

# The Role of Research Infrastructures in the Context of the Energy Transition on the Examples of the ERIGrid Projects

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# Background and Motivation

- Challenges and drivers



- Climate change
- Deep decarbonisation
- Energy transition



- Industrial competitiveness
- Business Innovation
- Digitalisation

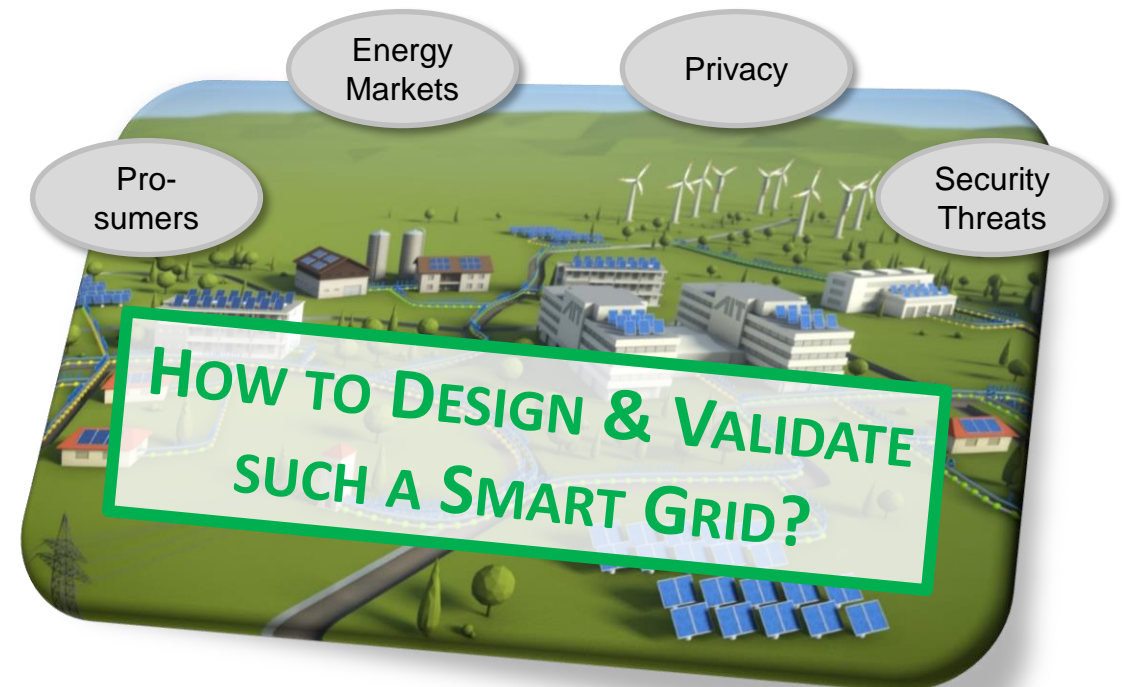


- Urban Transformation
- Infrastructure needs
- Societal changes

# Background and Motivation

- Planning and operation of the energy infrastructure becomes more complex
  - Large-scale integration of renewable sources (PV, wind, etc.)
  - Controllable loads (batteries, electric vehicles, heat pumps, etc.)
- Trends and future directions
  - Digitalisation of power grids
  - Deeper involvement of consumers and market interaction
  - Linking electricity, gas, and heat grids for higher flexibility and resilience

→ *Smart Grid or Cyber-Physical Energy Systems*

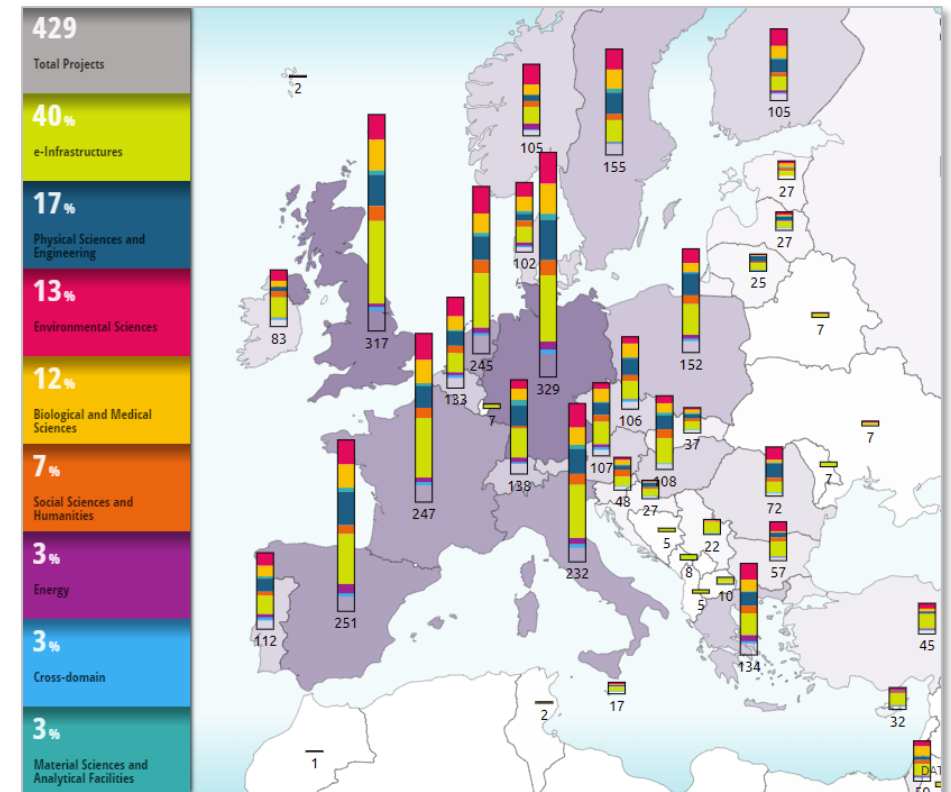


# European Research Infrastructures (RI)

- Provide resources (major scientific equipment) and services to communities
- Conduct research and foster innovation
- Are strategic investments in scientific and technological excellence
- Act as knowledge and innovation hubs (collections, archives or scientific data)
- Essential pillar of the European Research Area (ERA)

→ *Only a few cover energy-related topics*

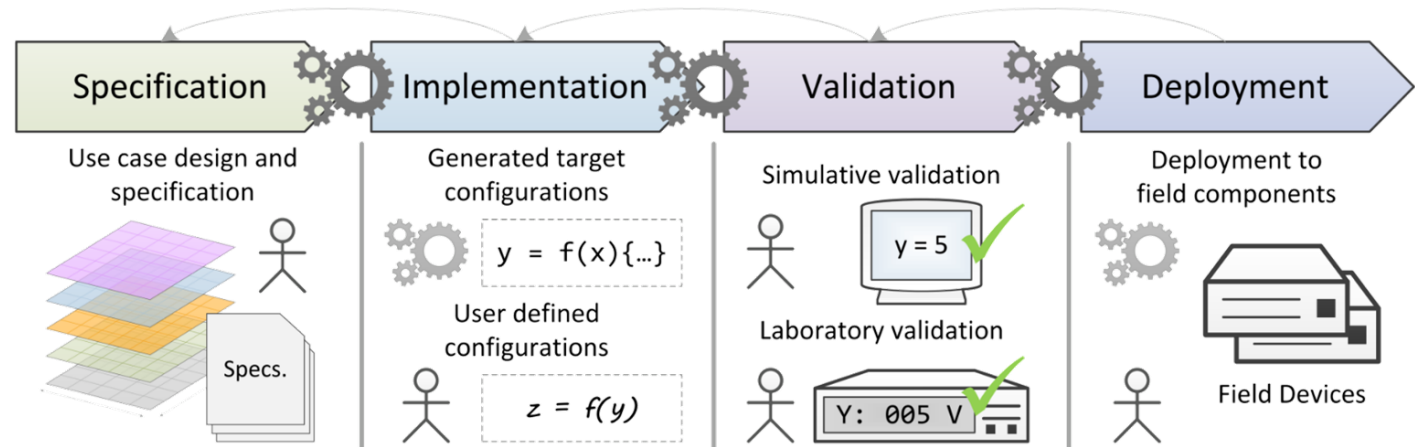
→ *Almost no one covers power system/smart grid topics*



Source: [European Commission](#) & [RICH2020](#)

# Vision and Research Directions

- Support for the integrated design, implementation, validation, and installation of smart grids and smart energy systems
  - Integrated system design
  - Validation and testing
  - Installation and roll out
- Future research needs
  - Improved development and testing services and tools
  - Extended and advanced research infrastructures and laboratories
  - Well educated researchers and engineers (“multi-domain understanding”)



# Integrated Smart Grid and Energy Systems RIs

- Long-term,
- Pan-European cooperation

2024



- GA-ID 5189299
- FP6 NoE (11/2005-10/2011)
- 3 Mio EUR funding
- 12 partner
- Networking of DER labs, pre-standardization



- GA-ID 228449
- FP7 RI IA (09/2009-12/2013)
- 5 Mio EUR funding
- 16 partner from 12 countries
- TNA to DER labs, pre-standardization
- ~800 access days for 100 user



- GA-ID 654113
- H2020 RI IA (11/2015-04/2020)
- 10 Mio EUR funding
- 18 partner from 11 countries
- TNA to Smart Grid and DER labs, pre-standardization
- ~1050 access days for 175 user



- GA-ID 870620
- H2020 RI IA (04/2020-09/2024)
- 10 Mio EUR funding
- 20 partner from 13 countries
- TNA & VA to Smart Grid, Smart Energy Systems and DER labs, pre-standardization
- ~1700 access days for 250 user

Legend:

DER ... Distributed Energy Resource    VA ... Virtual Access  
 RI ... Research Infrastructure        NoE ... Network of Excellence  
 TNA ... Trans-national Access

2005



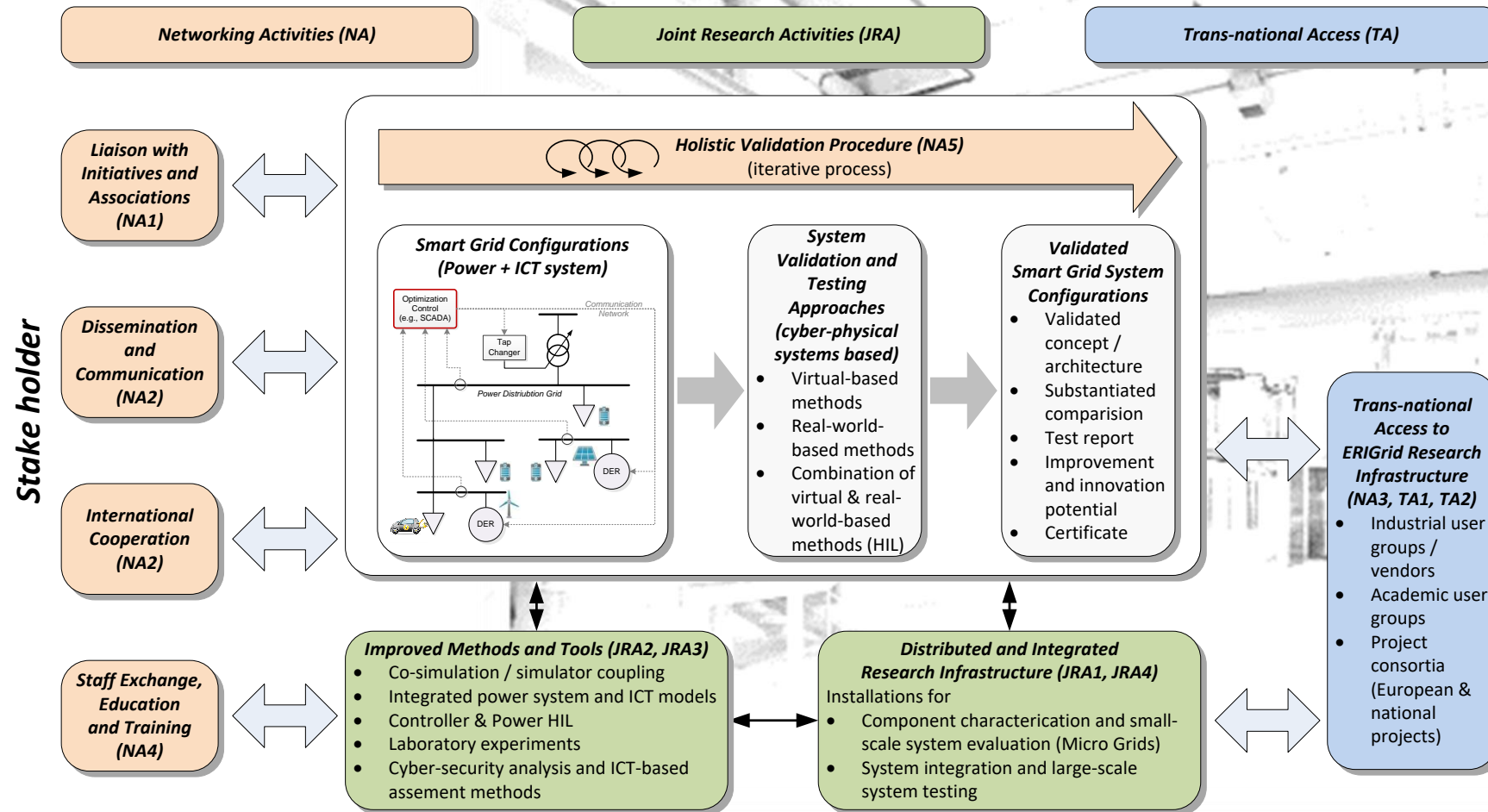


# Smart Grid RI “ERIGrid” - Overview

- Applied research for validation of
  - Sustainable power and energy systems/smart grid systems
  - Distributed Energy Resources (DER)
- Tight collaboration of partners
  - 11 European countries involved
  - 18 Partners from research and industry
  - 19 top-class smart grid and DER labs

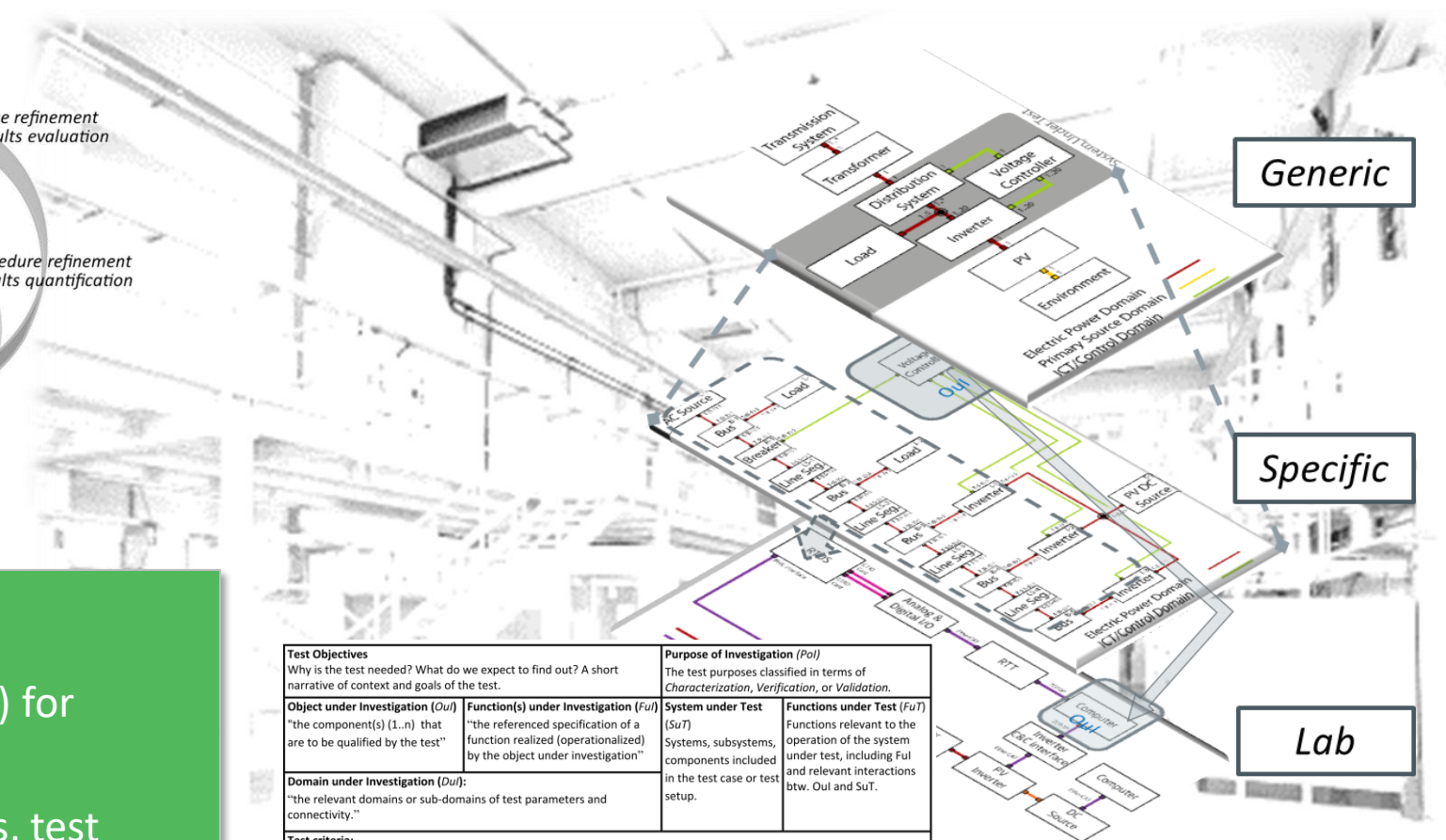
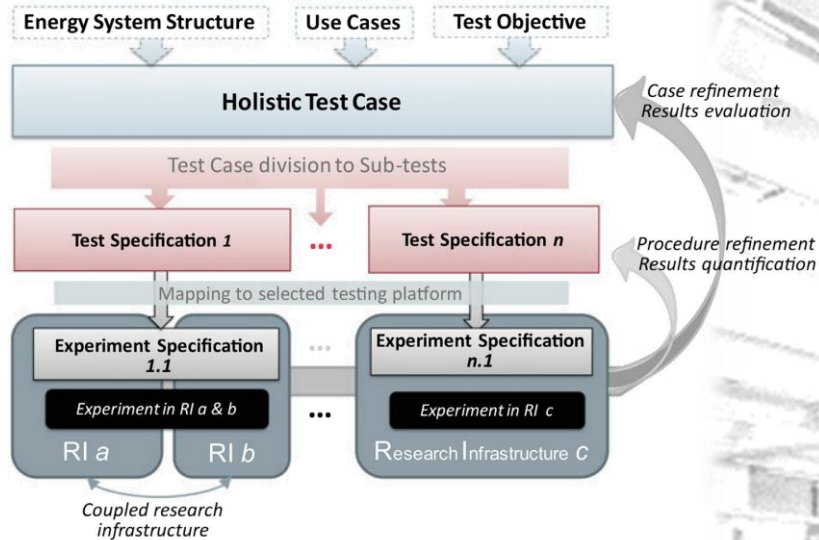


# Smart Grid RI “ERIGrid” - Approach





# Smart Grid RI “ERIGrid” - Achievements

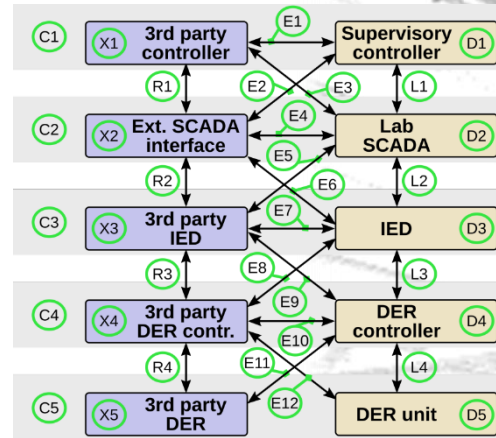
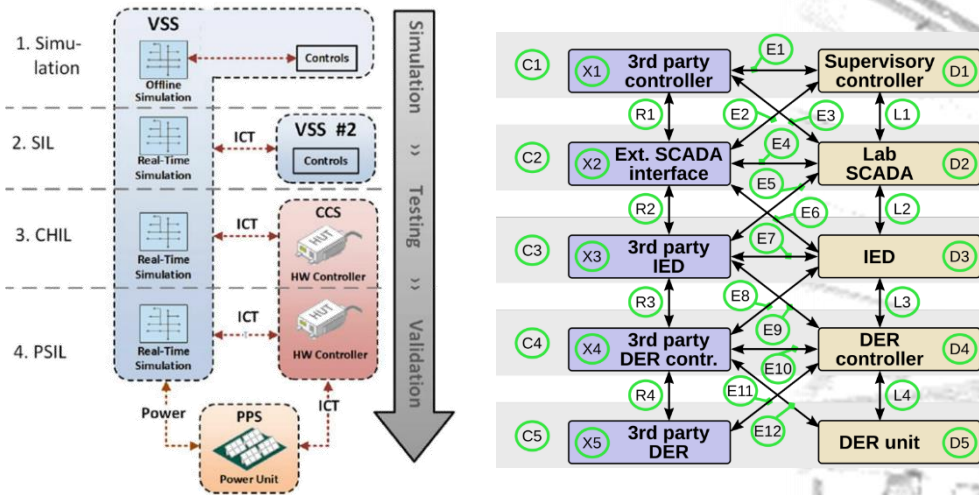


Advanced testing methods and tools

- Holistic validation approach (HTD) for smart grids
- Approach for specifying test cases, test specifications and experiments

<b>Test Objectives</b> Why is the test needed? What do we expect to find out? A short narrative of context and goals of the test.		<b>Purpose of Investigation (PoI)</b> The test purposes classified in terms of <i>Characterization, Verification, or Validation</i> .	
<b>Object under Investigation (Oul)</b> "the component(s) (1..n) that are to be qualified by the test"	<b>Function(s) under Investigation (FuI)</b> "the referenced specification of a function realized (operationalized) by the object under investigation"	<b>System under Test (SuT)</b> Systems, subsystems, components included in the test case or test setup.	<b>Functions under Test (FuT)</b> Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. Oul and SuT.
<b>Domain under Investigation (Dul):</b> "the relevant domains or sub-domains of test parameters and connectivity."			
<b>Test criteria:</b> Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.			
<b>target metrics</b> Measures required to quantify each identified test criteria	<b>variability attributes</b> controllable or uncontrollable factors and the required variability; ref. to PoI.	<b>quality attributes</b> threshold levels for test result quality as well as pass/fail criteria.	

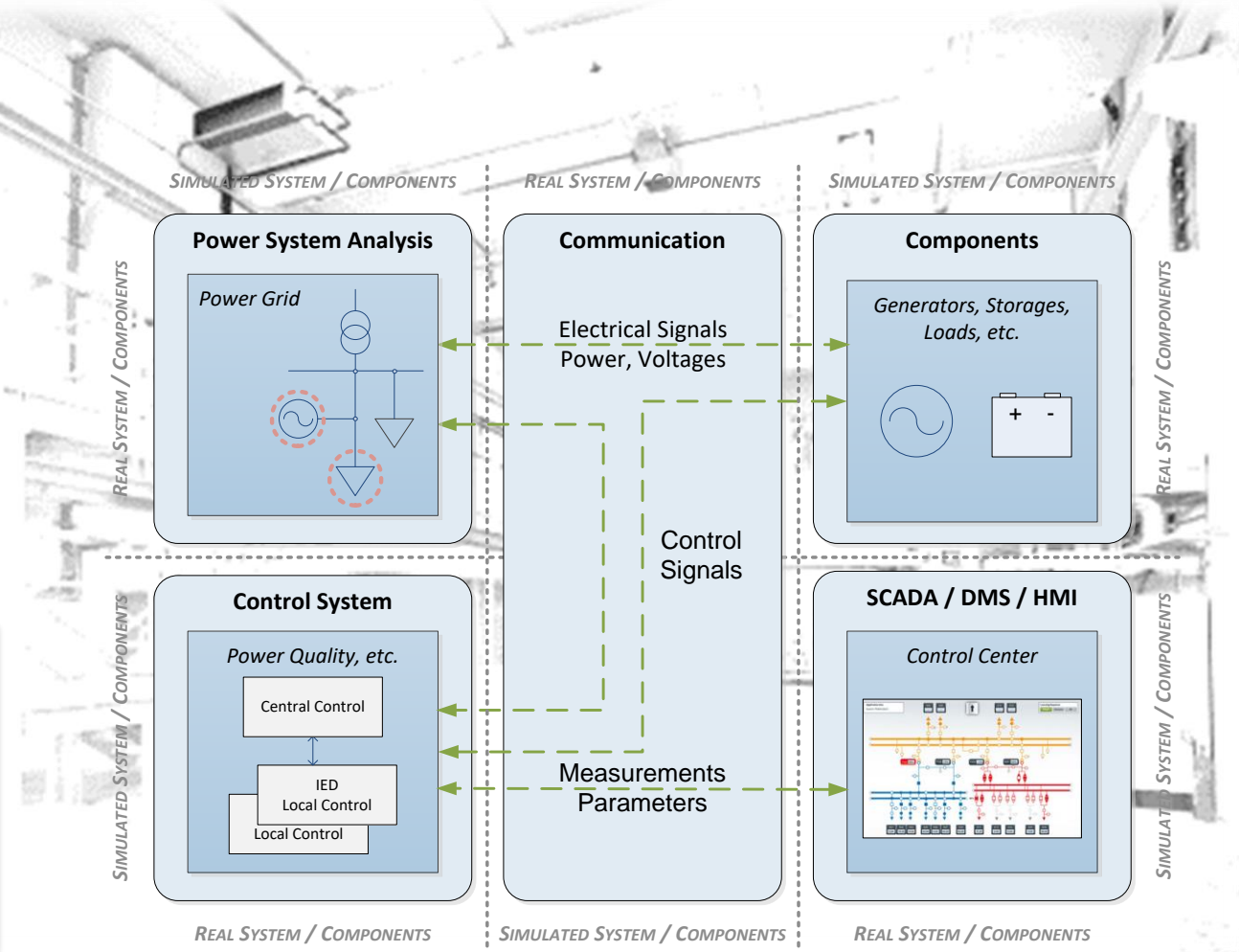
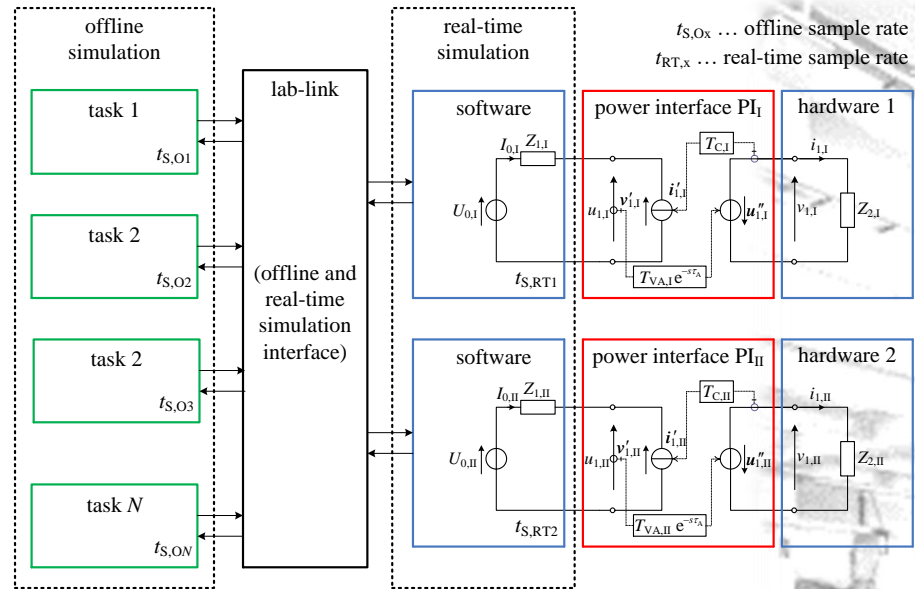
# Smart Grid RI “ERIGrid” - Achievements



Advanced testing methods and tools

- Test chain approach
- Coupling approach for smart grid labs
- Virtual Pan-European Smart Grid RI

# Smart Grid RI “ERIGrid” - Achievements



- Advanced testing methods and tools
- Co-simulation and hardware-in-the-loop based system-level testing
  - FMI-based simulation library



# Smart Grid RI “ERIGrid” - Achievements

73

user projects from all over the world gained lab access




175

engineers accessed best labs of Europe free of charge



20

had companies involved






4

multi-side projects (involving more than one laboratory)






1,000

for over 1,000 days collectively ERIGrid labs were in use





14

projects came from outside Europe

14

projects were led by companies






7

projects were from ERIGrid partners ("internal TA")

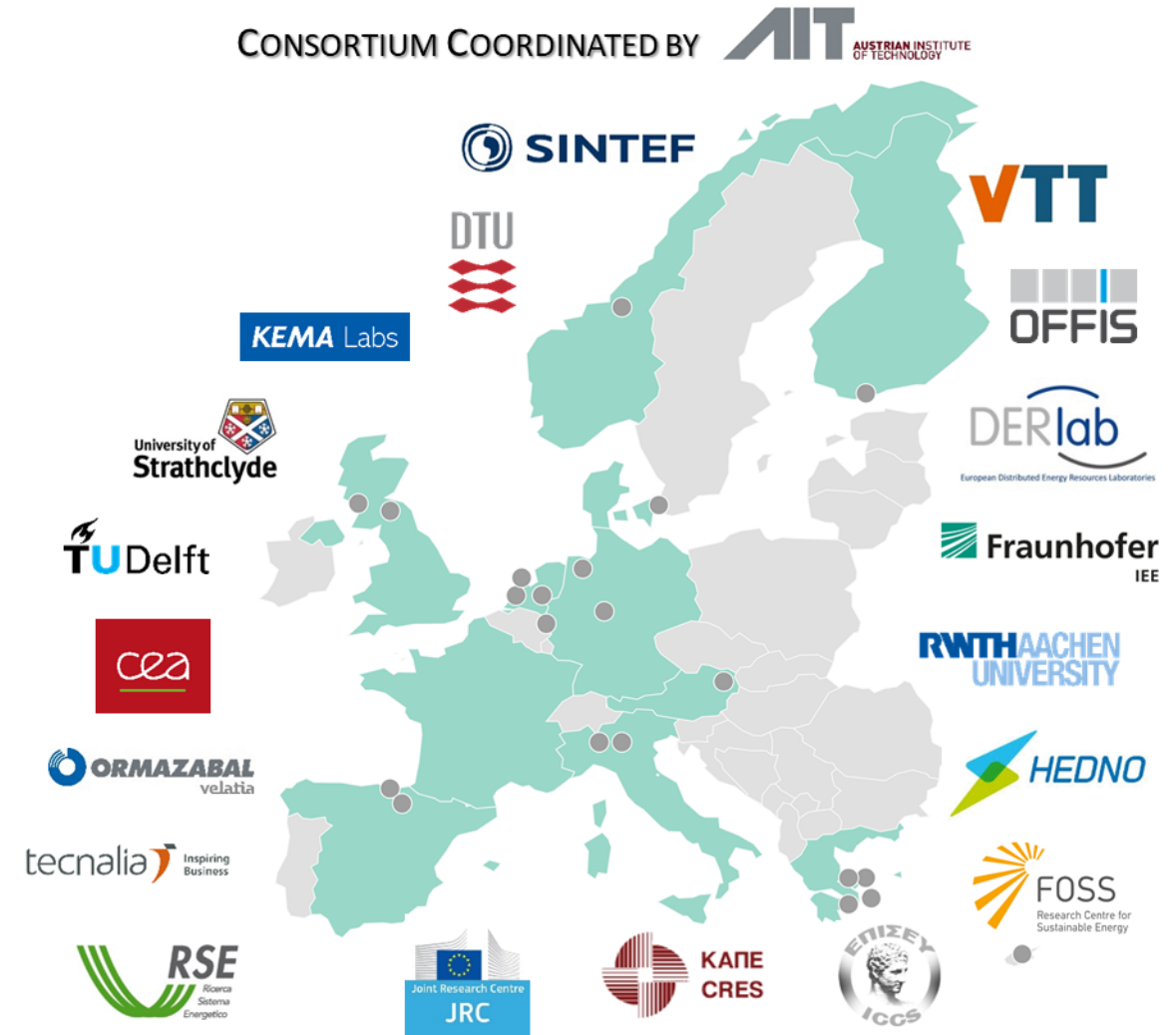


Free access for user groups to

- Power system,
- Smart grid and
- DER laboratories

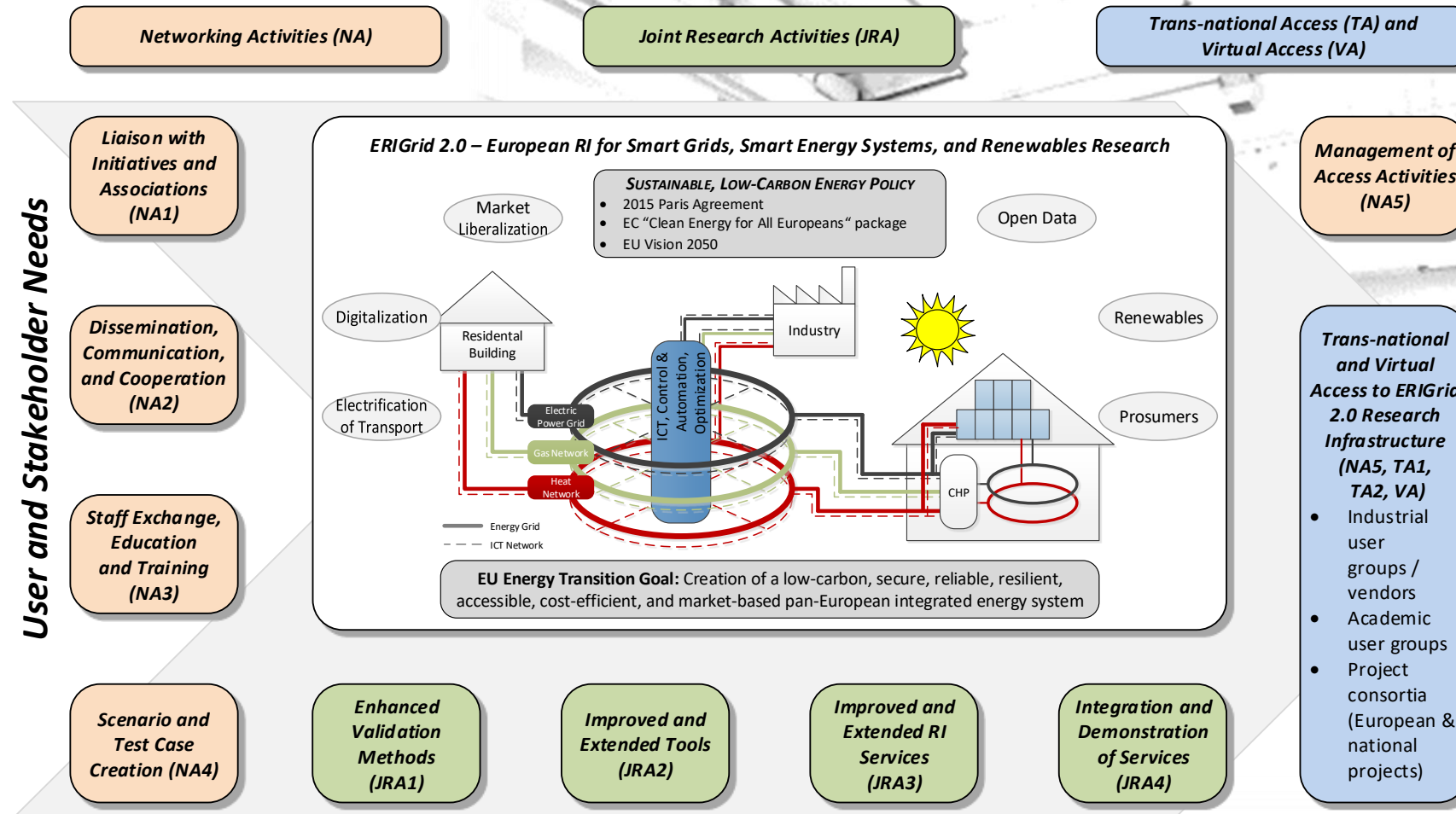
# Smart Energy Systems RI “ERIGrid 2.0” - Approach

- Extended and applied research based on ERIGrid topics and achievements for
  - Smart grid and smart energy systems
  - Digitalization with lab interfacing and data exchange for physical/virtual access
- Tight collaboration of partners
  - 13 European countries involved
  - 20 Partners from research and industry
  - 21 top-class smart grid, energy systems, and DER labs
  - 10 virtual facilities



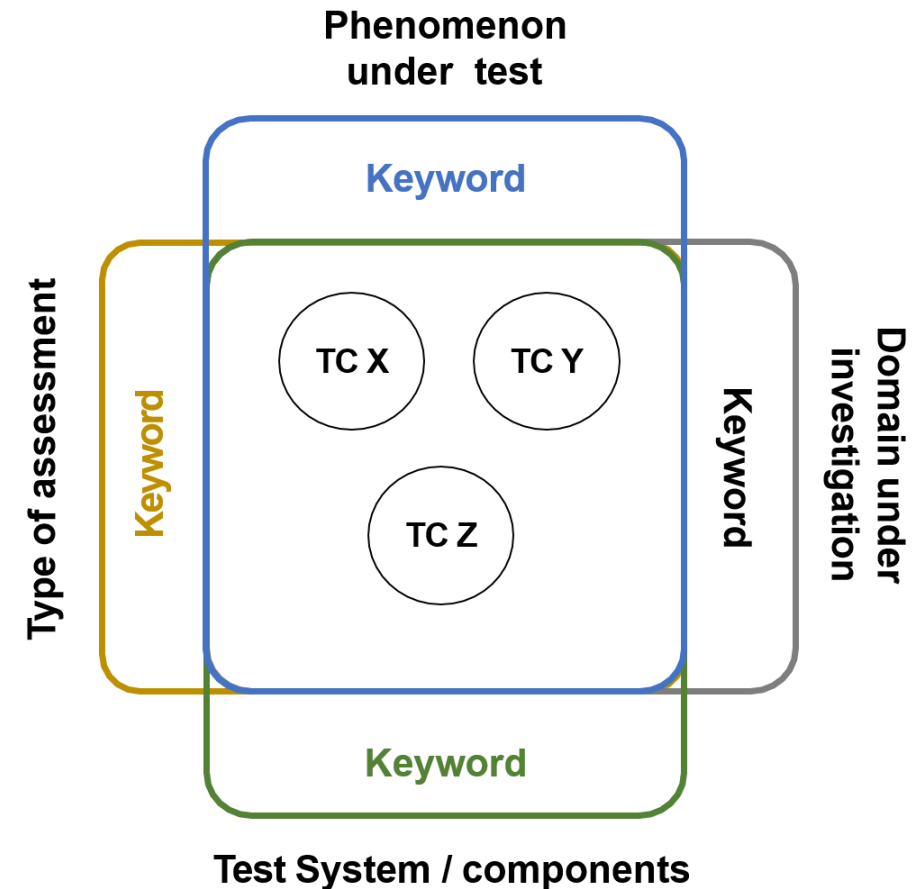


# Smart Energy Systems RI “ERIGrid 2.0” - Approach





- Derivation of Test Case Profiles (TPCs)
  - Collection of TCs that share similarities
  - Similarities in the context of application and testing facility properties
- Keywords focus on 4 dimensions
  1. Domain under investigation
  2. Phenomenon under test
  3. Type of assessment
  4. Test system

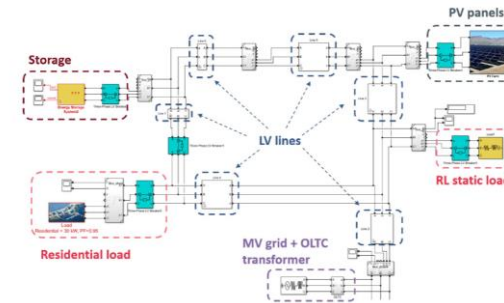


# Smart Energy Systems RI “ERIGrid 2.0” - Achievements

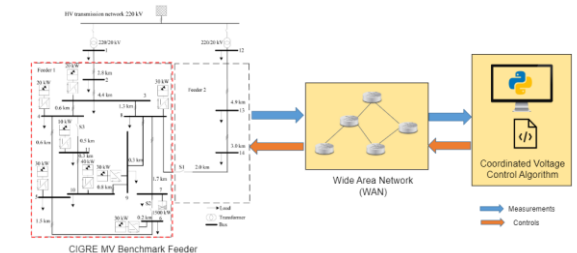
- Enhanced validation methods
  - Development of benchmark scenarios/models for different testing setups
  - Developing guidelines for test reproducibility and representation of data and uncertainty
  - Developing methods for test upscaling and domain extension

Name	Domain	Simulation Environment
Electrical Network	Electrical	MathWorks MATLAB/Simulink
Multi-Energy Networks	Electrical, Thermal	pandapower, Modelica, Python
ICT-Enhanced Power Systems	Electrical, ICT	DigSILENT PowerFactory, Mininet

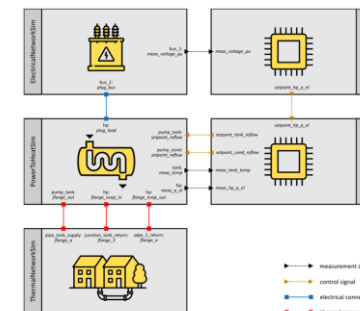
Electrical Network Benchmark



ICT-enhanced Power System Network Benchmark



Multi-Energy Network Benchmark



Documentation in GitHub

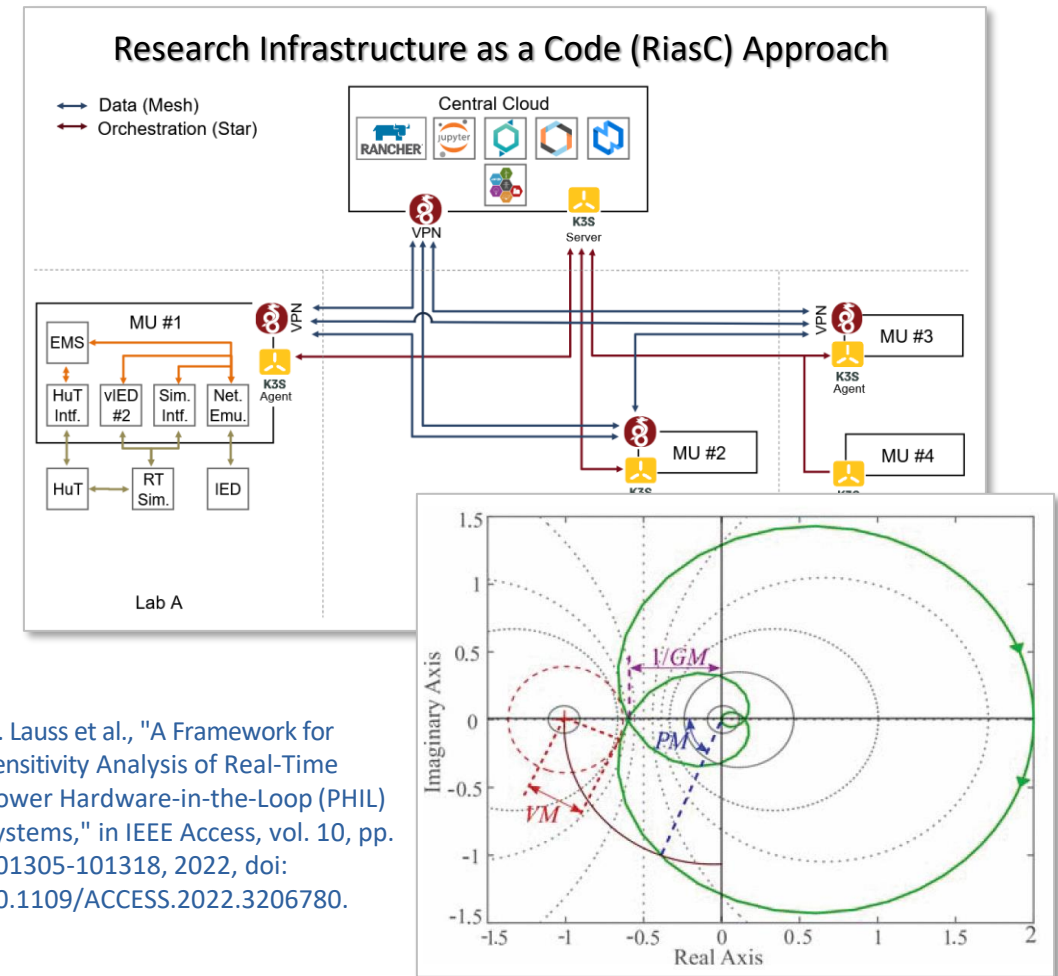
**benchmark-model-electrical-ict** Public  
Repository for the electrical and ICT benchmark model developed in the ERIGrid 2.0 project.  
Python 1 BSD-3-Clause 0 0 0 Updated 11 days ago

**benchmark-model-electrical-network** Public  
Documentation for the electrical network benchmark model developed in the ERIGrid 2.0 project. It includes the MATLAB/Simulink implementation files and a detailed model description according to the PricISE framework.  
0 0 0 Updated 23 days ago

**benchmark-model-multi-energy-networks** Public  
This repository contains the documentation and reference implementations of the multi-energy networks benchmark model developed in the ERIGrid 2.0 project.  
Python 0 0 0 Updated 11 days ago

# Smart Energy Systems RI “ERIGrid 2.0” - Achievements

- Improved and extended tools
  - Coupling multiple instances of non real-time simulators, real-time simulators, HIL components, and lab equipment (RiasC approach)
  - Demonstrate multi-domain co-simulation of physical infrastructures at multiple time scales
  - Develop and demonstrate methods for the coupling of real-time simulators with co-simulation and HIL
  - Sensitivity analysis of HIL experiments
  - Support distributed and remote experiments

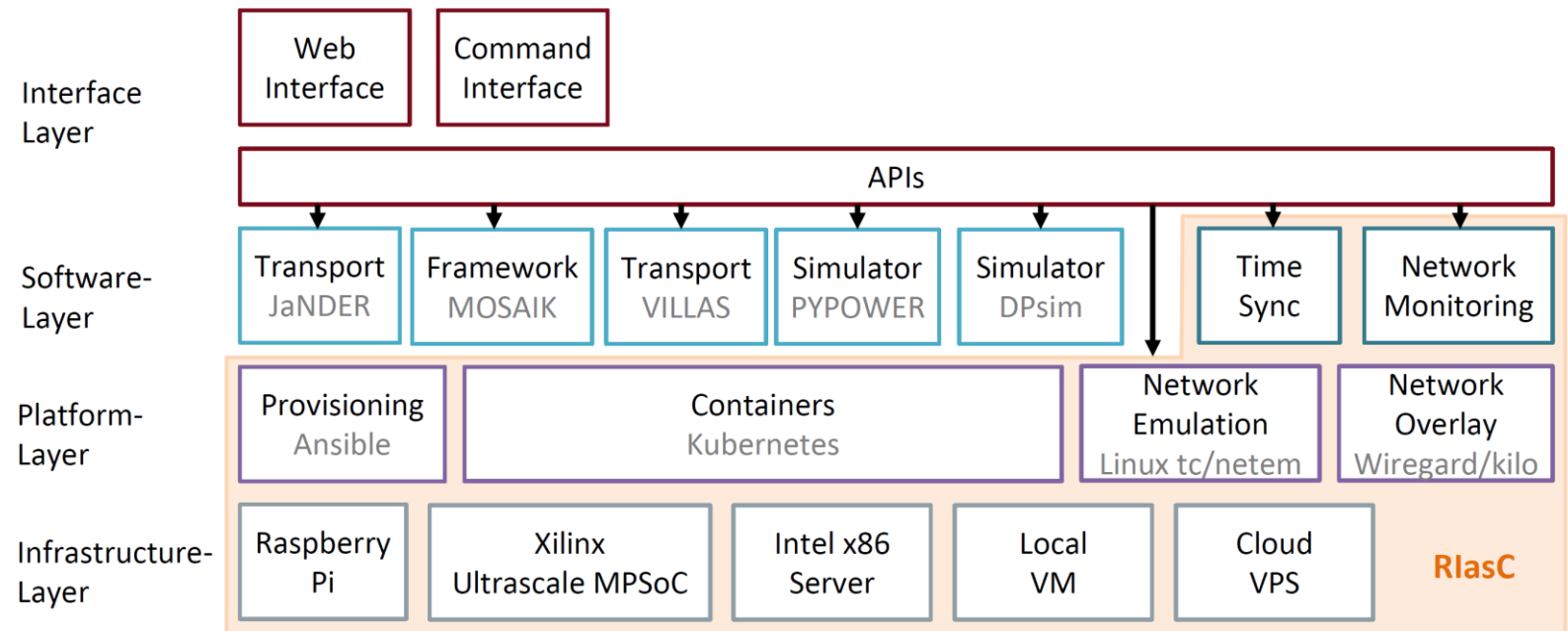


G. Lauss et al., "A Framework for Sensitivity Analysis of Real-Time Power Hardware-in-the-Loop (PHIL) Systems," in IEEE Access, vol. 10, pp. 101305-101318, 2022, doi: 10.1109/ACCESS.2022.3206780.



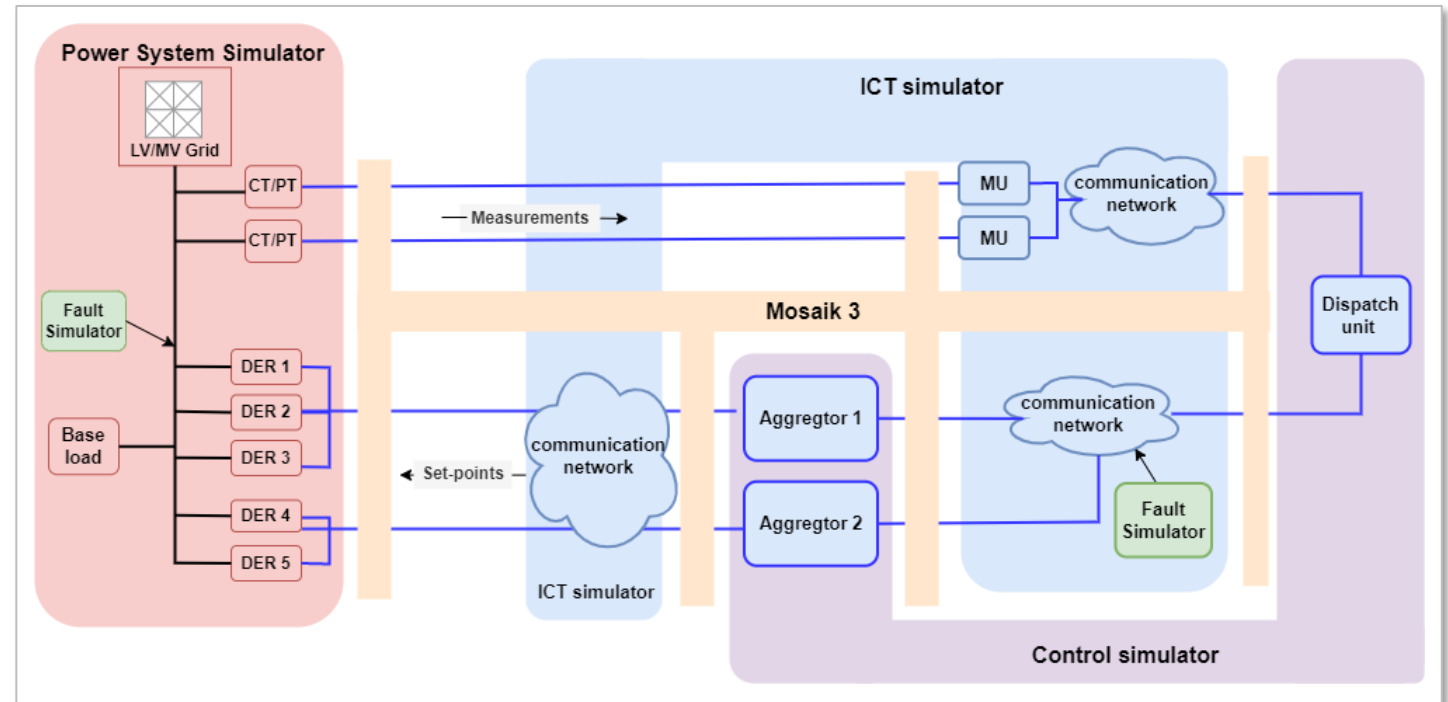
# Smart Energy Systems RI “ERIGrid 2.0” - Achievements

- Improved and extended RI services
  - Improve and extend well-established frameworks for lab coupling and multi-RI experiments
  - Develop a set of extended services for seamless interconnection with various lab facilities/RIs
  - Demonstrate the application of services with an abstract prototype
  - Implement simulation specific services along with integration of automation services



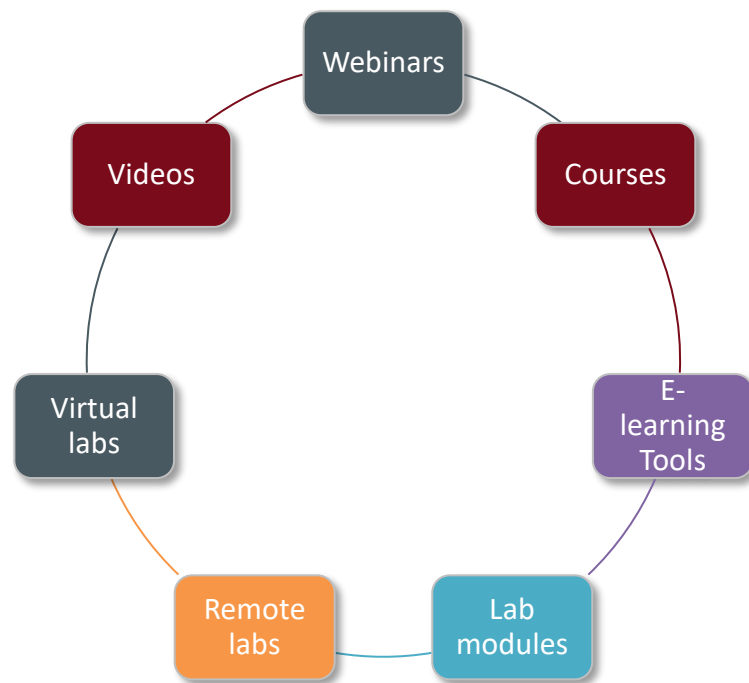
# Smart Energy Systems RI “ERIGrid 2.0” - Achievements

- Integration and demonstration of RI services
  - Definition of useful integration and demonstration test cases based on the identified functional scenarios and test cases
  - Implementation of inter-connection methodologies and tools for the simulation, co-simulation, HIL, and distributed lab infrastructure
  - Demonstration of the services of the ERIGrid 2.0 extended RI

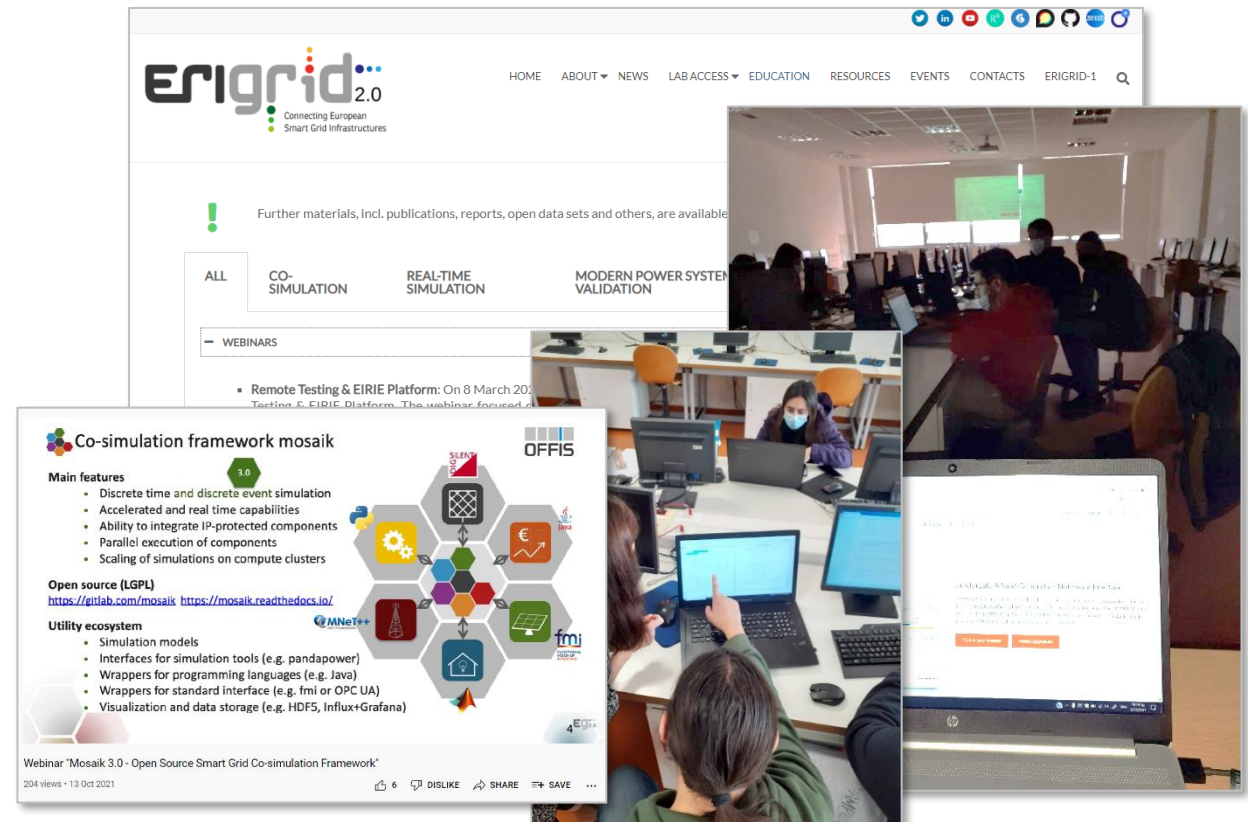


# Smart Energy Systems RI “ERIGrid 2.0” - Achievements

- Education on smart grid and smart energy systems as well as related validation approaches
- Development and provision of training and education material



[www.erigrd2.eu/education](http://www.erigrd2.eu/education)



**Co-simulation framework mosaik**

**Main features**

- Discrete time and discrete event simulation
- Accelerated and real time capabilities
- Ability to integrate IP-protected components
- Parallel execution of components
- Scaling of simulations on compute clusters

**Open source (LGPL)**  
<https://gitlab.com/mosaik> <https://mosaik.readthedocs.io/>

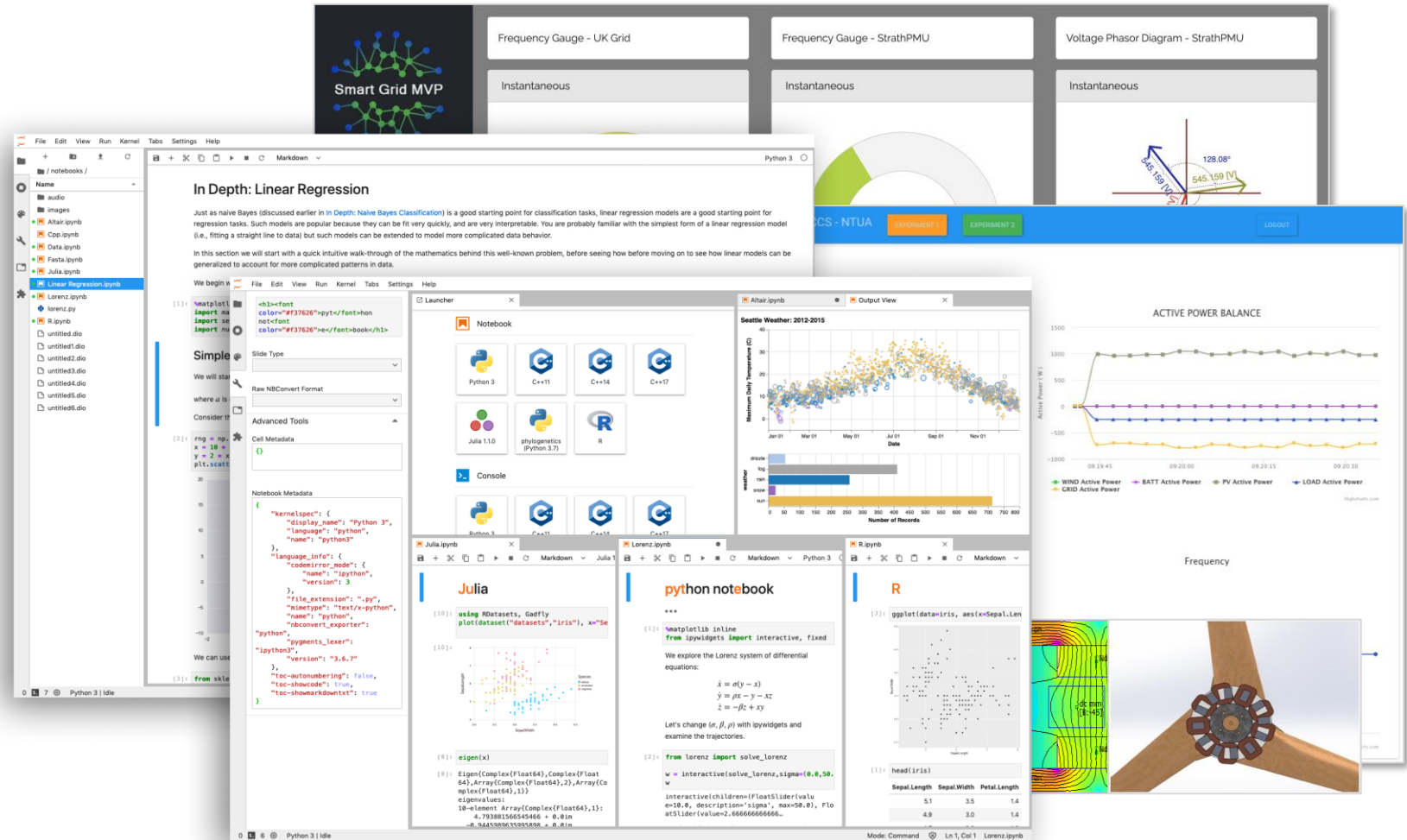
**Utility ecosystem**

- Simulation models
- Interfaces for simulation tools (e.g. pandapower)
- Wrappers for programming languages (e.g. Java)
- Wrappers for standard interface (e.g. fmi or OPC UA)
- Visualization and data storage (e.g. HDF5, Influx+Grafana)

# Smart Energy Systems “ERIGrid 2.0” - Virtual Services

■ Focus on

- Simulation-as-a-Service (SaaS)
- Open data, Data-as-a-Service (DaaS)
- Virtual labs



The image displays a collection of virtual services and data visualizations:

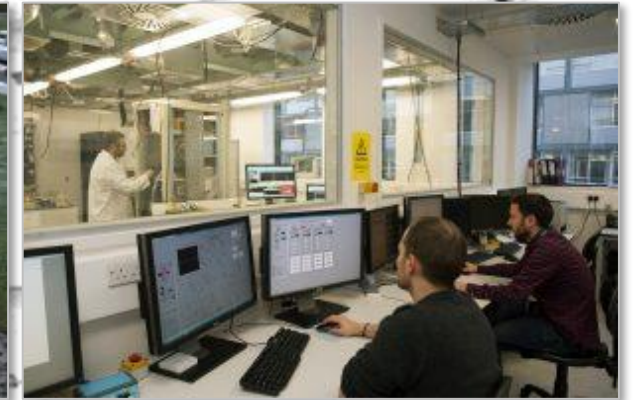
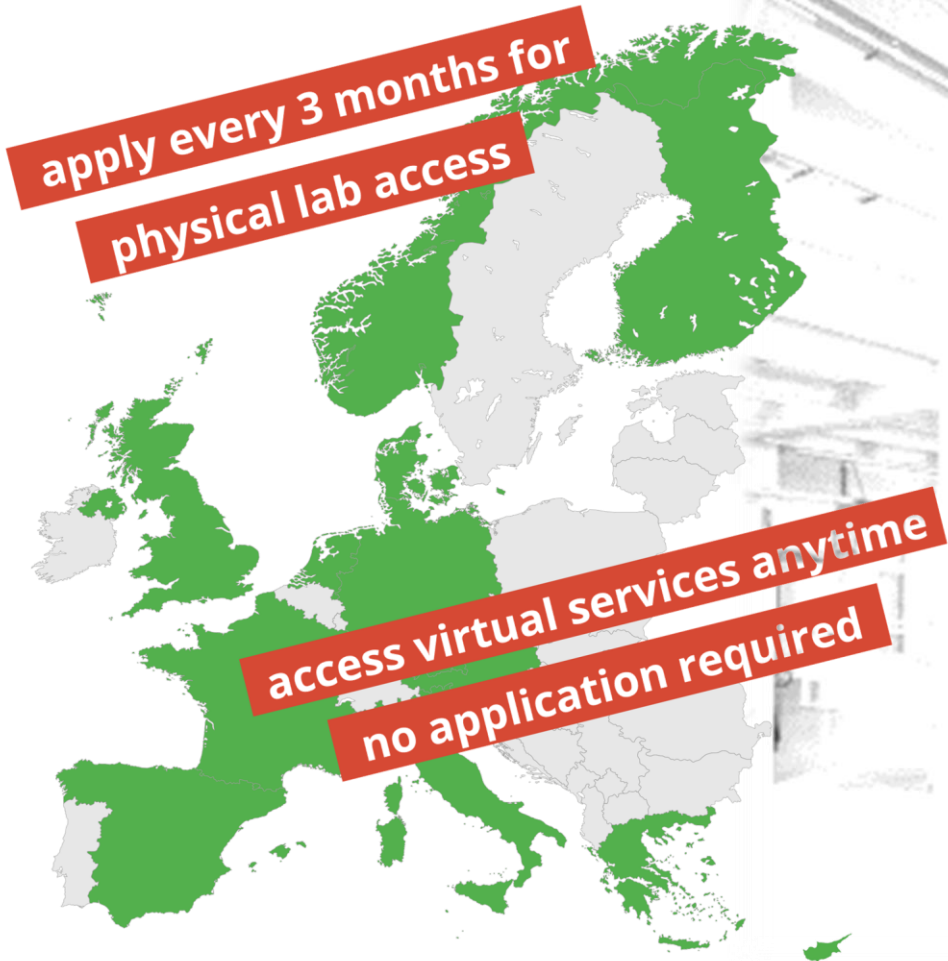
- Smart Grid MVP**: A central hub with a network diagram.
- Frequency Gauge - UK Grid** and **Frequency Gauge - StrathPMU**: Real-time monitoring dashboards.
- Voltage Phasor Diagram - StrathPMU**: A diagram showing phase angles (128.08°, 545.199°) and magnitudes.
- In Depth: Linear Regression**: A Jupyter notebook showing code for linear regression analysis.
- Seattle Weather: 2012-2015**: A scatter plot of maximum daily temperature over time.
- ACTIVE POWER BALANCE**: A line chart showing WIND, BATT, PV, and LOAD active power over time.
- Frequency**: A 3D visualization of a turbine or generator component.
- Other notebooks**: Julia, Python, and R notebooks are also visible, showing various data analysis and simulation outputs.

[www.erigrad2.eu/lab-access](http://www.erigrad2.eu/lab-access)





# Smart Energy Systems “ERIGrid 2.0” - Lab Access

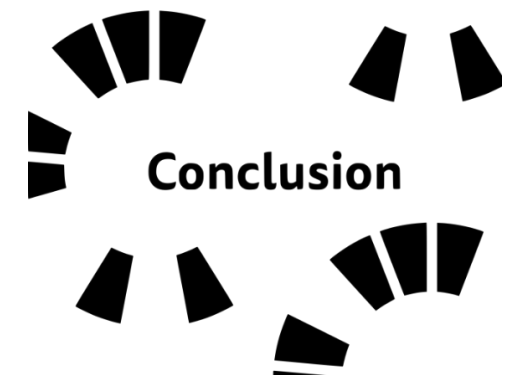


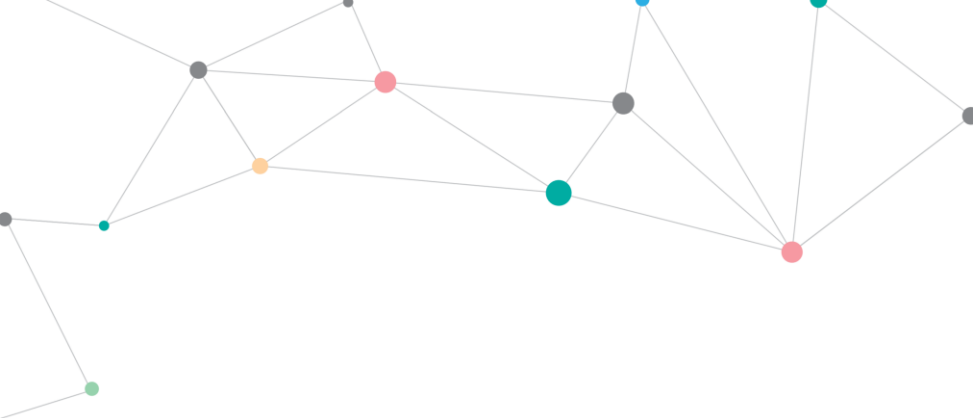
[www.erigrid2.eu/lab-access](http://www.erigrid2.eu/lab-access)



# Conclusions and Lessons Learned

- A large-scale rollout of smart grid and energy solutions and technologies can be expected in the future
- New technologies, suitable concepts, methods and approaches are necessary to support system analysis, evaluation and testing issues of integrated approaches
- Flexible integration of simulation-based methods, hardware-in-the-loop approaches, and lab-based testing looks promising for overcoming shortcomings
- Development of system-level validation procedures and benchmark criteria is important
- Open research results (open access, open data, joint publications) contribute to innovation
- Lab-based RIs are essential for energy transition
- Multi-domain education and training essential
- Collaboration on international basis important and beneficial (IEA ISGAN/SIRFN, EERA SG, IEEE-SA – standardization, etc.)
- Great feedback from lab access users





[www.erigrd2.eu](http://www.erigrd2.eu)



@ERIGrid 2.0 Project

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