 16: BES active power and SoC at 16/07/2023 (scenario 2)

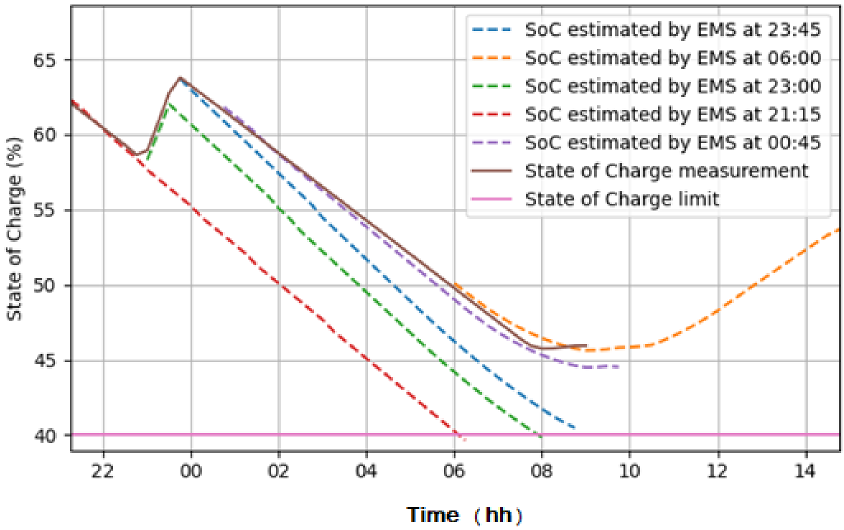


Figure 17: SoC estimation by ecoMicrogrid EMS at different intervals and SoC measurement at 19/07/2023 and 20/07/2023 (scenario 3).

A detailed performance analysis and test results are available in deliverable D4.1 – "Development of the ecoEMS, ecoMicrogrid and ecoDR" [7].

Following the laboratory experimentation, the ecoMicrogrid tool was field deployed and tested at three demo site in EU and India. Here, the performance results in **Gaidouromandra** microgrid on Kythnos Island is presented.

The Gaidouromandra microgrid consists of various equipment, including 11 kWp distributed PV arrays, a 22 kVA backup diesel generator and a 96 kWh/15 kW battery energy storage system. Additionally, there is an air conditioner installed in the system house of the microgrid. Table 8 provides details regarding the available assets.

Table 8: Available assets in Gaidouromandra microgrid

Equipment Type	Available Equipment
Diesel Generator	22kVA (Perkins 404A-22G engine), DSE8610 synchronizing auto start load share control module
Distributed PVs	6 distributed PV arrays with 11kWp
Batteries	96kWh (@20h), 48V
Air condition	Daikin, 9000 BTU, A++/A++, COP: 4.3 & EER: 3.8
Feeder Relays	SEL-751, feeder management, lots of protection features & schemes, metering units
Smart metering	Advanced smart meters and load controller (Smart Low-cost Advanced Meter - SLAMs), logger Data

	Manager M, Energy meters (commercial), feeder relays
Communication network	Fiber optic, Modbus TCP/IP, 1Gbps

The key functionalities of the ecoMicrogrid system were then validated through demonstration activities. The key results and findings are presented below.

Real time microgrid monitoring and data acquisition:

The real-time monitoring and data acquisition capabilities of the ecoMicrogrid tool was validated through real time data collection from energy meters, diesel generators, battery storage systems, and environmental sensors deployed within the microgrid. The ecoMicrogrid system implements sophisticated Supervisory Control and Data Acquisition (SCADA) functionality, enabling operators to maintain continuous visibility of the microgrid's operational status. The **system monitors 161 variables in real-time from 21 physical devices**, providing extensive coverage of the microgrid's operations.

The SCADA interface comprises four distinct operational screens, each serving specific monitoring and control functions. The main overview screen has three distinct parts as shown in Figure 18.

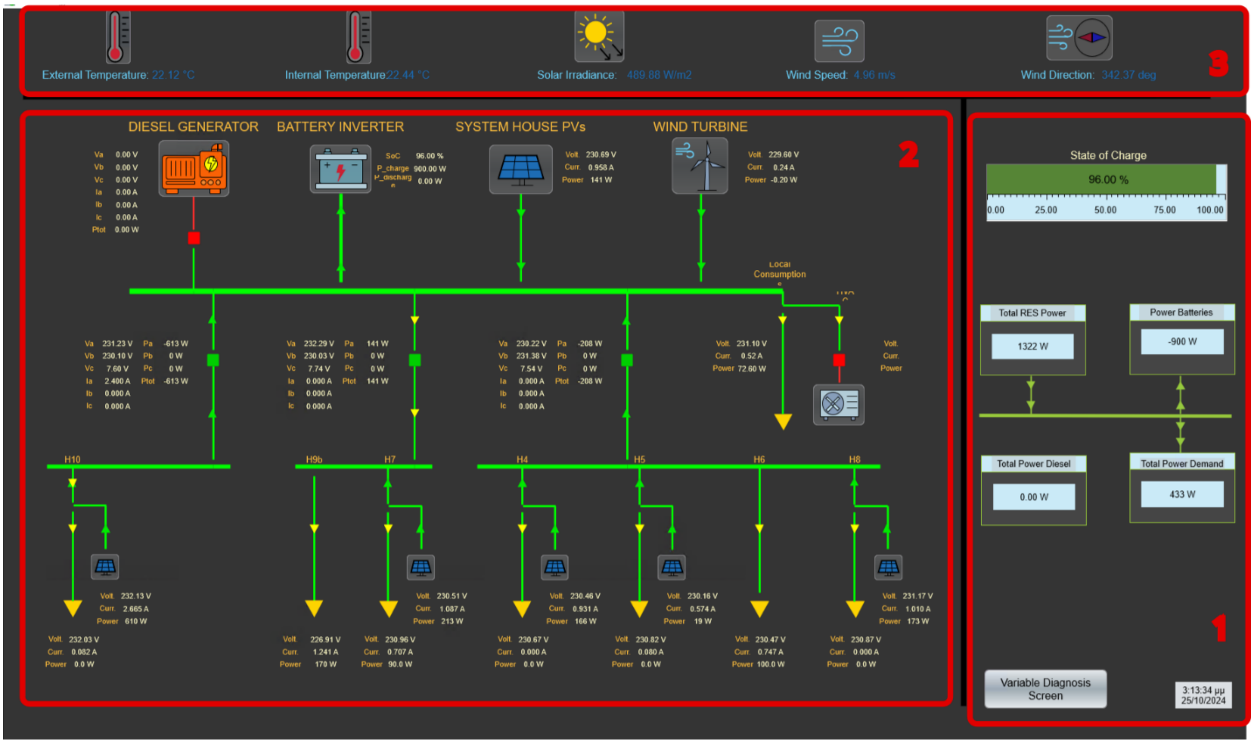


Figure 18 Main Landing Screen is divided into three distinct parts: 1) Energy Balance and SOC section, 2) Single-Line diagram of distribution network section, 3) Environmental data section

The demonstration effectively validated the ecoMicrogrid system's ability to:

- **Reliably Monitor Integrated Assets in Real-Time**: The system consistently provided real-time updates from all assets, ensuring operators had continuous visibility into the microgrid's status.

- **Ensure Accurate and Timely Data Acquisition**: Data collected from energy meters, generators, and environmental sensors was precise and updated in near real-time, supporting reliable monitoring and decision-making.
- **Maintain Stable Communication Across All Devices**: Facilitated robust and stable connections with each asset, ensuring that data flow remained uninterrupted throughout the demonstration.

Figure 19 provides a snapshot of the measurement data table illustrating stored numeric values from various assets. Figure 20 illustrates the number of entries per table within the SQL Server database, highlighting the distinction between measurement data (depicted in red) and application/system control data (shown in blue).

	Timestamp	AssetID int	MeasPropertyID int	NumericValue float
	Filter	Filter	Filter	Filter
1	2024-09-28 08:02:36	17	17 ActivePowerB	110
2	2024-09-28 08:02:36	17	5 CurrentB	0.945
3	2024-09-28 08:02:36	17	1 TotalActivePower	110
4	2024-09-28 08:02:36	16	18 ActivePowerC	0
5	2024-09-28 08:02:36	16	7 VoltageA	232.81
6	2024-09-28 08:02:36	16	6 CurrentC	0
7	2024-09-28 08:02:36	16	5 CurrentB	0
8	2024-09-28 08:02:36	16	4 CurrentA	8.85
9	2024-09-28 08:02:36	16	1 TotalActivePower	-2036
10	2024-09-28 08:02:36	15	18 ActivePowerC	0
11	2024-09-28 08:02:36	15	17 ActivePowerB	0
12	2024-09-28 08:02:36	15	9 VoltageC	6.18
13	2024-09-28 08:02:36	15	7 VoltageA	232.51
14	2024-09-28 08:02:36	15	6 CurrentC	0
15	2024-09-28 08:02:36	15	5 CurrentB	0
16	2024-09-28 08:02:36	15	1 TotalActivePower	33
17	2024-09-28 08:02:36	14	17 ActivePowerB	0
18	2024-09-28 08:02:36	14	16 ActivePowerA	-129
19	2024-09-28 08:02:36	14	9 VoltageC	6.23
20	2024-09-28 08:02:36	14	8 VoltageB	229.85
21	2024-09-28 08:02:36	14	7 VoltageA	231.47

Figure 19 Snapshot of the measurement data table illustrating stored numeric values from various assets.

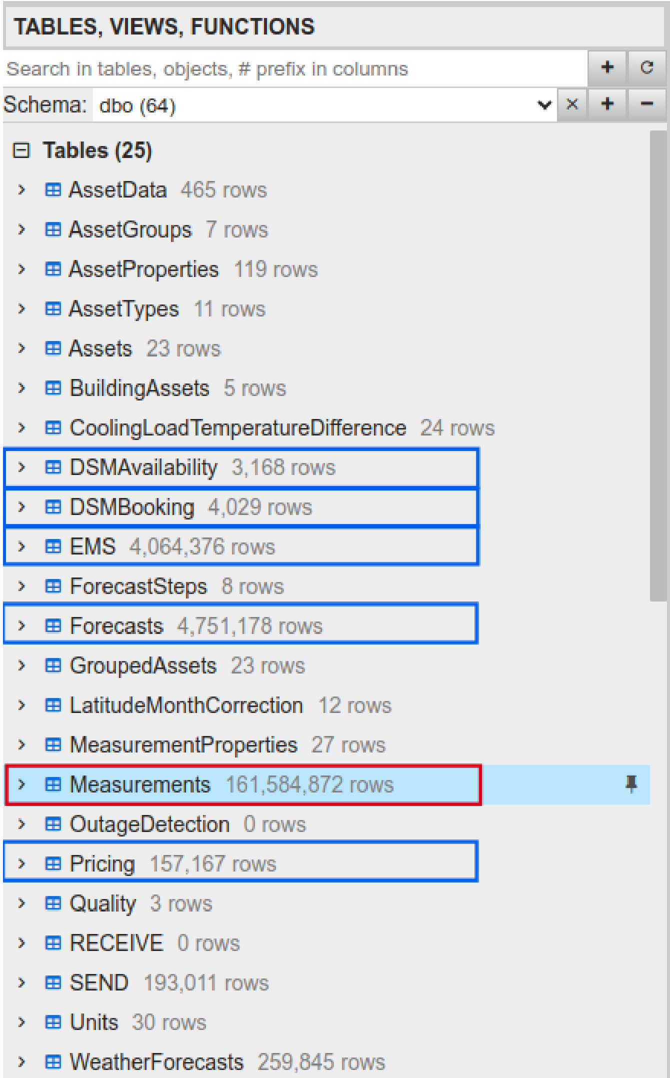


Figure 20 *Summary of SQL tables that highlights the number of records per table. In red the measurement data table. In blue the application/system control data tables.*

During the demonstration phase, the ecoMicrogrid system demonstrated effective data handling capabilities, with the Data Concentrator Module and SQL Server proving their ability to manage and store vast datasets efficiently. The storage device logged over 161 million measurement records, capturing real-time data from all monitored microgrid assets. Additionally, the system recorded substantial amounts of application data essential for operational management and forecasting, including records from forecast modules, demand-side management (DSM) modules, pricing, and EMS module.

A detailed field test and validation results are available in deliverable D7.4 - "Report demonstration round 1 (testing)" [13].

4.1.3 Assessment summary

ecoMicrogrid tool was rigorously tested in two phases:

Laboratory Testing:

- Initial performance evaluation was conducted at the ICCS-NTUA

- Hardware-in-the-loop (HIL) testing has been conducted at the ICCS-NTUA laboratory. This includes the integration of ecoMicrogrid with real-time simulators for validating control algorithms and system dynamics under various operational scenarios. deployment.

Field Deployment:

- The ecoMicrogrid tool was implemented in the Gaidouromandra microgrid on Kythnos Island, Greece.
- Field testing involved real-world scenarios such as battery management, load balancing, and integration of renewable energy sources. The results demonstrated the tool's capacity to optimize energy distribution and improve system reliability.

Overall, the ecoMicrogrid tool exhibited a high level of maturity, successfully achieving the project's targeted TRL of 7.

4.2 ecoEMS

4.2.1 Current stage of development

The performance of the developed ecoEMS tool was initially validated through rigorous testing in the ICCS-NTUA laboratory. It was subsequently deployed in field trials at two sites: the Bornholm microgrid in Denmark and the Kythnos demo site in Greece.

4.2.2 Test results, analysis and validation data

Following the successful completion of the development, the ecoEMS tool was tested at the Kythnos demo site in Greece and Bornholm microgrid in Denmark.

In **Kythnos demo site**, the ecoEMS tool was tested to validate functionalities like real time system monitoring and data acquisition and visualization, intercommunications and data exchange, Unit Commitment and Economic Dispatch algorithms.

The following figures illustrate the performance of ecoEMS integrated database architecture and speed of data transfers. The integrated database is scheduled to receive data from the source database that thermal generation data and load data are stored every minute, as shown in the following picture, and manipulate them in order to aggregate these data in hourly and quarter hourly intervals, to prepare them for the visualization of the previous use case, as well as for the Unit Commitment functionality that is described in the next use cases.

SQLQuery2.sql - 147...A_Islands (sr (67)) | SQLQuery1.sql - 147...A_Islands (sr (65))*

```sql
/****** Script for SelectTopNRows command from SSMS  ******/
SELECT TOP (1000) [Χρονική_Στιγμή]
      ,[Φόρτιση_HZ_1_kW]
      ,[Φόρτιση_HZ_2_kW]
      ,[Φόρτιση_HZ_3_kW]
      ,[Φόρτιση_HZ_4_kW]
      ,[Φόρτιση_HZ_5_kW]
      ,[Φόρτιση_HZ_6_kW]
      ,[Φόρτιση_HZ_7_kW]
  FROM [SCADA_Islands].[dbo].[Kythnos]

  order by [Χρονική_Στιγμή] desc
```

100 %

Results | Messages

	Χρονική_Στιγμή	Φόρτιση_HZ_1_kW	Φόρτιση_HZ_2_kW	Φόρτιση_HZ_3_kW	Φόρτιση_HZ_4_kW	Φόρτιση_HZ_5_kW	Φόρτιση_HZ_6_kW	Φόρτιση_HZ_7_kW
1	2024-10-01 15:04:00	540.18	0	0	0	0	0	568.65
2	2024-10-01 15:03:00	541.03	0	0	0	0	0	569.75
3	2024-10-01 15:02:00	529.28	0	0	0	0	0	562.8
4	2024-10-01 15:01:00	551.73	0	0	0	0	0	574.33
5	2024-10-01 15:00:00	553.82	0	0	0	0	0	576.12
6	2024-10-01 14:59:00	528.2	0	0	0	0	0	562.15
7	2024-10-01 14:58:00	527.08	0	0	0	0	0	560.82
8	2024-10-01 14:57:00	520.02	0	0	0	0	0	557.58
9	2024-10-01 14:56:00	499.15	0	0	0	0	0	545.55
10	2024-10-01 14:55:00	529.77	0	0	0	0	0	562.67
11	2024-10-01 14:54:00	520.9	0	0	0	0	0	558.55
12	2024-10-01 14:53:00	546.57	0	0	0	0	0	572.75
13	2024-10-01 14:52:00	534.13	0	0	0	0	0	566.82
14	2024-10-01 14:51:00	556.97	0	0	0	0	0	578.02
15	2024-10-01 14:50:00	555.67	0	0	0	0	0	577.48

Figure 21 Database table where Kythnos's actual generation and actual load are stored per minute

SQLQuery2.sql - 147...A_Islands (sr (67))* | SQLQuery1.sql - 147...A_Islands (sr (65))*

```sql
/****** Script for SelectTopNRows command from SSMS  ******/
SELECT TOP (1000) [Time_Index]
      ,[Time_stamp]
      ,[UnitId]
      ,[Value]
  FROM [SCADA_Islands].[dbo].[LT_Conv_Load]

  order by Time_stamp desc
```

100 %

Results | Messages

	Time_Index	Time_stamp	UnitId	Value
1	37253	2024-10-01 14:00:00.000	2	556.229
2	37253	2024-10-01 14:00:00.000	3	0
3	37253	2024-10-01 14:00:00.000	4	0
4	37253	2024-10-01 14:00:00.000	5	0
5	37253	2024-10-01 14:00:00.000	6	0
6	37253	2024-10-01 14:00:00.000	7	0
7	37253	2024-10-01 14:00:00.000	8	577.6765
8	37252	2024-10-01 13:00:00.000	2	549.349661016949
9	37252	2024-10-01 13:00:00.000	3	0
10	37252	2024-10-01 13:00:00.000	4	0
11	37252	2024-10-01 13:00:00.000	5	0
12	37252	2024-10-01 13:00:00.000	6	0
13	37252	2024-10-01 13:00:00.000	7	0
14	37252	2024-10-01 13:00:00.000	8	563.043898305085
15	37251	2024-10-01 12:00:00.000	2	520.193050847458

Figure 22 Database table where Kythnos's actual generation and actual load are raw data are transformed in hourly granularity

Since the data have been pulled and transformed in the backend of the application, the integrated database scheme, where they are stored, is shown in the next two pictures. There are both static tables where the data are rarely being modified, since they contain data that do not get any often alterations, e.g. the technical datasheets of the installed generation units, as well as tables that change every quarter of the hour or every hour, such as the forecasts and SCADA tables. The architecture of the integrated database provided not only instant responses of the tool, minimizing any data delay, but also the availability to debug and find if any failure had to do with the connections to the databases, the raw data from source databases and algorithms, or with the ecoEMS framework itself.

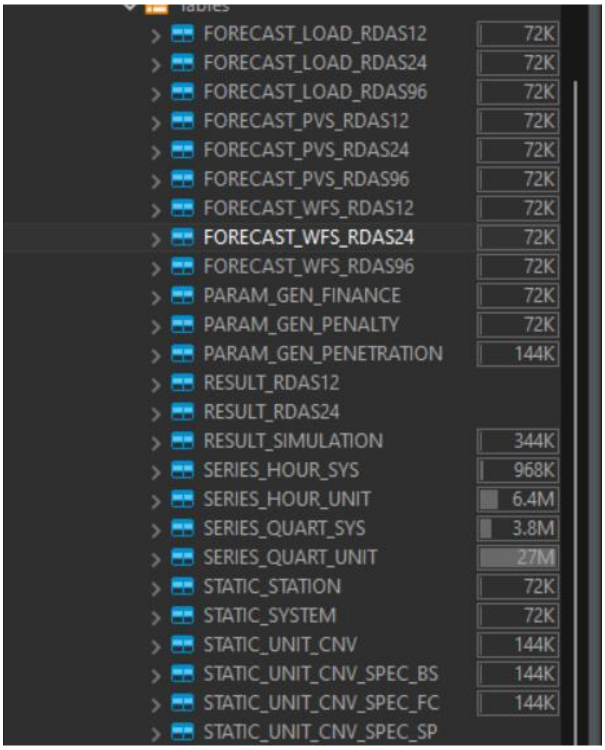


Figure 23 Database architecture from integrated in ecoEMS framework database

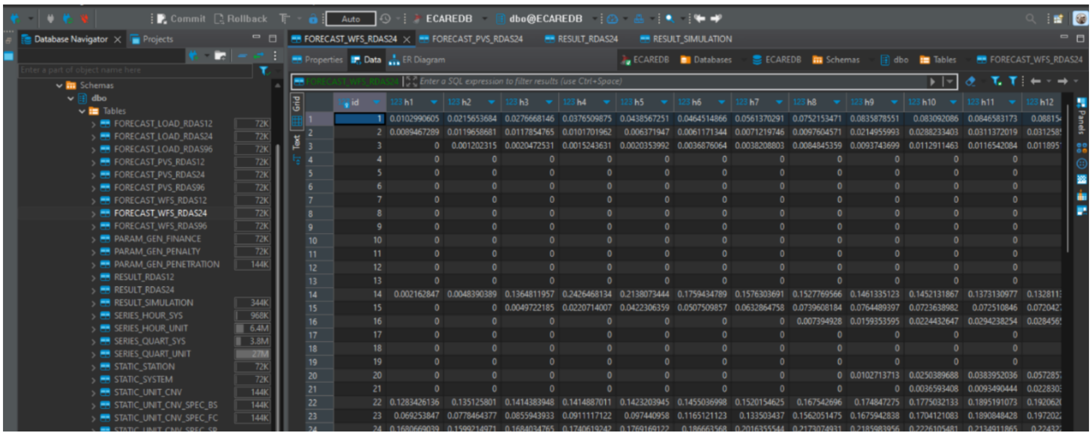


Figure 24 Database table from integrated in ecoEMS framework database showing the forecast of PVs

In the context of mid-term and short term RES and load forecasting functionality of ecoEMS, data were collected and analyzed from the integrated database, for the aforementioned time interval, and compared the forecasts with the actual values, i.e. load and PV forecasts compared with the actual values, as shown in the next two figures. It can be noticed that the load forecast is working in a satisfying level, while for the examined period the PV forecasts performed poorly, as the clouds and the unstable weather was not depicted in the forecasts.

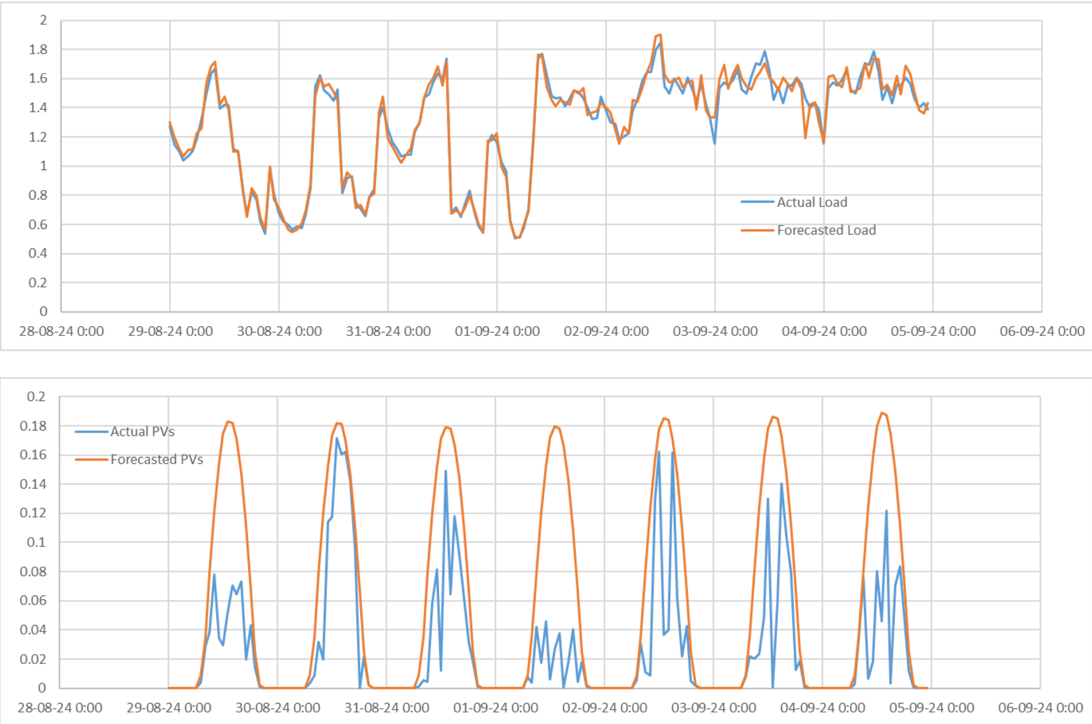


Figure 25 : Assessment of electrical load forecast (above) and PV forecast (below)

4.2.3 Assessment summary

ecoEMS tool has undergone rigorous testing and deployment to demonstrate its effectiveness:

Laboratory Testing:

- Laboratory testing was conducted at the ICCS-NTUA facilities, focusing on energy management system capabilities and integration.

Field Deployment:

- The ecoEMS tool was implemented in the Bornholm demo-site in Denmark and the Kythnos power system in Greece. In Bornholm, the tool utilized the flexibility of electric boilers of the district heating network, to co-optimize the electricity and the heating systems.
- On Kythnos, the ecoEMS was integrated to provide optimal dispatch order suggestions to the Operator, and in the future to allow full exploitation of the RES potential at reasonable costs in the isolated electricity system.

These two stages ensured the ecoEMS tool was robust, effective, and capable of addressing real-world challenges in energy management.

Overall, the ecoEMS tool exhibited a high level of maturity, achieving TRL of 7, almost reaching the project’s target of TRL 8. Since operating in operational environment at pre-commercial scale has been successful, the tool needs to mature a bit to be able to satisfy all technical processes and systems to support commercial activity in ready state, achieving TRL 8.

4.3 ecoPlanning

4.3.1 Current stage of development

The performance of the developed ecoPlanning tool was initially validated at ICCS-NTUA. It was subsequently applied at two sites: the Kythnos demo site in Greece and Keonjhar in India.

4.3.2 Test results, analysis and validation data

Following the successful completion of the development, the ecoPlanning tool was applied at the Kythnos microgrid in Greece and Keonjhar in India.

In Kythnos, the ecoPlanning tool was tested to validate its key functionalities. To test data collection and storage functionalities, the integrated database is scheduled to store data from the front end corresponding to the annual RES and load curves or importing data through the SQL management studio.

Since the data has been collected and transformed, the integrated database schema, where they are stored, is shown in the next two figures. They all are static tables in the meaning that they do not change dynamically, but only if the user creates or imports data. Also, the data is rarely being modified, since the contain data that do not get any often alterations, e.g. the technical datasheets of the installed generation units. The architecture of the integrated database provided not only instant responses of the tool, minimizing any data delay, but also the availability to debug and find if any failure had to do with the connections to the database or the raw data, or within the ecoPlanning framework itself.

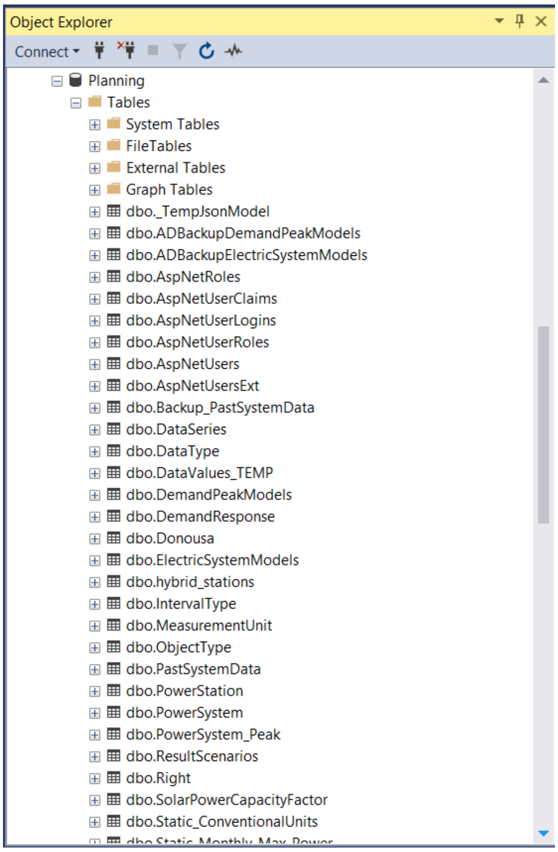


Figure 26 Database architecture from integrated in ecoPlanning framework database

	UnitId	PowerStationId	UnitName	TypeofUnit	InstallationDate	DeInstallationDate	StartDateAsSpare	FuelCoeffA	FuelCoeffB	FuelCoeffC	Fuelid	MinActivePower	MaxActivePower	RatedPower	DisplayCode	Busid
1	256	24	MITSUBISHI S16R-PTA	3	2006-01-01 00:00:00	2035-01-01 00:00:00	2006	266.89	-85.876	37.134	2	0.637	1.1	1.275	G1	256
2	257	24	MITSUBISHI S16R-PTA	3	2006-01-01 00:00:00	2035-01-01 00:00:00	2006	266.89	-85.876	37.134	2	0.637	1.1	1.275	G2	257
3	258	24	MITSUBISHI S16R-PTA	3	2006-01-01 00:00:00	2035-01-01 00:00:00	2006	266.89	-85.876	37.134	2	0.637	1.1	1.275	G7	258
4	259	24	MWM TBD603V12	3	1981-01-01 00:00:00	2035-01-01 00:00:00	1999	237.26	48.362	-103.49	2	0.265	0.4	0.53	G6	259
5	422	24	MWM TBD603V12	3	1981-01-01 00:00:00	2035-01-01 00:00:00	1999	237.26	48.362	-103.49	2	0.265	0.4	0.53	G3	422
6	423	24	MWM TBD603V12	3	1981-01-01 00:00:00	2035-01-01 00:00:00	1999	237.26	48.362	-103.49	2	0.265	0.4	0.53	G4	423
7	424	24	MWM TBD603V12	3	1981-01-01 00:00:00	2035-01-01 00:00:00	1999	237.26	48.362	-103.49	2	0.265	0.4	0.53	G5	424

Figure 27 Database table from integrated in ecoPlanning framework database showing the technical datasheet stored for each conventional unit

	DataSeriesID	DataTypeID	ObjectID	ObjectTypeID	StartDate	IntervalTypeID	MeasUnitID	DataSeriesName	LastModified	ModifiedByUser
1	20	1	21	1	2100-01-01 00:00:00	1	4		1900-01-01 00:00:00.000	0
2	51	2	21	1	2010-01-01 00:00:00	1	1	Καμπύλη Αιολικών 2010 (Κύθνος)	1900-01-01 00:00:00.000	0
3	82	3	21	1	2010-01-01 00:00:00	1	1		1900-01-01 00:00:00.000	0
4	113	4	21	1	2010-01-01 00:00:00	1	1		1900-01-01 00:00:00.000	0
5	144	5	21	1	2010-01-01 00:00:00	1	1		1900-01-01 00:00:00.000	0
6	443	1	21	1	2009-01-01 00:00:00	1	4	Ωριαία Φορτία Συστήματος 2009	1900-01-01 00:00:00.000	0
7	614	1	21	1	1900-01-01 00:00:00	1	4	Test Adonis 20/02	NULL	NULL
8	615	1	21	1	1900-01-01 00:00:00	1	4	Test 2 Adonis 20/02	NULL	NULL
9	616	1	21	1	1900-01-01 00:00:00	1	4	Test 4 Adonis 20/02	NULL	NULL
10	617	1	21	1	1900-01-01 00:00:00	1	4	Test 6 Adonis 20/02	NULL	NULL
11	618	1	21	1	1900-01-01 00:00:00	1	4	gm_test	NULL	NULL
12	619	1	21	1	1900-01-01 00:00:00	1	4	gm_test2	NULL	NULL
13	620	1	21	1	1900-01-01 00:00:00	1	4	Test 7 Adonis 20/02	NULL	NULL
14	621	1	21	1	1900-01-01 00:00:00	1	4	Test 7 Adonis 24/02	NULL	NULL

Query executed successfully. | 147.102.30.15 (15.0 RTM) | sr (67) | Planning | 00:00:00 | 18 rows

Figure 28 Database table from integrated in ecoPlanning framework database showing the timeseries stored for Kythnos demo site

Under the use case of Electrical models & demand peak models design, RES & Load estimation, the target was to create both demand-peak and electrical system models, as shown in the next pictures;

- for the demand peak model, after all methods were tested, the first of them, for the linear extrapolation was chosen to calculate the demand and the peak of the load for a 7-year horizon.
- For the electric system model all tabs were tested, and at the renewables management tab PVs were modeled, on the conventional units management tab 7 units were modeled with their technical characteristics, and finally at the parameters management tab reserves requirements were defined, among other cost parameters.

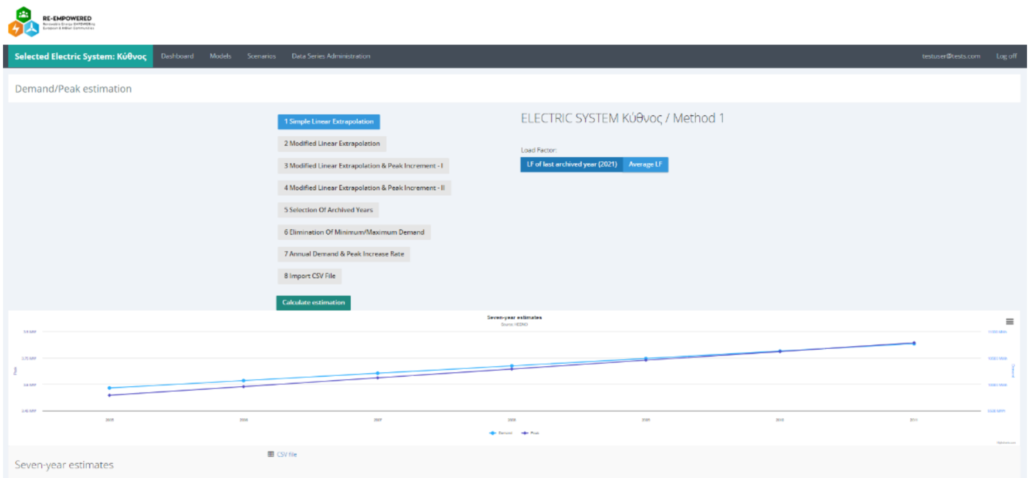


Figure 29 Page from ecoPlanning displaying the methodologies available for the demand/peak model and the estimation using the 1st method

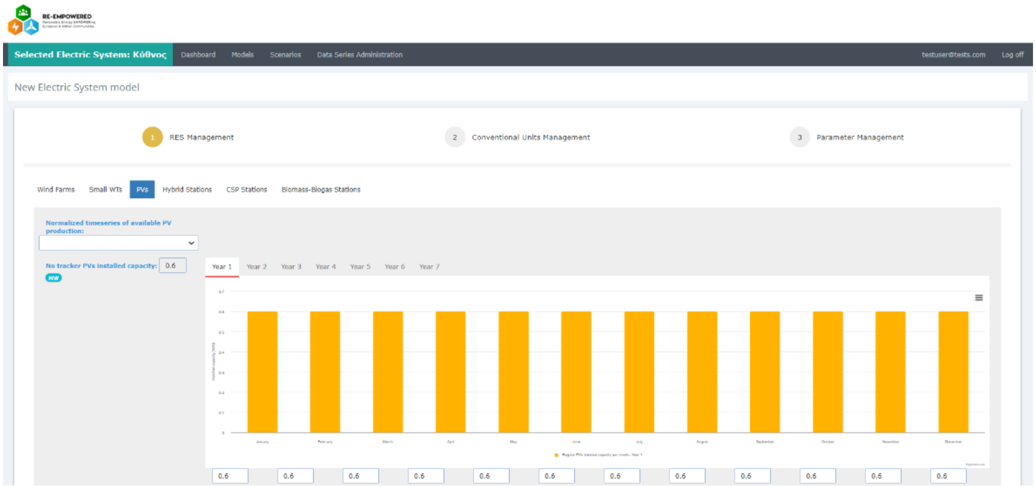


Figure 30 Page from ecoPlanning displaying the installed capacity of PVs in an electrical system model

For validation of optimization algorithm for mid to long term horizon (1 to 7 years), for hourly Unit Commitment, maximizing RES penetration and securing normal operation, as shown in the next pictures, a graph of the annual energy mix is exported, as well as a list of tables providing information about the aggregated results of annual thermal and RES production, fuel consumption, CO2 emissions, the input general parameters, the hours of operation of thermal units and various costs.

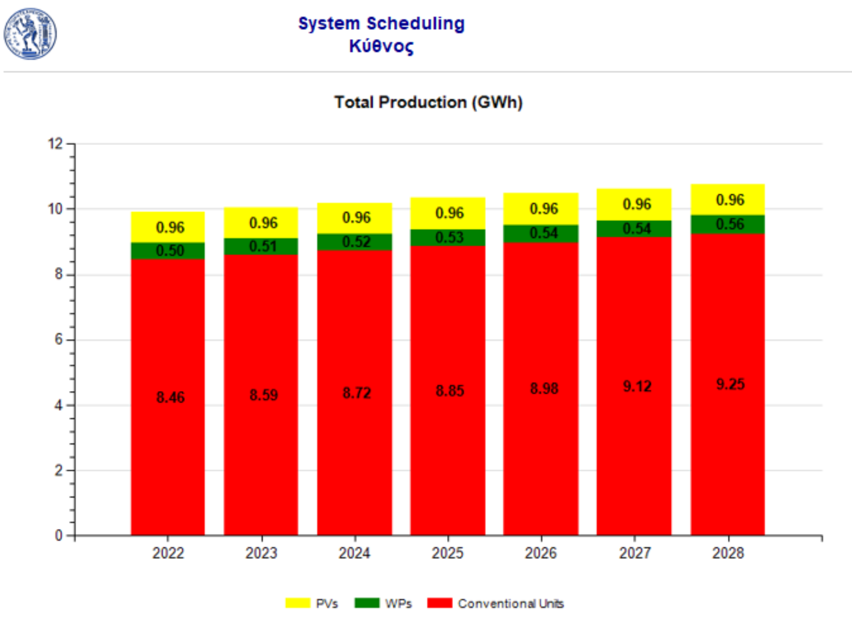


Figure 31 Report output from ecoPlanning displaying the energy mix over the selected horizon simulated

Aggregated results

	2022	2023	2024	2025	2026	2027	2028
Thermal production (MWh)	8,460.00	8,589.88	8,722.20	8,853.20	8,984.96	9,119.60	9,247.88
RES production (MWh)	1,467.50	1,477.32	1,484.70	1,493.30	1,501.24	1,506.30	1,517.72
Demand (MWh)	9,927.50	10,067.20	10,206.90	10,346.50	10,486.20	10,625.90	10,765.60
Annual RES penetration (% of load)	14.78	14.67	14.55	14.43	14.32	14.18	14.10
Maximum instantaneous	55.57	54.85	54.50	53.85	53.21	52.91	52.60
WPs equivalent full load hours (h)	2,397.42	2,436.20	2,480.53	2,546.34	2,597.16	2,647.28	2,718.65
WPs capacity factor (%)	11.53	11.75	11.92	12.12	12.30	12.41	12.67
Diesel consumption (klt)	2,306.04	2,340.94	2,376.27	2,410.30	2,445.39	2,481.30	2,515.00
Mazut consumption (tn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2 emissions (tn)	6,144.32	6,237.31	6,331.46	6,422.12	6,515.61	6,611.31	6,701.10

General parameters

	2022	2023	2024	2025	2026	2027	2028
Reserves: N-1 Rule	No	No	No	No	No	No	No
Reserves: per Load	Max	Max	Max	Max	Max	Max	Max
Reserves: per RES	Max	Max	Max	Max	Max	Max	Max
Proportional dispatch of conventional units	No	No	No	No	No	No	No
Economic dispatch of conventional units	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Unit Cost - Heavy Diesel (€/tn)	480.00	480.00	480.00	480.00	480.00	480.00	480.00
Unit Cost - Light Diesel (€/klit)	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00
CO2 emissions price (€/tn)	22.00	22.00	22.00	22.00	22.00	22.00	22.00
RES Penetration (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Instantaneous wind penetration CD (%)	35.00	35.00	35.00	35.00	35.00	35.00	35.00
Wind dynamic margin: CD per Load	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind dynamic margin: CD per Load (variation)	No	No	No	No	No	No	No
Wind dynamic margin: CD per committed conventional	No	No	No	No	No	No	No
Wind dynamic margin: Sum of conventional and	No	No	No	No	No	No	No

Figure 32 Report output from ecoPlanning displaying the aggregated results and the general parameters over the selected horizon simulated

More detailed field test and validation results are available in deliverable D7.4 - “Report demonstration round 1 (testing)” [13].

4.3.3 Assessment summary

The ecoPlanning tool was applied in the Kythnos demo site, Greece as well as in Keonjhar, India. It was designed to aid in the mid-term planning for electricity generation, considering both conventional and renewable energy sources. The tool performs energy planning for islands and regions with weak or non-existent grids, offering capabilities such as assessing renewable energy sources' hosting capacity, evaluating interconnection advantages, and providing energy production forecasts, fuel consumption estimates, cost calculations, and CO2 emission reductions.

During its deployment at Kythnos, the tool has undergone initial testing and real-world application in line with the project's goals. The tool can help to optimize the energy mix and resource management for the area, considering various long-term factors.

During its deployment at Keonjhar, the tool operated as a real-world application in line with the project's goals, to assess the growth of the energy mix in an optimal way considering factors such as the growth of the population, the evolution of electrical demand, etc.

Overall, the ecoPlanning tool demonstrated a high degree of reliability and robustness and showed the capability of addressing real-world challenges, thereby successfully achieving project goals and demonstrating technology readiness level of 9 (TRL 9). It should be noted that the start TRL of ecoPlanning was 9, as it was a mature solution that has been updated and expanded in RE-EMPOWERED.

4.4 ecoDR

4.4.1 Current stage of development

The performance of the developed ecoDR tool was initially validated in the CSIR-CMERI laboratory through a series of experiments. It was subsequently deployed in field trials at all the four demo sites: Ghoramara and Keonjhar in India, Gaidouromantra (Kythnos) in Greece and in Denmark.

4.4.2 Test results, analysis and validation data

The ecoDR tool has undergone a rigorous evaluation and laboratory testing process to assess its capabilities and functionalities. A series of experiments was performed using the laboratory facilities at CSIR-CMERI. These experiments aimed to thoroughly test the functionalities of the energy meter prior to their deployment in the field. In these series of tests, ecoDR was tested for its measuring precision and accuracy for electric power, voltage and current, and its advanced functionalities, e.g., maximum power and energy threshold, variable cut off delay, and non-critical load scheduling using actual load. Finally, the whole hardware was tested in a setup providing evidence of the precision and robustness of the operation of the meter. Tests were also conducted to test the bi-directional communication between the ecoDR and the ecoMicrogrid.

A detailed performance analysis and test results are available in deliverable D4.1 – “Development of the ecoEMS, ecoMicrogrid and ecoDR” [7].

Following the successful laboratory experimentation, the ecoDR tool was field deployed and tested at all the four demo site in EU and India.

At Gaidouromantra demo site, the ecoDR tool has been installed at the system house to interface with the flexible load of the Heating Ventilation and Air Conditioning (HVAC) system. This installation is designed to monitor the energy consumption of the flexible load and support the start/stop functionality of the flexible load. The real time monitoring of energy consumption was validated by providing real-time energy consumption data. This data is accessible through both the local display screen and the Modbus TCP interface. The ecoDR system includes a display unit for real-time visualization of energy measurements, while the Modbus TCP interface enables external acquisition of energy parameters for further analysis.

Figure 33 ecoDR installed in Gaidouromantra

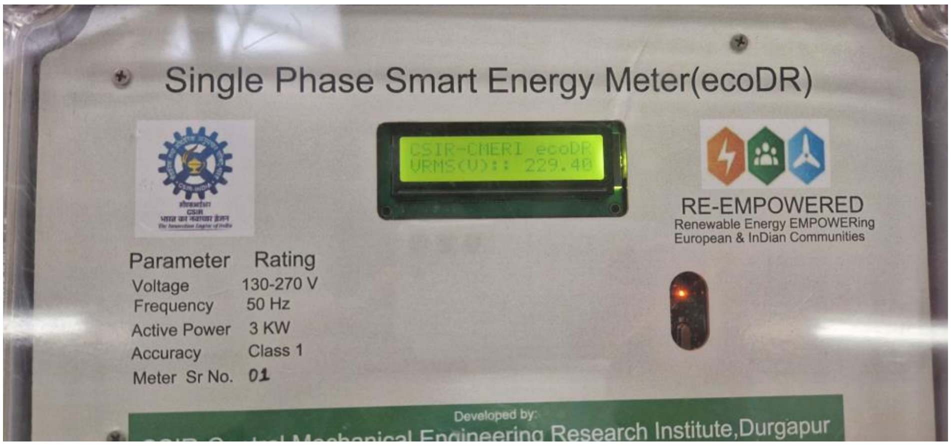


Figure 34 The display of ecoDR in Gaidouromandra

Similarly, at Ghoramara demo site, the real time monitoring of energy consumption was validated by installing one ecoDR tool at the demo site and connecting the electrical appliances (such as lights and fans) of the high school as load. As can been seen in the below figure, the real time data of electrical parameters such as voltage, current, energy consumption are being monitored and displayed.

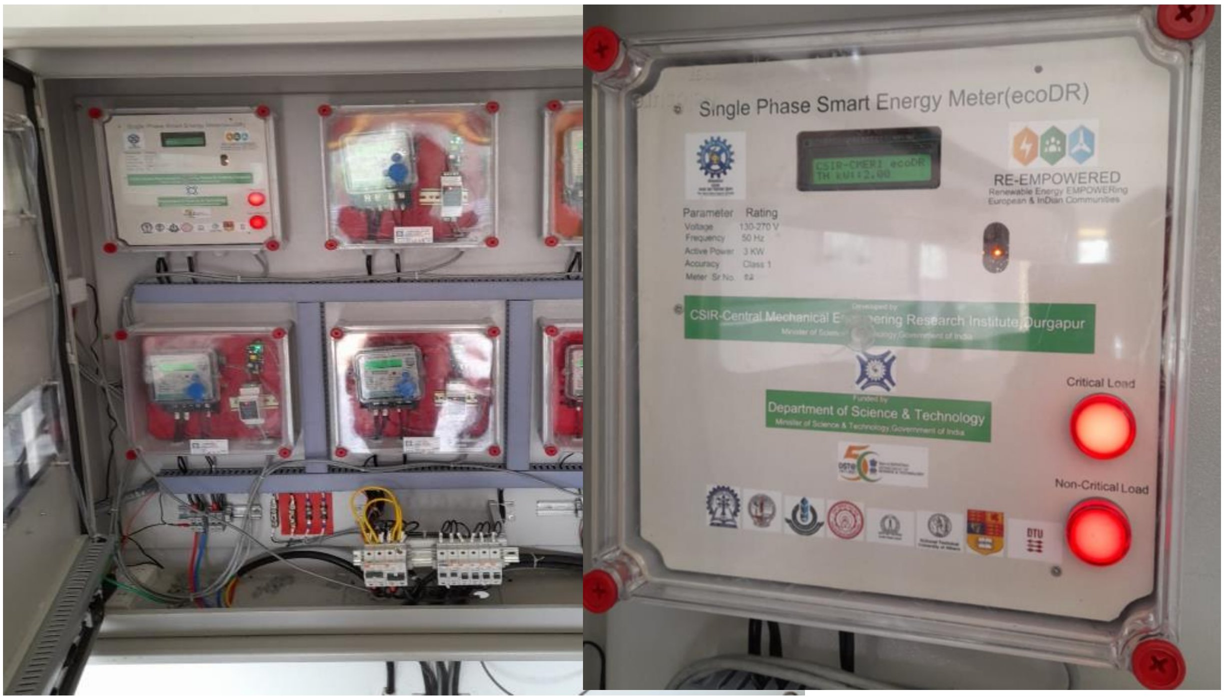


Figure 35 ecoDR (top left of the left picture) installed at Ghoramara and ecoDR monitoring load threshold data

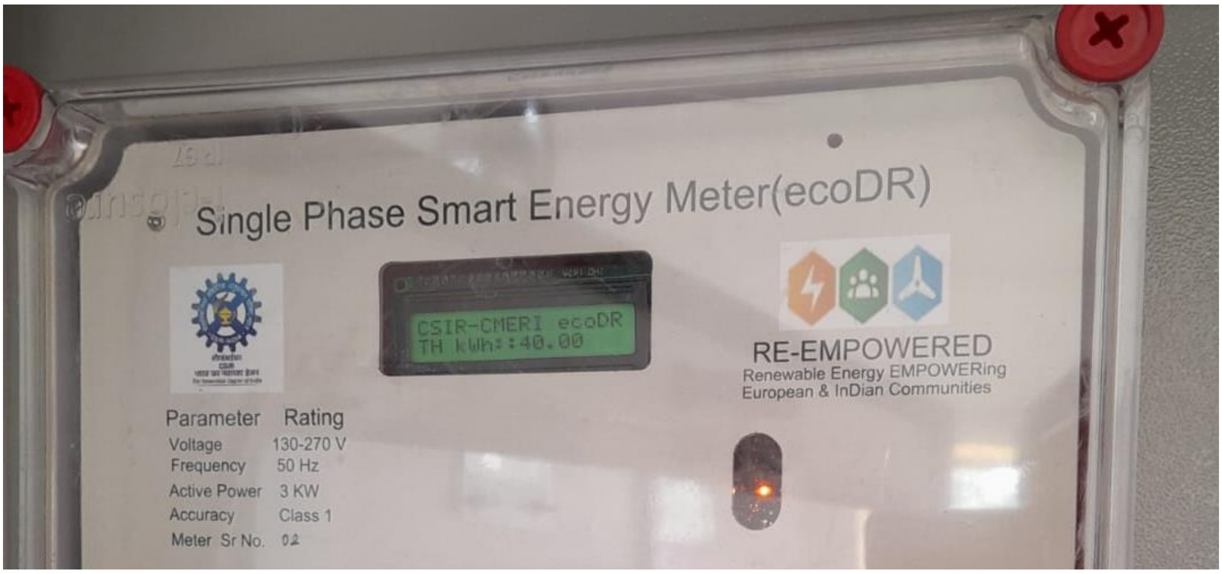


Figure 36 ecoDR monitoring energy consumption for connected load

The load scheduling functionality was validated by issuing a load ON/OFF command to a load connected to the non-critical port of the ecoDR device. The figure below demonstrates that upon receiving load scheduling commands, such as a disconnect instruction, there is no energy consumption recorded for loads connected to the non-critical port.

Figure 37 : ecoDR demonstrating energy consumption (as nil) of non-critical load when load scheduling command received from ecoMicrogrid

The following table validates the status of non-critical load due to load scheduling commands received from ecoMicrogrid.

Table 9: Validation for status of non-critical load due to load scheduling commands from ecoMicrogrid

Sl no.	Command sent from ecoMicrogrid (PC) via MODBUS	Status of the Critical Load	Status of the Non-critical Load
1.	Initial State	ON	ON
2.	Coil 1 set to 0	ON	OFF
3.	Coil 1 set to 1	ON	ON

A detailed field test and validation results are available in deliverable D7.4 "Report demonstration round 1 (testing)" [13].

4.4.3 Assessment summary

The ecoDR tool has undergone both laboratory testing and field demonstration at project demonstration sites. In particular, during field trials at Ghoramara, ecoDR was tested for its measuring precision and accuracy for electric power, voltage and current, and its advanced functionalities, e.g., maximum power and energy threshold, variable cut off delay and non-critical load scheduling using actual load. Tests were also conducted to assess the bi-directional communication between the ecoDR and the ecoMicrogrid.

During the tests of ecoDR, the accuracy of measurements of voltage and current was deemed satisfactory. Moreover, ecoDR promptly responded to programmable load and energy limits set via MODBUS communication, enabling quick load cutoff at meter output on detection of overloads. Also, ecoDR functionality for scheduling of non-critical load proved to be reliable, successfully enabling the activation and deactivation of non-critical meter ports within a short interval after transmission of commands via MODBUS.

The demonstration of the ecoDR tool at the Gaidouromantra system house successfully validated its real-time energy monitoring capabilities. The tool's display unit provided accurate real-time visualization of energy consumption data for the HVAC system's flexible load.

Overall, the ecoDR tool demonstrated a high degree of reliability, successfully achieving project goals and demonstrating TRL 7.

4.5 ecoPlatform

4.5.1 Current stage of development

The performance of the developed ecoPlatform (A) was initially validated at DTU. It was subsequently deployed in field trials at Bornholm demo site in Denmark. ecoPlatform (B) was deployed in field trials at Kythnos, Keonjhar and Ghoramara.

4.5.2 Test results, analysis and validation data

At Bornholm demo site, the primary objective was to ensure stable and seamless data exchange across all tools and assets. This involves conducting multiple full-cycle data exchanges to thoroughly assess the platform's functionality, identify any technical issues, and implement necessary fixes.

During testing at Bornholm, the Sensors originated from two primary sources. One, the biomass fueled heat plant in Østerlars. Two, the project participants and their related consumptions and temperatures from each smart meter.

Data from heat plant

Inside the heat plant a SCADA system is used to control operation. A data integration from the SCADA system to the ecoTools have been established. A continuous export to a SQL database is landing inside the company data platform using Azure Data Factory. From Data Factory the data is wrangled to a curated dataset using Azure Databricks. From Databricks a number of pipelines are created to run the related to notebooks to finally publish data to the ecoPlatform using MQTT protocol.

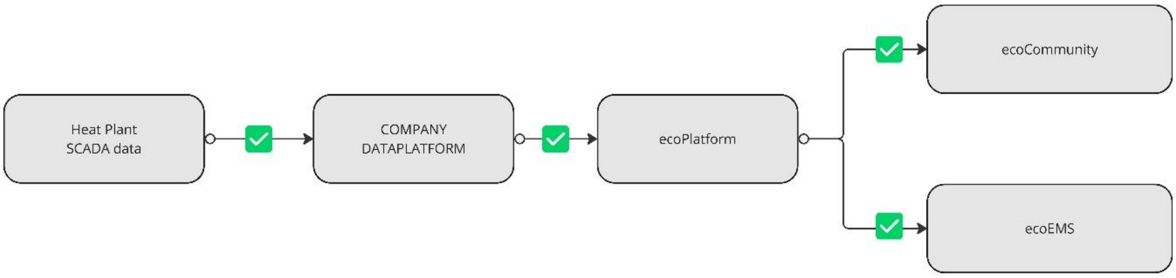


Figure 38 Process diagram illustrating the dataflow from SCADA to ecoTools

Figure 39 Pipeline wrangling the raw SCADA data to the specific needs of RE-EMPOWERED

The ecoPlatform is also designed to manage and process time series data, which consists of time-value pairs. To submit data into the ecoPlatform, users must utilize the platform's MQTT or HTTP APIs. These APIs facilitate interaction between data providers and consumers and ensure secure data transactions. Figure 40 illustrates a temperature plot of the outlet electric boiler as displayed on the ecoPlatform, which is an efficient way of visualizing the data in the data stream.

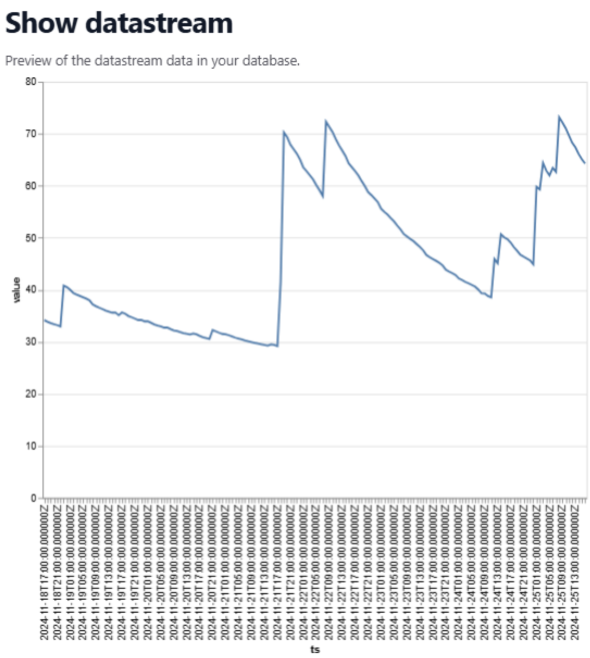


Figure 40 Temperature of the outlet electric boiler on ecoPlatform.

Before submitting time series data, datasets and data streams must first be created via the ecoPlatform web UI. Any user with access to the web UI can create datasets, becoming their respective owners. Dataset owners can manage data streams, assign additional dataset owners, and define critical attributes such as data bounds and silence periods. Figure 41 shows a sample view of the ecoPlatform dataset configuration.

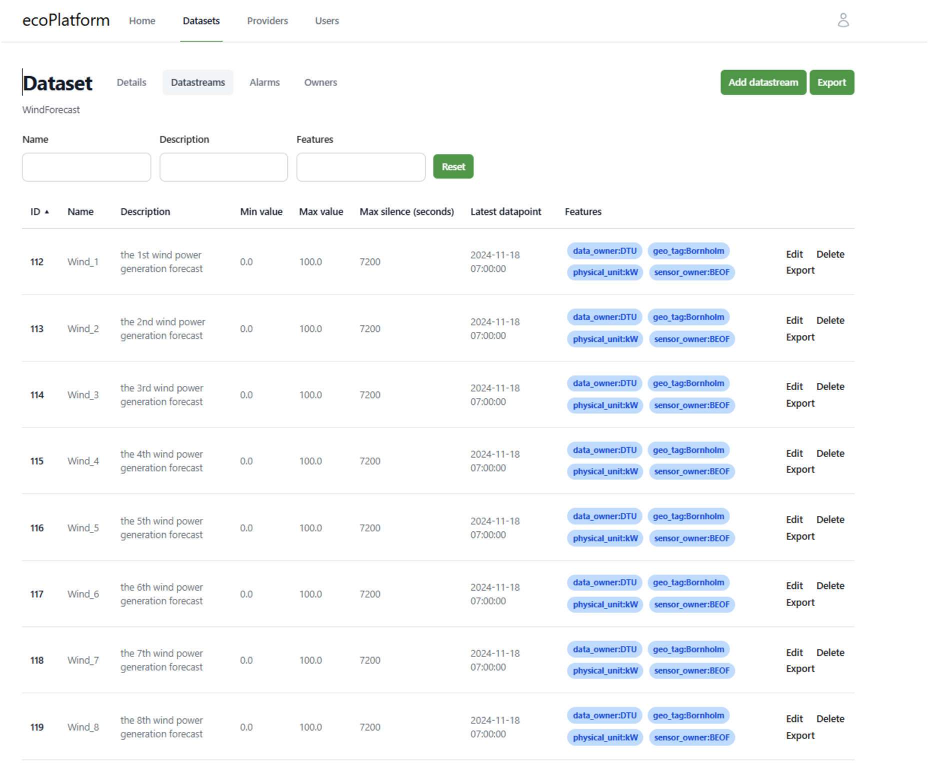
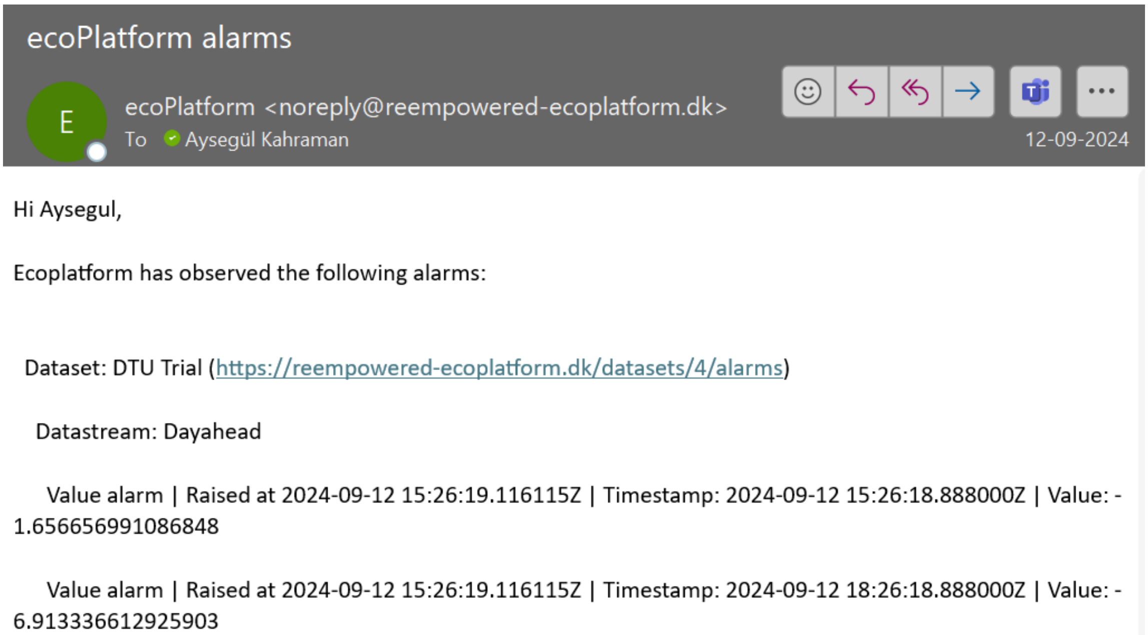


Figure 41 Screenshot of ecoPlatform dataset configuration showing minimum and maximum value bounds and maximum silence settings.

Figure 42 Figure 42 shows how the ecoPlatform notifies dataset owners of observed alarms, such as value alarms or silence alarms. The email contains details including the dataset name, the data stream name, the type of alarm, the timestamp, and the corresponding value of the datapoint that triggered the alarm. This feature ensures that dataset owners can promptly address data irregularities maintaining the integrity of time series data.



ecoPlatform alarms

ecoPlatform <noreply@reempowered-ecoplatform.dk>
To Aysegül Kahraman
12-09-2024

Hi Aysegul,

Ecoplatform has observed the following alarms:

Dataset: DTU Trial (https://reempowered-ecoplatform.dk/datasets/4/alarms)

Datastream: Dayahead

Value alarm | Raised at 2024-09-12 15:26:19.116115Z | Timestamp: 2024-09-12 15:26:18.888000Z | Value: -1.656656991086848

Value alarm | Raised at 2024-09-12 15:26:19.116115Z | Timestamp: 2024-09-12 18:26:18.888000Z | Value: -6.913336612925903

Figure 42 Example of an email notification from the ecoPlatform alarm system.

By implementing these robust data cleansing and management protocols, the ecoPlatform ensures high-quality data storage and seamless communication between various ecoTools, including ecoEMS, ecoCommunity, ecoDR, ecoMonitor, forecasting services, and edge devices. This approach establishes a reliable foundation for further analytical processing and system-wide interoperability.

A more detailed field test and validation results are available in deliverable D7.4 - "Report demonstration round 1 (testing)" [13].

4.5.3 Assessment summary

The ecoPlatform tool has undergone rigorous testing and deployment to demonstrate its effectiveness.

Laboratory Testing:

- Laboratory testing was conducted at the DTU facilities, focusing on facilitating optimization of energy distribution and support integration across various decentralized energy resources.

Field Deployment:

- The ecoPlatform (A) tool was implemented in the Bornholm island in Denmark. The tool was tailored to meet the specific needs of the application, by collecting and transferring data between various tools and assets that helped manage electricity consumption and optimize the performance of heating systems, like electric boilers, to match renewable energy availability.

These two stages validated the real world functionality and performance in a dynamic energy environment of the ecoPlatform tool.

Overall, the ecoPlatform tool exhibited a high level of maturity, successfully achieving the project's targeted TRL of 8.

4.6 ecoConverter

4.6.1 Current stage of development

The performance of the developed ecoConverter tool was initially validated in the laboratory of IIT Kharagpur. It has then been planned for field validation at Ghoramara demo site in India.

4.6.2 Test results, analysis and validation data

Following the successful development, prototypes of PPC and plug-and-play type inverter have been developed in laboratory at 10 kW power level. Photographic views of these prototypes are shown in Figure 43. Using these prototypes of PPC and inverter, a Microgrid is developed for the testing of various RE-EMPOWERED developed ecoTools.

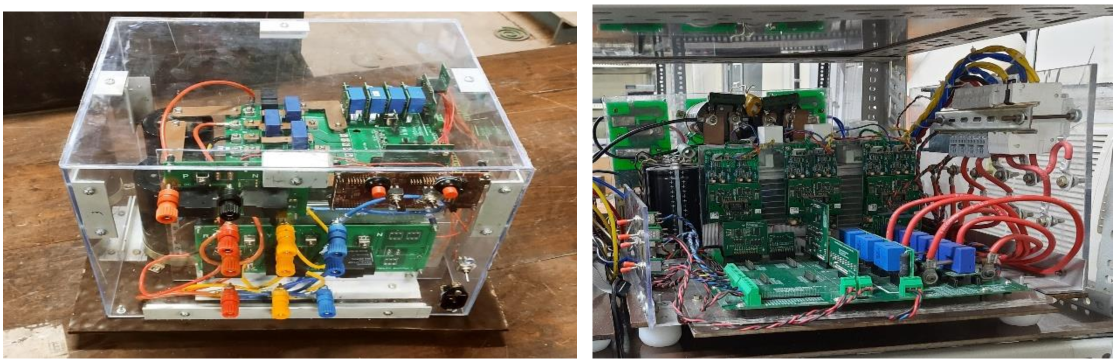


Figure 43: (a) Prototype of plug-and-play type dc-ac inverter (b) Prototype of PPC.

To overcome the issue of partial shading, a Particle Swarm Optimization (PSO) based method was proposed which has capability to find out the global peak at less time with good accuracy. Performance of the PSO based search algorithm is shown in Figure 44. The hardware of the microgrid is initially tested in grid-connected mode. The current waveforms are sinusoidal containing THD.

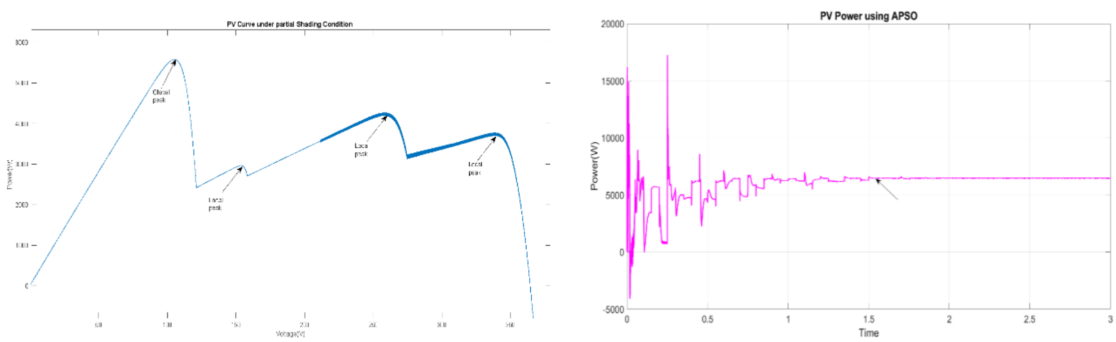


Figure 44: (a) Searching of global power peak using PSO (b) Error in searching the global peak

Figure 45 ecoConverter developed for field testing in Ghoramara

ecoConverter was deployed at Ghoramara demo site. However, its full scale demonstration is in progress.

More details are available in deliverable D7.4 - "Report demonstration round 1 (testing)" [13].

4.6.3 Assessment summary

The ecoConverter tool was successfully developed and validated in a relevant environment representing field conditions, thereby achieving TRL of 5. It was deployed in Ghoramara demo site, but demonstration is still in progress due to technical difficulties, therefore the target TRL 8 has not been reached.

4.7 ecoMonitor

4.7.1 Current stage of development

The performance of the developed ecoMonitor tool was initially validated in the CSIR-CMERI laboratory. It was subsequently deployed in field trials at the three demo sites: Ghoramara in India, Kythnos in Greece and in Denmark.

4.7.2 Test results, analysis and validation data

The ecoMonitor tool has undergone a rigorous evaluation and field testing process to assess its capabilities and functionality.

During laboratory performance evaluation, the ecoMonitor tool was installed in outdoor environment within the premises of CSIR-CMERI. The outdoor air quality index parameter data acquired in real time at serial monitor output is displayed in following figure. It can be seen that the acquired air quality index data are all within the acceptable limit.

```
15:56:08.682 -> Ambient NO2 concentration is: 0.06 PPM
15:56:08.824 ->
15:56:17.593 -> Ambient SO2 concentration is: 0.40 PPM
15:56:17.687 ->
15:56:26.666 -> Ambient CO concentration is: 0.00 PPM
15:56:26.761 ->
15:56:35.239 -> Ambient O3 concentration is: 0.00 PPM
15:56:35.333 ->
15:56:43.651 -> PM2.5 concentration:77 ug/m3
15:56:44.645 -> PM10 concentration:88 ug/m3
15:56:59.295 ->  Temperature:29.61C Humidity:78.67%
15:57:21.156 -> Ambient NO2 concentration is: 0.06 PPM
15:57:21.251 ->
15:57:29.828 -> Ambient SO2 concentration is: 0.40 PPM
15:57:29.923 ->
15:57:38.938 -> Ambient CO concentration is: 0.00 PPM
15:57:39.033 ->
15:57:47.473 -> Ambient O3 concentration is: 0.00 PPM
15:57:47.614 ->
15:57:55.890 -> PM2.5 concentration:75 ug/m3
15:57:56.882 -> PM10 concentration:87 ug/m3
15:58:11.540 ->  Temperature:29.61C Humidity:78.82%
15:58:33.431 -> Ambient NO2 concentration is: 0.06 PPM
15:58:33.526 ->
15:58:42.310 -> Ambient SO2 concentration is: 0.40 PPM
15:58:42.402 ->
15:58:51.384 -> Ambient CO concentration is: 0.00 PPM
15:58:51.479 ->
15:58:59.954 -> Ambient O3 concentration is: 0.00 PPM
15:59:00.049 ->
15:59:08.364 -> PM2.5 concentration:80 ug/m3
15:59:09.351 -> PM10 concentration:94 ug/m3
15:59:24.008 ->  Temperature:29.61C Humidity:78.28%
15:59:45.851 -> Ambient NO2 concentration is: 0.06 PPM
15:59:45.993 ->
15:59:54.775 -> Ambient SO2 concentration is: 0.40 PPM
15:59:54.870 ->
16:00:03.832 -> Ambient CO concentration is: 0.00 PPM
16:00:03.926 ->
16:00:12.392 -> Ambient O3 concentration is: 0.00 PPM
16:00:12.487 ->
16:00:20.793 -> PM2.5 concentration:72 ug/m3
16:00:21.801 -> PM10 concentration:85 ug/m3
16:00:36.442 ->  Temperature:29.63C Humidity:78.28%
16:00:58.324 -> Ambient NO2 concentration is: 0.00 PPM
16:00:58.418 ->
16:01:07.205 -> Ambient SO2 concentration is: 0.40 PPM
16:01:07.299 ->
16:01:16.304 -> Ambient CO concentration is: 0.00 PPM
16:01:16.399 ->
16:01:24.859 -> Ambient O3 concentration is: 0.00 PPM
16:01:24.953 ->
16:01:33.267 -> PM2.5 concentration:78 ug/m3
16:01:34.278 -> PM10 concentration:92 ug/m3
16:01:48.924 ->  Temperature:29.61C Humidity:78.59%
16:02:10.800 -> Ambient NO2 concentration is: 0.06 PPM
16:02:10.895 ->
16:02:19.665 -> Ambient SO2 concentration is: 0.30 PPM
16:02:19.760 ->
16:02:28.754 -> Ambient CO concentration is: 0.00 PPM
16:02:28.848 ->
16:02:37.309 -> Ambient O3 concentration is: 0.00 PPM
16:02:37.405 ->
16:02:45.698 -> PM2.5 concentration:71 ug/m3
16:02:46.700 -> PM10 concentration:82 ug/m3
16:03:01.373 ->  Temperature:29.61C Humidity:78.65%
16:03:23.227 -> Ambient NO2 concentration is: 0.06 PPM
16:03:23.322 ->
16:03:32.103 -> Ambient SO2 concentration is: 0.30 PPM
16:03:32.243 ->
16:03:41.182 -> Ambient CO concentration is: 0.00 PPM
16:03:41.323 ->
16:03:49.773 -> Ambient O3 concentration is: 0.00 PPM
16:03:49.869 ->
16:03:58.179 -> PM2.5 concentration:73 ug/m3
16:03:59.172 -> PM10 concentration:85 ug/m3
16:04:13.828 ->  Temperature:29.58C Humidity:78.73%
16:04:35.706 -> Ambient NO2 concentration is: 0.06 PPM
16:04:35.801 ->
16:04:44.598 -> Ambient SO2 concentration is: 0.30 PPM
16:04:44.693 ->
16:04:53.663 -> Ambient CO concentration is: 0.00 PPM
16:04:53.756 ->
16:05:02.241 -> Ambient O3 concentration is: 0.00 PPM
16:05:02.335 ->
16:05:10.632 -> PM2.5 concentration:71 ug/m3
16:05:11.622 -> PM10 concentration:86 ug/m3
16:05:26.278 ->  Temperature:29.57C Humidity:79.11%
```

Figure 46: Outdoor air quality index data acquired in real time

After laboratory testing, the ecoMonitor tool was field deployed for its performance evaluation. In Kythnos demo site, the ecoMonitor tool was installed at Merichas Primary School. Merichas, the primary port of Kythnos Island, serves as a significant hub for maritime activities, making it useful to monitor air quality in this area. Key activities conducted during this field validation included:

- **On-Device Monitoring:** Monitored critical AQI parameters, including CO, Ozone, SO_2, NO_2, PM2.5, PM10, temperature, and humidity in real time, to capture environmental conditions and ensure continuous air quality assessment.

Figure 47 illustrates a sample of the collected measurements at Kythnos demo site.

Figure 47 Real time monitoring of air quality parameters SO2 (left) and Temperature (right).

Similarly, its performance was evaluated in field by installing at Ghoramara demo site and capturing real time data. key AQI parameters such as CO, Ozone, SO2, NO2 PM2.5 and PM10, temperature and humidity parameters are monitored in real time. The following figures demonstrate that most of the AQI parameters are within permissible limit.

Figure 48 Real time monitoring of air quality parameters CO (left) and Ozone (right)

A detailed field test and validation results are available in deliverable D7.4 "Report demonstration round 1 (testing)" [13].

4.7.3 Assessment summary

The ecoMonitor tool has undergone both laboratory testing and field demonstration at project demonstration sites.

The monitoring process was successfully validated. During the first demonstration period, all AQI parameters were found to be within permissible limit. This outcome demonstrated the effective operation of the ecoMonitor platform in monitoring environmental parameters.

Overall, the ecoMonitor tool was successfully demonstrated in field operation with a high degree of reliability, thereby successfully achieving project goals and demonstrating TRL 7.

4.8 ecoCommunity

4.8.1 Current stage of development

The performance of the developed ecoCommunity tool was initially validated in the ICL London. It was subsequently tested in field trials at Gaidouromandra (Kythnos), Bornholm and Keonjhar. It was partly tested at Ghoramara, India.

4.8.2 Test results, analysis and validation data

Following the successful development, the first round of demonstrations of the ecoCommunity tool in Gaidouromandra (Kythnos) demo site was conducted on 8th October 2024. To validate the functionality of displaying dynamic pricing information, a pricing module has been developed whose screenshot is provided below.

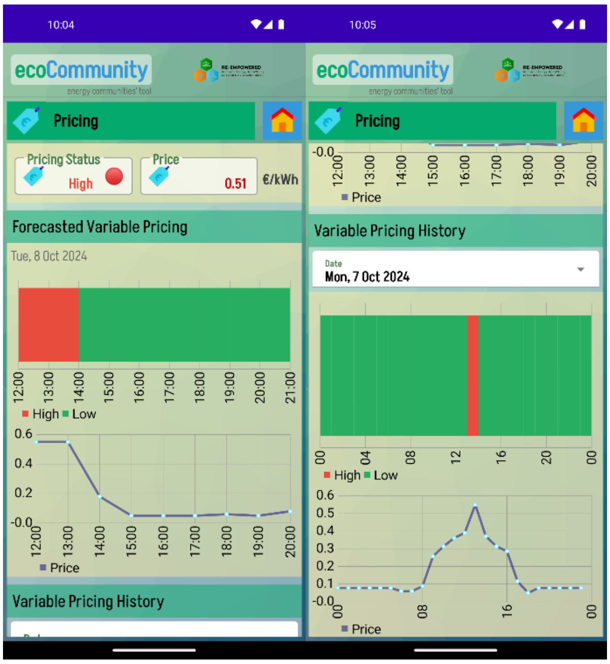


Figure 49 Screenshots of ecoCommunity Pricing Module for Gaidouromandra demo site (Left) Forecasted pricing for next set of hours (Right) pricing variation during the previous day

A red-green pricing band indicates the high-low forecasted pricing for the following hours. The forecast is updated every hour based on the data received from ecoMicrogrid. It provides consumers with an indication of whether or not they should use the noncritical loads. The module aims for voluntary control over the consumption of the consumers, so that the energy system stays stable and efficient.

Data security and privacy is considered as an important requirement for the tool. The access to the tool is restricted through username and password. The user will have to enter the login credentials when they are using the tool on a new device.

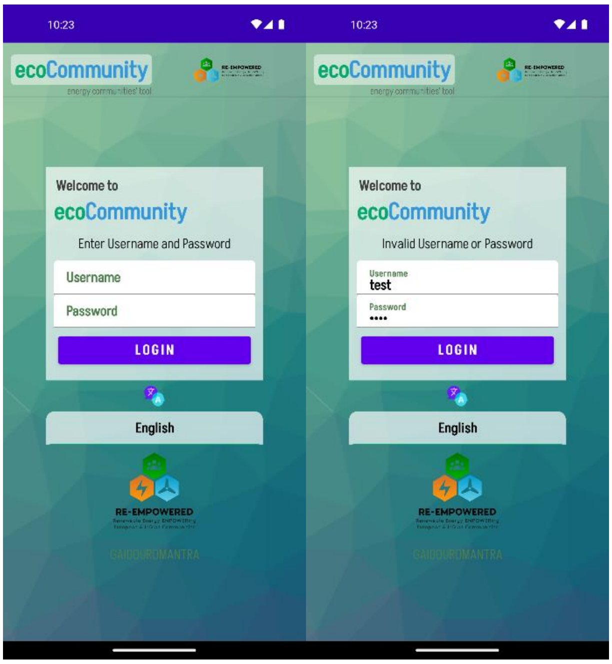


Figure 50 Screenshots of ecoCommunity login page for Gaidouromandra demo site (Left) login page (Right) error message for invalid credentials

A total of four consumers and two administrators were included to the tool user database during the first round of demonstration.

The functionality of facilitating(display) of the scheduling and shifting of non-critical and flexible loads was demonstrated by indicating a set of time slots which can be booked by the consumers for the use of noncritical consumer loads. In case of Gaidouromandra the consumers utilized this facility to book time slots for the use of water pumps based on the available energy. The screenshots of the booked time slot from the consumer user interface and the increase in energy consumption during that period are shown in the following screenshots.

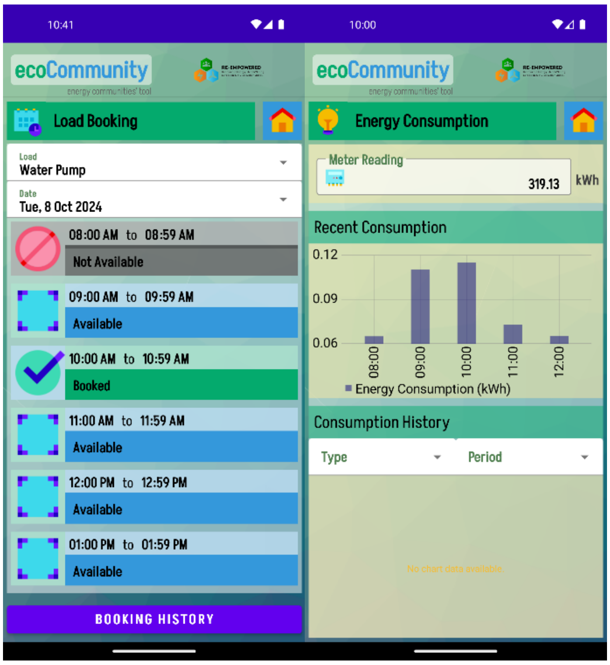


Figure 51 Screenshots of flexible load booking use case in Gaidouromandra demo site (Left) consumer interface showing the booking details (Right) consumer consumption during the booked period

A more detailed field test and validation results are available in deliverable D7.4 - "Report demonstration round 1 (testing)" [13].

4.8.3 Assessment summary

The ecoCommunity was tested in by ICL and subsequently demonstrated in an relevant environment representing project demo sites. This tool is designed to enhance community engagement, increase participation in energy projects, and promote acceptance of advanced energy technologies.

The tool's functionalities include dynamic pricing mechanisms for residential loads, electronic billing, feedback mechanisms, and managing non-critical loads, all tailored to meet the specific needs of energy-disadvantaged communities. Its deployment at field allowed for real-world testing in an environment focused on sustainability and community-driven energy management, advancing its TRL.

Overall, the ecoCommunity tool was tested in an environment representing field conditions, thereby successfully achieving a TRL of 7. It has advanced more than the anticipated TRL 6.

4.9 ecoVehicle

4.9.1 Current stage of development

The performance of the developed ecoVehicle tool (charger) was initially validated in the laboratory of VNIT Nagpur. It was subsequently planned for field testing at Ghoramara and Keonjhar demo sites in India.

4.9.2 Test results, analysis and validation data

Following the successful development of 1.5 kW battery charger prototype, its functionalities were tested in laboratory. The fabricated charger and control circuit mounted on PCB is shown in Figure 52. The hardware testing of the setup is done in the laboratory and experimental results are shown in Figure 53.

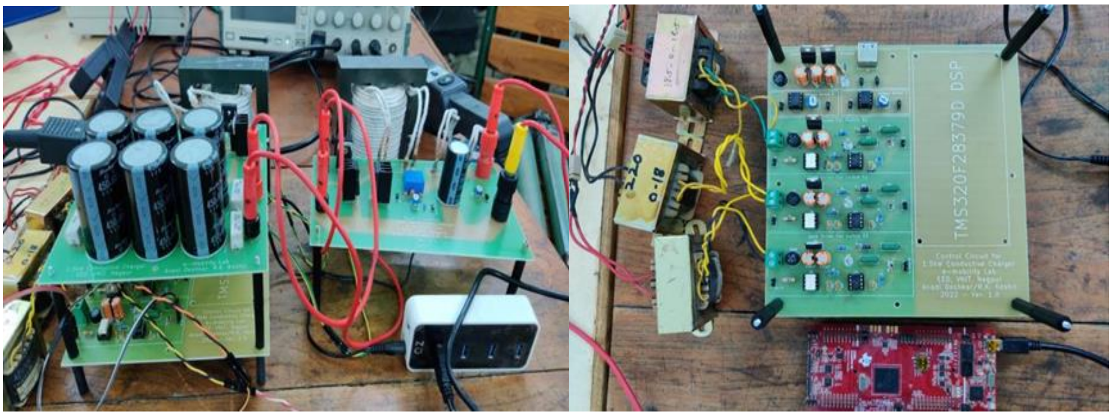


Figure 52: Fabricated Charger and control circuit on PCB.

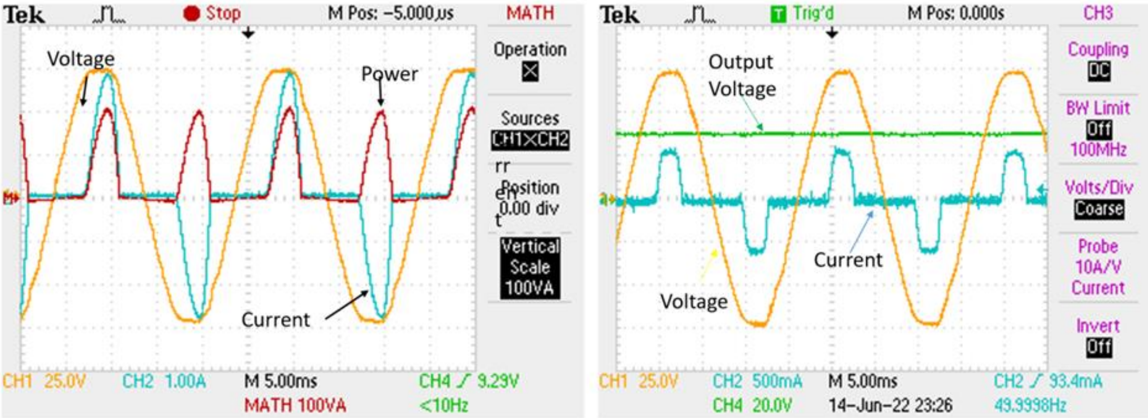


Figure 53: Hardware Results without PFC.

The hardware results of DC bus voltage with pre charging and pulse charging is shown in Figure 54.

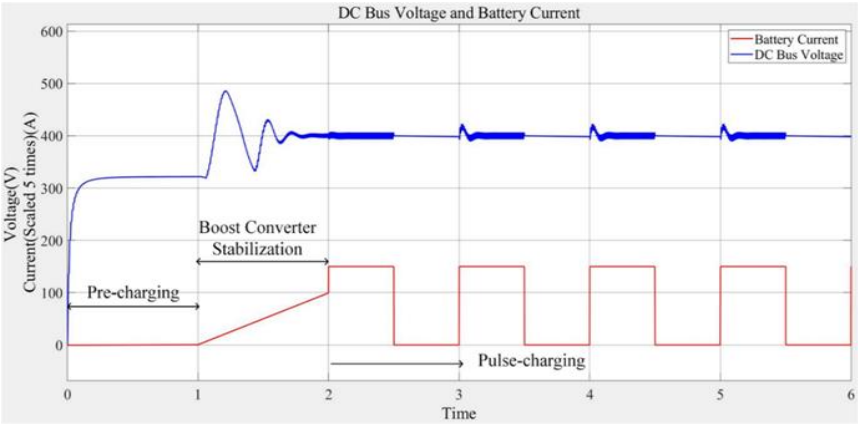


Figure 54: DC Bus Voltage with pre charging and pulse charging.

The hardware results of PLL are shown in Figure 55Figure 55: Hardware Results of PLL.Figure 55: Hardware Results of PLL.. The pink color waveform indicates the supply voltage followed by the other desired waveforms.

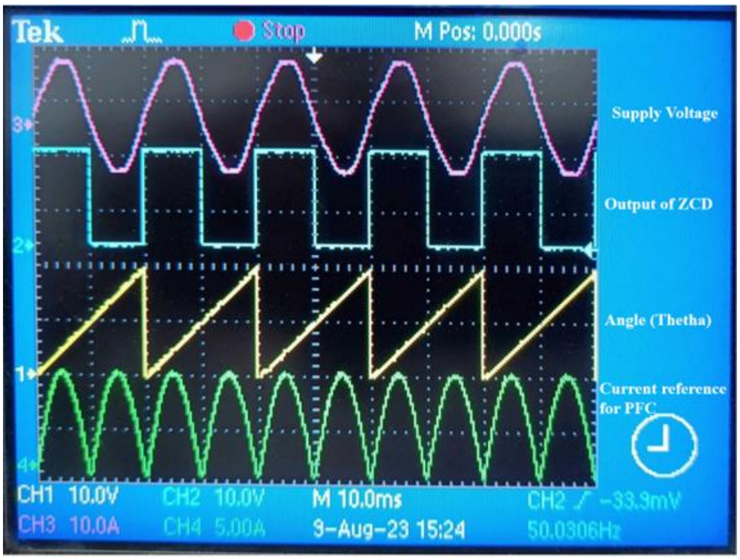


Figure 55: Hardware Results of PLL.

A more detailed description of ecoConverter tool is available in D4.2 – "*Development of the ecoConverter and ecoVehicle*" [8].

4.9.3 Assessment summary

The ecoVehicle tool was successfully developed and tested in a laboratory environment representing field conditions, thereby achieving TRL of 5. Until now, it has not been possible to achieve the target TRL 8.

4.10 ecoResilience

4.10.1 Current stage of development

The performance of the developed cyclone resilient support structure PV and hybrid support structure for wind under ecoResilience tool was initially validated in the laboratory of CSIR-CMERI Durgapur. It was subsequently field tested at Ghoramara demo site in India.

The performance of the developed LMSWT under ecoResilience tool was initially tested in both the laboratories of ICCS-NTUA and CSIR-CMERI Durgapur. It was subsequently field tested at Kythnos Island in Greece. Testing in Ghoramara demo site is expected soon.

4.10.2 Test results, analysis and validation data

Following the successful development of PV support structure under ecoResilience tool, its performance was validated through wind tunnel testing having base and add-on structures configurations.

Figure 56 Preliminary design with numerical simulations. The structure had some low-frequency oscillations

It is observed that the mechanism was working fine for many flow velocities with both head and tail wind conditions. It was noticed that the experiments with angle sections at the vertical support experienced some vibrations during the activation of the mechanism. Further, it is noticed that supporting the solar panels through only solar PV frame have induced bent of panels at extreme wind conditions (See above structure). Hence, the vertical support is made with a box structure with stiffeners and a rectangular frame is attached with each PV panel for ensuring stability.

Figure 57: Final fabricated prototype of the solar PV support structures being installed at Ghoramara demo site.

Following the successful development of hybrid support structure for wind turbine under ecoResilience tool, its performance was validated at Ghoramara demo site. The following figure shows the hybrid structure installed at Ghormara demo site.

Figure 58: Installation of tower at testing at CSIR-CMERI & demo site, Ghoramara for power generation.

Correspondingly, after the successful manufacturing of LMSWT system under ecoResilience tool at NTUA with the student team, it was then installed in December 2022 at the demo site of Gaidouromantra on Kythnos island, along with project partner DAFNI, as part of the RE-EMPOWERED project. During the installation workshop, ICCS-NTUA researchers and DAFNI staff, along with students from the mechanical engineering school of the NTUA, marked the footprint of the tower on the site, placed the tower anchors and concrete blocks, installed the tower and guy wires, raised the small wind turbine, and connected it to the local micro-grid of Gaidouromantra (Figure 59).

Figure 59: The LMSWT installed in the microgrid (left), Inverter, over-voltage protection and dump loads (right)

More detailed field test and validation results, including performance results of the LMSWT are available in deliverable D7.4 - "Report demonstration round 1 (testing)" [13] and D4.3 – "*Development of the ecoMonitor and ecoResilience*" [9].

4.10.3 Assessment summary

The cyclone resilient support structure for PV and hybrid support structure for wind under ecoResilience tool has undergone rigorous design and analysis phases, with prototype development, testing, and implementation at demonstration sites like Ghoramara Island in India. The cyclone-resilient support structures for ground-mounted solar PV systems are optimized to minimize aerodynamic wind loads through numerical simulations, wind tunnel experiments, and field tests. On the other hand, the hybrid support structures for wind turbines are tailored for extreme weather resilience, these structures are intended for small wind turbines. Local manufacturing are emphasized to leverage community resources, enabling faster maintenance and minimizing downtime. This part of the ecoResilience tool was successfully developed and validated in a relevant environment representing field conditions, thereby achieving TRL of 6.

The other part of ecoResilience tool, a small wind turbine system was successfully manufactured and tested in collaboration with local communities and academic collaborations. Workshops, such as one held in 2024 at CSIR-CMERI in India, emphasized practical construction techniques and the use of simple, durable designs. The turbine was further validated in Gaidouromantra (Kythnos), demonstrating feasibility for deployment in real-world conditions. This part of ecoResilience tool was successfully demonstrated in field operation with a high degree of reliability, thereby successfully achieving TRL 7.

5 Conclusions

The primary goal of this document is to systematically assess and document the maturity of the 10 developed ecoTools namely ecoMicrogrid, ecoEMS, ecoPlanning, ecoDR, ecoPlatform, ecoConverter, ecoMonitor, ecoCommunity, ecoVehicle and ecoResilience within the framework the RE-EMPOWERED project. This evaluation provides insight into the tools' technical and commercial readiness and identifies gaps or next steps to promote further development toward market deployment and scalability.

Each ecoTool was assessed using the TRL framework, which ranks from TRL 1 (basic principles observed) to TRL 9 (fully operational in relevant environment). The assessment involved laboratory level prototype testing and pilot implementations. For TRL evaluation, the self-assessment questionnaire based TRL evaluation process has been adopted. In this process, the ecoTool developers were provided with a set of questions comprising of 4 parts (general questionnaire, ecoTool specific questionnaire, top level questionnaire and detailed questionnaire). The questionnaire was distributed to ecoTool developers for completion, and the filled-in responses were obtained for evaluation.

The summary of the findings and TRL assessment are provided below:

The ecoCoverter and ecoVehicle tool were successfully developed and validated in a relevant environment representing field conditions, thereby achieving TRL of 5, which however is lower than the target TRL of 8. These tools are progressing toward field demonstration but need further refinement in robustness.

The cyclone resilient support structure for PV and hybrid support structure for wind under ecoResilience tool have undergone rigorous design and analysis phases, with prototype development, testing, and implementation at demonstration sites like Ghoramara Island in India. This part of the ecoResilience tool was successfully developed and validated in a relevant environment representing actual operational scenario, thereby achieving TRL of 6 (i.e. the target TRL).

The other part of ecoResilience tool, i.e. the small wind turbine system, was successfully manufactured and tested in collaboration with local communities and academic collaborations. Workshops, such as one held in 2024 at CSIR-CMERI in India, emphasized practical construction techniques and the use of simple, durable designs. The wind turbine was validated in Gaidouromantra (Kythnos), demonstrating feasibility for deployment in real-world conditions. This part of ecoResilience tool was successfully demonstrated in field operation with a high degree of reliability, thereby successfully achieving TRL 7. This is higher than the target TRL of 6.

The ecoCommunity tool was successfully deployed and demonstrated in an operational environment in several demo-sites thereby successfully achieving TRL 7, which is higher than the target TRL of 6.

The ecoPlatform (A) tool was successfully deployed and demonstrated at the Bornholm demo-site allowing the interoperable operation of several ecoTools and other assets. The achieved TRL is 8, which is also the target TRL.

The ecoDR tool has undergone both laboratory testing and field demonstration at project demonstration sites Ghoramara in India and Gaidouromandra microgrid in Kythnos Island in Greece. In particular, during field trials, ecoDR was tested for its measuring precision and accuracy for electric power, voltage and current, and its advanced functionalities, e.g., maximum power and energy threshold, variable cut off delay and non-critical load scheduling using actual load. Tests were also conducted to assess the bi-directional communication between the ecoDR and the ecoMicrogrid. The demonstration of the ecoDR tool at the Gaidouromantra microgrid successfully validated its real-time energy monitoring capabilities. Overall, the ecoDR tool demonstrated a high degree of reliability, successfully achieving project goals and demonstrating TRL 7 (i.e. the target TRL).

The ecoMonitor tool has undergone both laboratory testing and field demonstration at project demonstration sites in Ghoramara and Kythnos microgrid in Greece. During the first demonstration period, all AQI parameters were found to be within permissible limit. Overall, the ecoMonitor tool was successfully demonstrated in field operation with a high degree of reliability, thereby achieving project goals and demonstrating TRL 7 (i.e. the target TRL).

The ecoMicrogrid tool was rigorously tested in two phases: HIL laboratory testing was followed by implementation and fully successful field demonstration at the Gaidouromandra microgrid (Kythnos) and Keonjhar demo site. Field testing results demonstrated the tool's capacity to optimize energy scheduling and improve system reliability in real world scenarios. Overall, the ecoMicrogrid tool exhibited a high level of maturity, successfully achieving TRL 7 (i.e. the target TRL).

ecoEMS tool has undergone rigorous testing and deployment at both Bornholm in Denmark and the Kythnos power system in Greece to demonstrate its effectiveness in real world scenarios. The tool supported a high-penetration renewable energy environment, enhancing grid flexibility and demand response management. This demonstration ensured the ecoEMS tool was robust, effective, and capable of addressing real-world challenges in energy management. Overall, the ecoEMS tool exhibited a high level of maturity, thereby achieving TRL 7. This is lower than the target TRL of 8.

The ecoPlanning tool was demonstrated in the Kythnos power system and Keonjhar demo site. The tool has undergone initial testing and real-world application in line with the project's goals. The tool helps to optimize the energy mix and resource planning for the area, considering various long-term factors. Overall, the ecoPlanning tool demonstrated a high degree of reliability, robustness, and the capability of addressing real-world challenges, thereby successfully achieving project goals and demonstrating TRL 9 (i.e. the target TRL). It should be noted that the start TRL of ecoPlanning was 9, as it was a mature solution that has been updated and expanded in RE-EMPOWERED.

Table 10 compares the TRL achieved for each ecoTool with the target TRL level according to the Grant Agreement (GA). The table also includes the starting TRL level of each ecoTool.

Table 10: TRL achieved versus target TRL

ecoTool name	ecoTool type	Starting TRL (GA)	Target TRL (GA)	TRL achieved
ecoMicrogrid	Hardware	5	7	7
ecoEMS	Software	6	8	7
ecoPlanning	Software	9	9	9
ecoDR	Hardware	6	7	7
ecoPlatform	Software	5	8	8

ecoConverter	Hardware	5	8	5
ecoMonitor	Hardware	4	7	7
ecoCommunity	Software	3	6	7
ecoVehicle	Hardware	5	8	5
ecoResilience	Hardware	3	6	6-7

6 References

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[2] C. G. Manning, Technology Readiness Levels, NASA, Sept. 2023 [Online] https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

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[4] European Exascale Software Initiative 2 (EESI2), "D6.1: "Report on operational software maturity level methodology (V1.2)", 2015.

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[6] Department of Defense, USA, "Technology Readiness Assessment Guidebook", June 2023 [Online] https://www.cto.mil/wp-content/uploads/2023/07/TRA-Guide-Jun2023.pdf

[7] RE-EMPOWERED project, "*D4.1: Development of the ecoEMS, ecoMicrogrid and ecoDR"*, 2023.

[8] RE-EMPOWERED project, "*D4.2: Development of the ecoConverter and ecoVehicle"*, 2023.

[9] RE-EMPOWERED project, "*D4.3: Development of the ecoMonitor and ecoResilience"*, 2023.

[10] RE-EMPOWERED project, "*D3.4: ecoPlanning Tool"*, 2023.

[11] RE-EMPOWERED project, "*D5.2*: *ecoPlatform Tool"*, 2023.

[12] RE-EMPOWERED project, "*D5.3*: *ecoCommunity Tool"*, 2023.

[13] RE-EMPOWERED project, "*D7.4: Report demonstration round 1 (testing)*", 2024.

Annex

A. TRL Self Assessment Questionnaire Completed by ecoTool Developers

In this section, a self assessment questionnaire corresponding of each ecoTool was prepared to evaluate various aspects of ecoTools. The questionnaire was divided into four parts: General questionnaire covering basic questions applicable to all ecoTools, ecoTool specific questionnaire focusing on unique features and functionalities of each ecoTool, top level questionnaire aimed at determining anticipated TRL and detailed questionnaire includes in-depth queries for a comprehensive assessment. The questionnaire was distributed to ecoTool developers for completion, and the filled-in responses are attached.

A.1: ecoMicrogrid

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoMicrogrid
2.	**Principal Investigator(s) (ecoTool lead)**	Athanasios Vasilakis, Dimitris Lagos
3.	**Principal Investigator Institute**	ICCS/NTUA
4.	**Participating Institute(s) (other collaborators)**	PROTASIS, IISC
5.	**Starting TRL**	5
6.	**Anticipated Ending TRL**	8
7.	**Current Status**	6-7
8.	**Actual Ending TRL**	NA
9.	**Date**	01/02/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer

Energy Management System tailored for Microgrids and small offGrid systems

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
Validate the robustness on teal world applications.

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer

- **Cost Optimization**: The tool aims to optimize the cost of energy management within the microgrid, ensuring efficient allocation of resources and minimizing operational expenses.
- **Integration of multiple energy vectors**: It enables the integration and coordination of various energy sources and vectors within the microgrid, allowing for efficient utilization and management of available resources.
- **Forecast**: The tool incorporates forecasting capabilities to predict load and generation patterns, enabling proactive decision-making and effective energy management.
- **Improve Reliability**: The ecoMicrogrid tool strives to enhance the reliability and resilience of the microgrid by implementing predictive control strategies.
- **Scalability**: The tool is designed to be scalable, accommodating the growth and expansion of the microgrid system over time, without compromising performance or functionality.
- **Interoperability**: The ecoMicrogrid tool emphasizes interoperability, facilitating open protocol and technologies that ensure integration with other systems and devices within the microgrid ecosystem, enabling smooth communication and coordination.

F) Which is the problem which should be solved by the ecoTool?

Information/Answer

2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

   What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer

All the software components of ecoMicrogrid have been concluded. Here is the list of the main modules with a short explanation:

A. **Data Connector**: The Connector component establishes direct connections to the microgrid devices using various protocols such as DNP3, IEC 61850MMS, and Modbus. Once configured, the Connector can either pull data from these systems or subscribe to updates, enabling the retrieval of real-time data from the microgrid devices.

B. **Communication Data Processor (CDP):** The CDP component is responsible for converting the data from the protocol-specific format to the internal data model of the ecoMicrogrid system. It processes and transforms the incoming data and writes it to the SQL Storage Device for further analysis and utilization.

C. **EMS module**: This module is responsible for ensuring the optimal operation of the microgrid, coordinating the control and optimization algorithms to maximize performance.

D. **Forecast module**: The Forecast module utilizes meteorological and static data to provide accurate forecasts for renewable energy sources (RES) within the microgrid. Additionally, it offers load forecasting based on historical data, enabling better planning and utilization of available energy resources

E. **Load Scheduling**: The Load Scheduling module calculates various time slots available for flexible private loads as part of Demand-Side Management (DSM) strategies, optimizing the utilization of available energy.

F. **Outage detection module**: This module detects power outages within the microgrid and identifies their location, allowing for timely response and maintenance.

G. **Dynamic Pricing**: The Dynamic Pricing module calculates in real-time the levelized cost of electricity of the microgrid over a multi-hour time horizon. By considering the energy mix, it enables effective pricing strategies within the microgrid.

H. **Storage Device**: The Storage Device plays a crucial role in archiving and data storage within the ecoMicrogrid system. It serves as an intermediary component that separates the activities of the Data Concentrator from the High-Level Functions. The

Storage Device efficiently stores and manages the collected data, ensuring reliable access and utilization for various modules.

I. **ecoMicrogrid Manager**: The ecoMicrogrid Manager orchestrates the operation of the different modules within the High-Level Functions. It ensures synchronization, coordination, and efficient workflow among the modules, facilitating the seamless operation of the ecoMicrogrid system.

J. **Transport module**: The Transport Module facilitates communication with external systems, such as ecoCommunity. It enables seamless integration and data exchange between the microgrid and external platforms, enhancing interoperability and supporting the collaborative functionality of the ecoMicrogrid system.

3. Describe the envisioned deployment of this technology.

A) Where will this technology be deployed?

Information/Answer
EcoMG will be deployed at he folllowing pilot sites: • Ghoramara island • Keonjhar • Gaidouromadra

B) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Microgrids and small off-grid systems

C) Please describe the end users of the technology, and how they will use it.

Information/Answer
The operation of the Microgrid will be mainly determined by the ownership and roles of the various stakeholders. Three general models: Integrated Utility or DSO owns and operates the Microgrid. Prosumers own and operate DER to minimize electricity bills or maximize revenues (Local Energy Community Microgrid) Market Aggregators (ESCOs) maximize the value of the aggregated DER participation in local energy markets. Industries with critical processes that need to stay online (Oil and petrochemical refining, Pulp and paper manufacturing, Mining and metals processing, Water and wastewater treatment plants.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
The ecoMicrogrid tool has undergone a rigorous evaluation and laboratory testing process to assess its capabilities and functionality, utilizing of a Hardware in the Loop test bed with a digital twin.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
All modules have been independently tested before intagrated to the ecoMicrogrid for evaluating their performance.

C) How representative is the test environment to the intended operational environment?

Information/Answer
The HIL test bed offers a significant advantage in testing the ecoMicrogrid tool as a single hardware solution under realistic operating conditions. It provides a controlled environment that closely resembles real-world conditions, allowing to thoroughly evaluate the tool's performance.

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
• Simulation Studies: Create detailed simulation models that replicate the microgrid environment and dynamics. Simulations can help assess the expected functionality of the ecoTool by mimicking real-world scenarios and evaluating its performance under various conditions. • Theoretical Analysis: Conduct a comprehensive theoretical analysis of the ecoTool's algorithms and functionalities. Mathematical models and theoretical frameworks can be used to predict how the tool should behave in different situations, providing insights into its expected performance. • Benchmarking Against Standards: Compare the ecoTool's expected functionality against industry standards and best practices. This involves assessing whether the tool aligns with established benchmarks for microgrid energy management systems. • Expert Review and Validation: Engage domain experts, researchers, and stakeholders to review the design and specifications of the ecoTool. Their expertise can provide valuable insights into the expected functionality, potential challenges, and areas for improvement.

- Use Case Analysis: Analyze potential use cases and scenarios to understand how the ecoTool is expected to perform in specific operational conditions. This analysis can help confirm the tool's individual functionalities and its ability to handle different combinations of factors.

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

A) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
Pilot sites closely align with the design requirements, and furthermore, the tools have been customized to fit the specific needs of the pilot sites.

B) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
Yes detailed simulation have been conducted.

7. How has the user community been included in the technology development process?

A) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
Workshops that present the functionalities of the tool have been conducted for the microgrid managers.

B) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
NA

C) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
In the case of Ghoramara Island, the optimization objectives have been adjusted to meet the specific needs of the pilot.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	**Have the basic process technology process principles been observed and reported?**	**Yes** ☑ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL2: Application formulated	**Has an equipment and process concept been formulated?**	**Yes** ☑ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL3: Proof of concept	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ☑ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL4: Components validated in laboratory environment	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ☑ **No** ☐

If Yes, then basis and Supporting Documentation:		
TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☑ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☑ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ☐ **No** ☐ **In Progress**
If Yes, then basis and Supporting Documentation:		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐ **No** ☑ ☐
If Yes, then basis and Supporting Documentation:		

TRL9: Outcome refined & adopted	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?	Yes	No☑
If Yes, then basis and Supporting Documentation:			

Part D: Detailed questionnaire

TRL	Question	Start of Project		Current status		<Date>
		Yes	No	Yes	No	
1	Do rough calculations support the concept?	☑		1 ☑		
1	Do basic principles (physical, chemical, mathematical) support the concept?	☑		☑		
1	Do paper studies confirm basic scientific principles of new technology?	☑		☑		
1	Has a scientific methodology or approach been developed?	☑		☑		
TRL 1 Achieved	**Basic principles observed and reported.**					
2	Has potential system or component applications been identified?	☑		☑		
2	Have paper studies confirmed system or component application feasibility?	☑		☑		
2	Has an apparent design solution been identified?	☑		☑		
2	Have the basic components of the technology been identified?	☑		☑		
2	Have technology or system components been at least partially characterized?	☑		☑		
2	Have performance predictions been documented for each component?	☑		☑		

2	Has a functional requirements generation process been initiated?	☑		☑		
2	Does preliminary analysis confirm basic scientific principles?	☑		☑		
2	Are basic scientific principles confirmed with calculation based analytical studies?	☑		☑		
TRL 2 Achieved	**Technology concept and/or application formulated.**					
3	Have calculated predictions of components of technology capability been validated?	☑		☑		
3	Can all science applicable to the technology be modeled or simulated?	☑		☑		
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?	☑		☑		
3	Do experiments verify feasibility of application of technology?	☑		☑		
3	Do paper studies indicate that technology or system components can be integrated?	☑		☑		
3	Has scientific feasibility of proposed technology been fully demonstrated?	☑		☑		
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?	☑		☑		
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**					
4	Has acceptance testing of individual components been performed?	☑		☑		
4	Has performance of components and interfaces between components been demonstrated?	☑		☑		
4	Does draft system architecture plan exist?		☑	☑		

4	Have end user technology/system requirements been documented?	☑		☑		
4	Does technology demonstrate basic functionality in simplified environment?	☑		☑		
4	Have performance characteristics been demonstrated in a laboratory environment?	☑		☑		
4	Have low-fidelity assessments of system integration and engineering been completed?		☑	☑		
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**					
5	Have internal system interface requirements been documented?		☑	☑		
5	Has analysis of internal interface requirements been completed?		☑	☑		
5	Can all system specifications be simulated and validated within a laboratory environment?	☑		☑		
5	Have individual component functions been verified through testing?	☑		☑		
5	Is component integration demonstrated in a laboratory environment?	☑		☑		
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**					
6	Have system integration issues been addressed?		☑	☑		
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		☑	☑		
6	Have performance characteristics been verified in a simulated operational environment?		☑	☑		
6	Has prototype been tested in a simulated operational environment?		☑	☑		

6	Has system been tested in realistic environment outside the laboratory?		☑	☑		
6	Has engineering feasibility been fully demonstrated?		☑	☑		
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		☑	☑		
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**					
7	Have all interfaces been tested individually under stressed and anomalous conditions?		☑	☑		
7	Has technology or system been tested in a relevant environment?		☑	☑		
7	Are available components representative of production components?		NA	NA		
7	Are available components ready to be fully integrated in the final outcome?		☑	☑		
7	Has operational testing of technology/system in relevant environment been completed?		☑		☑	
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		☑	☑		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**					
8	Are all technology/system components form, fit, and function compatible?		☑	☑		
8	Is technology/system form, fit, and function compatible with operational environment?		☑		☑	
8	Has technology/system form, fit, and function been demonstrated in operational environment?		☑		☑	

8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		☑		☑	
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**					
9	Does technology/system function as defined in Operational Concept document?		☑	☑		
9	Has technology/system has been deployed in intended operational environment?		☑	☑		
9	Has technology/system been fully demonstrated?		☑		☑	
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		☑		☑	
9	Is the outcome adopted by the user community?		☑		☑	
TRL 9 Achieved	**Actual system proven through successful mission operations.**					

A.2: ecoEMS

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoEMS
2.	**Principal Investigator(s) (ecoTool lead)**	George Milionis
3.	**Principal Investigator Institute**	ICCS/NTUA
4.	**Participating Institute(s) (other collaborators)**	Imperial, DTU
5.	**Starting TRL**	TRL 6
6.	**Anticipated Ending TRL**	TRL 8
7.	**Current Status**	TRL 7
8.	**Actual Ending TRL**	TRL 7
9.	**Date**	01/10/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
Energy Management System tailored for isolated power systems for large scales

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
System Failures and Fault Tolerance: Handling system failures and ensuring robustness in cases where ecoTools or Neogrid devices fail to publish data on time. Cybersecurity and Data Privacy: Ensuring the system is secure, particularly when dealing with sensitive community data and interconnected devices.

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer
• **Cost Efficiency:** It focuses on minimizing energy management costs by optimizing resource allocation and reducing operational expenditures. • **Energy Source Integration:** The tool facilitates the coordination of various energy sources, ensuring efficient use and management of available resources within the microgrid. • **Enhanced Reliability:** By utilizing predictive control strategies, the tool works to strengthen the reliability and resilience of the power system.

F) Which is the problem which should be solved by the ecoTool?

Information/Answer
Minimize the operational cost and the CO_2 emissions.

2. Describe the various constituent parts of the technology. How do they fit together and interact with one another?

What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer
• Data Manager is responsible for the collection of the data, the data cleaning, and the storing, through all external sources. • Module Manager supports the correct order and timing of the algorithm execution of the ecoEMS software. Especially, the Module Manager is responsible for orchestrating the algorithm execution in the right time and order after ensuring that all previous algorithms have been successfully executed and results are stored back in the database. • Scheduler: The Scheduler's responsibility is the periodic execution of the algorithms; mainly the forecasts (load & RES), as well as the training phase. • Application Manager is a stand-alone application with a user interface that mediates for the execution of the DAS, as well as for the monitoring of the Economic Dispatch executions. • Web Server takes over retrieving, transforming and visualizing all the results as well as the interface of the user and create and deliver the reports of the results. • The database is deployed on a Microsoft SQL Server and composes the heartbeat of the software. The database mapping is described along with the tables with the basic data concerning the thermal units, the real time data and the results of the algorithmic elements of the module.

3. Describe the envisioned deployment of this technology.

A) Where will this technology be deployed?

Information/Answer
ecoEMS will be deployed at the folllowing pilot sites: • Kythnos island • Bornholm demo site

B) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Island power systems

C) Please describe the end users of the technology and how they will use it.

Information/Answer
The operation of the ecoEMS will be mainly DSO that owns and operates the power system.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer

The ecoEMS tool has undergone laboratory testing process to assess its capabilities and functionality, with a UAT environment as a digital twin only for testing.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer

All modules have been tested before integration to the ecoEMS framework, during the development phase.

C) How representative is the test environment to the intended operational environment?

Information/Answer

The UAT environment is a staging environment identical with the production one, so it emulates the final deployment, with the only difference of running on local server.

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer

- Optimal design: Perform an in-depth theoretical analysis of the ecoTool's algorithms and capabilities. Through literature review, end up with best practices.
- Emulations: Replicate the conditions and dynamics for each component so that a simulation could run as most realistic real-world scenario for functionality testing.
- Expert Evaluation and Confirmation: Collaborate with industry specialists, researchers, and key stakeholders to assess and verify the ecoTool's design and features.

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

A) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer

Pilot sites closely align with the design requirements, and furthermore, the tools have been customized to fit the specific needs of the pilot sites.

B) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer

The hardware components of the tool are not up for testing, so all the aforementioned testing corresponds to software testing based on simulations.

7. How has the user community been included in the technology development process?

A) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
No during design and development phase. Workshops (such as exploitation) offered the opportunity to receive feedback and proceed to necessary changes.

B) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
--

C) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
In the case of Bonrholm demo site, the optimization objective has been adjusted to meet the specific needs of the pilot.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	**Have the basic process technology process principles been observed and reported?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL2: Application formulated	**Has an equipment and process concept been formulated?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		

TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes No** **In Progress**
If Yes, then basis and Supporting Documentation:		

TRL8: Outcome proven in operational environment	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?	Yes	No ☑
If Yes, then basis and Supporting Documentation:			
TRL9: Outcome refined & adopted	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes**	**No☑**
If Yes, then basis and Supporting Documentation:			

Part D: Detailed questionnaire

TRL	Question	Start of Project		Current status		<Date>
		Yes	No	Yes	No	
1	Do rough calculations support the concept?	☑		☑		
1	Do basic principles (physical, chemical, mathematical) support the concept?	☑		☑		
1	Do paper studies confirm basic scientific principles of new technology?	☑		☑		
1	Has a scientific methodology or approach been developed?	☑		☑		
TRL 1 Achieved	**Basic principles observed and reported.**					

2	Has potential system or component applications been identified?	☑		☑		
2	Have paper studies confirmed system or component application feasibility?	☑		☑		
2	Has an apparent design solution been identified?	☑		☑		
2	Have the basic components of the technology been identified?	☑		☑		
2	Have technology or system components been at least partially characterized?	☑		☑		
2	Have performance predictions been documented for each component?	☑		☑		
2	Has a functional requirements generation process been initiated?	☑		☑		
2	Does preliminary analysis confirm basic scientific principles?	☑		☑		
2	Are basic scientific principles confirmed with calculation based analytical studies?	☑		☑		
TRL 2 Achieved	**Technology concept and/or application formulated.**					
3	Have calculated predictions of components of technology capability been validated?	☑		☑		
3	Can all science applicable to the technology be modeled or simulated?	☑		☑		
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?	☑		☑		
3	Do experiments verify feasibility of application of technology?	☑		☑		

3	Do paper studies indicate that technology or system components can be integrated?	☑		☑		
3	Has scientific feasibility of proposed technology been fully demonstrated?	☑		☑		
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?	☑		☑		
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**					
4	Has acceptance testing of individual components been performed?	☑		☑		
4	Has performance of components and interfaces between components been demonstrated?	☑		☑		
4	Does draft system architecture plan exist?	☑		☑		
4	Have end user technology/system requirements been documented?	☑		☑		
4	Does technology demonstrate basic functionality in simplified environment?	☑		☑		
4	Have performance characteristics been demonstrated in a laboratory environment?	☑		☑		
4	Have low-fidelity assessments of system integration and engineering been completed?	☑		☑		
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**					
5	Have internal system interface requirements been documented?		☑	☑		

5	Has analysis of internal interface requirements been completed?		☑	☑		
5	Can all system specifications be simulated and validated within a laboratory environment?		☑	☑		
5	Have individual component functions been verified through testing?		☑	☑		
5	Is component integration demonstrated in a laboratory environment?		☑	☑		
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**					
6	Have system integration issues been addressed?		☑	☑		
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		☑	☑		
6	Have performance characteristics been verified in a simulated operational environment?		☑	☑		
6	Has prototype been tested in a simulated operational environment?		☑	☑		
6	Has system been tested in realistic environment outside the laboratory?		☑	☑		
6	Has engineering feasibility been fully demonstrated?		☑	☑		
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		☑	☑		
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**					

7	Have all interfaces been tested individually under stressed and anomalous conditions?		☑	☑		
7	Has technology or system been tested in a relevant environment?		☑	☑		
7	Are available components representative of production components?		☑	☑		
7	Are available components ready to be fully integrated in the final outcome?		☑	☑		
7	Has operational testing of technology/system in relevant environment been completed?		☑	☑		
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		☑	☑		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**					
8	Are all technology/system components form, fit, and function compatible?		☑		☑	
8	Is technology/system form, fit, and function compatible with operational environment?		☑		☑	
8	Has technology/system form, fit, and function been demonstrated in operational environment?		☑		☑	
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		☑		☑	
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**					

9	Does technology/system function as defined in Operational Concept document?		☑		☑	
9	Has technology/system has been deployed in intended operational environment?		☑		☑	
9	Has technology/system been fully demonstrated?		☑		☑	
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		☑		☑	
9	Is the outcome adopted by the user community?		☑		☑	
TRL 9 Achieved	**Actual system proven through successful mission operations.**					

A.3: ecoPlannning

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoPlanning
2.	**Principal Investigator(s) (ecoTool lead)**	George Milionis
3.	**Principal Investigator Institute**	ICCS-NTUA
4.	**Participating Institute(s) (other collaborators)**	
5.	**Starting TRL**	TRL 9
6.	**Anticipated Ending TRL**	TRL 9
7.	**Current Status**	TRL 9
8.	**Actual Ending TRL**	TRL 9
9.	**Date**	1/10/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
Long term energy studies based on hourly Unit Commitment

B) Have preliminary engineering designs for system components been developed?

Information/Answer
No

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
No

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer

- Unit Commitment: Algorithm achieves the most economic generation mix considering the locally available energy sources.
- Demand/Peak modelling: The tool enables modelling the expectations of how the load demand growth will be over the next 7 years. User defines various demand/peak (retrievable and editable for configuration at any point in time).
- Energy Planning: supports decision making based on KPIs about determination of how the energy system will be upscaled in the coming years to cover the growing needs of the local population
- Applicability: The tool is applicable for smaller systems and larger island areas with multi-microgrids/interconnections operation
- DSM Schemes: Consumer engagement through Demand Response, so the tool may support the efficient and secure operation of the system

F) Which is the problem which should be solved by the ecoTool?

Information/Answer
Optimize the energy mix.

2. Describe the various constituent parts of the technology. How do they fit together and interact with one another?

What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer
N/A

3. Describe the envisioned deployment of this technology.

A) Where will this technology be deployed?

Information/Answer
ecoEMS will be deployed at the folllowing pilot sites: • Kythnos island • Keonjhar demo site

B) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Island power systems

C) Please, describe the end users of the technology, and how they will use it.

Information/Answer
The operation of the ecoPlanning will be mainly DSO that owns and operates the power system.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
ecoPlanning tool has undergone laboratory testing process to assess its capabilities and functionality, with a UAT environment as a digital twin only for testing.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
All modules have been tested before integration to ecoPlanning framework, during the development phase.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: **Basic principles & research**	**Have the basic process technology process principles been observed and reported?**	**Yes ☑ No**

If Yes, then basis and Supporting Documentation:		
TRL2: **Application formulated**	**Has an equipment and process concept been formulated?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes ☑ No**
If Yes, then basis and Supporting Documentation:		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes ☑ No**

If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	☑ **Yes** ☑ **No**
If Yes, then basis and Supporting Documentation:		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☑ **No**
If Yes, then basis and Supporting Documentation:		
TRL9: **Outcome refined & adopted**	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	☑ **Yes** ☑ **No**
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	**Question**	**Start of Project**		**Current status**		**<Date>**
		Yes	**No**	**Yes**	**No**	

1	Do rough calculations support the concept?	☑		☑		
1	Do basic principles (physical, chemical, mathematical) support the concept?	☑		☑		
1	Do paper studies confirm basic scientific principles of new technology?	☑		☑		
1	Has a scientific methodology or approach been developed?	☑		☑		
TRL 1 Achieved	**Basic principles observed and reported.**					
2	Has potential system or component applications been identified?	☑		☑		
2	Have paper studies confirmed system or component application feasibility?	☑		☑		
2	Has an apparent design solution been identified?	☑		☑		
2	Have the basic components of the technology been identified?	☑		☑		
2	Have technology or system components been at least partially characterized?	☑		☑		
2	Have performance predictions been documented for each component?	☑		☑		
2	Has a functional requirements generation process been initiated?	☑		☑		
2	Does preliminary analysis confirm basic scientific principles?	☑		☑		
2	Are basic scientific principles confirmed with calculation based analytical studies?	☑		☑		
TRL 2 Achieved	**Technology concept and/or application formulated.**					

3	Have calculated predictions of components of technology capability been validated?	☑		☑		
3	Can all science applicable to the technology be modeled or simulated?	☑		☑		
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?	☑		☑		
3	Do experiments verify feasibility of application of technology?	☑		☑		
3	Do paper studies indicate that technology or system components can be integrated?	☑		☑		
3	Has scientific feasibility of proposed technology been fully demonstrated?	☑		☑		
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?	☑		☑		
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**					
4	Has acceptance testing of individual components been performed?	☑		☑		
4	Has performance of components and interfaces between components been demonstrated?	☑		☑		
4	Does draft system architecture plan exist?	☑		☑		
4	Have end user technology/system requirements been documented?	☑		☑		
4	Does technology demonstrate basic functionality in simplified environment?	☑		☑		

4	Have performance characteristics been demonstrated in a laboratory environment?	☑		☑		
4	Have low-fidelity assessments of system integration and engineering been completed?	☑		☑		
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**					
5	Have internal system interface requirements been documented?	☑		☑		
5	Has analysis of internal interface requirements been completed?	☑		☑		
5	Can all system specifications be simulated and validated within a laboratory environment?	☑		☑		
5	Have individual component functions been verified through testing?	☑		☑		
5	Is component integration demonstrated in a laboratory environment?	☑		☑		
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**					
6	Have system integration issues been addressed?	☑		☑		
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?	☑		☑		
6	Have performance characteristics been verified in a simulated operational environment?	☑		☑		
6	Has prototype been tested in a simulated operational environment?	☑		☑		

6	Has system been tested in realistic environment outside the laboratory?	☑		☑		
6	Has engineering feasibility been fully demonstrated?	☑		☑		
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?	☑		☑		
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**					
7	Have all interfaces been tested individually under stressed and anomalous conditions?	☑		☑		
7	Has technology or system been tested in a relevant environment?	☑		☑		
7	Are available components representative of production components?	☑		☑		
7	Are available components ready to be fully integrated in the final outcome?	☑		☑		
7	Has operational testing of technology/system in relevant environment been completed?	☑		☑		
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?	☑		☑		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**					
8	Are all technology/system components form, fit, and function compatible?	☑		☑		

8	Is technology/system form, fit, and function compatible with operational environment?	☑		☑		
8	Has technology/system form, fit, and function been demonstrated in operational environment?	☑		☑		
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?	☑		☑		
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**					
9	Does technology/system function as defined in Operational Concept document?	☑		☑		
9	Has technology/system has been deployed in intended operational environment?	☑		☑		
9	Has technology/system been fully demonstrated?	☑		☑		
9	Has Operational Test and Evaluation (OT&E) been successfully completed?	☑		☑		
9	Is the outcome adopted by the user community?	☑		☑		
TRL 9 Achieved	**Actual system proven through successful mission operations.**					

A.4: ecoDR

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoDR

2.	**Principal Investigator(s) (ecoTool lead)**	Anirudh Kumar, Santu Kr Giri, Siddheswar Sen
3.	**Principal Investigator Institute**	CSIR-CMERI
4.	**Participating Institute(s) (other collaborators)**	ICCS-NTUA, ICL, DTU, PROTASIS, IIT BBS, VNIT & IISc
5.	**Starting TRL**	TRL 6
6.	**Anticipated Ending TRL**	TRL 7
7.	**Current Status**	TRL 7
8.	**Actual Ending TRL**	TRL 7
9.	**Date**	31/01/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
The ecoDR tool technology is basically an advanced metering infrastructure (AMI) with inbuilt load controller and protection functionalities. In addition to measurement and billing of household energy consumption, it facilitates remote monitoring and control of non-critical loads based on user preference. This tool will be capable to communicate with ecoCommunity tool to access services such as demand-side management, to implement control of non-critical loads via load shedding.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer
Smart Meter

F) Which is the problem which should be solved by the ecoTool?

Information/Answer
Real time and remote monitoring of energy consumption data and centralized control of output ports of energy meters

2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

   What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer
Figure A1 shows the block diagram of smart meter developed by CSIR- CMERI. Below we have detailed each block of ecoDR.

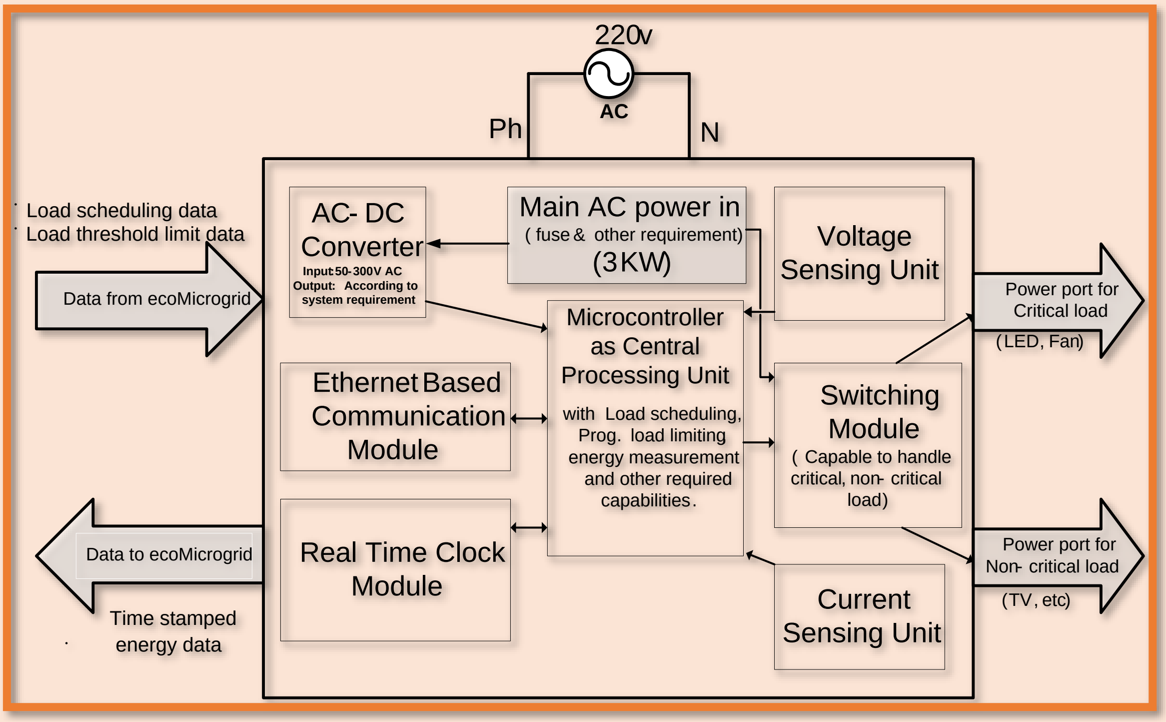


Figure A1:Block diagram of ecoDR

AC-DC converter: It is used in ecoDR to fulfill power requirement of various electronics module, most probably 12v for switching module and 5v for the rest of element of ecoDR. Considering the limitation of other system which are coupled with ecoDR and ambient condition, there is a high possibility for having very wide fluctuations in the input voltage of ecoDR. So it is much necessary for the ecoDR to use an AC-DC converter with wide input voltage range. For our intended purpose, an AC input voltage range of 110v ~ 275V has been selected. Therefore an AC-DC converter with 12v and 5v output voltage with 1Amp current rating is sufficient for fulfilling power requirements of ecoDR.

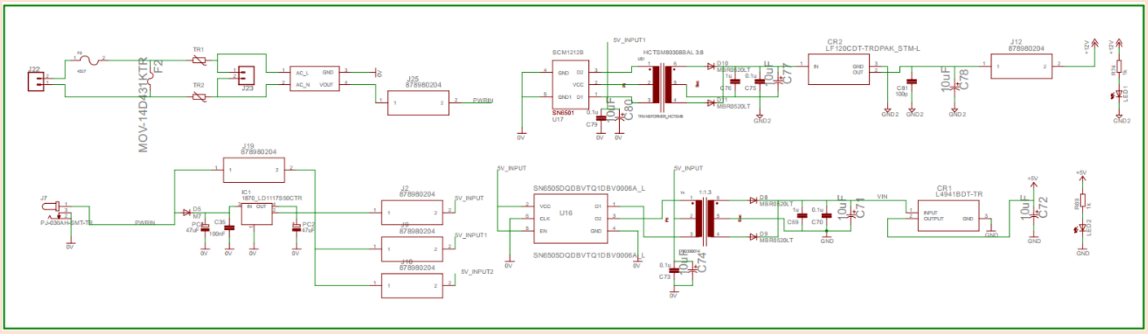


Figure A2: Schematic for power and switching unit of ecoDR

Voltage Sensing Unit: This unit is used in ecoDR for sensing AC voltage. Voltage sensing unit consist of sensors (ADE7953) for voltage sensing and additional signal condition circuitry which is helpful for micro-controller to convert analog signal to equivalent digital signal.

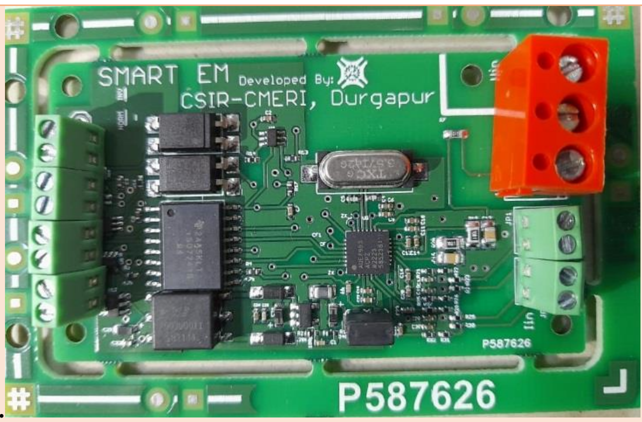


Figure A3(a): PCB for voltage and current sensing unit of ecoDR

Current Sensing Unit: This unit is used in ecoDR for sensing AC load current. Current sensing unit consist of current sensor module (50A:50mA) and addition signal condition circuitry which is helpful for micro-controller to convert analog signal to equivalent digital signal. Based on this sensed signal micro-controller compute energy and power to perform various task relation to load controller, energy and power measurement.

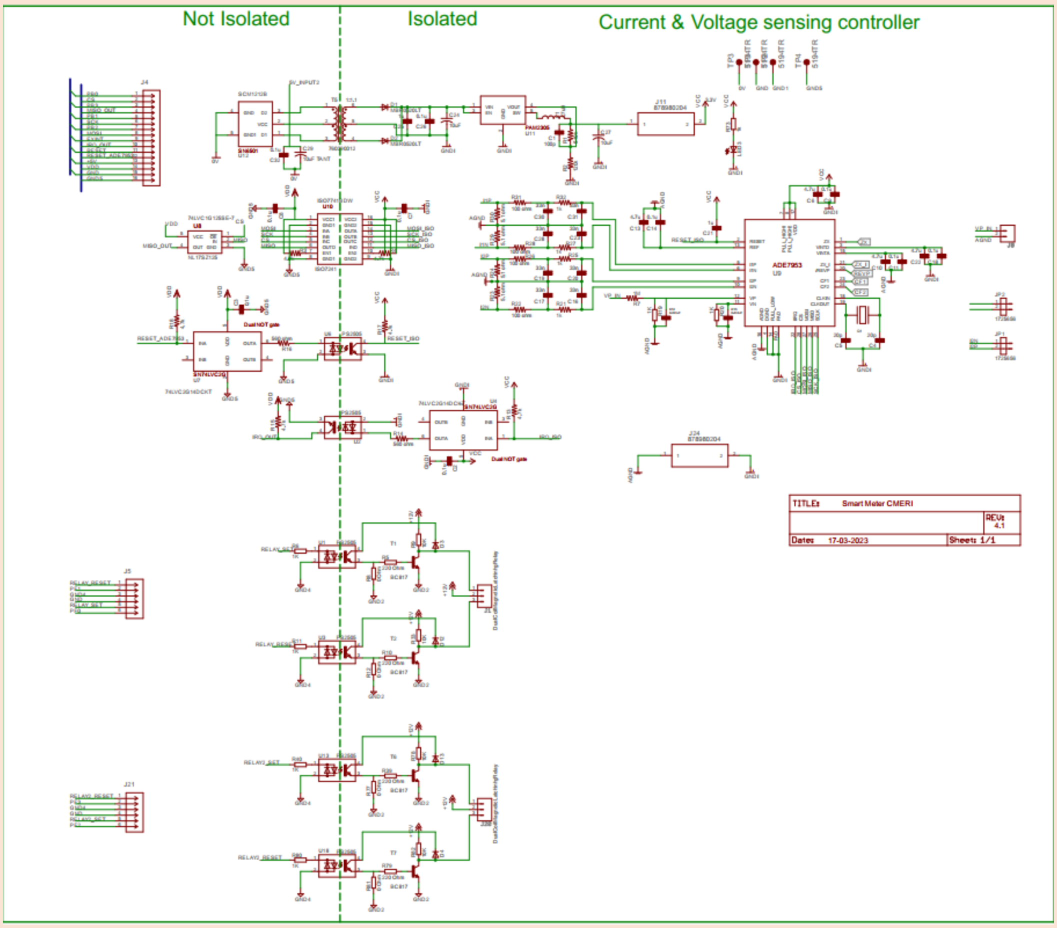


Figure A3(b): Schematic for current and voltage sensing unit of ecoDR

Switching Module: It is an actuation module, consisting of 2 relay, transistors and other required circuit which is helpful to turn on/off power derived from critical and non-critical port whenever needed.

Real Time Clock Module: For real time pricing, it is needed to create timestamped data packets. So, this RTC module has been incorporated to fulfill time measurement requirements. Data packet is further transmitted by communication module to ecoMicrogrid.

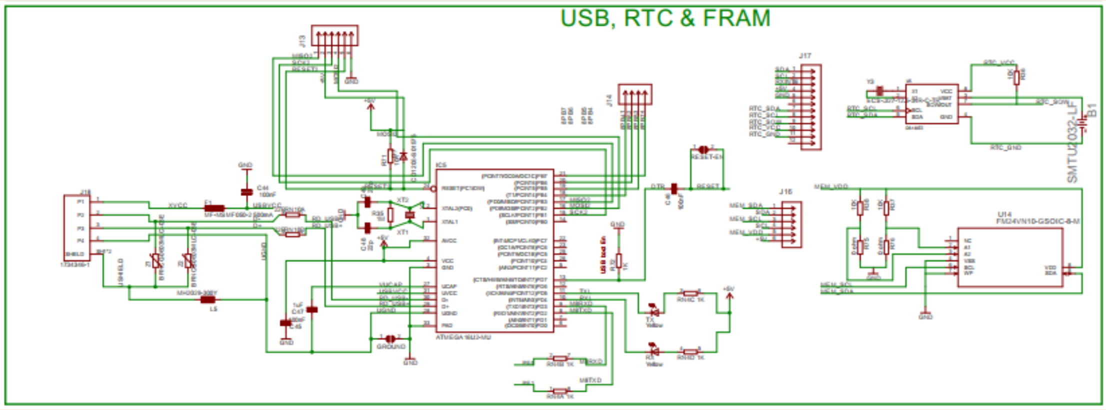


Figure :A3(c) Schematic for RTC, USB and FRAM unit

Communication Module: A system related to energy measurement never be advanced without capability of communication because it is the era of networking, in modern technology everyone is trying to develop a system which is capable to connect various system directly or indirectly. Our system has been incorporated with Ethernet unit to communicate with ecoMicrogrid so that measured energy and other parameter so transmitted to ecoMicrogrid from ecoDR.

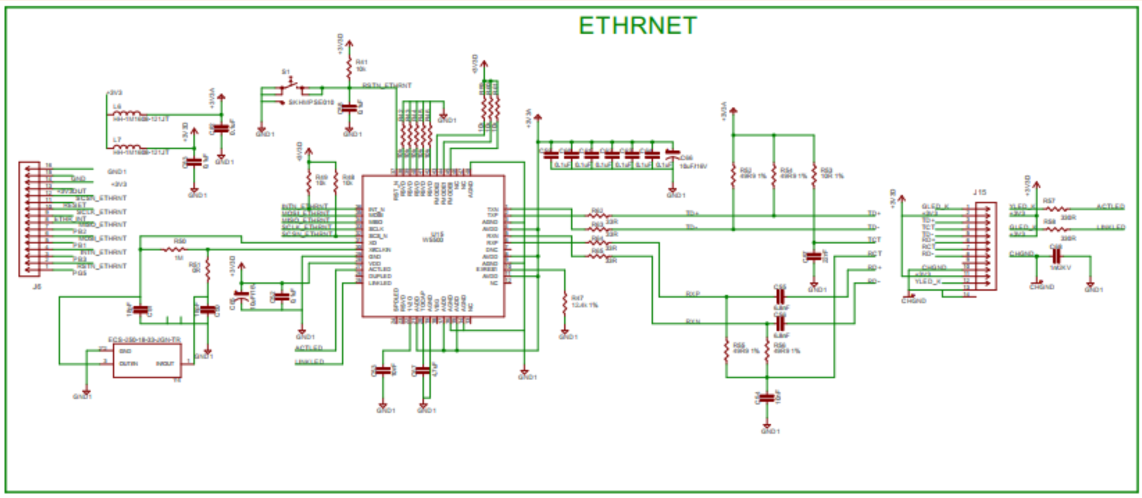


Figure A3(d) : Schematic for communication unit

3. Describe the envisioned deployment of this technology.

A) Where will this technology be deployed?

Information/Answer

It will be deployed in Ghoramara, Keonjhar, Bornholm and Kythnos demo sites.

B) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Communication infrastructure (Ethernet cable), electrical input and output cables, electrical poles for installation

C) Please, describe the end users of the technology, and how they will use it.

Information/Answer
ecoMG operators and home residents.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
At Laboratory

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
The experimental setup for ecoDR consists of 2 PCs, 1 hardware unit developed meter, physical electrical loads (kettles of 1.3 kW and 1.5kW) and one unit of GENUS ACHOOK- 1080 in hardware. Out of 2 PCs one PC was used for receiving serial debugging data of ecoDR and second PC was connected via RJ45 cable to the ecoDR. Second PC has been used to emulates the role of ecoMicrogrid in context of ecoDR. For ecoDR, ecoMG is solely communicating via MODBUS (MBAP) for controlling non-critical loads, reading ecoDR measured timestamped parameters like RMS voltage, RMS current etc. and modify the threshold energy and threshold load limits. For this Modbus ActiveX control for Excel (32 bit) has been utilized to develop an excel file on PC2. This developed excel file was used by PC2 to communicate with ecoDR via MODBUS. Figure 1 shows the screenshot for the excel file on PC2 to emulate ecoMG. PC1 has been used to display debugging data like measured RMS voltage, RMS current etc., status of MODBUS client, new commands received via MODBUS.

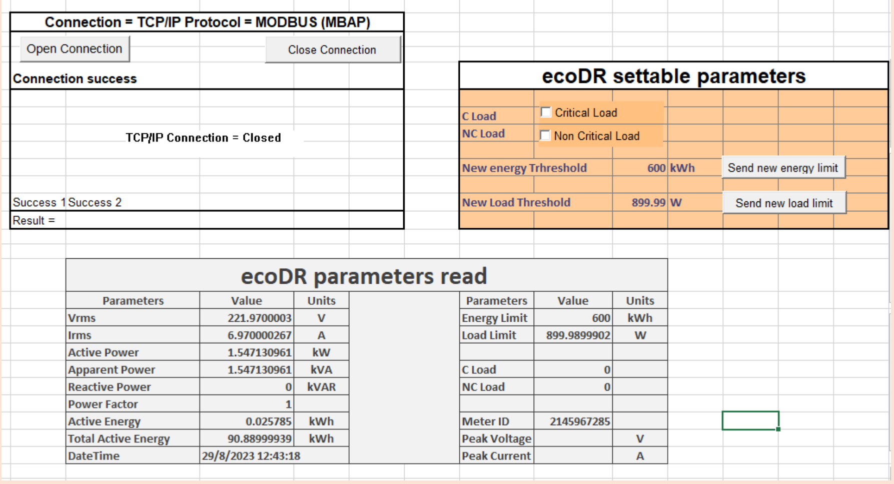


Figure A4: Second PC emulating ecoMicrogrid

To check load limiting functionality, two electric loads (kettles of 1.3 kW and 1.5kW) were used at output side of the smart meter. To check accuracy for voltage measurement autotransformer of (0 to 260V) has been used as power source at source side of the smart meter and the measurement of voltage and current of developed energy meter was validated using GENUS ACHOOK- 1080 measurements. Figure 2 shows a block diagram for experimental setup.

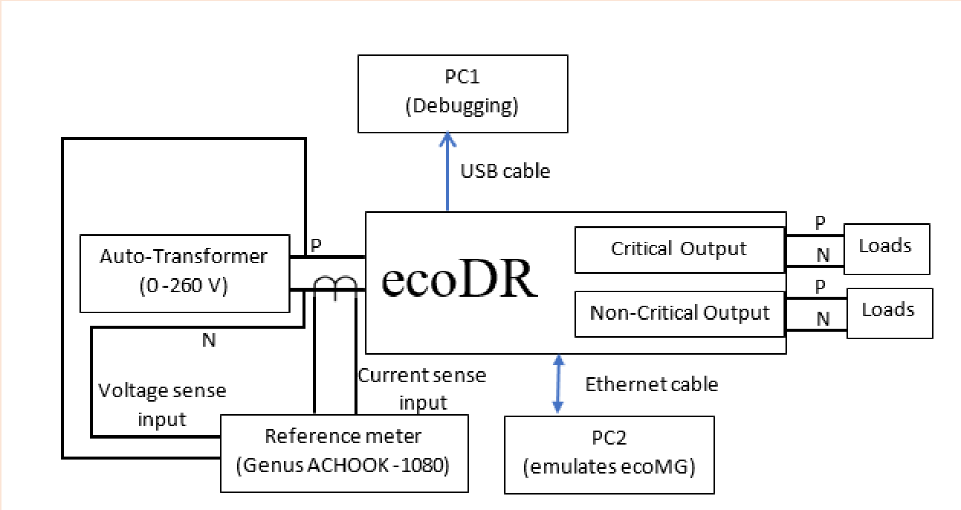


Figure A5: Block diagram for experimental setup

C) How representative is the test environment to the intended operational environment?

Information/Answer
To a great extent

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
Yes

6. **Has a demonstration of the full technology been conducted, or a prototype constructed?**

A) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
Yes

B) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
Yes

7. **How has the user community been included in the technology development process?**

A) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
Yes

B) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
Yes

C) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
Feedback for tool was satisfactory, so no revisions were needed to address the feedback.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	Have the basic process technology process principles been observed and reported?	Yes ☒ No ☐

If Yes, then basis and Supporting Documentation:

There is a considerable amount of published research on smart meters and related technologies. Researchers and organizations worldwide have explored various aspects of smart meters, including their design, functionality, security, and impacts on energy efficiency. Here are a few key research papers and publications that delve into smart meter technologies:

1) **Title:** "Advanced Metering Infrastructure for Future Smart Grid: A Review"
Authors: A. A. Khan, S. M. Zubair, and N. Javaid
Published in: Energies, 2015
This paper provides a comprehensive review of advanced metering infrastructure (AMI) and its role in future smart grids. It covers communication protocols, security, and potential challenges.

2) **Title:** "Smart Metering System for Efficient Energy Management in Smart Grid"
Authors: Yang Xiao, Student Member, IEEE, Bin Xiao, Senior Member, IEEE, and Xuemin (Sherman) Shen, Fellow, IEEE
Published in: IEEE Transactions on Industrial Informatics, 2015

3) **Title:** "A Survey on Smart Metering and Smart Grid Communication"
Authors: M. A. A. Ghani, A. B. M. Shawkat Ali, and I. Y. Soon
Published in: Journal of King Saud University - Computer and Information Sciences, 2017
The paper presents a survey on smart metering and communication technologies in smart grids, discussing various communication protocols and their efficiency.

4) **Title:** "Security in the Advanced Metering Infrastructure of the Smart Grid"
Authors: A. C. Squicciarini, C. You, and F. Kuhlmann
Published in: IEEE Transactions on Dependable and Secure Computing, 2011
This paper focuses on the security aspects of advanced metering infrastructure in smart grids, discussing potential threats and proposing security solutions.

5) **Title:** "A Comprehensive Survey on Demand Response in Smart Grid: objectives and mechanisms"
Authors: A. Y. Abdelaziz, A. S. Mohamed, and A. I. Khalil
Published in: Renewable and Sustainable Energy Reviews, 2016
The paper explores the role of demand response in smart grids and its connection to smart metering technologies.

6) Title: "Smart Grids and Smart Meters: A Survey"
Authors: A. Al-Sumaiti, M. M. Ettouney, and H. Selim
Published in: IEEE Transactions on Industrial Informatics, 2015
This survey provides an overview of smart grids and smart meters, discussing challenges, technologies, and future trends.

TRL2: **Application formulated**	**Has an equipment and process concept been formulated?**	**Yes** ☑ **No** ☐

If Yes, then basis and Supporting Documentation:

The basic concept of a smart energy meter revolves around the integration of advanced technologies to enhance the monitoring, measurement, and management of energy consumption. Unlike traditional meters that simply record energy usage, smart energy meters incorporate features that enable real-time data collection, communication, and analysis. Here is a breakdown of the basic concept:

Real-Time Monitoring: Smart energy meters continuously monitor and record electricity usage in real-time. They provide instant feedback on energy consumption, allowing users to make informed decisions about their electricity usage.

Two-Way Communication: Smart meters have the capability to communicate with utility providers and other connected devices. This two-way communication allows for remote management, such as reading meter data without physical access and facilitating demand response programs.

Data Collection and Analytics:The meters collect detailed data on energy usage patterns, voltage, and other relevant parameters. Advanced analytics can be applied to this data to identify trends, anomalies, and opportunities for energy efficiency improvements.

Remote Access and Control:Users can access their energy consumption data remotely, often through online platforms or mobile apps. Some smart meters also allow users to control connected devices or appliances remotely, contributing to energy conservation.

Few publications:

[1] Yan, Y. F., Zhang, S. F., Zhang, Y. H., Zuo, F. G., & Li, F. D. (2013). Design of network power meter based on modbus TCP. Applied Mechanics and Materials, 325, 939-943.

[2] Meikandasivam, S., Vijayakumar, D., Kavitha, B. R., Palanisamy, K., & Gupta, P. (2021, November). Smart Metering System. In 2021 Innovations in Power and Advanced Computing Technologies (i-PACT) (pp. 1-5). IEEE.

[3] Avancini, D. B., Rodrigues, J. J., Rabêlo, R. A., Das, A. K., Kozlov, S., & Solic, P. (2021). A new IoT-based smart energy meter for smart grids. International Journal of Energy Research, 45(1), 189-202.

TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ☑ **No** ☐

If Yes, then basis and Supporting Documentation:

SL NO	Function Name	Function Description

1	Receive load scheduling command from ecoMicrogrid.	ecoDR receives load scheduling data from ecoMicrogrid and accordingly controls the non-critical output port.
2	Receive load limiting command from ecoMicrogrid.	ecoDR receives load limiting data from ecoMicrogrid and stores it locally at a location in its non-volatile memory. For load limiting ecoDR disconnects critical and non-critical load via switching module on the event of overload.
3	Data transmission to ecoMG	Time stamped energy data sent to ecoMicrogrid from ecoDR (approx. once in 10 minutes).
4	On board voltage measurement	In ecoDR, it has voltage sensing unit and arrangement to measure the supply voltage.
5	On board current measurement	In ecoDR, it has a current sensing unit and arrangement to measure the load current.
6	On board time & date measurement	In ecoDR, RTC unit measures time & date.
7	On board computation of power	Based on measured voltage and current, power is computed locally.
8	On board computation of energy	Based on derived power and time interval energy is computed.
9	time stamp packet creation	As ecoMicrogrid platform needs time stamp data, ecoDR creates time stamped energy data using computed energy and measured time-date.
10	Load scheduling based on stored data	non-critical load is scheduled by controlling switching module on the event of receiving load scheduling command from ecoMicrogrid.
11	Programmable Load limiting based on stored data	Based on stored data in non-volatile memory for load limiting threshold, received from ecoMicrogrid, total load (critical + non-critical) is limited by controlling switching module.
12	Ethernet based Integrated communication module	Data and commands are exchanged between ecoMicrogrid and ecoDR using an Ethernet based integrated communication module.
13	Power failure	ecoDR ensures integrity of data in non-volatile memory on power failure by saving important data at top priority basis.

TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ■ **No** ☐

If Yes, then basis and Supporting Documentation:

Development boards energy metering ASIC was developed and was interfaced with central microcontroller development board . Then this system was tested in laboratory in simulated environment.

TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation: Development boards for power supply, real time clock, non-volatile memory, energy metering ASIC, central microcontroller were developed/procured and interfaced with each other. Then this system was tested in laboratory in simulated environment.		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation: Deliverable 4.1 details the result for testing for the developed prototype of ecoDR		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation: Deliverable 4.1 details the result for testing for the developed prototype of ecoDR.		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐ **No** ■
If Yes, then basis and Supporting Documentation:		

TRL9: Outcome refined & adopted	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?	Yes ☐ No ■
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	Question	Start of Project			Current status			<Date>
		Yes	No	NA	Yes	No	NA	
1	Do rough calculations support the concept?			X			X	
1	Do basic principles (physical, chemical, mathematical) support the concept?	X			X			Basic Physics and Maths for electric power and energy
1	Do paper studies confirm basic scientific principles of new technology?	X			X			
1	Has a scientific methodology or approach been developed?			X			X	
TRL 1 Achieved	**Basic principles observed and reported.**	X			X			
2	Has potential system or component applications been identified?	X			X			
2	Have paper studies confirmed system or component application feasibility?	X			X			
2	Has an apparent design solution been identified?	X			X			
2	Have the basic components of the technology been identified?	X			X			March 2023

2	Have technology or system components been at least partially characterized?	**X**			**X**			
2	Have performance predictions been documented for each component?			**X**			**X**	
2	Has a functional requirements generation process been initiated?	**X**			**X**			April 2022
2	Does preliminary analysis confirm basic scientific principles?			**X**			**X**	
2	Are basic scientific principles confirmed with calculation based analytical studies?			**X**			**X**	
TRL 2 Achieved	**Technology concept and/or application formulated.**	**X**			**X**			
3	Have calculated predictions of components of technology capability been validated?			**X**			**X**	
3	Can all science applicable to the technology be modeled or simulated?			**X**			**X**	
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?			**X**			**X**	
3	Do experiments verify feasibility of application of technology?	**X**			**X**			
3	Do paper studies indicate that technology or system components can be integrated?	**X**			**X**			
3	Has scientific feasibility of proposed technology been fully demonstrated?	**X**			**X**			
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?			**X**			**X**	
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**	**X**			**X**			
4	Has acceptance testing of individual components been performed?	**X**			**X**			

4	Has performance of components and interfaces between components been demonstrated?	**X**			**X**			
4	Does draft system architecture plan exist?	**X**			**X**			
4	Have end user technology/system requirements been documented?	**X**			**X**			
4	Does technology demonstrate basic functionality in simplified environment?	**X**			**X**			
4	Have performance characteristics been demonstrated in a laboratory environment?	**X**			**X**			
4	Have low-fidelity assessments of system integration and engineering been completed?	**X**			**X**			
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**	**X**			**X**			
5	Have internal system interface requirements been documented?	**X**			**X**			
5	Has analysis of internal interface requirements been completed?	**X**			**X**			
5	Can all system specifications be simulated and validated within a laboratory environment?	**X**			**X**			
5	Have individual component functions been verified through testing?	**X**			**X**			
5	Is component integration demonstrated in a laboratory environment?	**X**			**X**			
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**	**X**			**X**			
6	Have system integration issues been addressed?	**X**			**X**			
6	Is the operational environment fully known (i.e., user community, physical	**X**			**X**			

	environment, and input data characteristics as appropriate)?							
6	Have performance characteristics been verified in a simulated operational environment?	**X**			**X**			
6	Has prototype been tested in a simulated operational environment?	**X**			**X**			
6	Has system been tested in realistic environment outside the laboratory?		**X**			**X**		
6	Has engineering feasibility been fully demonstrated?	**X**			**X**			
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?	**X**			**X**			
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**	**X**			**X**			
7	Have all interfaces been tested individually under stressed and anomalous conditions?		**X**		**X**			
7	Has technology or system been tested in a relevant environment?		**X**		**X**			
7	Are available components representative of production components?		**X**		**X**			
7	Are available components ready to be fully integrated in the final outcome?		**X**		**X**			
7	Has operational testing of technology/system in relevant environment been completed?		**X**		**X**			
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		**X**		**X**			
TRL 7 Achieved	**System prototype demonstration in an operational environment.**		**X**		**X**			

8	Are all technology/system components form, fit, and function compatible?		**X**			**X**		
8	Is technology/system form, fit, and function compatible with operational environment?		**X**			**X**		
8	Has technology/system form, fit, and function been demonstrated in operational environment?		**X**			**X**		
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		**X**			**X**		
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**		**X**			**X**		
9	Does technology/system function as defined in Operational Concept document?		**X**			**X**		
9	Has technology/system has been deployed in intended operational environment?		**X**			**X**		
9	Has technology/system been fully demonstrated?		**X**			**X**		
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		**X**			**X**		
9	Is the outcome adopted by the user community?		**X**			**X**		
TRL 9 Achieved	**Actual system proven through successful mission operations.**		**X**			**X**		

A.5: ecoPlatform

Part A: General questionnaire

Sl. No.	Item	Information

1.	**ecoTool Name**	ecoPlatform
2.	**Principal Investigator(s) (ecoTool lead)**	Guangya Yang, Aysegul Kahraman
3.	**Principal Investigator Institute**	DTU
4.	**Participating Institute(s) (other collaborators)**	ICCS-NTUA, BV, IIT KGP, CSIR-CMERI, IISc, IITD, ICL
5.	**Starting TRL**	3
6.	**Anticipated Ending TRL**	6
7.	**Current Status**	5 is completed.
8.	**Actual Ending TRL**	NA
9.	**Date**	30.06.2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
The technology is a lightweight, cloud-based platform that ensures secure and reliable da processing, exchange and handling of heterogeneous data between various tools.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes, the architecture design has been developed and confirmed with the project demo site.

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes, the required visualizations have been executed as a follow-up to the design.

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No.

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer
The ecoPlatform enables data exchange between various sites in real-time, enhancing optimization and reliability by ensuring all ecoTools are interconnected and integrated.

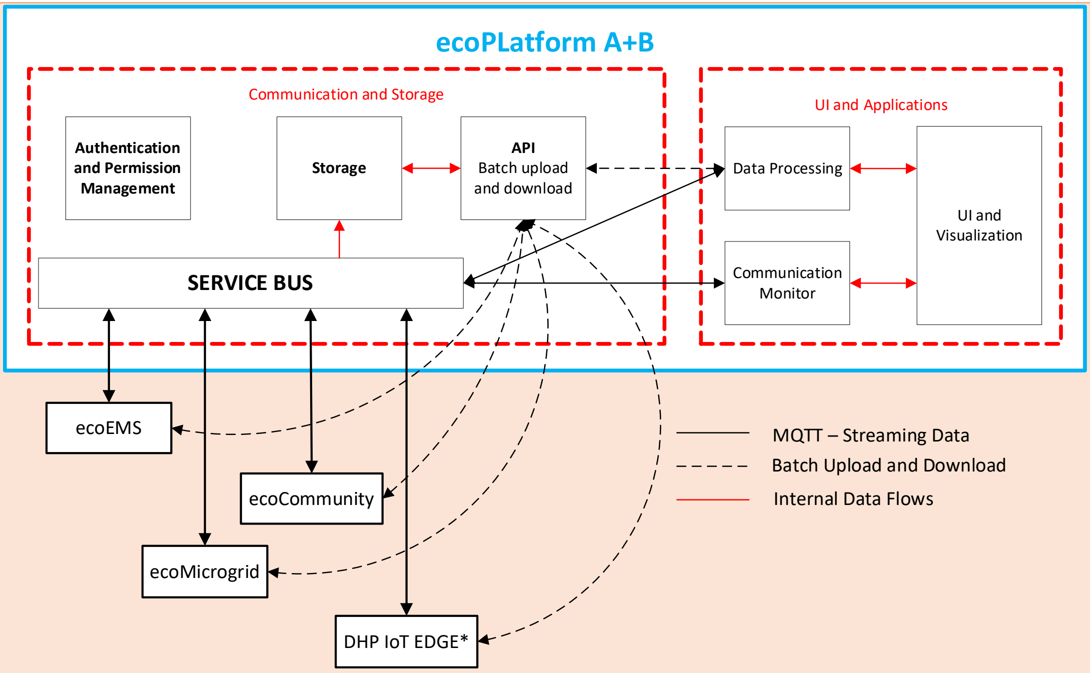
F) Which is the problem which should be solved by the ecoTool?

Information/Answer
The platform aims to enable final customers or operators to freely customize the applications and acquire necessary data streams for operations. It addresses: • Communication and data exchange between different tools. • Data storage. • Data governance. • User interface. • Communication and asset status monitoring. • Interface for data pre-processing algorithms.

2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

   What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer
The ecoPlatform's basic functionalities include effective and reliable communication with other tools.



Communication monitoring is conducted through logs for tracking message delivery and alarm notifications for missing messages and connection losses. The platform also offers data storage, allowing received data from other tools across demo sites to be stored until a specified limit. Access to the platform is based on the assigned permissions, enabling operators to visualize site specific data and send alarms and notifications related to system operations.

The service bus facilitates communication between tools, supporting two data flow options: streaming and batch.

In the streaming option, messages are formatted in JSON with parameters such as ID and value (integer, float, or string).

In the batch option, data from other tools is sent to the ecoPlatform in CSV format (timestamped integer, float, or string). Data can be stored, or tools can request data via API using parameter identifiers. Relevant ecoTools within a specific demo site can publish, store, and retrieve data only within that group or demo site environment.

3. Describe the envisioned deployment of this technology.

D) Where will this technology be deployed?

Information/Answer

ecoPlatform-A will be deployed at the Bornholm demo site.

E) What is the operational environment for this technology (at the point of implementation)?

Information/Answer

The platform operates in environments that require specifically real time data exchange between the multiple sites to conclude a one or more task.

F) Please, describe the end users of the technology, and how they will use it.

Information/Answer
End users include operators, data providers, consumers, and tool leaders who will interact with the platform.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
The platform has been tested using dummy data to validate sending, receiving and storing capabilities. Individual tests with other tool and demo site leaders have been executed separately.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
Various tool modules were tested to verify their functionality.

C) How representative is the test environment to the intended operational environment?

Information/Answer
With network connection, any test environment can closely represent the main operational environment.

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
Communication and data exchange with other ecoTools and the Bornholm demo-site have been tested to verifying the connections.

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

C) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
No

D) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
NA

7. How has the user community been included in the technology development process?

D) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
Demo site leader and relevant ecotools connected and tested with dummy data. Further tests will be conducted, but targeted users/costumers have not been included yet.

E) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
NA

F) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
From the other ecotool leaders has not been reported any specific issue with respect to the completed tests.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: **Basic principles & research**	**Have the basic process technology process principles been observed and reported?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation:		

TRL2: **Application formulated**	**Has an equipment and process concept been formulated?**	**Yes** ■	**No** ☐
If Yes, then basis and Supporting Documentation:			
TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ■	**No** ☐
If Yes, then basis and Supporting Documentation:			
TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ■	**No** ☐
If Yes, then basis and Supporting Documentation:			
TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■	**No** ☐
If Yes, then basis and Supporting Documentation:			
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☐	**No** ■

If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		
TRL9: **Outcome refined & adopted**	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	**Question**	**Start of Project**		**Current status**		**<Date>**
		Yes	**No**	**Yes**	**No**	
1	Do rough calculations support the concept?	✓		✓		
1	Do basic principles (physical, chemical, mathematical) support the concept?	✓		✓		

1	Do paper studies confirm basic scientific principles of new technology?	✓		✓		
1	Has a scientific methodology or approach been developed?	✓		✓		
TRL 1 Achieved	**Basic principles observed and reported.**					
2	Has potential system or component applications been identified?	✓		✓		
2	Have paper studies confirmed system or component application feasibility?	✓		✓		
2	Has an apparent design solution been identified?	✓		✓		
2	Have the basic components of the technology been identified?	✓		✓		
2	Have technology or system components been at least partially characterized?	✓		✓		
2	Have performance predictions been documented for each component?	✓		✓		
2	Has a functional requirements generation process been initiated?	✓		✓		
2	Does preliminary analysis confirm basic scientific principles?	✓		✓		
2	Are basic scientific principles confirmed with calculation based analytical studies?	✓		✓		
TRL 2 Achieved	**Technology concept and/or application formulated.**					
3	Have calculated predictions of components of technology capability been validated?	✓		✓		
3	Can all science applicable to the technology be modeled or simulated?					NA
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?	✓		✓		
3	Do experiments verify feasibility of application of technology?		✓	✓		

3	Do paper studies indicate that technology or system components can be integrated?	✓		✓		
3	Has scientific feasibility of proposed technology been fully demonstrated?		✓	✓		
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?					NA
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**					
4	Has acceptance testing of individual components been performed?		✓	✓		
4	Has performance of components and interfaces between components been demonstrated?		✓	✓		
4	Does draft system architecture plan exist?	✓		✓		
4	Have end user technology/system requirements been documented?		✓	✓		
4	Does technology demonstrate basic functionality in simplified environment?		✓	✓		
4	Have performance characteristics been demonstrated in a laboratory environment?		✓	✓		
4	Have low-fidelity assessments of system integration and engineering been completed?					NA
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**					
5	Have internal system interface requirements been documented?		✓	✓		
5	Has analysis of internal interface requirements been completed?		✓	✓		
5	Can all system specifications be simulated and validated within a laboratory environment?		✓	✓		

5	Have individual component functions been verified through testing?		✓	✓		
5	Is component integration demonstrated in a laboratory environment?					NA
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**					
6	Have system integration issues been addressed?		✓	✓		
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		✓	✓		
6	Have performance characteristics been verified in a simulated operational environment?		✓	✓		
6	Has prototype been tested in a simulated operational environment?		✓	✓		
6	Has system been tested in realistic environment outside the laboratory?		✓		✓	
6	Has engineering feasibility been fully demonstrated?		✓		✓	
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		✓		✓	
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**					
7	Have all interfaces been tested individually under stressed and anomalous conditions?		✓		✓	
7	Has technology or system been tested in a relevant environment?		✓		✓	
7	Are available components representative of production components?		✓		✓	

7	Are available components ready to be fully integrated in the final outcome?		✓		✓	
7	Has operational testing of technology/system in relevant environment been completed?		✓		✓	
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		✓		✓	
TRL 7 Achieved	**System prototype demonstration in an operational environment.**					
8	Are all technology/system components form, fit, and function compatible?		✓		✓	
8	Is technology/system form, fit, and function compatible with operational environment?		✓		✓	
8	Has technology/system form, fit, and function been demonstrated in operational environment?		✓		✓	
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		✓		✓	
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**					
9	Does technology/system function as defined in Operational Concept document?		✓		✓	
9	Has technology/system has been deployed in intended operational environment?		✓		✓	
9	Has technology/system been fully demonstrated?		✓		✓	
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		✓		✓	
9	Is the outcome adopted by the user community?		✓		✓	

TRL 9 Achieved	**Actual system proven through successful mission operations.**					

A.6: ecoConverter

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoConverter
2.	**Principal Investigator(s) (ecoTool lead)**	Dr. Suman Maiti
3.	**Principal Investigator Institute**	IIT KGP
4.	**Participating Institute(s) (other collaborators)**	IIT BBS
5.	**Starting TRL**	TRL-4
6.	**Anticipated Ending TRL**	TRL-6
7.	**Current Status**	Testing in the Lab Environment
8.	**Actual Ending TRL**	TRL-6
9.	**Date**	31/07/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?

Information/Answer
This ecoConverter tool is a dc-dc and dc-ac converter set which has a rating of 10kW. There a basically 3 input energy vectors integrating PV String, Wind Turbines and a battery bank (along wi suitable converters) and a dc-ac Converter which is connected to a grid.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes.

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes.

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No.

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer
DC-DC and DC-AC Converter set.

F) Which is the problem which should be solved by the ecoTool?

Information/Answer
We can store the energy in the battery bank and deliver the power as per the requirement.

2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

   What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer
A 10 kW microgrid system is fabricated in the laboratory, in the framework of RE-EMPOWERED project, which will be deployed to Ghoramara island for demonstration. Several eco-tool-developed in the project will be validated in the framework of this hardware. The microgrid can integrate three different energy sources, i.e., solar, wind, and energy storage, and is able to feed islanded ac loads. Multiple power peaks may be generated under the presence of partial shading which may not be tracked accurately by a conventional P&O MPPT method. To address this issue, a Particle Swarm Optimization (PSO) based MPPT search algorithm is proposed that can find the

global peak with good accuracy in less time. The use of PPC and plug-and-play type converters in the microgrid makes it more efficient and flexible.

3. Describe the envisioned deployment of this technology.

G) Where will this technology be deployed?

Information/Answer
It will be deployed at Ghoramara Island at West Bengal.

H) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Electrical input and output cables are required along with the ecoMicrogrid ecotool is required as it will be integrated with that.

I) Please, describe the end users of the technology, and how they will use it.

Information/Answer
The users will be school and the 5 houses near the control room where it will be placed for operation.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
At the laboratory environment.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
Both the AC side and the DC side of the microgrid system have been tested.

C) How representative is the test environment to the intended operational environment?

Information/Answer
To a great extent.

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
Yes

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

E) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
Yes

F) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
Yes

7. How has the user community been included in the technology development process?

G) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
Yes

H) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
Yes

I) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
Feedback is satisfactory.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	Have the basic process technology process principles been observed and reported?	Yes ☑ No ☐

If Yes, then basis and Supporting Documentation:

There is a considerable amount of published research on smart meters converters technologies. Researchers and organizations worldwide have explored various aspects of converter topologies, including their design, functionality, and efficiency. Here are a few key research papers and publication regarding our technologies:

1. J. M. Carrasco *et al.*, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," in *IEEE Transactions on Industrial Electronics*, vol. 53, no. 4, pp. 1002-1016, June 2006, doi: 10.1109/TIE.2006.878356.
   Summary: In this paper, new trends in power electronics for the integration of wind and photovoltaic (PV) power generators are presented. A review of the appropriate storage-system technology used for the integration of intermittent renewable energy sources is also introduced.

2. N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," in *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963-973, July 2005, doi: 10.1109/TPEL.2005.850975.
   Summary: In this paper it is shown that, in order to limit the negative effects associated to the above drawbacks, the P&O MPPT parameters must be customized to the dynamic behaviour of the specific converter adopted.

3. B. Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," in *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 89-98, Jan. 2013, doi: 10.1109/TSTE.2012.2202294.
   Summary: In this paper, a detailed description and then classification of the MPPT techniques have made based on features, such as number of control variables involved, types of control strategies employed, types of circuitries used suitably for PV system and practical/commercial applications.

4. E. Isen and A. F. Bakan, "10 kW grid-connected three-phase inverter system: Control, simulation and experimental results," *2012 3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Aalborg, Denmark, 2012, pp. 836-840, doi: 10.1109/PEDG.2012.6254098.
   Summary: In this study, implementation of a 10kW three-phase grid-connected inverter system is discussed. The system includes a high voltage dc-link, a two-level inverter and filter inductances. It is observed that at 9 kHz switching frequency, 650V dc-link voltage and 10 kW output power, the total harmonic distortion of the grid current is less than 3.4%, and power factor is higher than 0.99.

5. Thanh-Vu Tran, Tae-Won Chun, Hong-Hee Lee, Heung-Geun Kim and Eui-Cheol Nho, "Control for grid-connected and stand-alone operations of three-phase grid-connected inverter," *2012*

International Conference on Renewable Energy Research and Applications (ICRERA), Nagasaki, Japan, 2012, pp. 1-5, doi: 10.1109/ICRERA.2012.6477348.
Summary: This paper describes a simple grid current control method for the grid-connected operation, and inverter voltage control method based on the phase locked loop (PLL) for the intentional islanding operation at the three-phase grid-connected inverter.

6. G. E. Mejía-Ruiz, J. R. Rodríguez, M. R. A. Paternina, N. Muñoz-Galeano and A. Zamora, "Grid-Connected Three-Phase Inverter System with LCL Filter: Model, Control and Experimental Results," *2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America)*, Gramado, Brazil, 2019, pp. 1-6, doi: 10.1109/ISGT-LA.2019.8895017.
Summary: This paper implements a grid-connected two-level three-phase inverter with both active and reactive power flow capabilities. This inverter is an effective power electronic interface for renewable energy systems. The system has been implemented using a NI SB-Rio development board, a high voltage DC-link, a Phase Locked Loop (PLL) algorithm, and a LCL filter.

7. K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors," in IEEE Transactions on Energy Conversion, vol. 19, no. 2, pp. 392-399, June 2004, doi: 10.1109/TEC.2004.827038.
Summary: In this article, the possibility of adopting the PMG in the onboard dc grid instead of the WRG is studied. The power extraction strategy is mentioned in this document for the diode bridge PMSG interface.

8. H. Wang, C. Nayar, J. Su and M. Ding, "Control and Interfacing of a Grid-Connected Small-Scale Wind Turbine Generator," in IEEE Transactions on Energy Conversion, vol. 26, no. 2, pp. 428-434, June 2011, doi: 10.1109/TEC.2011.2116792.
Summary: This paper describes how these converters incorporate maximum power point tracking based on its power feed to the grid at different wind speeds. Using the permanent magnet generator voltage, grid current, and grid voltage samples, the proposed system achieves an enhanced dynamic behaviour.

TRL2: **Application formulated**	**Has an equipment and process concept been formulated?**	**Yes** ■ **No** ☐

If Yes, then basis and Supporting Documentation:

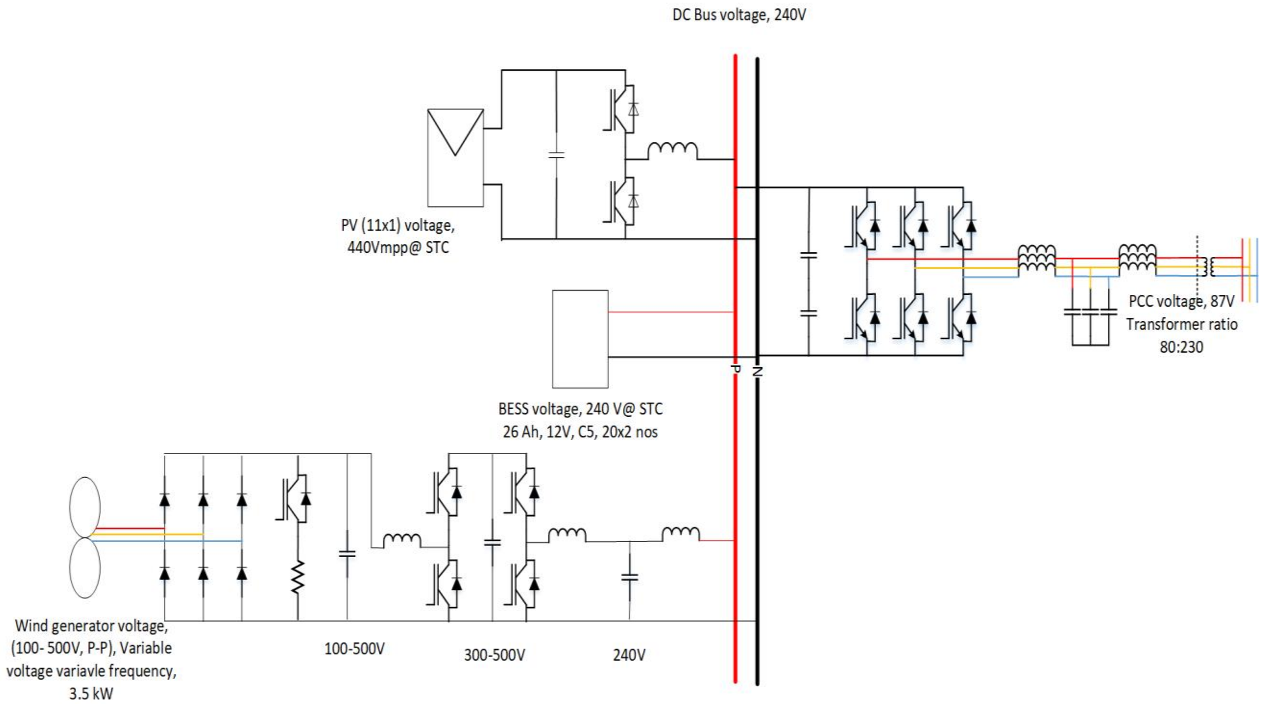
A 10 kW microgrid system is fabricated in the laboratory, in the framework of RE-EMPOWERED project, which will be deployed to Ghoramara island for demonstration. Several eco-tool- developed in the project will be validated in the framework of this hardware. The microgrid can integrate three different energy sources, i.e., solar, wind, and energy storage, and is able to feed islanded ac loads. Multiple power peaks may be generated under the presence of partial shading which may not be tracked accurately by a conventional P&O MPPT method. To address this issue, a Particle Swarm Optimization (PSO) based MPPT search algorithm is proposed that can find the global peak with good accuracy in less time. The use of PPC and plug-and-play type converters in the microgrid makes it more efficient and flexible.

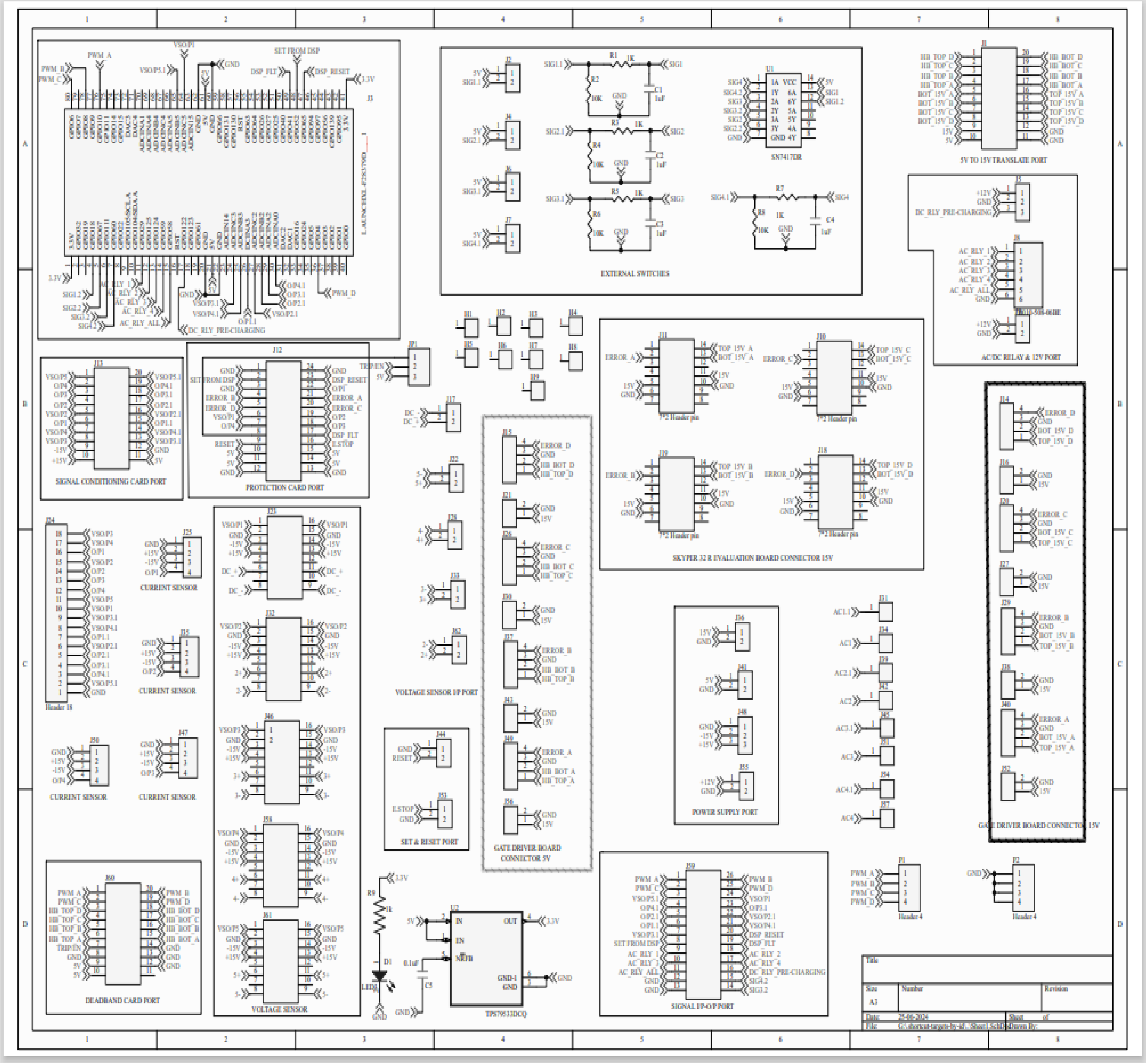
This tool is deployed because it has these features:

- 3 input and 1 output ports
- Lower losses
- High power capture during partial shading
- No shut down at low voltage MPP
- Particle Swarm Optimization (PSO) algorithm for global peak search
- Fast MPPT tracking
- Islanded operation

TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ☑ **No** ☐

If Yes, then basis and Supporting Documentation:





Converter Side Details	Inverter side details
PV converter Details	Inverter DC Bus Voltage: 240V (220-260V)
PV details: 11 panels in series	Two level Inverter, Standalone Mode
PV Voltage 1: (300-550) 440 VMPP	Inv o/p Voltage: 80V (Phase Voltage)
I/P current of DC-DC Converter (PV) - 13 Amp	Inverter current: 22 Amp (rms)

Output side current DC-DC Converter (PV): 23.8 Amp @MPP	Inverter Rating: (3x80x22) = 5.28 kW
PV Power: 5.94kW @ STC	**Transformer Details**
Battery Details	Transformer rating: 6 kVA
BESS Details: 9.6 kWh	Primary side voltage taping: 80V, 115V, 230V
Single battery: 20Ah, C5 (0.2C) BESS current: 8 Amp (Charging Mode)	Secondary side voltage: 230V
BESS Voltage: 220-260V (20*12V)	**Load Details**
Wind Converter details	5 houses consuming 300W, School building load, Toto charger
Wind Voltage (100-500V), Variable frequency, 3.5 kW 3-ph.	**Micro Controller details**
Input side max current of Wind converter: 7A DC (1.65A (rms) 3ph)	Micro Controller: LAUNCHXL – F28379D Development Kit
Output side Voltage of Wind converter: 240V (220-260V)	
Output side max current of Wind converter: 14.58 A	

TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ☑	**No** ☐

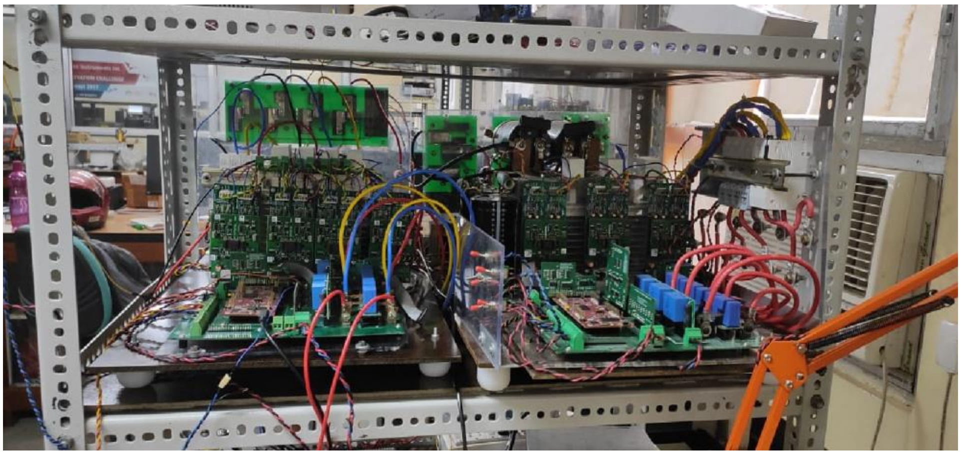
If Yes, then basis and Supporting Documentation:

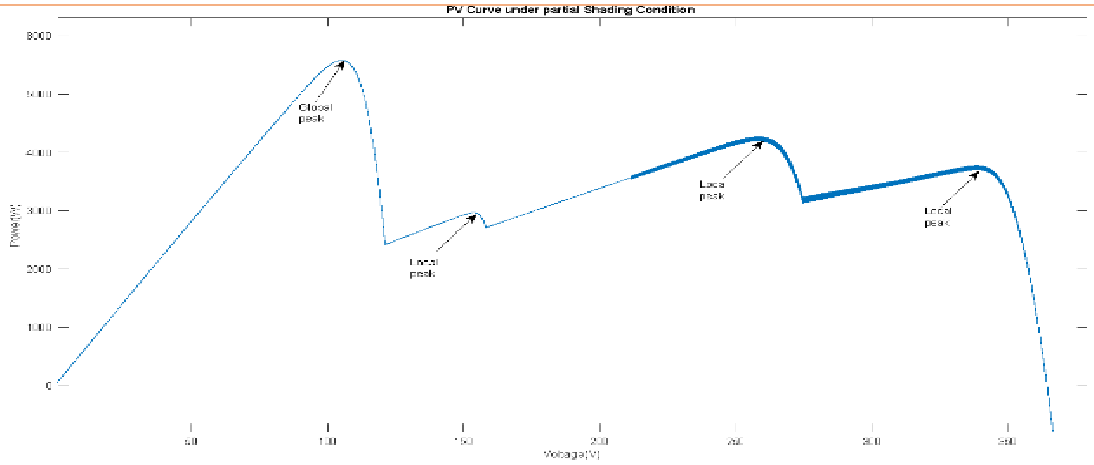
Development boards were made and the circuits were tested in the lab environment.

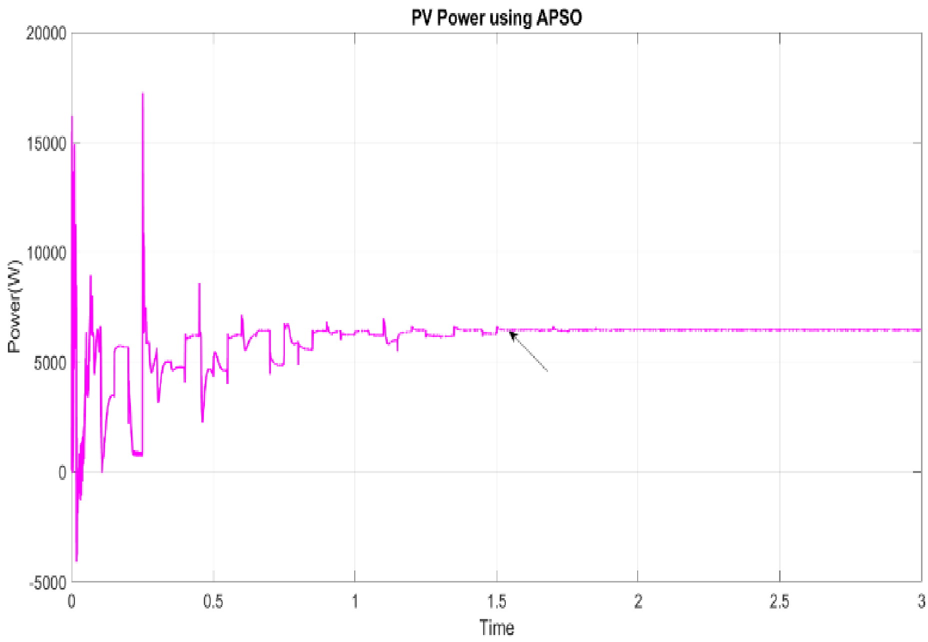
TRL5:	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☑	**No** ☐

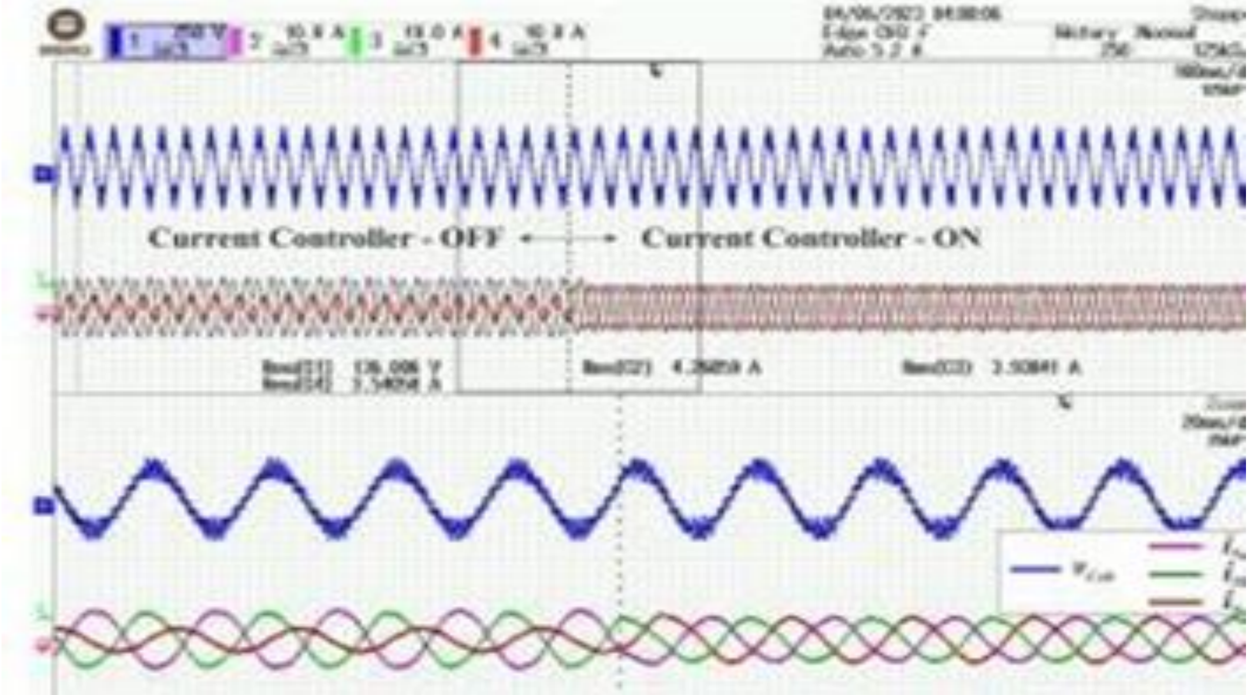
Integrated components demonstrated in a laboratory environment		
If Yes, then basis and Supporting Documentation: Development boards were made and the circuits were tested in the lab environment.		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■ **No** ☐

If Yes, then basis and Supporting Documentation:




PV Curve under partial Shading Condition
Global peak
Local peak
Local peak
Local peak
Voltage(V)


PV Power using APSO
20000
15000
10000
5000
0
-5000
Power(W)
0
0.5
1
1.5
2
2.5
3
Time



TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ☐	**No** ■
If Yes, then basis and Supporting Documentation:			
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐	**No** ■
If Yes, then basis and Supporting Documentation:			
TRL9:	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes** ☐	**No** ■

Outcome refined & adopted		
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	Question	Start of Project			Current status			<Date>
		Yes	No	NA	Yes	No	NA	
1	Do rough calculations support the concept?		X			X		
1	Do basic principles (physical, chemical, mathematical) support the concept?	X			X			
1	Do paper studies confirm basic scientific principles of new technology?	X			X			
1	Has a scientific methodology or approach been developed?	X			X			
TRL 1 Achieved	**Basic principles observed and reported.**	X			X			
2	Has potential system or component applications been identified?	X			X			
2	Have paper studies confirmed system or component application feasibility?	X			X			
2	Has an apparent design solution been identified?	X			X			
2	Have the basic components of the technology been identified?	X			X			
2	Have technology or system components been at least partially characterized?	X			X			

2	Have performance predictions been documented for each component?			**X**			**X**	
2	Has a functional requirements generation process been initiated?	**X**			**X**			
2	Does preliminary analysis confirm basic scientific principles?			**X**			**X**	
2	Are basic scientific principles confirmed with calculation based analytical studies?			**X**			**X**	
TRL 2 Achieved	**Technology concept and/or application formulated.**	**X**			**X**			
3	Have calculated predictions of components of technology capability been validated?			**X**			**X**	
3	Can all science applicable to the technology be modeled or simulated?			**X**			**X**	
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?			**X**			**X**	
3	Do experiments verify feasibility of application of technology?	**X**			**X**			
3	Do paper studies indicate that technology or system components can be integrated?	**X**			**X**			
3	Has scientific feasibility of proposed technology been fully demonstrated?	**X**			**X**			
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?			**X**			**X**	
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**	**X**			**X**			
4	Has acceptance testing of individual components been performed?	**X**			**X**			
4	Has performance of components and interfaces between components been demonstrated?	**X**			**X**			

4	Does draft system architecture plan exist?	X			X			
4	Have end user technology/system requirements been documented?	X			X			
4	Does technology demonstrate basic functionality in simplified environment?	X			X			
4	Have performance characteristics been demonstrated in a laboratory environment?	X			X			
4	Have low-fidelity assessments of system integration and engineering been completed?	X			X			
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**	X			X			
5	Have internal system interface requirements been documented?	X			X			
5	Has analysis of internal interface requirements been completed?	X			X			
5	Can all system specifications be simulated and validated within a laboratory environment?	X			X			
5	Have individual component functions been verified through testing?	X			X			
5	Is component integration demonstrated in a laboratory environment?	X			X			
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**	X			X			
6	Have system integration issues been addressed?	X			X			
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?	X			X			

6	Have performance characteristics been verified in a simulated operational environment?	**X**			**X**			
6	Has prototype been tested in a simulated operational environment?	**X**			**X**			
6	Has system been tested in realistic environment outside the laboratory?		**X**			**X**		
6	Has engineering feasibility been fully demonstrated?	**X**			**X**			
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?	**X**			**X**			
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**	**X**			**X**			
7	Have all interfaces been tested individually under stressed and anomalous conditions?		**X**			**X**		
7	Has technology or system been tested in a relevant environment?		**X**			**X**		
7	Are available components representative of production components?		**X**			**X**		
7	Are available components ready to be fully integrated in the final outcome?		**X**			**X**		
7	Has operational testing of technology/system in relevant environment been completed?		**X**			**X**		
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		**X**			**X**		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**		**X**			**X**		
8	Are all technology/system components form, fit, and function compatible?		**X**			**X**		

8	Is technology/system form, fit, and function compatible with operational environment?		**X**			**X**		
8	Has technology/system form, fit, and function been demonstrated in operational environment?		**X**			**X**		
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		**X**			**X**		
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**		**X**			**X**		
9	Does technology/system function as defined in Operational Concept document?		**X**			**X**		
9	Has technology/system has been deployed in intended operational environment?		**X**			**X**		
9	Has technology/system been fully demonstrated?		**X**			**X**		
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		**X**			**X**		
9	Is the outcome adopted by the user community?		**X**			**X**		
TRL 9 Achieved	**Actual system proven through successful mission operations.**		**X**			**X**		

A.7: ecoMonitor

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoMonitor
2.	**Principal Investigator(s) (ecoTool lead)**	Santu Kr Giri, Anirudh Kumar, Siddheswar Sen

3.	**Principal Investigator Institute**	CSIR-CMERI
4.	**Participating Institute(s) (other collaborators)**	-
5.	**Starting TRL**	TRL 4
6.	**Anticipated Ending TRL**	TRL 7
7.	**Current Status**	TRL 6-7
8.	**Actual Ending TRL**	NA
9.	**Date**	31/01/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
ecoMonitor is a digital control platform equipped with multiple sensors and a microcontroller based processing unit for real time monitoring of the local ambient air quality parameters, such as NO_2, O_3, SO_2, CO, PM2.5 and PM10 micro particles, including ambient temperature and relative humidity. The measured air quality data are transmitted to the central control station via MODBUS/MQTT gateway for display and further analysis.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer

Performance evaluation in actual operating environment

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer

Real time monitoring of ambient air quality parameters

F) Which is the problem which should be solved by the ecoTool?

Information/Answer

Real time monitoring and remote analysis of ambient air quality parameters data from a central control station

2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer

The following figure shows the major components of the ecoMonitor tool.

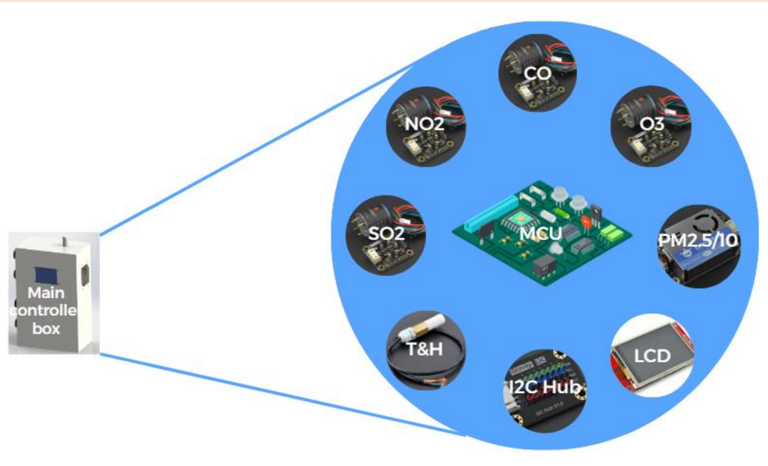


Figure A6 : Major components of ecoMonitor Tool

The following components have been incorporated with the main controller box for monitoring the ambient air quality parameters as well as display the readings in a local display unit. All the sensors are obtained from commercial sources suitable for outdoor applications.

Gas sensors: There are four gas sensors which help to detect specific gasses (NO_2, O_3, SO_2, CO) present in the environment. All the sensor probes use electrochemical principles, providing strong stability and sensitivity with a lifespan of up to two years. These sensors have widespread applications in safety production, industrial manufacturing, and environmental protection, making

it the ideal choice for settings such as coal mines, chemical industries, chemical laboratories, and environmental management.
Following are the specifications of the gas sensor probes.

- Working Voltage: 3.3～5.5V DC
- Working Current: <5mA
- Working Temperature: -20～50℃
- Working Humidity: 15～90%RH (non-condensing)
- Lifespan: >2 years (in the air)
- Model no.: SEN0466, SEN0470, SEN0471, SEN0472,
- Make: DFRobot

Temperature and Humidity sensor probe: This is a SHT20 I2C temperature & humidity sensor with waterproof probe. It can measure surrounding environment temperature and relative air humidity precisely. Besides the capacitive type humidity sensor and the band gap temperature sensor, the chip contains an amplifier, A/D converter, OTP memory and a digital processing unit. The inner PCB has perfusion and encapsulation protection, and the probe enclosure is made of PE waterproof materials. This is a special waterproof breathable material that allows water molecules to seep in, blocking water droplets from seeping in.
Following are the specifications of the temperature and humidity sensor probe.

- Operating Voltage: 3.3V/5V
- Protection Class: waterproof anti-condensation
- RH Response Time: 8s (tau63%)
- Accuracy: ±3% RH / ±0.3 ℃
- Model no: SEN 0227
- Make: DFRobot

Particulate Matter sensor (PM2.5/PM10): This sensor can measure particulate matter like PM2.5, PM1.0, PM10, with easy-to-use interface. This sensor adopts the principle of laser scattering, that is, to make the laser irradiate the suspended particles in the air produce scattering, and at the same time collect the scattered light at a certain angle, and obtain the curve of the intensity of the scattered light with time. Furthermore, the microprocessor, based on the MIE theory algorithm, obtains the equivalent particle size of the particles and the number of particles of different particle sizes per unit volume. The following figure shows the functional block diagram depicting the interconnection of PM sensors components.
Following are the specifications of the Particulate matter sensor.

- Working Voltage: 3.3~5.0V
- Maximum Working Current: 100 mA
- Standby Current: ≤2 mA
- Particle Measurement Range: 0.3 ~ 1.0 µm; 1.0 ~ 2.5µm; 2.5 ~ 10µm
- Model no: SEEN0460
- Make: DFRobot

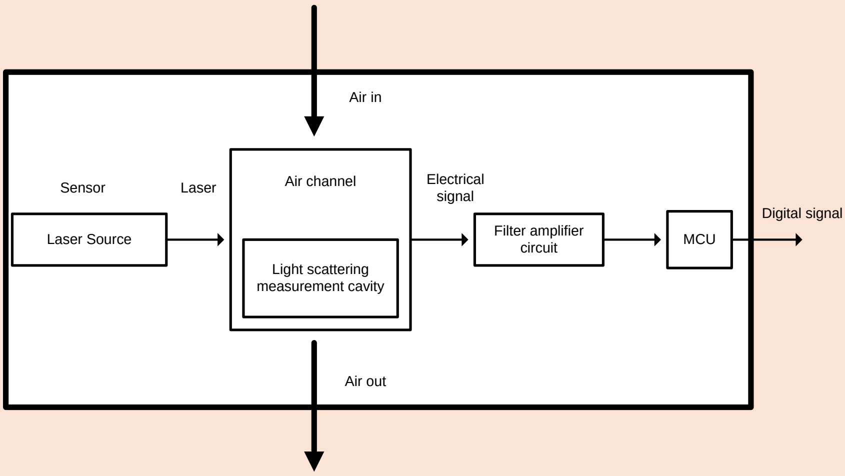


Figure A7: Particulate Matter sensor functional block diagram

LCD Display: This is Thin Film Transistor (TFT) display of 2.8” (diagonal), bright and colorful having 240×320 pixels with individual RGB pixel control. This display has a controller built into it with RAM buffering so that almost no work is done by the microcontroller. This 2.8 inch SPI screen module is wrapped up into an easy-to-use breakout board, with SPI connections. The display has been selected such that it gives a wide viewing angle. The following figure displays the readings of ambient air quality parameters in the local display unit.

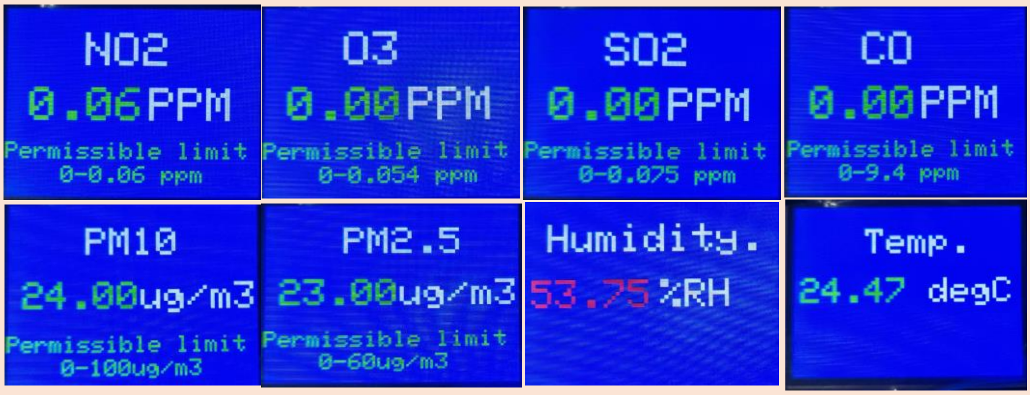


Figure A8: Display of ambient air quality parameters readings

Following are the specifications of the LCD display

- Working Voltage: 3.3 to 5V DC
- Pixel Resolution: 240 x 320
- PCB Size (L x W) mm: 85 x 48
- Display Size(inch): 2.8

Digital control platform: The digital control platform is responsible for collecting real-time data from the ambient air quality monitoring sensors. The platform gathers data from sensors and other sources for further processing. A robust communication network enables seamless data transmission between ecoMonitor and central control station via Ethernet unit using MODBUS protocol. The following figure shows the digital control platform block (shaded region) depicting major components. The details about the major components are provided below.

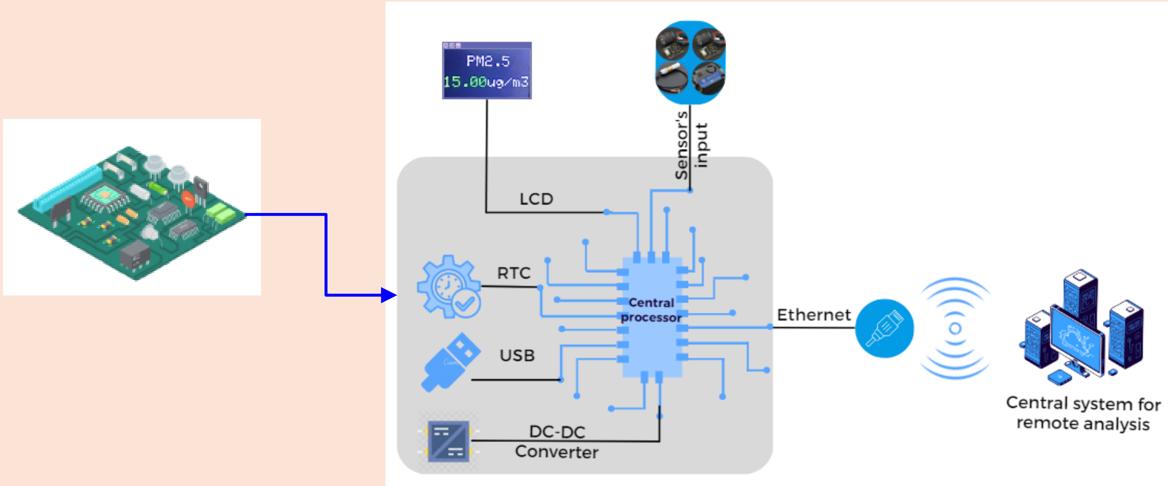


Figure A9: Digital control platform block depicting major components

DC-DC converter: It is used in ecoMonitor to fulfill power requirement of all the electronics components, which are operated under 5v power supply. The input power source of the ecoMonitor is from 12V supply. Two DC-DC converters of 12V to 5V and 1 A current rating have been used to meet the power requirement of all the components. The following figure shows the schematic diagram of the two dc-dc power converter modules used in this development.

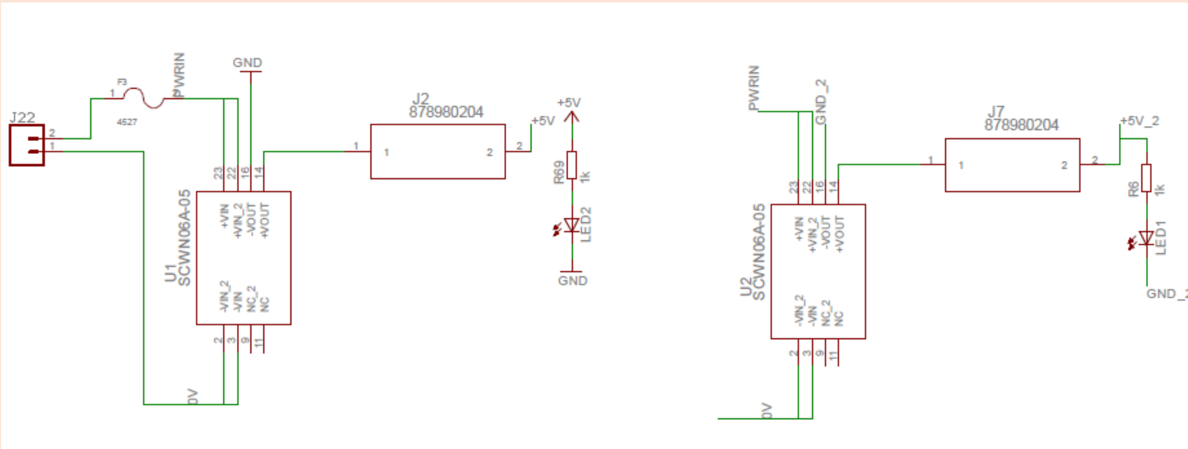


Figure A10: Schematic diagram of power module

Real Time Clock Module: The use of RTC unit in the ecoMonitor to transmit the collected real time data from the digital control unit to central management dash board. The transmitted data are further analyzed to provide useful insights regarding possible corrective actions, such as RES integration. The following figure shows the schematic diagram of the RTC module used in the digital control platform.

Communication Module: Ethernet interface module, allows the ecoMonitor devices to connect and communicate with the central control station for the remote analysis via MODBUS protocol. The Ethernet unit contains an Ethernet controller chip, which handles the low-level data link layer functions, such as framing data into Ethernet packets and managing access to the physical medium. illustrates the schematic diagram of Ethernet based communication module.

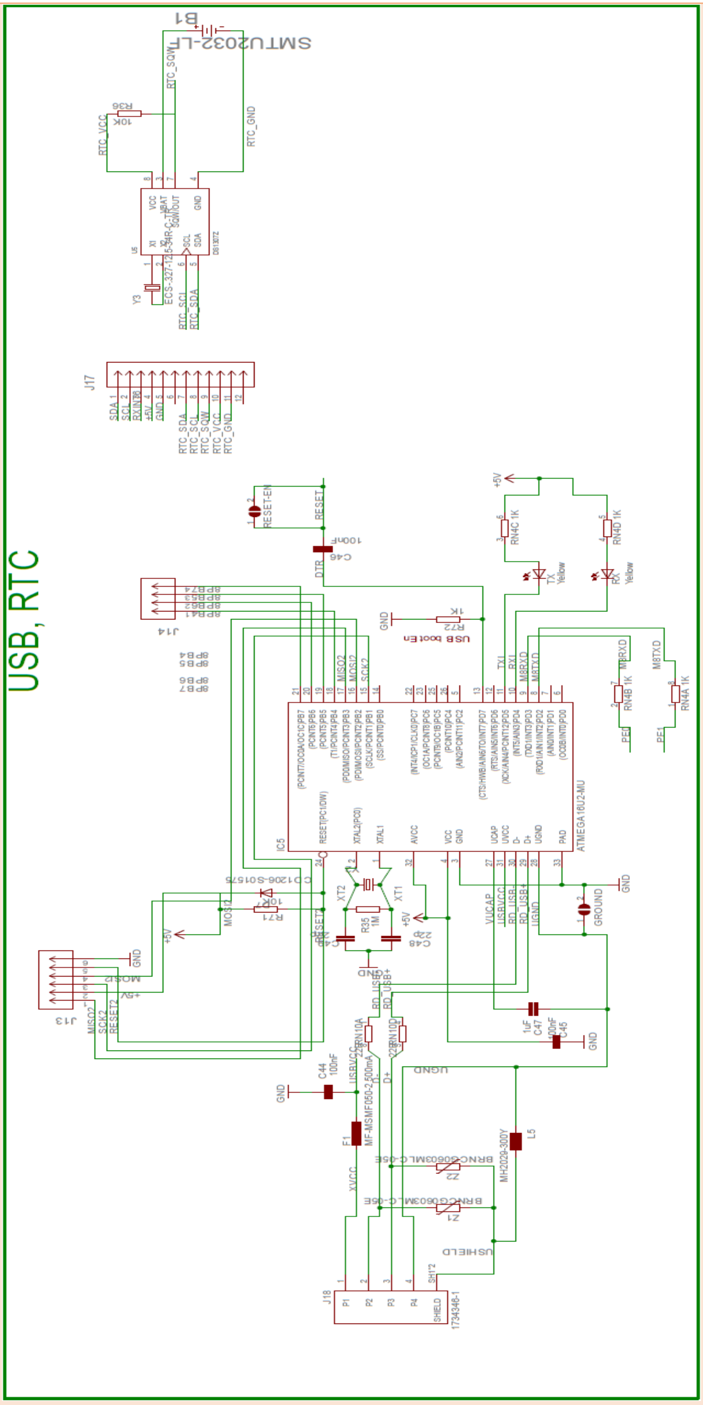


Figure A11: Schematic diagram of USB and RTC unit

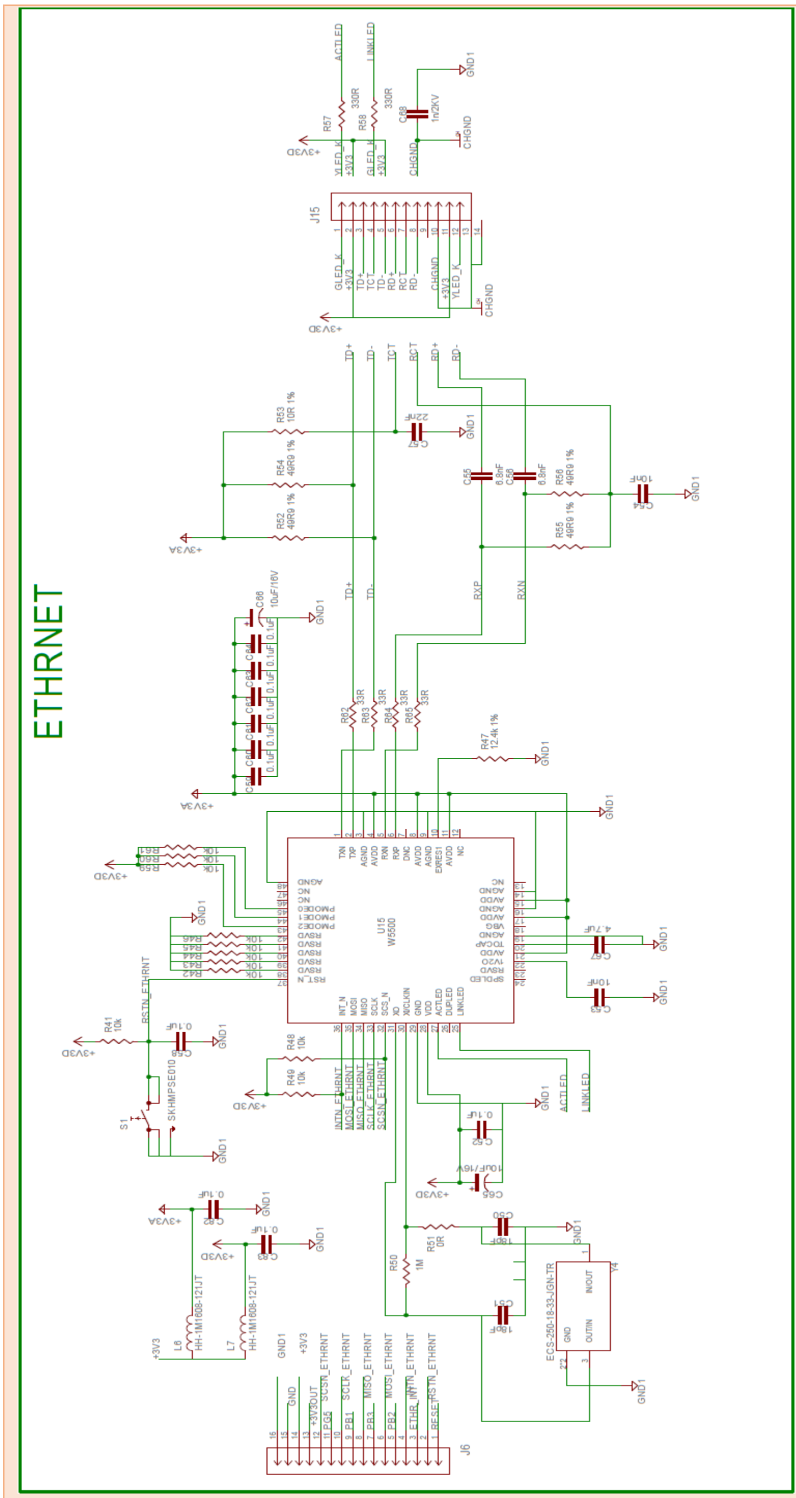


Figure A12: Schematic diagram of Ethernet unit

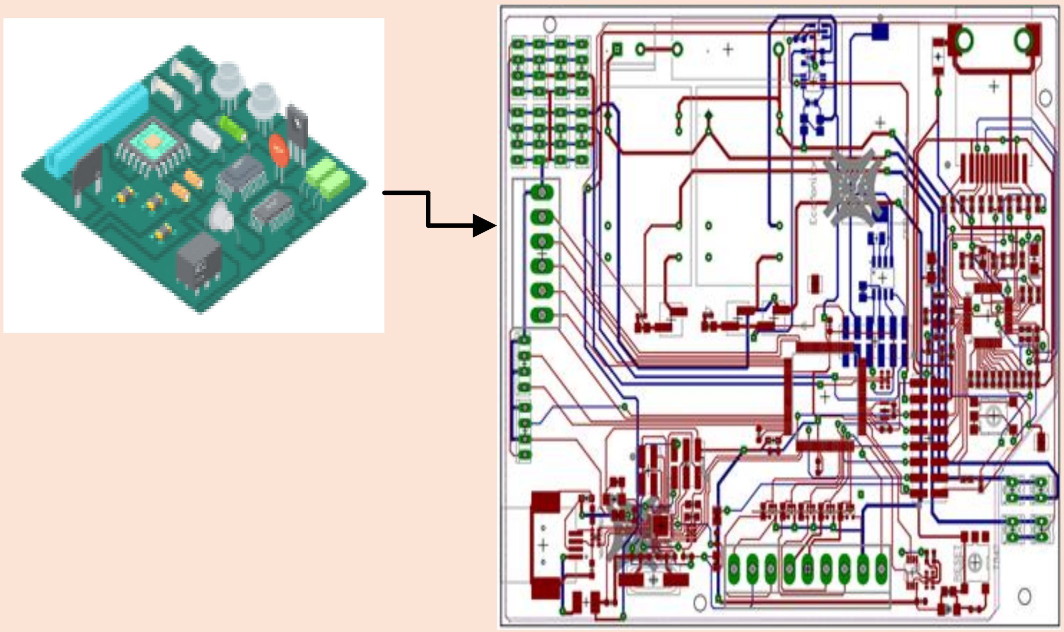


Figure A13: PCB layout of the digital control platform combining all modules

The above figure shows the complete PCB layout of the digital control platform of the ecoMonitor tool.

3. Describe the envisioned deployment of this technology.

J) Where will this technology be deployed?

Information/Answer
It will be deployed in Ghoramara, Bornholm and Kythnos demo sites.

K) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
Communication infrastructure (Ethernet cable), solar panel/dc power

L) Please, describe the end users of the technology, and how they will use it.

Information/Answer
Different pollution control boards (PCBs), smart cities etc.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
At Laboratory and controlled outdoor environment.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
The experiments have been conducted in laboratory environment and then validated at outdoor environment. The ambient air quality sensors module has been interfaced with the microcontroller (MCU) using the I2C protocol to collect data for display and further analysis. First, individual sensors were tested, and their performance was evaluated. During this phase, the time duration between consecutive data readings was set to 10 seconds. After testing the individual sensors, they were integrated to create a comprehensive air quality monitoring system. In this integrated setup, the time interval between repetitions of the parameters was approximately 1 minute and 12 seconds, while the time interval between readings of two successive parameters was about ten seconds. This configuration allowed for efficient data collection and ensured accurate and reliable monitoring of air quality parameters.

C) How representative is the test environment to the intended operational environment?

Information/Answer
To a great extent

5. How has the integration of the various components and systems been tested?

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
For testing purposes, the sensors are interfaced with the controller using the I2C communication protocol. The data have been acquired continuously for 48 hours in lab environment.

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

G) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
A prototype has been developed.

H) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
NA

7. How has the user community been included in the technology development process?

J) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
Yet to be done

K) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
NA

L) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
No feedback received from the users.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: **Basic principles & research**	**Have the basic process technology process principles been observed and reported?**	**Yes** ☐ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL2: **Application formulated**	**Has an equipment and process concept been formulated?**	**Yes** ☐ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL3: **Proof of concept**	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ☐ **No** ☐
TRL4: **Components validated in laboratory environment**	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ☐ **No** ☐
If Yes, then basis and Supporting Documentation: Development boards energy metering ASIC was developed and was interfaced with central microcontroller development board . Then this system was tested in laboratory in simulated environment.		
TRL5: **Integrated components demonstrated in a laboratory environment**	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☐ **No** ☐

If Yes, then basis and Supporting Documentation:		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☒ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		
TRL9: **Outcome refined & adopted**	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes** ☐ **No** ☒
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	Question	Start of Project			Current status			<Date>
		Yes	No	NA	Yes	No	NA	
1	Do rough calculations support the concept?			X			X	
1	Do basic principles (physical, chemical, mathematical) support the concept?	X			X			Basic Physics and Maths for electric power and energy
1	Do paper studies confirm basic scientific principles of new technology?	X			X			
1	Has a scientific methodology or approach been developed?			X			X	
TRL 1 Achieved	**Basic principles observed and reported.**	X			X			
2	Has potential system or component applications been identified?	X			X			
2	Have paper studies confirmed system or component application feasibility?	X			X			
2	Has an apparent design solution been identified?	X			X			
2	Have the basic components of the technology been identified?	X			X			
2	Have technology or system components been at least partially characterized?	X			X			
2	Have performance predictions been documented for each component?			X			X	
2	Has a functional requirements generation process been initiated?	X			X			
2	Does preliminary analysis confirm basic scientific principles?			X			X	

2	Are basic scientific principles confirmed with calculation based analytical studies?			**X**			**X**	
TRL 2 Achieved	**Technology concept and/or application formulated.**	**X**			**X**			
3	Have calculated predictions of components of technology capability been validated?			**X**			**X**	
3	Can all science applicable to the technology be modeled or simulated?			**X**			**X**	
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?			**X**			**X**	
3	Do experiments verify feasibility of application of technology?	**X**			**X**			
3	Do paper studies indicate that technology or system components can be integrated?	**X**			**X**			
3	Has scientific feasibility of proposed technology been fully demonstrated?	**X**			**X**			
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?			**X**			**X**	
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**	**X**			**X**			
4	Has acceptance testing of individual components been performed?	**X**			**X**			
4	Has performance of components and interfaces between components been demonstrated?	**X**			**X**			
4	Does draft system architecture plan exist?	**X**			**X**			
4	Have end user technology/system requirements been documented?	**X**			**X**			

4	Does technology demonstrate basic functionality in simplified environment?	**X**			**X**			
4	Have performance characteristics been demonstrated in a laboratory environment?	**X**			**X**			
4	Have low-fidelity assessments of system integration and engineering been completed?			**X**			**X**	
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**	**X**			**X**			
5	Have internal system interface requirements been documented?		**X**		**X**			
5	Has analysis of internal interface requirements been completed?		**X**		**X**			
5	Can all system specifications be simulated and validated within a laboratory environment?		**X**		**X**			
5	Have individual component functions been verified through testing?		**X**		**X**			
5	Is component integration demonstrated in a laboratory environment?		**X**		**X**			
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**		**X**		**X**			
6	Have system integration issues been addressed?		**X**		**X**			
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		**X**		**X**			
6	Have performance characteristics been verified in a simulated operational environment?		**X**		**X**			
6	Has prototype been tested in a simulated operational environment?		**X**		**X**			

6	Has system been tested in realistic environment outside the laboratory?		X		X			
6	Has engineering feasibility been fully demonstrated?		X		X			
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		X			X		
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**	X			X			
7	Have all interfaces been tested individually under stressed and anomalous conditions?		X			X		
7	Has technology or system been tested in a relevant environment?		X		X			
7	Are available components representative of production components?		X			X		
7	Are available components ready to be fully integrated in the final outcome?		X			X		
7	Has operational testing of technology/system in relevant environment been completed?		X			X		
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		X			X		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**		X			X		
8	Are all technology/system components form, fit, and function compatible?		X			X		
8	Is technology/system form, fit, and function compatible with operational environment?		X			X		

8	Has technology/system form, fit, and function been demonstrated in operational environment?		**X**			**X**		
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		**X**			**X**		
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**		**X**			**X**		
9	Does technology/system function as defined in Operational Concept document?		**X**			**X**		
9	Has technology/system has been deployed in intended operational environment?		**X**			**X**		
9	Has technology/system been fully demonstrated?		**X**			**X**		
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		**X**			**X**		
9	Is the outcome adopted by the user community?		**X**			**X**		
TRL 9 Achieved	**Actual system proven through successful mission operations.**		**X**			**X**		

A.8: ecoCommunity

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoCommunity
2.	**Principal Investigator(s) (ecoTool lead)**	
3.	**Principal Investigator Institute**	Imperial College London

4.	**Participating Institute(s) (other collaborators)**	ICCS-NTUA, DTU, BV, IIT KGP, CSIR-CMERI, IISc, IITD
5.	**Starting TRL**	3
6.	**Anticipated Ending TRL**	6
7.	**Current Status**	Laboratory prototype tested and validated. Awaiting deployment and validation in actual environment.
8.	**Actual Ending TRL**	
9.	**Date**	31-01-2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?.

Information/Answer
ecoCommunity is a digital platform that enables engagement and support for the members of the energy community in a local energy system.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
The system architecture and list of modules relevant to a generic microgrid system as well as catering for the specific needs of the project demo sites were developed.

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
The module interdependencies and data communication requirements with other ecoTools and external services were identified.

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No

E) *Which will be the proposed/expected outcome of the ecoTool?*

Information/Answer
The active engagement of energy system users in the efficient operation of the microgrid system through active demand side management techniques. Enabling energy users to resolve the simple problems and issues associated with the various system components to guidance materials and report serious problems to the administrators.

F) *Which is the problem which should be solved by the ecoTool?*

Information/Answer
• Easy access to the energy consumption information • Effective participation of energy users in demand side management • Resolving the problems and issues associated with energy system and its components.

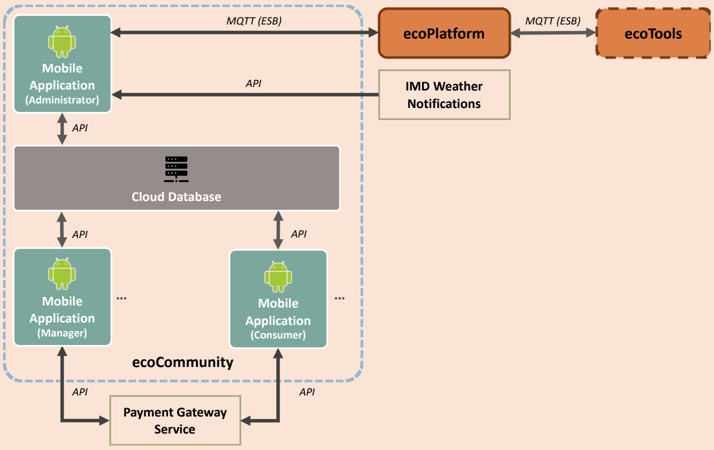
2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer

The tool includes the following subsystems.

1. Mobile Application
2. Cloud Database



The mobile application is the key component of the ecoCommunity tool which acts as the interface to the users of the energy community. The modules and tasks performed by the application depend on the type of users. The administrator user instance of the application is primarily responsible for the management of the tool database and communication with other tools. The consumer and manager user instances of the application utilise the data stored in the cloud database for visualisation and storing the user inputs. The second component of the tool is the cloud database which is utilised for storing all the data associated with the tool.

Communication with other ecoTools is facilitated through ecoPlatform tool using MQTT. The communication with external services and the cloud database utilises API.

3. **Describe the envisioned deployment of this technology.**

M) Where will this technology be deployed?

Information/Answer
Microgrids and Local Energy Systems largely rely on renewable energy sources.

N) What is the operational environment for this technology (at the point of implementation)?

Information/Answer

O) Please, describe the end users of the technology, and how they will use it.

Information/Answer
Energy System Consumers and Administrators

4. **Testing information**

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
The various modules of the tool has been tested in the laboratory environment using dummy data.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
The various tool modules were tested to verify their capabilities using test inputs.

C) How representative is the test environment to the intended operational environment?

Information/Answer
The tool utilises internet connectivity to fetch the data from the cloud database and other ecoTools. In the case of the intended operational environment of the tool, it is expected to suffer from network intermittencies.

5. **How has the integration of the various components and systems been tested?**

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
The communication with other ecoTools are tested for verifying the data exchange capabilities.

6. Has a demonstration of the full technology been conducted, or a prototype constructed?

I) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
No

J) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
NA

7. How has the user community been included in the technology development process?

M) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
No

N) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
NA

O) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
NA

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	**Have the basic process technology process principles been observed and reported?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL2: Application formulated	**Has an equipment and process concept been formulated?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL3: Proof of concept	**Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL4: Components validated in laboratory environment	**Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?**	**Yes** ■ **No** ☐
If Yes, then basis and Supporting Documentation:		
TRL5: Integrated components demonstrated in a laboratory environment	**Has bench-scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■ **No** ☐

If Yes, then basis and Supporting Documentation:		
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ☐ **No** ■
If Yes, then basis and Supporting Documentation:		
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** ☐ **No** ■
If Yes, then basis and Supporting Documentation:		
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** ☐ **No** ■
If Yes, then basis and Supporting Documentation:		
TRL9: **Outcome refined & adopted**	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes** ☐ **No** ■
If Yes, then basis and Supporting Documentation:		

Part D: Detailed questionnaire

TRL	Question	Start of Project		Current status		<Date>
		Yes	No	Yes	No	
1	Do rough calculations support the concept?	✓				
1	Do basic principles (physical, chemical, mathematical) support the concept?	✓				
1	Do paper studies confirm basic scientific principles of new technology?	✓				
1	Has a scientific methodology or approach been developed?	✓				
TRL 1 Achieved	**Basic principles observed and reported.**					
2	Has potential system or component applications been identified?	✓				
2	Have paper studies confirmed system or component application feasibility?	✓				
2	Has an apparent design solution been identified?	✓				
2	Have the basic components of the technology been identified?	✓				
2	Have technology or system components been at least partially characterized?	✓				
2	Have performance predictions been documented for each component?	✓				
2	Has a functional requirements generation process been initiated?	✓				
2	Does preliminary analysis confirm basic scientific principles?	✓				
2	Are basic scientific principles confirmed with calculation based analytical studies?					NA
TRL 2 Achieved	**Technology concept and/or application formulated.**					

3	Have calculated predictions of components of technology capability been validated?	✓				
3	Can all science applicable to the technology be modeled or simulated?					NA
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?					NA
3	Do experiments verify feasibility of application of technology?		✓	✓		
3	Do paper studies indicate that technology or system components can be integrated?	✓				
3	Has scientific feasibility of proposed technology been fully demonstrated?		✓	✓		
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?	✓				
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**					
4	Has acceptance testing of individual components been performed?		✓	✓		
4	Has performance of components and interfaces between components been demonstrated?		✓	✓		
4	Does draft system architecture plan exist?		✓	✓		
4	Have end user technology/system requirements been documented?		✓	✓		
4	Does technology demonstrate basic functionality in simplified environment?		✓	✓		
4	Have performance characteristics been demonstrated in a laboratory environment?		✓	✓		
4	Have low-fidelity assessments of system integration and engineering been completed?					

TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**					
5	Have internal system interface requirements been documented?		✓	✓		
5	Has analysis of internal interface requirements been completed?					
5	Can all system specifications be simulated and validated within a laboratory environment?		✓	✓		
5	Have individual component functions been verified through testing?		✓	✓		
5	Is component integration demonstrated in a laboratory environment?		✓	✓		
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**					
6	Have system integration issues been addressed?		✓	✓		
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		✓	✓		
6	Have performance characteristics been verified in a simulated operational environment?		✓	✓		
6	Has prototype been tested in a simulated operational environment?		✓	✓		
6	Has system been tested in realistic environment outside the laboratory?		✓		✓	
6	Has engineering feasibility been fully demonstrated?		✓		✓	
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		✓		✓	
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**					

7	Have all interfaces been tested individually under stressed and anomalous conditions?		✓		✓	
7	Has technology or system been tested in a relevant environment?		✓		✓	
7	Are available components representative of production components?		✓		✓	
7	Are available components ready to be fully integrated in the final outcome?		✓		✓	
7	Has operational testing of technology/system in relevant environment been completed?		✓		✓	
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		✓		✓	
TRL 7 Achieved	**System prototype demonstration in an operational environment.**					
8	Are all technology/system components form, fit, and function compatible?		✓		✓	
8	Is technology/system form, fit, and function compatible with operational environment?		✓		✓	
8	Has technology/system form, fit, and function been demonstrated in operational environment?		✓		✓	
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		✓		✓	
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**					
9	Does technology/system function as defined in Operational Concept document?					

9	Has technology/system has been deployed in intended operational environment?					
9	Has technology/system been fully demonstrated?					
9	Has Operational Test and Evaluation (OT&E) been successfully completed?					
9	Is the outcome adopted by the user community?					
TRL 9 Achieved	**Actual system proven through successful mission operations.**					

A.9: ecoResilience

Part A: General questionnaire

Sl. No.	Item	Information
1.	**ecoTool Name**	ecoResilience
2.	**Principal Investigator(s) (ecoTool lead)**	Dr. T. Murugan, Dr. Santu Kr Giri
3.	**Principal Investigator Institute**	CSIR-CMERI, Durgapur
4.	**Participating Institute(s) (other collaborators)**	
5.	**Starting TRL**	TRL 3
6.	**Anticipated Ending TRL**	TRL 7
7.	**Current Status**	TRL 6-7
8.	**Actual Ending TRL**	TRL 6-7
9.	**Date**	31/01/2024

Part B: ecoTool specific questionnaire

1. Technology Description

A) What is the technology?

Information/Answer
The technology is the development of resilient ground mounted solar PV and wind turbine support structure to handle the extremely wind loading resulting from cyclone. In ground mounted solar PV support structure, the aerodynamic wind load is minimized by incorporating passive aerodynamic surfaces with the main frame of the solar PV panels. The placement of PV module frame on the central base support is optimized through numerical simulations, wind tunnel testing, and field tests to reduce the aerodynamic loads and moments. For wind turbine support structure, wind loads during cyclone is reduced by minimizing the tower height through mechanical operated chain pulley drive and removal of the blades connected with the generator. Removal of blades are essential to preserve them as the cyclonic wind velocity is completely three dimensional. The hybrid tower has a ladder to access the wind turbine for the removal wind turbine blades during extreme weather conditions and the reattachment of blades after the cyclone to operate in normal conditions for the generation of wind energy.

B) Have preliminary engineering designs for system components been developed?

Information/Answer
Yes. The preliminary components of the systems were designed based on the aerodynamic concepts.

C) Have drawings, diagrams, outlines, or other conceptual aids been prepared?

Information/Answer
Yes. Other components to assist the passive aerodynamic components were also designed using the basic concepts of aerodynamics

D) Are there remaining technical or design-related challenges? Please describe.

Information/Answer
No. However there are other challenges due to location of demo site, Ghoramara island as it is situated in the tropical region at latitude of around 22.23°N (Approx.) from the equator. It experiences huge wind velocity close to 200 mph during cyclone. Further, it is severely affected by high tides and often it is fully waterlogged to a height of 3 to 5 feet. The water level in the river around the island fluctuates to a few 10 feet during the day which cause huge challenge in the transportation of items. Further, taking the items to the installation site for their deployment is also highly challenging due to non-availability of proper transportation vehicles. Also, Availability of manpower for deployment work of the tools at proposed demo site is very difficult and manage the working hour during deployment is very challenging.

E) Which will be the proposed/expected outcome of the ecoTool?

Information/Answer
Innovative technologies to handle the severe and chaotic wind loads during cyclone for ground mounted PV and wind turbine systems

F) Which is the problem which should be solved by the ecoTool?

Information/Answer
The demo site, Ghoramara Island often experiences severe cyclonic storms and most of the commercially available technologies for ground mounted and rooftop PV arrays are designed with a maximum wind speed of 50 m/s (~ 110 mph). At higher velocities PV panels gets damaged due to wind loads. Our proposed support structure helps the PV panels to withstand cyclonic loads up to a velocity of 250 kmph and able to continuously harnessing solar energy. Though the demo site, Ghoramara Island has a good wind profile for harnessing wind energy, frequent cyclone affects the wind energy systems. Hence, we have come-up with an option of retractable tower with an option to remove blades. The commercially available support structures have no arrangement to prevent the damage of wind turbine blades during cyclones. But our proposed wind turbine support structure is designed such a manner that the wind loads during cyclone is reduced by minimizing the tower height and removal of blades. The proposed

wind turbine with hybrid tower can withstand extreme weather conditions. It helps to increase exploitation of wind energy and the life span of wind turbine systems.

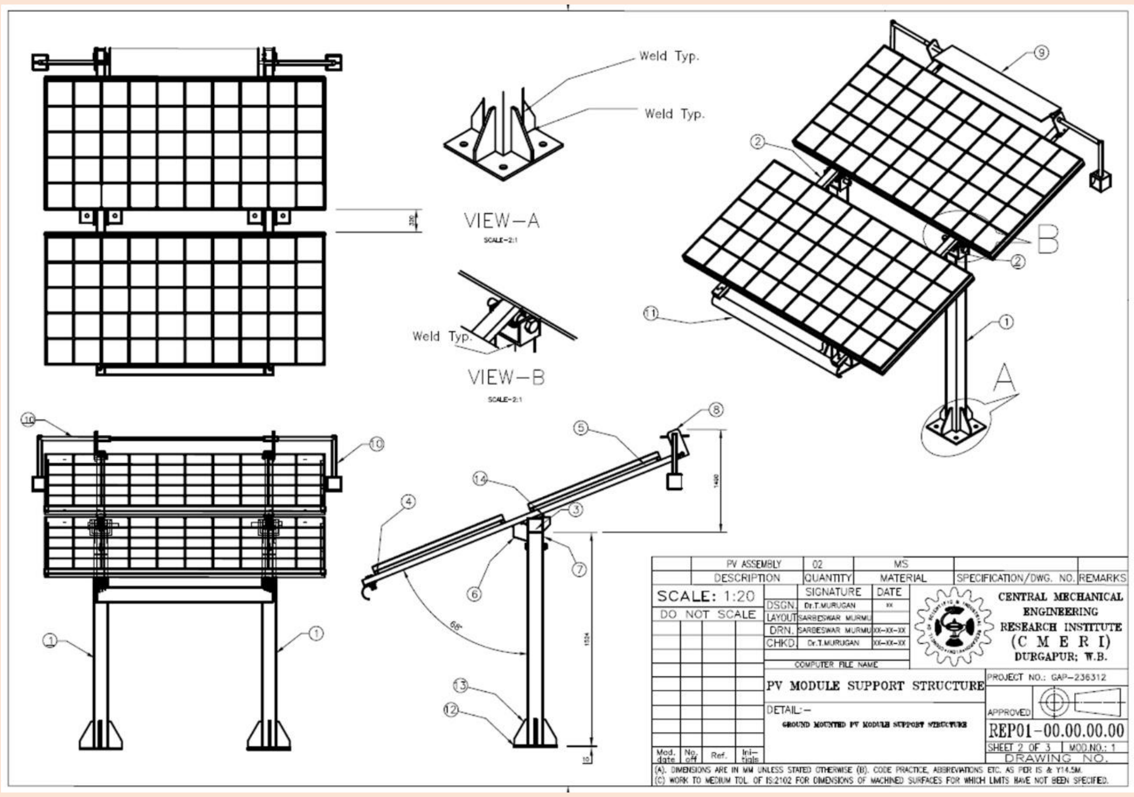
2. **Describe the various constituent parts of the technology. How do they fit together and interact with one another?**

What are the subsystems and components of the technological system? What is the status of those subsystems and components?

Information/Answer

Ground mounted PV module support structure:

The designed final resilient PV support structure has a movable horizontal frames which supports the solar PV panels. It is connected with the vertical columns with two roller bearings as shown in the Fig. A14. The vertical column (100x100x5 mm hollow sq. bar) height of PV module support structure is 5 foot (1.524m) above the civil foundation. Two number of Solar PV system (0.5 kW) is mounted with frame by bolt joints over the two column structures. PV module frame is connected with the vertical column by simple roller bearing, which assist panels frame to change its orientation according to wind flow. A flat plate with two miniature buckets at its two end at the top end of the frame and a semicircle structure at the bottom end of the frame helps to align the PV module frame along the horizontal frame during the designed cyclonic velocity.



PART NO.	DWG. NO.	QTY/ASSY.	MATERIAL	DESCRIPTION	REMARKS
16	REP01–00.00.00.00	02	PV MODULE SUPPORT STRUCTURE		––
15	REP01–00.00.00.00	02	PV FRAME ASSEMBLY		––
14		02	PILLOW BLOCK BALL BEARING	BEARING HOLE–30MM	––
13	REP01–00.00.00.13	08	MS BOTTOM BASE SUPPORT PLATE		––
12	REP01–00.00.00.12	02	BASE PLATE	300x300X10	––
11	REP01–00.00.00.11	01	SEMI CIRCLE PART		––
10	REP01–00.00.00.10	02	BUCKET ASSEMBLY		––
09	REP01–00.00.00.09	01	ALUMINIUM FLAT PLATE	1000x170x5	––
08	REP01–00.00.00.08	02	FLAT PLATE SUPPORT		––
07	REP01–00.00.00.07	02	BACK STOPER		––
06	REP01–00.00.00.06	02	FRONT STOPER	70x70X5	––
05	REP01–00.00.00.05	04	LATTERAL MEMBER	25x25X2	––
04	REP01–00.00.00.04	04	LATTERAL MEMBER	25x25X2	––
03	REP01–00.00.00.03	02	C SECTION	150x100X10	––
02	REP01–00.00.00.02	02	MS HOLLOW PIPE	60x40X2.6	––
01	REP01–00.00.00.01	02	MS SQ. HOLLOW BAR	100x100X5	––

Fig. A14 Resilient Solar PV support structure with passive aerodynamic surfaces

When the wind comes from left to right, two miniature buckets resist the air flow and tilt the trailing edge of the flat plate in the vertical direction which provide negative lift. On the other hand, the left side convex shape allows a smooth air flow and provide less drag compared to the flat plate at the top side. The negative lift increases with increase in wind velocity and it moves the rear end of the panel towards downward direction at the designed critical velocity. Similarly, when the wind comes from right to left, buckets resist the air flow and tilt the trailing edge of the flat plate in the vertical direction which also provide negative lift. The left side concave shape resists the air flow and provide huge drag force compared to the flat plate at the top side. This drag force along with negative lift from topside create a couple which moves the solar PV frame along the horizontal level to minimize the drag. This mechanism provides much lesser drag than our earlier design which shown in Fig. A15.

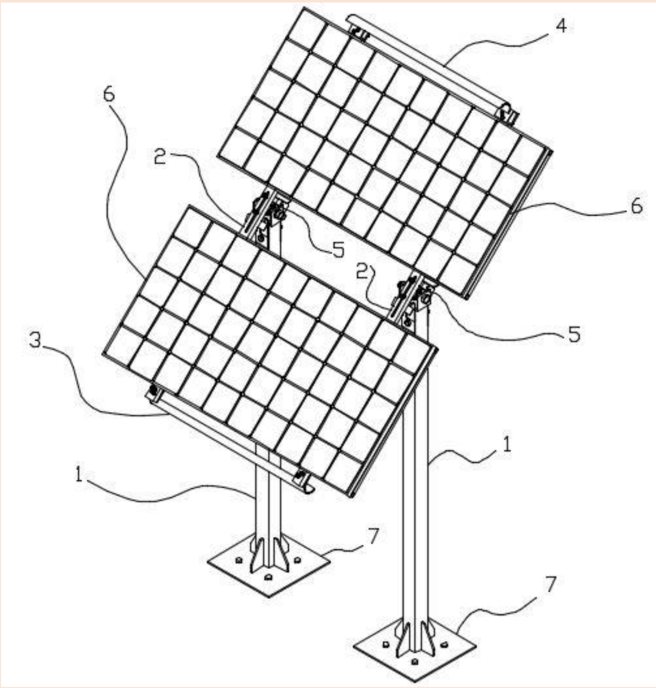


Fig. A15 Resilient Solar PV support structure with concave and convex aerodynamic surfaces

Fig. A16 Wind tunnel testing of 1:10 scale down models of solar PV support structures

Fig. A17 Proto type of solar PV support structures

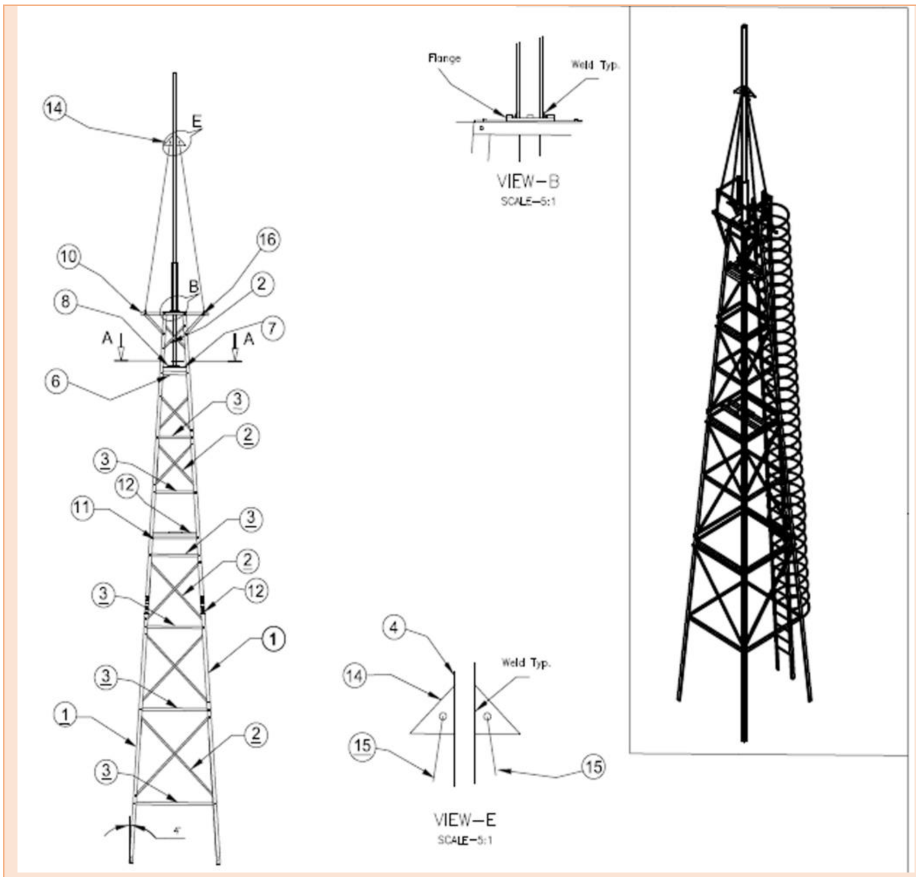
The performance of the designed resilient PV support structures was examined through wind tunnel testing using scale down models. Experiments were performed with different variants of PV systems with multiple orientations as shown in Fig.A16. Few variants of Prototypes were made (Fig. A17) and final variant was transported to demo site for installation. The installation will be performed in May 2024.

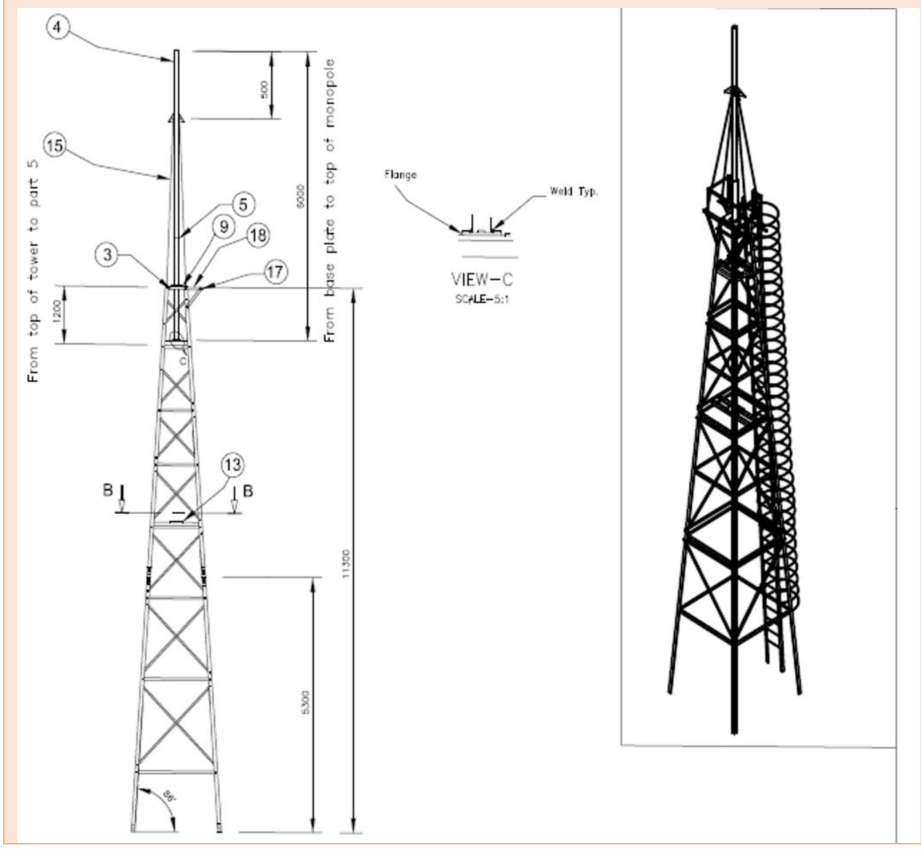
The designed PV support structure has the following response with respect to the designed wind velocity and direction.

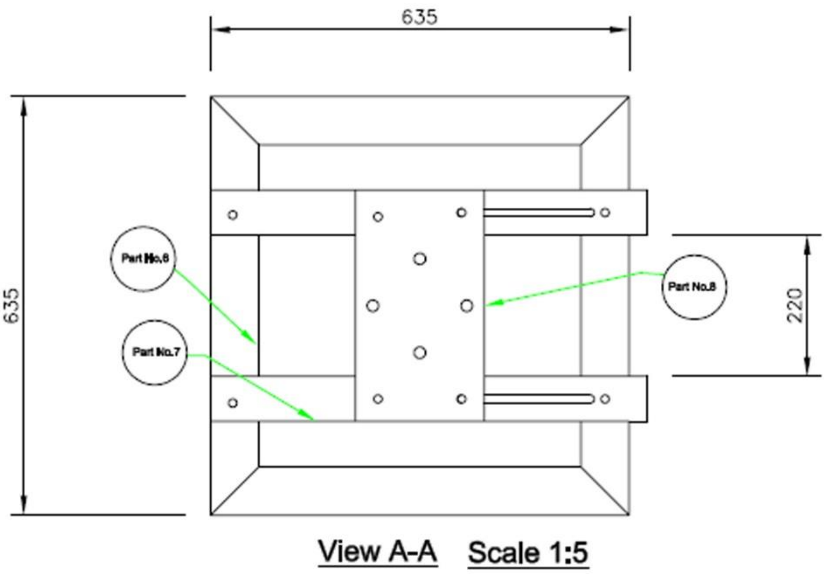
Designed solar panel Inclination angle at the demo site: 20°-30° (adjustable with a base support)
Designed critical left to right velocity to move the panel: 35 m/s (125 kmph)
Designed critical right to left velocity to move the panel: 30 m/s (108 kmph)
Cross flow: No response (minimal loads on panels)

Hybrid wind turbine support structure:

The resilient wind turbine support structure has overall height of 18 m. It has a fixed 12 m truss structure and 6 m movable monopole structure as shown in Fig. A18. The truss structure is made of different types of structural members (Basically angle and hollow bars). The vertical members are divided into three pieces and all are connected by bolt joints. All cross members and horizontal members of tower are connected to vertical members by bolt joints. The monopole structure has a height of 6 m and the wind turbine system is attached on top of it with a stiffened flange. The bottom of the mono pole is attached at 1.2 m from the top of the truss structure. The monopole is also supported on top of the truss structure with an 1 m height hollow pipe having a diameter of 105 mm. Further, the monopole is also attached with eight guy wires (tension cable) from the top which provide additional stability and safety to vertical monopole structure even in high winds. Here, the guy wires are extended till the top of truss structure due to the availability of less space for installation of the wind turbine system.


Flange
Weld Typ.
VIEW-B
SCALE-5:1
Weld Typ.
VIEW-E
SCALE-5:1


From top of tower to part 5
From base plate to top of monopole
Flange
Weld Typ.
VIEW-C
SCALE-5:1



PART NO.	DWG. NO.	QTY/ASSY.	MATERIAL	DESCRIPTION	REMARKS
19	REP01–00.00.00.19	16	JOINT ANGLE		
18	REP01–00.00.00.18	02	TOP CHACKER PLATE SUPPORT MEMBER		
17	REP01–00.00.00.17	02	TOP CHACKER PLATE SUPPORT MEMBER		
16	REP01–00.00.00.16	04	TOP SUPPORT MEMBER		
15	REP01–00.00.00.15	08	METAL TENSION WIRE ROPE(Guy Wire)	DIA–10MM	––
14	REP01–00.00.00.14	01	MONOPOLE TRIANGLE ASSEMBLY		––
13	REP01–00.00.00.13	01	MS BOTTOM BASE PLATE	300X300X20	––
12	REP01–00.00.00.12	02	BOTTOM HOLLOW GUIDE BAR	70X70X5	––
11	REP01–00.00.00.11	04	MONOPOLE BOTTOM SUPPORT	75x75X5	––
10	REP01–00.00.00.10	02	HORIZONTAL TOP MEMBER		––
09	REP01–00.00.00.09	01	TOP PLATE	490X300X8	––
08	REP01–00.00.00.08	01	TOP BASE PLATE	360X200X20	––
07	REP01–00.00.00.07	02	MONOPOLE GUIDE BAR		––
06	REP01–00.00.00.06	04	MONOPOLE SUPPORT		––
05	REP01–00.00.00.05	01	MONOPOLE GUIDE		––
04	REP01–00.00.00.04	01	MONOPOLE		––
03	REP01–00.00.00.03	TABLE 3	HORIZONTAL MEMBER	50x50X5	––
02	REP01–00.00.00.02	TABLE 2	CROSS MEMBER	35x35X5	––
01	REP01–00.00.00.01	TABLE 1	VERTICAL MEMBER	75x75X5	––

Fig. A18 Resilient wind turbine support structure

The monopole is installed rigidly on a plate which has a provision to slide on the rail attached with the truss structure. This allows bringing the monopole down with the help of chain pulley (capacity of 1 ton) very easily to remove the wind turbine blades for preventing damage of blades and tails during adverse weather condition and maintenance of the wind turbine system. A ladder with safety precautions is attached with the hybrid tower to climb up safely to dismantle the turbine blades and maintenance of wind turbine systems. The stress distribution on various members of the tower and their deformations at different wind loads were examined through numerical analysis using static structural analysis available in commercial software ANSYS. A prototype of the tower is made and installed at CSIR-CMERI Durgapur for field testing as shown in Figure A19.

The required foundation was made and the hybrid wind turbine support structure is assembled manually as the demo site does not have any provision to commission the tower with a help of any machinery or vehicle. The monopole and the wind turbine systems were lifted to a platform made on top of truss structure using chain hoists. Once, the wind turbine system along with tail and blades assembled on top of monopole structure, the monopole is lifted to its operational height of 18 m with the help of chain hoists. The wind turbine was working fine without any vibration, however, there was some noise due to fluctuations in wind velocity.

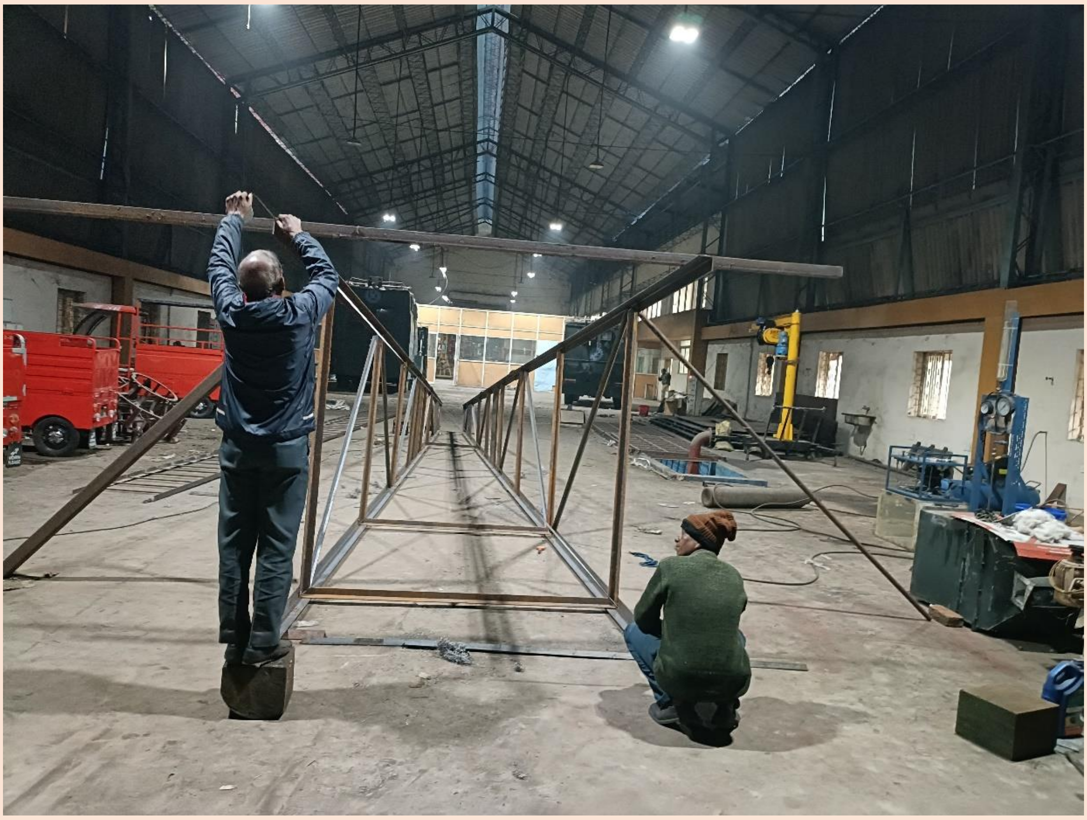


Fig. A19 Fabrication, installation of wind turbine system with resilient structure

The exercise of bringing the monopole down, removal of wind turbine blades and lifting of monopole to its operational height is performed multiple times to check the reliability of the support structure. The truss and monopole support structure was rigid for local maximum velocity of 25 m/s

Fig. A20 Operation of the wind turbine system at CSIR-CMERI Durgapur

The resilient wind turbine support structure is dismantled and transported to demo site for their installation. They will be installed and operational from May 2024.

3. **Describe the envisioned deployment of this technology.**

   P) Where will this technology be deployed?

Information/Answer

It will be deployed in Ghoramara demo sites experiencing severe cyclones which is located approx. 92 km south of Kolkata, in the Sundarban at the Bay of Bengal.

Q) What is the operational environment for this technology (at the point of implementation)?

Information/Answer
It can be deployed at locations which have space restriction and cyclonic wind velocities. It can also be installed at locations having moderate and low wind profiles with lesser capital cost by reducing size of the support structures.

R) Please, describe the end users of the technology, and how they will use it.

Information/Answer
These technologies can be best suited for costal regions having high cyclonic velocities as the free movement of solar panels frame in PV system and lowering of monopole (to remove or lock wind turbine blades) reduce wind loads on structures which increase the life span of these systems.

4. Testing information

A) How and where has the technology—and constituent elements—been tested?

Information/Answer
All PV support structures are tested in the Laboratory through scale down wind tunnel testing and the wind turbine support structure is tested in controlled outdoor environment.

B) Have experiments on system components been conducted? In what settings were these experiments undertaken?

Information/Answer
The designed solar PV and wind turbine support systems structural stability due to wind loads were examined through CFD simulations and structural analysis using commercial software ANSYS which is accepted as on optimization tool around the world. Next, experimental study with scale down models were performed inside a low speed wind tunnel to examine loads on the structures and the advantages of add-on passive aerodynamic structures. Finally, prototype was made and installed over a foundation to check their load bearing capabilities.

Few stiffeners were added close to the foundation to minimize the deformation of box channels.

Wind turbine support structure subjected to different wind loads is examined through numerical simulations. Various structural components were optimized from the stress distribution and deformation obtained from static structural analysis. The prototype was made after repeated numerical analysis considering different safety standards. The operation of the resilient wind turbine support structure with wind turbine systems is examined through field testing using load cell. The support structure was stable at a wind velocity of 30 m/s (106 kmph) which is much higher than the local wind speed at demo site varying from 7 to 10 m/s. The lifting and bring town operations of monopole is tested multiple times and the operation was smooth with chain hoist.

C) How representative is the test environment to the intended operational environment?

Information/Answer
At normal operating conditions of the demo site, the tested operation environment is much superior. The ground mounted PV systems will perform well in the demo site during severe cyclone. However, the wind turbine system installed over the mono pole needs to be brought down to remove the blades and tail during cyclone which condition is not experimentally validated.

5. **How has the integration of the various components and systems been tested?**

If experiments have not been conducted, how will their expected functionality be confirmed, both individually and in combination?

Information/Answer
Complete systems of resilient PV and wind turbine support structures were tested with all its components.

6. **Has a demonstration of the full technology been conducted, or a prototype constructed?**

K) What was the scale and setting of the demonstration, compared to the envisioned deployment of this technology? Was this demonstration indicative of how the final technology may be expected to perform in the field?

Information/Answer
Prototypes are tested in the laboratory environment, and they work well. They will be demonstrated in the demo site in May 2024.

L) Have computer simulations for system design, construction, or operations been conducted? Have case studies been conducted for other components of non-hardware or software technologies? Please describe the results.

Information/Answer
Rigorous computational fluid dynamics and static structural analysis simulations were performed for both resilient structures

7. How has the user community been included in the technology development process?

P) Have usability experiments been conducted or prototypes deployed to intended users?

Information/Answer
It is yet to be done.

Q) If prototypes have been produced and field tested with the intended end users, do those users use the technology as intended? If not, how has it been adapted?

Information/Answer
Field test yet to be performed at the demo site.

R) If feedback from these users about the technology has been received, how has the technology been revised (if at all) to address this feedback?

Information/Answer
No feedback received from the users.

Part C: Top level questions for determining anticipated TRL

Sl. No.	Questions	Feedback
TRL1: Basic principles & research	Have the basic process technology process principles been observed and reported?	Yes ☐ No ☐
If Yes, then basis and Supporting Documentation:		
TRL2: Application formulated	Has an equipment and process concept been formulated?	Yes ☐ No ☐
If Yes, then basis and Supporting Documentation:		
TRL3: Proof of concept	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	Yes ☐ No ☐
If Yes, then basis and Supporting Documentation: Proof of concept is demonstrated through numerical simulations and scale down wind tunnel and field testing.		
TRL4: Components validated in laboratory environment	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?	Yes ☐ No ☐
If Yes, then basis and Supporting Documentation: Scale down wind tunnel testing and full scale numerical simulations were performed. Both studies suggested a great reduction in loads with add-on passive aerodynamic structures and lowering of wind turbine systems.		
TRL5: Integrated components demonstrated in a laboratory environment	Has bench-scale equipment/process testing been demonstrated in a relevant environment?	Yes ☐ No ☐

If Yes, then basis and Supporting Documentation: **Scale down wind tunnel testing and full scale numerical simulations were performed. Both studies suggested a great reduction in loads with add-on passive aerodynamic structures and lowering of wind turbine systems.**			
TRL6: **Field or full-scale test demonstrated in relevant environment**	**Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment?**	**Yes** ■	**No** □
If Yes, then basis and Supporting Documentation: **Field tests were perfromed in a similar envoronment.**			
TRL7: **Fully integrated outcome demonstrated in operational environment**	**Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?**	**Yes** □	**No** ■
If Yes, then basis and Supporting Documentation: **Yet to be done.**			
TRL8: **Outcome proven in operational environment**	**Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?**	**Yes** □	**No** ■
If Yes, then basis and Supporting Documentation:			
TRL9: **Outcome refined & adopted**	**Has the actual equipment/process successfully operated in the full operational environment (hot operations)?**	**Yes** □	**No** ■
If Yes, then basis and Supporting Documentation:			

Part D: Detailed questionnaire

TRL	Question	Start of Project			Current status			<Date>
		Yes	No	NA	Yes	No	NA	
1	Do rough calculations support the concept?	√			√			
1	Do basic principles (physical, chemical, mathematical) support the concept?	√			√			
1	Do paper studies confirm basic scientific principles of new technology?	√			√			
1	Has a scientific methodology or approach been developed?		√		√			
TRL 1 Achieved	**Basic principles observed and reported.**		√		√			
2	Has potential system or component applications been identified?		√		√			
2	Have paper studies confirmed system or component application feasibility?	√			√			
2	Has an apparent design solution been identified?		√		√			
2	Have the basic components of the technology been identified?		√		√			
2	Have technology or system components been at least partially characterized?		√		√			
2	Have performance predictions been documented for each component?		√		√			
2	Has a functional requirements generation process been initiated?		√		√			
2	Does preliminary analysis confirm basic scientific principles?	√			√			

2	Are basic scientific principles confirmed with calculation based analytical studies?	√			√			
TRL 2 Achieved	**Technology concept and/or application formulated.**		√		√			
3	Have calculated predictions of components of technology capability been validated?		√		√			
3	Can all science applicable to the technology be modeled or simulated?		√		√			
3	Do experiments or modeling and simulation (M&S) validate performance predictions of technology capability?		√		√			
3	Do experiments verify feasibility of application of technology?		√		√			
3	Do paper studies indicate that technology or system components can be integrated?			√			√	
3	Has scientific feasibility of proposed technology been fully demonstrated?		√		√			
3	Does analysis of present technologies show that proposed technology or system fills a capability gap?		√		√			
TRL 3 Achieved	**Analytical and experimental critical function and/or characteristic proof-of-concept.**		√		√			
4	Has acceptance testing of individual components been performed?		√		√			
4	Has performance of components and interfaces between components been demonstrated?		√		√			
4	Does draft system architecture plan exist?			√			√	
4	Have end user technology/system requirements been documented?		√		√			

4	Does technology demonstrate basic functionality in simplified environment?		√		√			
4	Have performance characteristics been demonstrated in a laboratory environment?		√		√			
4	Have low-fidelity assessments of system integration and engineering been completed?		√		√			
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**		√		√			
5	Have internal system interface requirements been documented?		√		√			
5	Has analysis of internal interface requirements been completed?		√		√			
5	Can all system specifications be simulated and validated within a laboratory environment?		√		√			
5	Have individual component functions been verified through testing?		√		√			
5	Is component integration demonstrated in a laboratory environment?		√		√			
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**		√		√			
6	Have system integration issues been addressed?		√		√			
6	Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)?		√		√			
6	Have performance characteristics been verified in a simulated operational environment?		√		√			

6	Has prototype been tested in a simulated operational environment?		√		√			
6	Has system been tested in realistic environment outside the laboratory?		√		√			
6	Has engineering feasibility been fully demonstrated?		√		√			
6	Does the field or full-scale experiment satisfy all operational/functional requirements, when confronted with realistic problems?		√		√			
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**		√			√		
7	Have all interfaces been tested individually under stressed and anomalous conditions?		√			√		
7	Has technology or system been tested in a relevant environment?		√			√		
7	Are available components representative of production components?		√		√			
7	Are available components ready to be fully integrated in the final outcome?		√		√			
7	Has operational testing of technology/system in relevant environment been completed?		√			√		
7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		√			√		
TRL 7 Achieved	**System prototype demonstration in an operational environment.**		√			√		

8	Are all technology/system components form, fit, and function compatible?		√			√		
8	Is technology/system form, fit, and function compatible with operational environment?		√			√		
8	Has technology/system form, fit, and function been demonstrated in operational environment?		√			√		
8	Is technical Developmental Test and Evaluation (DT&E) successfully completed?		√			√		
TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**		√			√		
9	Does technology/system function as defined in Operational Concept document?		√			√		
9	Has technology/system has been deployed in intended operational environment?		√			√		
9	Has technology/system been fully demonstrated?		√			√		
9	Has Operational Test and Evaluation (OT&E) been successfully completed?		√			√		
9	Is the outcome adopted by the user community?		√			√		
TRL 9 Achieved	**Actual system proven through successful mission operations.**		√			√		