After the RISEnergy Transnational Access, Users are required to submit a User Report. This should be done within 4 weeks after the Access is completed unless otherwise agreed. The User Report will be given to the User(s) by the WP2 leader. The report contains sections related to the work performed, the main results and observations that were achieved.

This document should be completed, signed, and sent by e-mail to risenergy@for.kit.edu.

Summary questionnaire for Users who have been granted Transnational Access (TA) under the RISEnergy project Horizon Europe TA scheme. More information on RISEnergy TA can be found in "General Rules" and in "Access Policy" which can be found on the RISEnergy webpage.

Please complete, sign, and send this form, together with the Cost claim by e-mail to risenergy@for.kit.edu with title: RISEnergy APP206 - reports.

General information about the project	
Project title (as used in Application)	Robust Operation of a Multi-energy Port Microgrid with Hydrogen
Project number (APPXXX) and acronym (max 15 characters)	APP206, RAMP-H
RISEnergy RI(s) accessed	TA25 – ICCS-EES-lab
Keywords (up to five, free text)	smart grids, hydrogen, energy storage
Arrival date (in town where RI is located)	November 9, 2025
Departure date (from town where RI is located)	December 21, 2025
Starting date of Access (first day at RI)	November 10, 2025
Finishing date of Access (last day at RI)	December 19, 2025
Number of days not using the RI (during the above period)	14
Reason for not using RI those days (describe)	November 9 (Sunday): Arrival in Athens; no laboratory activities were conducted on the day of arrival. November 17: Public holiday in Athens; the laboratory was closed. November 10 to December 19: A total of 10 weekend days, during which the laboratory was not in operation. December 20–21 (weekend): Time allocated for packing and return travel; flight back to Finland took place during this period.
Number of days using the RI	29

Number of Users granted Access (group size)	2
Comments	access period adheres to the definitions as specified above. ➢ Arrival date (city where the RI is located): December 10, 2025 ➢ Starting date of access (first day at RI): December 11, 2025 ➢ Finishing date of access (last day at RI): December 16, 2025 ➢ Departure date (city where the RI is located): December 17, 2025
User	
User group leader or sole applicant (user group member 1)	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
User group member 2	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
Comments	
Please insert more fields if your groups had more than four members.	
Access Summary Report - work performed and initial results	
Brief description of the objectives of your project (up to 200 words)	
This project proposes a framework for the optimal scheduling of the hydrogen-integrated Multi-energy Port Microgrid (MEPM) under multiple uncertainties. Additionally, experimental validation in the ICCS-EES-lab has been conducted. The objectives (Obj) of the proposed project are: <u>Obj1: Develop an operation model for an MEPM with hydrogen.</u>	

Therein, the multi-energy coordination and the scheduling of distributed energy resources (DERs), e.g., electrolyzers and storage systems, are considered to minimize costs and emissions.

Obj 2: Propose a two-stage distributionally robust optimization (DRO) method for the MEPM operation under multiple uncertain factors.
The first stage determines the scheduling of DERs before the realization of uncertain factors, while the second stage focuses on the adjustment of flexible DERs to mitigate the adverse impacts of uncertainties. The second-stage adjustment decisions will be made under the worst-case probability distribution of port energy demands, renewable generation, and cold Ironing loads to minimize the redispatch cost and ensure the port's operational reliability.

Obj 3: Validate the developed operation model and DRO methodologies using a Real-Time Digital Simulator (RTDS).
This step includes simulating a microgrid system, conducting systematic performance analyses and comparisons, and demonstrating the advantages of the proposed approach.

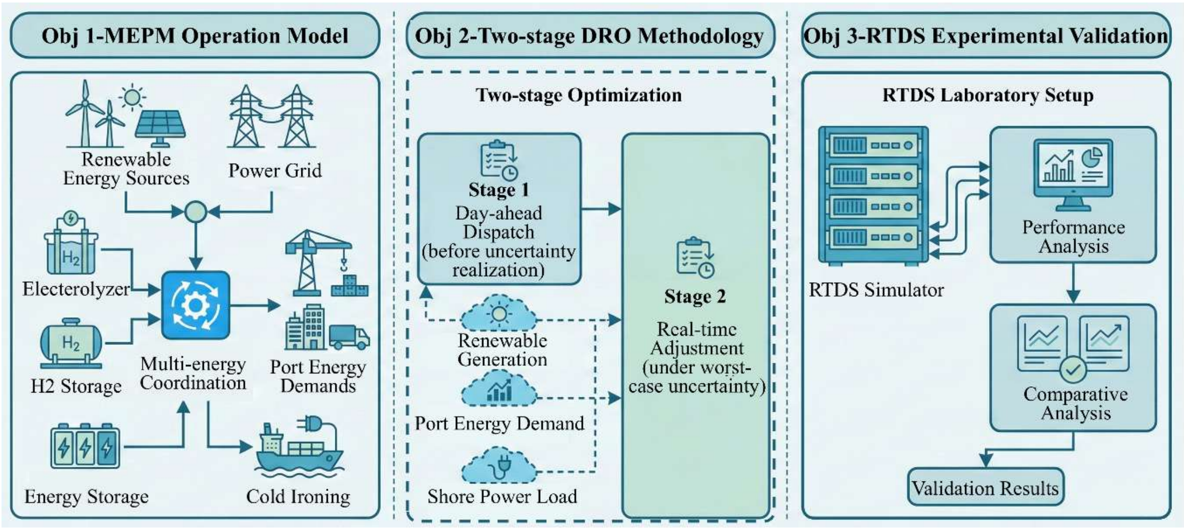

Fig. 1. Overview of the project objectives.

Activities performed (up to 600 words)

During the project period, a series of discussions, modelling, implementation, and experimental validation activities were carried out to develop the MEPM framework in RTDS and test the performance of the proposed DRO method.

At the initial stage, discussions were conducted with laboratory staff (Nikos, Panos, Alkistis Maria, etc.) to clarify the experimental objectives, available infrastructure, and technical constraints of the RTDS platform. Based on these discussions, a detailed experimental plan was jointly formulated, including MEPM system architecture design, component parameterization, data exchange mechanisms, and validation procedures. Regular weekly meetings were then held with laboratory personnel to report progress, identify implementation challenges, and adjust the experimental plan when necessary.

A detailed multi-energy port microgrid structure was designed and implemented in the RTDS environment. The system architecture included port electrical loads, port logistics load, grid connections, and distributed energy sources (e.g., renewables, battery, electrolyzers, combined heat and power, etc.). For key components such as battery energy storage systems and hydrogen electrolyzers, capacity limits, operational constraints, and dynamic characteristics were carefully defined to ensure realistic system behavior. The port distribution network parameters were informed by both technical specifications and values reported in the literature. In addition, parameter selection was done to ensure numerical stability and physical consistency in the real-time simulation. Specifically, electrical parameters such as line resistance and reactance, battery capacity, and electrolyzer stack number were selected by both technical specifications and values reported in the literature.

To enable real-time data exchange between the MATLAB-based optimization and the RTDS simulation, communication interfaces were developed using the Modbus protocol. Specifically, MATLAB scripts were written to transmit optimized variables and set points to RTDS via Modbus, as well as to receive real-time measurement data from RTDS back into MATLAB. During this process, debugging was performed to resolve issues related to data types, scaling factors, and communication timing. Additionally, to enhance the realism of the port microgrid model, a targeted literature review was conducted to identify typical voltage levels and network configurations used in practical port energy systems.

Once the core microgrid model was successfully deployed in RTDS, baseline validation was conducted. Specifically, first-stage validation experiments were performed. Then, Active power injections and power flow results within the port microgrid were analysed and compared against corresponding MATLAB-based optimization outputs.

After successful baseline validation, two operational cases were implemented in RTDS: a Stochastic programming (SP) -based control case and a DRO-based control case. For each case, optimized first-stage decisions were applied to the RTDS model, and real-time system responses were recorded. These results were then used for out-of-sample performance evaluation, focusing on power balance and expected cost under uncertainties.

Finally, a comprehensive performance analysis was conducted to compare the deterministic and DRO-based strategies. The analysis highlighted the differences in operational behaviour, which can provide valuable insights into the benefits of the proposed DRO method in the multi-energy port microgrid operation under uncertainties.

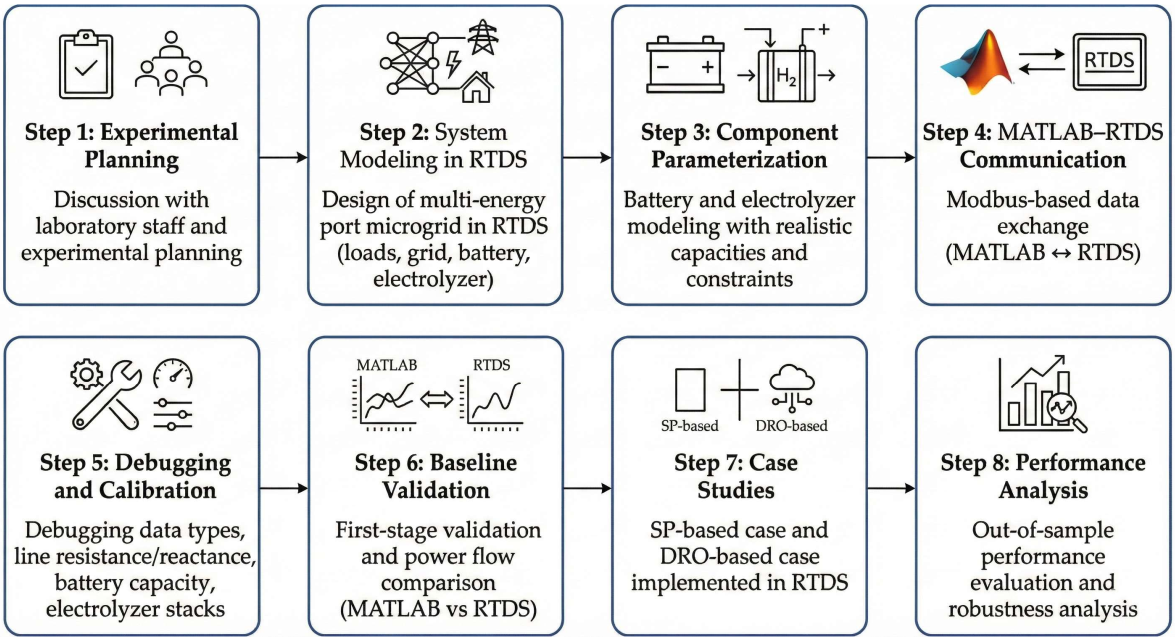

Fig. 2. Overview of the performed activities.

Scientific results (up to 800 words)

The experimental results validate the proposed MEPM model and DRO method through comparative analysis between the theoretical Matlab model and the Real-Time Digital Simulator (RTDS)

Firstly, Fig. 3 illustrates the MEPM implementation within the RTDS environment, which operates in a grid-connected mode. The architecture integrates renewable energy sources and CHP units with diverse loads, such as port logistics, desalination units, and electrolyzers. Notably, the simulation incorporates nonlinear electrolyzer models to capture realistic dynamic behaviours. Furthermore, communication is established via the Modbus protocol, which employs data conversion between IEEE floating-point standards and integers to ensure accurate signal transmission. In addition, Fig. 4 presents the real-time monitoring dashboard, which tracks key metrics, such as power generation, voltage stability, and hydrogen output during the runtime.

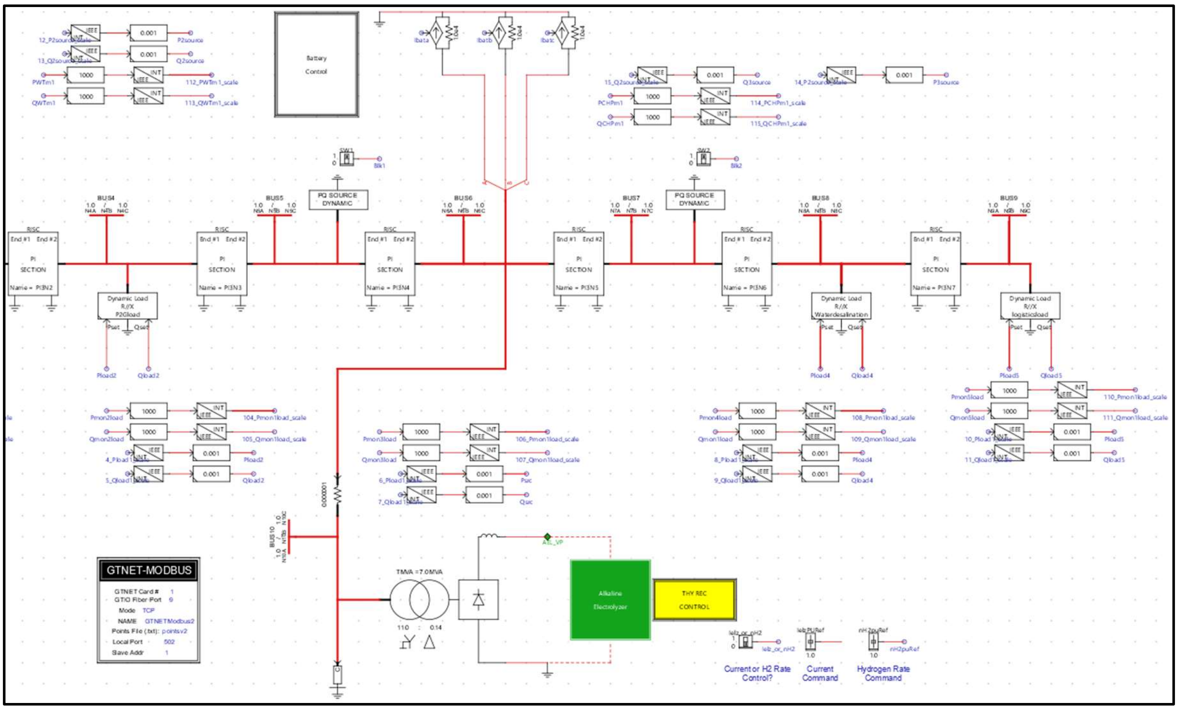

Fig 3. The MEPM structure in RTDS.

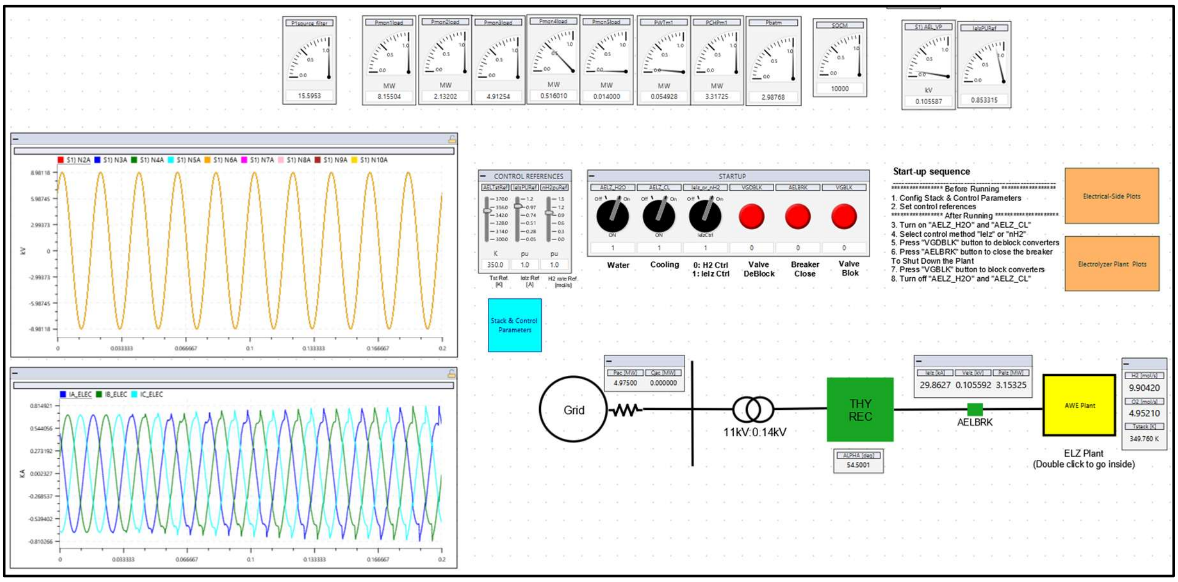

Fig 4. The real-time monitoring dashboard.

Fig. 5 compares the grid power exchange in RTDS against the Matlab simulation benchmark. It can be observed that the RTDS trajectory consistently remains slightly above the Matlab curve. This indicates that the RTDS includes system power losses in the real-time environment while validating that the controller accurately tracks theoretical setpoints. Additionally, a statistical anomaly appears between hours 18 and 20, where the relative error presents a significant high value. This is because during these periods, the denominator in the relative error calculation approaches zero, which amplifies the numerical value of the error despite the absolute difference remaining small. Further, it can be found that the MEPM increases power imports during low-price intervals (hours 3–6, 14–16, 22–24) and shifts to export mode during peak-price windows (hours 18–20) to maximize economic returns.

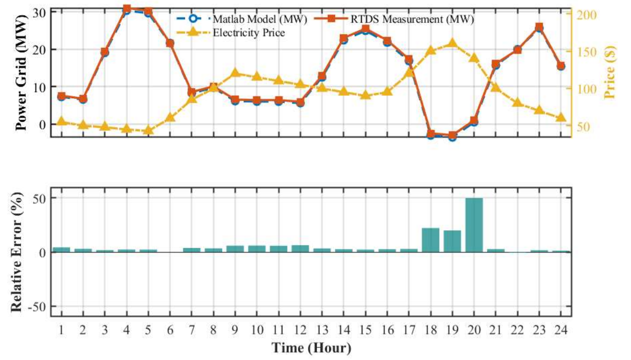

Fig. 5. The grid power exchange.

The voltage stability analysis across the 9 MEPM nodes is presented in Fig. 6. It can be observed that, based on the 11 kV distribution network reference, the phase voltages remained strictly within the safety bounds of 6.03 kV to 6.66 kV throughout the operation. Node 1, which is the substation, maintains a constant voltage. Additionally, nodes 2–9 exhibited consistent fluctuation patterns driven by load and DERs output variations. Despite these fluctuations, no over-voltage or under-voltage faults were detected, which validates that the MEPM's operation is within the safe limit of power quality standards.

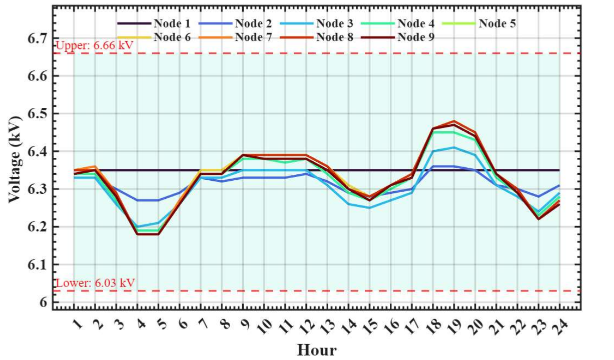

Fig. 6. The voltage stability analysis.

The results related to the battery energy storage system (BESS) are illustrated in Figs. 7 and 8. Fig. 7 shows that the battery power output in RTDS accurately tracks the reference setpoints of results from Matlab simulation. Similarly, Fig. 8 displays that the RTDS State of Charge (SoC) closely follows the Matlab simulation, remaining within the safe operating range (around 20–100%). Moreover, the observed cycle in Fig. 7 reflects a typical

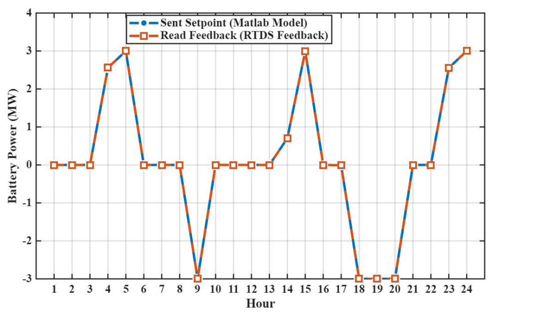

Fig. 7. Charging and discharging of BESS.

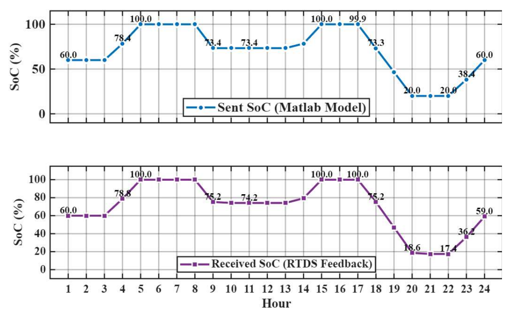

Fig. 8. SoC of BESS.

arbitrage strategy. Specifically, the BESS charges during low-price intervals, such as hours 3–5, and discharges during peaks, such as hours 17–20. By doing so, the BESS can add operational flexibility to the MEPM.

Fig. 9 presents the operational results of the electrolyzer. Specifically, Figs. 9(a) and 9(b) compare the theoretical calculations from Matlab with the real-time monitoring data from the RTDS. It is observed that a deviation of approximately 0.1 MW persists when the Matlab reference value is zero. This difference occurs because the electrolyzer units in RTDS maintain a minimum base load to prevent frequent startup and shutdown cycles. Furthermore, during active operation, the deviation at hours 4, 5, 23, and 24 is significantly smaller than at hours 6 and 22. This difference is because of the nonlinear characteristics of the electrolyzer model. Specifically, the simulation error decreases as the output power approaches its rated capacity. Finally, the results of the hydrogen production in the RTDS are illustrated in Fig. 9 (c), which shows a strong positive correlation between power consumption and hydrogen production.

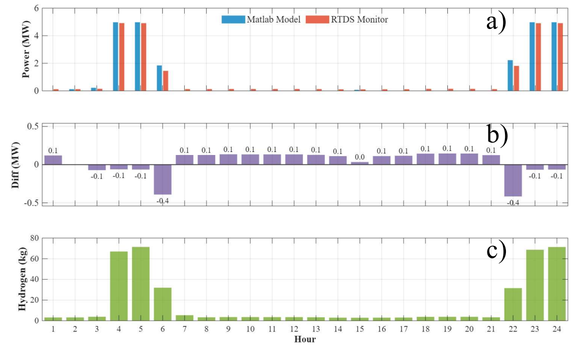

Fig. 9. The operational results of the electrolyzer.

Finally, an out-of-sample performance comparison between Stochastic Programming (SP) and DRO was conducted over 200 scenarios based on the RTDS results. As illustrated in Fig. 10, where the box represents the interquartile range (middle 50% redispatch cost) and the central line indicates the median, the DRO strategy yields a lower median redispatch cost compared to SP. Furthermore, the redispatch cost distribution for DRO is narrower with a lower upper bound. In contrast, the SP strategy exhibits a wider spread and larger extreme points. These results confirm that DRO provides a more robust solution when uncertainties are realized at the second stage.

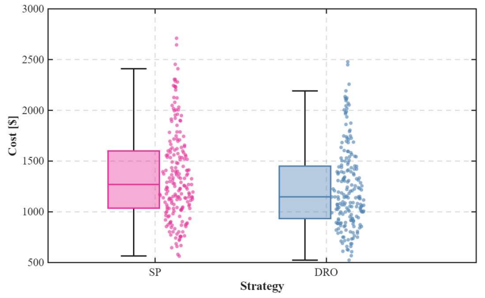

Fig. 10. Out-of-sample performance comparison.

Interpretation of the results (up to 400 words)

The obtained results demonstrate the effectiveness of the completed work in achieving the objectives of developing a MEPM operation model, formulating a two-stage DRO method, and experimentally validating using the RTDS.

First, the results confirm the effectiveness of the developed MEPM operation model. Specifically, the time-series results of power flows indicate that the proposed operation model coordinates power exchange and dispatching DERs to dynamically balance energy supply and demand in MEPM. In particular, the BESS enhances the operational flexibility by charging when electricity prices are relatively low and discharging during peak demand. Meanwhile, the electrolyzer operated primarily during off-peak hours, which is beneficial for reducing energy costs.

Another important finding of this study is the demonstration of better performance of the DRO strategy over traditional SP. While SP minimizes costs based on an assumed probability distribution, it suffers from a higher out-of-sample redispatch cost. The comparative analysis shows that DRO not only reduces the expected redispatch cost (lower median) but also enhances system robustness. Specifically, by accounting for the worst probability distribution of uncertainties, DRO tightens the range of redispatch cost outcomes and eliminates extremely high-cost outliers observed in the SP results. This implies that the proposed DRO can provide a robust solution for the energy management of MEPM with volatile renewable generation and variable port energy demand. In this way, the operation of the MEPM is more reliable.

Finally, the RTDS experimental data validate the real-time applicability of the proposed framework. The monitored system responses in the RTDS environment closely follow the operational trends obtained from the offline optimization results implemented in the MATLAB environment. This consistency confirms the effectiveness of the proposed MEPM structure under real-time dynamics. Moreover, the RTDS experiments incorporate power losses and the nonlinear characteristics of the electrolyzer. By doing so, the experimental results provide a more realistic representation of MEPM operational behavior. Overall, the developed MEPM structure implemented in the RTDS environment serves as a valuable experimental platform for testing and validating advanced operation models and optimization algorithms for MEPM.

Main achievements during the TA related work (up to 250 words)

The main outputs of the TA work include the development of the MEPM operation model and a two-stage DRO algorithm, and validation in an RTDS environment. Detailed component models were developed and implemented in the RTDS environment, including BESS and electrolyzer models with practical nonlinear characteristics. These models were fully integrated into the RTDS platform to enable real-time simulation. In addition, comparative analyses were conducted to evaluate the performance of the proposed DRO-based strategy against benchmark approaches under multiple uncertainty realizations.

Based on the obtained results, it is concluded that the proposed operation model can enhance the operational flexibility of the MEPM while reducing overall operating costs. Furthermore, the developed DRO algorithm effectively hedges against uncertainties arising from renewable generation and load variations. Importantly, even when power losses and real-time operational constraints are considered in the RTDS environment, the proposed model and method can maintain safe and reliable MEPM operation.

As a next step, the research will be extended to incorporate network reconfiguration strategies to further reduce power losses and enhance the system operation flexibility. The enhanced framework will subsequently be tested in the RTDS environment with Hardware-in-the-Loop (HIL) implementation, to strengthen its real-time applicability and practical relevance.

The outcomes of this TA work have the potential to contribute to the development of technical standards and best practices for port electrification and hydrogen applications. Moreover, the results are expected to strengthen international research collaboration, support future publications in high-impact international journals and conferences, and serve as valuable input for future project proposals.

Data Management

The data generated throughout the project will be managed in compliance with both the RISEnergy guidelines and the data policies of the ICCS-EES-lab and the User Group's home institution.

Data definition
The project generates three main categories of data:
1) Simulation and experimental input data: port multi-energy demand profiles, renewable generation curves, market price data, operational parameters of DERs, port power distribution network parameters, and the MEPM model implemented in the RTDS environment.
2) Operational output data of the MEPM: real-time scheduling commands for DERs, economic and environmental performance indicators, and results from comparative analyses with different uncertainty handling methods.
3) Documentation and supporting materials: model descriptions, experimental configurations, and source code developed during the project.

Further usage and storage of project data
The final datasets and analysis scripts will be stored in two locations to ensure data security and accessibility. One copy will be maintained on the internal research servers of the ICCS-EES Lab, while a second copy will be stored on the Aalto University cloud repository in accordance with institutional data management policies. The data will be used for further analysis and dissemination of research results, such as journal publications and conference presentations.
Sensitive or confidential data components will remain accessible only to authorized project partners and will be shared strictly under appropriate licensing or data-sharing agreements.

Responsibilities
The User Group member, Zhineng Fei, under the supervision of Zhengmao Li, is responsible for coordinating data collection, documentation, version control, and the upload of finalized datasets and scripts to the designated repositories. The ICCS-EES Lab technical team will provide support for local data storage and access.

Difficulties during the TA related work (up to 250 words)

During the TA period, the main challenges encountered are related to acquiring new technical skills required for the experimental implementation of the project. Becoming familiar with the RTDS environment and establishing communication using the Modbus protocol required an initial learning and adaptation phase. Despite these technical challenges, full access was granted to all necessary equipment, facilities, and databases required for the successful completion of the research activities.

With the strong support of the staff at the ICCS-EES-lab, the identified challenges are effectively addressed. The technical team provides us guidance on RTDS operation, communication configuration, and troubleshooting, which greatly accelerates the learning process and ensures stable system operation. As a result, the experimental setup is completed, and the planned simulations and validations are carried out as intended.

Intended publications

The outcomes of this project are expected to lead to several high-quality scientific publications in **international journals and conferences**.

As a next step, the research will be extended to include network reconfiguration strategies, as described in the "Main achievements during the TA related work" part. Based on the enhanced operation framework and the RTDS experimental results, a journal paper is intended to be prepared and submitted to IEEE Transactions on Smart

Grid. This work focuses on the coordinated operation, network reconfiguration, and uncertainty-aware optimization of MEPM.

In addition, the knowledge and insights gained during the project, particularly from the systematic investigation of port energy management and hydrogen integration, will be consolidated into a comprehensive review paper. This review is planned to be submitted to Cyber-Physical Energy Systems, with an emphasis on hydrogen integration, energy optimization, real-time validation, and emerging challenges in port-scale cyber–physical energy systems.

Finally, the related outcomes will also be published in some top-level conference venues, such as PES General Meeting.

Expected impact

The expected results of this project could have a meaningful impact on both current and future research, as well as practical applications in the field of standard port electrification and hydrogen integration.

From a research perspective, the developed hydrogen-integrated MEPM operation model, combined with the DRO method and real-time validation, provides **a systematic framework for studying port energy management under uncertainties**. The modeling and experimental insights gained through RTDS-based validation could support future academic research on multi-energy coordination and real-time control strategies for maritime applications.

In terms of practical impact, the project contributes to the advancement of **standardized port electrification architectures**. In particular, it demonstrates how electricity, hydrogen, and energy storage can be jointly coordinated to enhance flexibility and reliability in MEPM. These findings can provide insights for port authorities and system operators when operating next-generation low-carbon port energy infrastructures.

Finally, the TA work is expected to lead to **follow-on research proposals and collaborative projects** in the areas of green maritime transport, ship–port energy coordination, and hydrogen-based energy systems. The established collaboration between NTUA and Aalto University also lays the foundation for potential future innovation activities.

Conclusions / additional comments

The Transnational Access funded by RISEnergy and provided by the ICCS–EES Lab has been an extremely valuable opportunity to advance this research and to strengthen international collaboration. Access to the technical infrastructure and expert support contributes to the successful completion of the planned research activities.

It is a great pleasure to work in the ICCS–EES Lab and to learn from its members. In particular, the users would like to sincerely thank Prof. Nikos Hatziargyriou, Aris, Panos, Alkistis, Maria, Ilias, and all colleagues at NTUA for their technical guidance, constructive discussions, and continuous support throughout the TA period. The collaborative and inspiring research environment greatly enhances the scientific quality of the work.

This TA experience has laid a solid foundation for further collaboration between the involved institutions, especially in the areas of ship and port energy systems, hydrogen integration, and green maritime technologies. The knowledge exchange and joint research efforts established during this project are expected to continue and expand in future collaborative projects and scientific activities.

Did you complete the European Commission User questionnaire https://ec.europa.eu/eusurvey/runner/RIsurveyUSERS?	
☑ *Yes* ☐ *No*	
Feedback – HSE, Ethics and Satisfaction	
Please rate on a scale from 1 (excellent) to 5 (poor). Feel free to provide additional comments	

Practical information on how to apply for Transnational Access and the overall application process	1 (excellent)	2	3 (neutral)	4	5 (poor)
	☑	☐	☐	☐	☐
Comment					

Information provided, once your project was accepted, on how to proceed	1 (excellent)	2	3 (neutral)	4	5 (poor)
	☑	☐	☐	☐	☐
Comment					

Support received at the site(s) regarding technical/scientific matters and logistics	Have you got sufficient support from the RI staff during the project? If not, please, specify the problems. ☑ *Yes* ☐ *No*
Please specify any problems RI staff are warm-hearted. They always give users help when we need.	
RI extension / upgrades required	In your opinion, is the RI needed to be upgraded? If yes, please give an explanation. ☐ *Yes* ☑ *No*
Please specify The equipment is updated. It is sufficient for our experiment.	
Problems with local regulations	Have you had any problems with regulations of the visited RI owner (HSE, lab working hours, etc.)? If yes, please, specify ☐ *Yes* ☑ *No*
Please specify Due to the support of the RISEnergy coordinator and the RI provider, everything goes well.	
Health and safety issues	Did you encounter any health or safety issue during your research? Please provide details. ☐ *Yes* ☑ *No*

Please provide details We did not encounter any health or safety issues during my research.	
Environment & Ethics	Did your research involve the use of elements that may cause harm to the environment, to animals or plants? Please provide details. ☐ *Yes* ☑ *No*
Please provide details Our research does not involve the use of elements that may cause harm to the environment, to animals, or to plants.	
Environment & Ethics	Did your research deal with endangered fauna and/or flora and/or protected areas? Please provide details. ☐ *Yes* ☑ *No*
Please provide details Our research does not deal with endangered fauna or flora or protected areas.	
Environment & Ethics	Did your research involve the use of elements that may cause harm to humans, including research staff? Please provide details. ☐ *Yes* ☑ *No*
Please provide details Our research does not involve the use of elements that may cause harm to humans.	
Environment & Ethics – Dual use	Does your research have the potential for military applications? Please provide details. ☐ *Yes* ☑ *No*
Please provide details Our research does not have the potential for military applications.	
Environment & Ethics – Misuse	Does your research have the potential for malevolent /criminal/terrorist abuse? Please provide details. ☐ *Yes* ☑ *No*
Please provide details Our research does not have the potential for malevolent /criminal/terrorist abuse.	
Environmental issues	Were any potentially dangerous substances (materials / gases etc.) released into the environment (atmosphere, water, or land)? Please provide details. ☐ *Yes* ☑ *No*
Please provide details There are no potentially dangerous substances (materials/gases, etc.) released into the environment (atmosphere, water, or land).	
Ethics issues	Are there any other ethics issues that should be taken into consideration? Please specify ☐ *Yes* ☑ *No*
Please provide details There are no other ethical issues that should be taken into consideration.	
Overall impression of communication and interaction	1 (excellent) | 2 | 3 (neutral) | 4 | 5 (poor)

after finishing your TA and related work	☑	☐	☐	☐	☐

Comment
Suggestions for facilities not included in RISEnergy which you would use for your research
[Please provide suggestions for specific type of facilities missing (RI gaps) or measurement / experiments you would like to perform which cannot be done on current RISEnergy facilities.] The facilities in TA25 – ICCS-EES-lab are enough for our project.
Suggestions how RISEnergy can improve future TA programme, how to make the TA more impactful and how to enable the achievement of high TRL levels
[Your suggestions] It is perfect, Thanks a lot.

Feedback – Pro-active Innovation Support

Awareness	Did you know about the pro-active innovation support of RISEnergy? ☒ Yes ☐ No
[Please specify how you learned about the pro-active innovation support] We learned about the pro-active innovation support through discussions with colleagues and information available on relevant websites.	
Personal experience	Have you taken advantage of or benefited from the pro-active innovation support? ☒ Yes ☐ No
[*Please provide details]* The pro-active innovation support helped us identify and access the relevant information needed for the project.	

	1 (excellent)	2	3 (neutral)	4	5 (poor)
Information/service provided by the pro-active innovation support?	☒	☐	☐	☐	☐

[*Please provide details]* It is great. Thanks

I declare that the above provided information and especially that information on the number of days visited the RI is correct.

☒ *I have read the [RISEnergy privacy policy] for participation in the RISEnergy TA and consent to participation and the associated data processing.*

Your full name:

Your signature: