Integrated Energy Services, Cyber Security Issues, and Analytical Services

Institute Mihajlo Pupin, University of Belgrade, Serbia

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Overview

- **Motivation (Challenges in the energy sector)** **10’**
  - EU Policy framework
  - SINERGY Partnership (PUPIN, AIT, NUIG), H2020

- **Technologies and Concepts for the Next-generation Integrated Energy Services** **30’**
  - **Example 1** – Decarbonization Scenarios for PUPIN R&D Campus (Serbia)
  - **Example 2** - Poligono Industrial Las Cabezas (Spain)

This project has received funding from the H2020
programme of the European Union under GA No. 952140

Overview

- **Analytical services** **20’**
  - **Example 1** – Hybrid ensemble neural network approach for photovoltaic production forecast
  - **Example 2** – Framework for optimizing neural network hyper parameters for accurate wind production forecasting
- **Cyber Security Issues of Cloud-based Dynamic Line Rating** **30’**
- **Questions** **30’**

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Motivation & Challenges in the the energy sector

Institute Mihajlo Pupin, University of Belgrade, Serbia

https://www.pupin.rs/en/research-and-development-projects/european-rd-projects/

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Motivation

- **Combat climate change and reduce greenhouse gas emissions**
- Renewable sources of energy (wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass and biofuels) are alternatives to fossil fuels that help cut greenhouse gas emissions, diversify the energy supply and reduce dependence on unreliable and volatile fossil fuel markets, particularly oil and gas.
- EU legislation to promote renewables has evolved significantly over the past 15 years.

EU Policy Framework

- **Clean Energy for All, June 2019; European Green Deal, December 2019**
- **European Strategy for Data, February 2020; Energy System Integration Strategy, July 2020; Data Governance Act, Nov. 2020**
- **AI Act, April 2021**
- **"Fit for 55" package, 2021**
  cut greenhouse-gas emissions by at least 55% in 2030 compared with 1990 levels; 45% share of RES in a final energy consumption by 2030
- **Energy Efficiency Directive, 2023**
  reduce energy demand at EU level by 11.7% by 2030 (compared to projections made in 2020)

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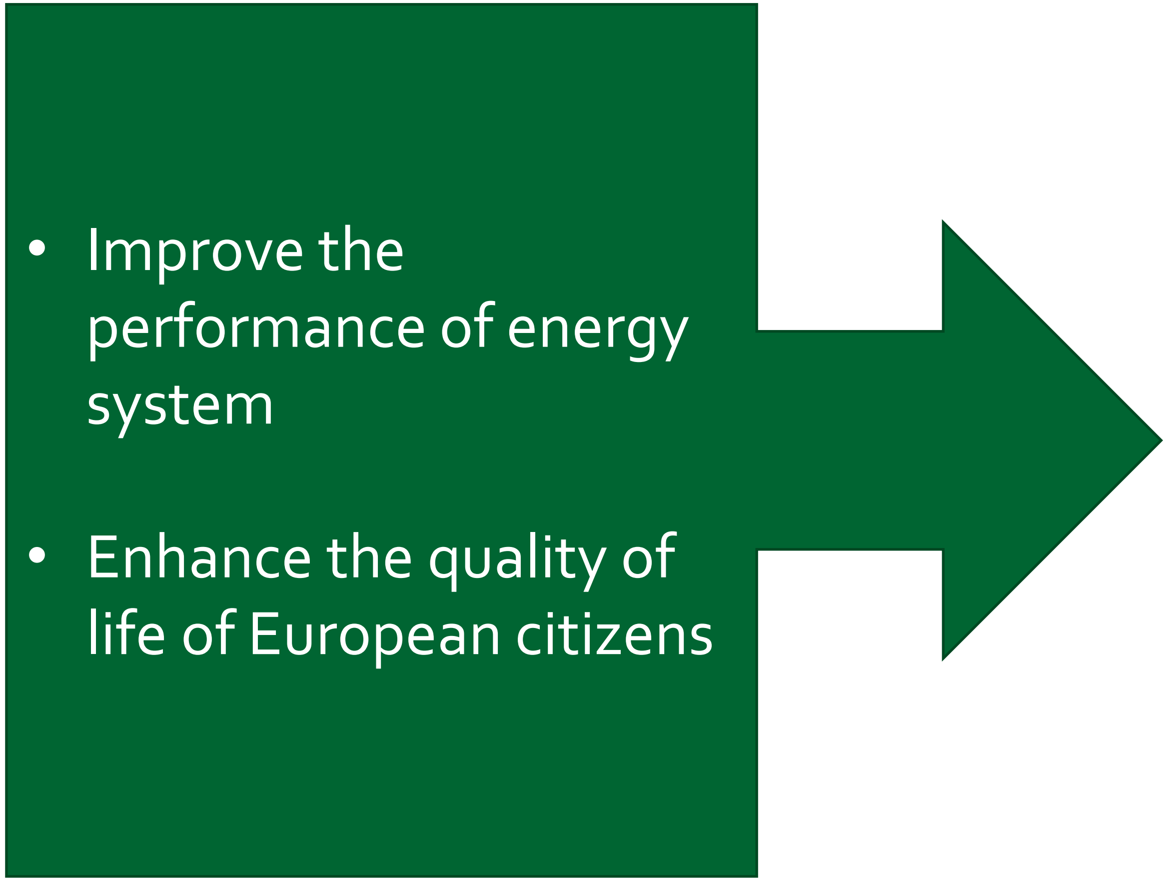
Challenges

- Energy Management Applications are fragmented, developed against energy data silos, and data exchange is limited to few applications
- Penetration of distributed generation (Wind / PV / Solar Power Plants) increases the variability and degree of uncertainty of power output from renewable sources

Modernisation of the European electricity grid focuses on

- New smart grids services through **knowledge exploitation** => innovative **data-driven services**
- **Multi-party data exchange** while ensuring data governance and data sovereignty
- **Data Ecosystems - Architectures**
  - Digitalization (IoT, AI, Big Data)
  - Platforms

Expected impact



- Improve the performance of energy system
- Enhance the quality of life of European citizens

- In Europe, **Citizen Energy Communities** (CEC) concept was promoted with a primary objective to enhance self-consumption of **locally produced renewable energy**.

Directive (EU) 2019/944…common rules for the internal market for electricity..

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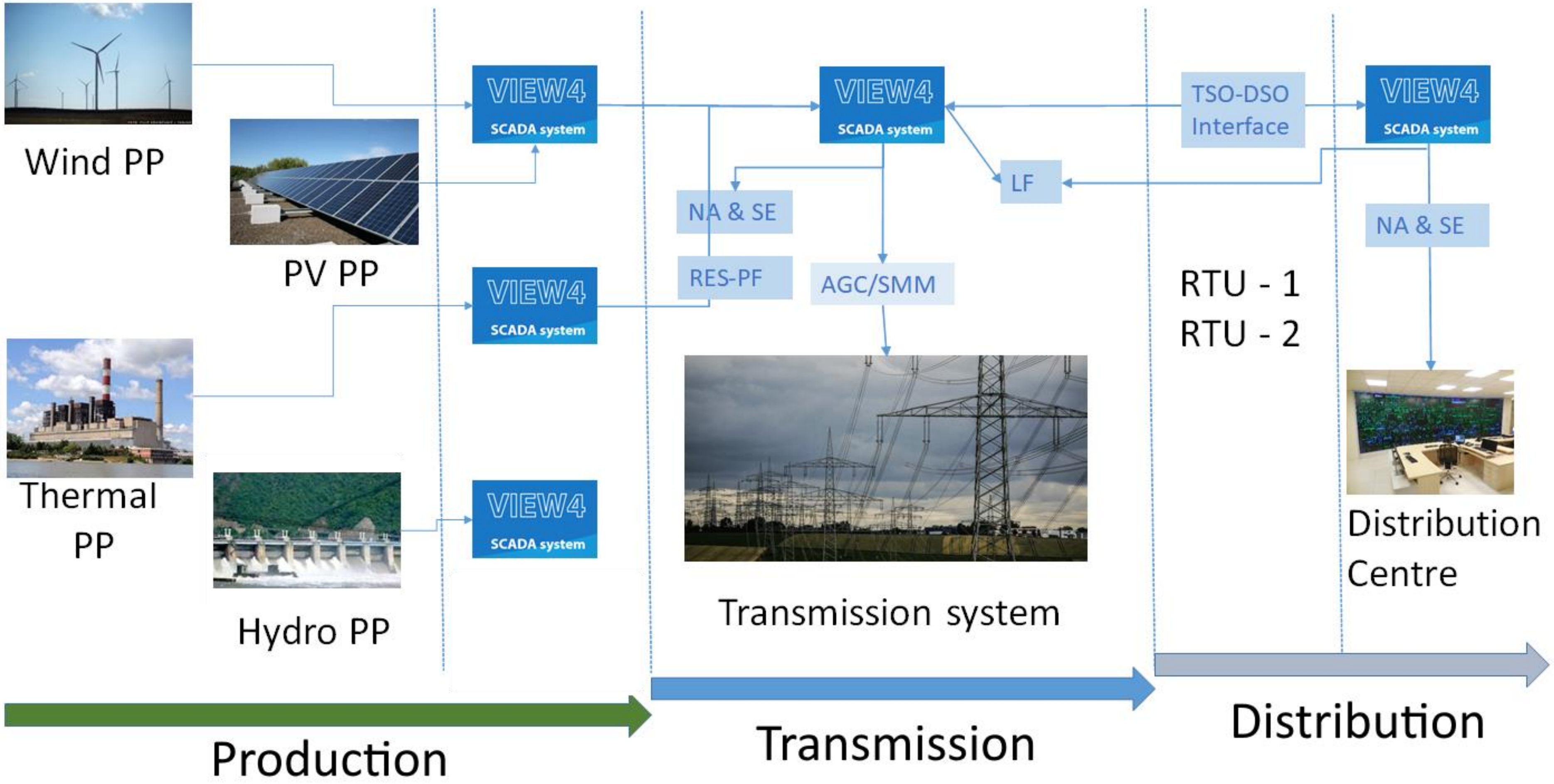
Electricity value chain - centralized system



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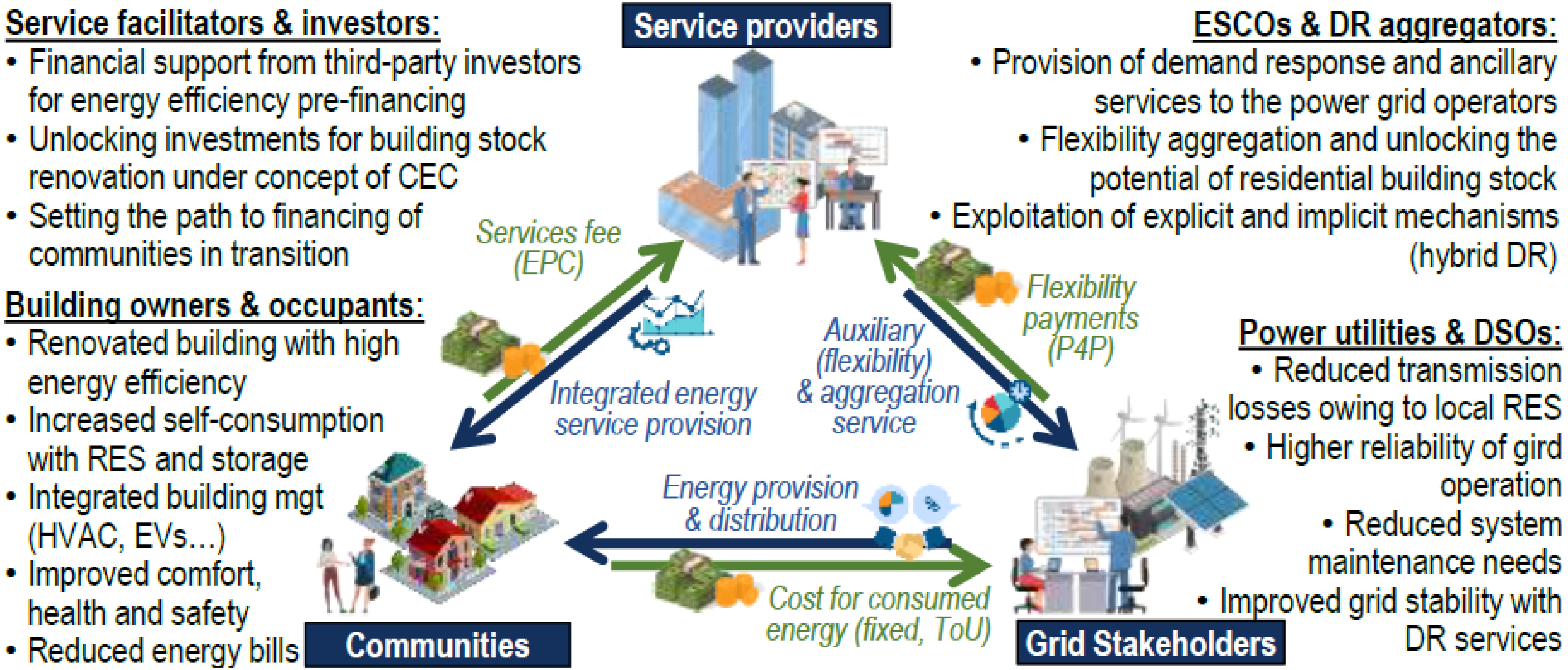
Directive (EU) 2019/944

› provides legal and business foundations for Citizen Energy Communities



Service facilitators & investors:

- Financial support from third-party investors for energy efficiency pre-financing
- Unlocking investments for building stock renovation under concept of CEC
- Setting the path to financing of communities in transition

Building owners & occupants:

- Renovated building with high energy efficiency
- Increased self-consumption with RES and storage
- Integrated building mgt (HVAC, EVs…)
- Improved comfort, health and safety
- Reduced energy bills

ESCOs & DR aggregators:

- Provision of demand response and ancillary services to the power grid operators
- Flexibility aggregation and unlocking the potential of residential building stock
- Exploitation of explicit and implicit mechanisms (hybrid DR)

Power utilities & DSOs:

- Reduced transmission losses owing to local RES
- Higher reliability of gird operation
- Reduced system maintenance needs
- Improved grid stability with DR services

Smart Energy Management

- Smart Energy Management (SEM) refers to a variety of novel concepts and technologies, serving at both energy generation and consumption side, such as energy efficiency, demand management, Smart Grid, micro- grids, renewable energy sources, and other emerging solutions.
- SEM tools are build upon advanced edge-cloud computing frameworks, Big Data Analytics techniques, AI-driven methodologies, novel integration approaches based on semantic technologies and others.
- SEM solutions are deployed on the consumers' side (buildings, districts) in order to achieve holistic optimization of the use of local distributed energy resources (wind, solar, EV charging stations, batteries), improve the self-consumption and lower the costs of the electricity used from the grid.

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IMP Motivation & Vision

Regional Centre of Excellence in Smart Energy Management

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Commercial Projects,
https://www.pupin.rs/en/references

- Dispatching centers in Serbia
- Supervision of transmission network
- Supervision of entire distribution network
- Integrated monitoring and balancing the SMM block

This project has received funding f
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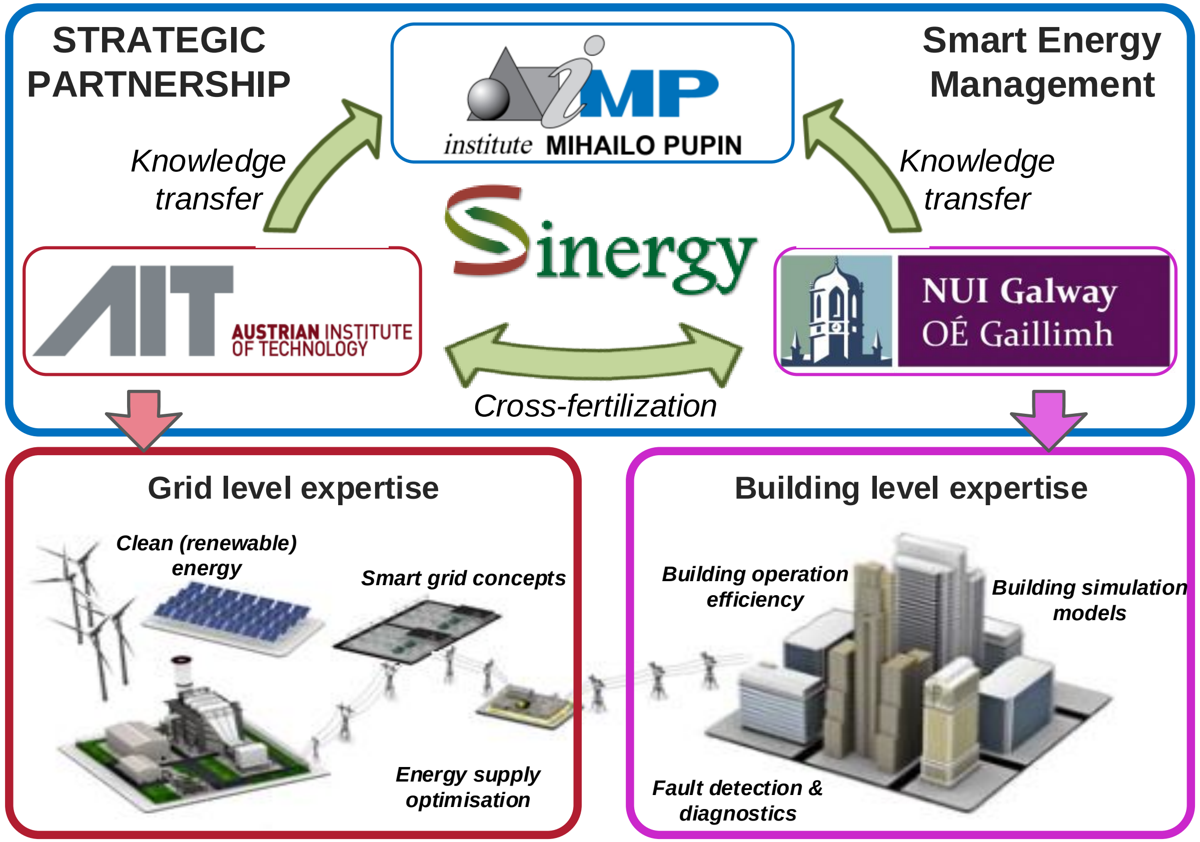
SINERGY Motivation & Vision

- **Strategic partnership and transfer of multidisciplinary “know-how”** from leading EU research institutions
- **Building research potential through the collaboration with the AIT and NUIG** in domain of advanced smart grids and building operation efficiency, covering both energy supply and demand side
- **Establish knowledge and technology transfer platform** with necessary infrastructure and equipment



STRATEGIC PARTNERSHIP

Smart Energy Management

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Knowledge transfer

Knowledge transfer

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Cross-fertilization

Grid level expertise

Building level expertise

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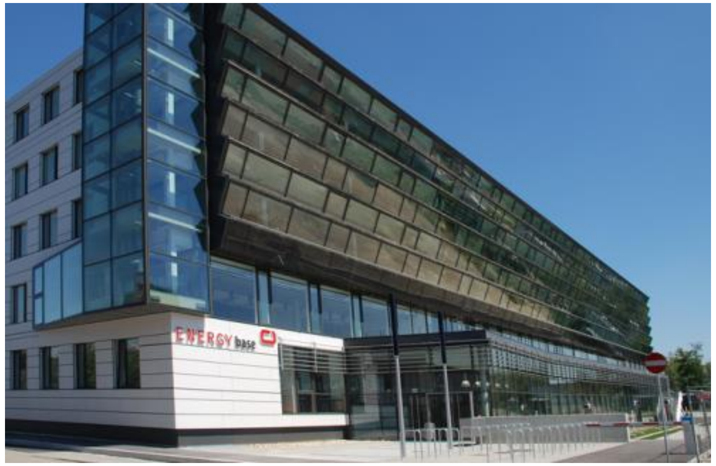
Knowledge & technology transfer platform

with necessary infrastructure and equipment

EnergyBase, TechBase
(Vienna)



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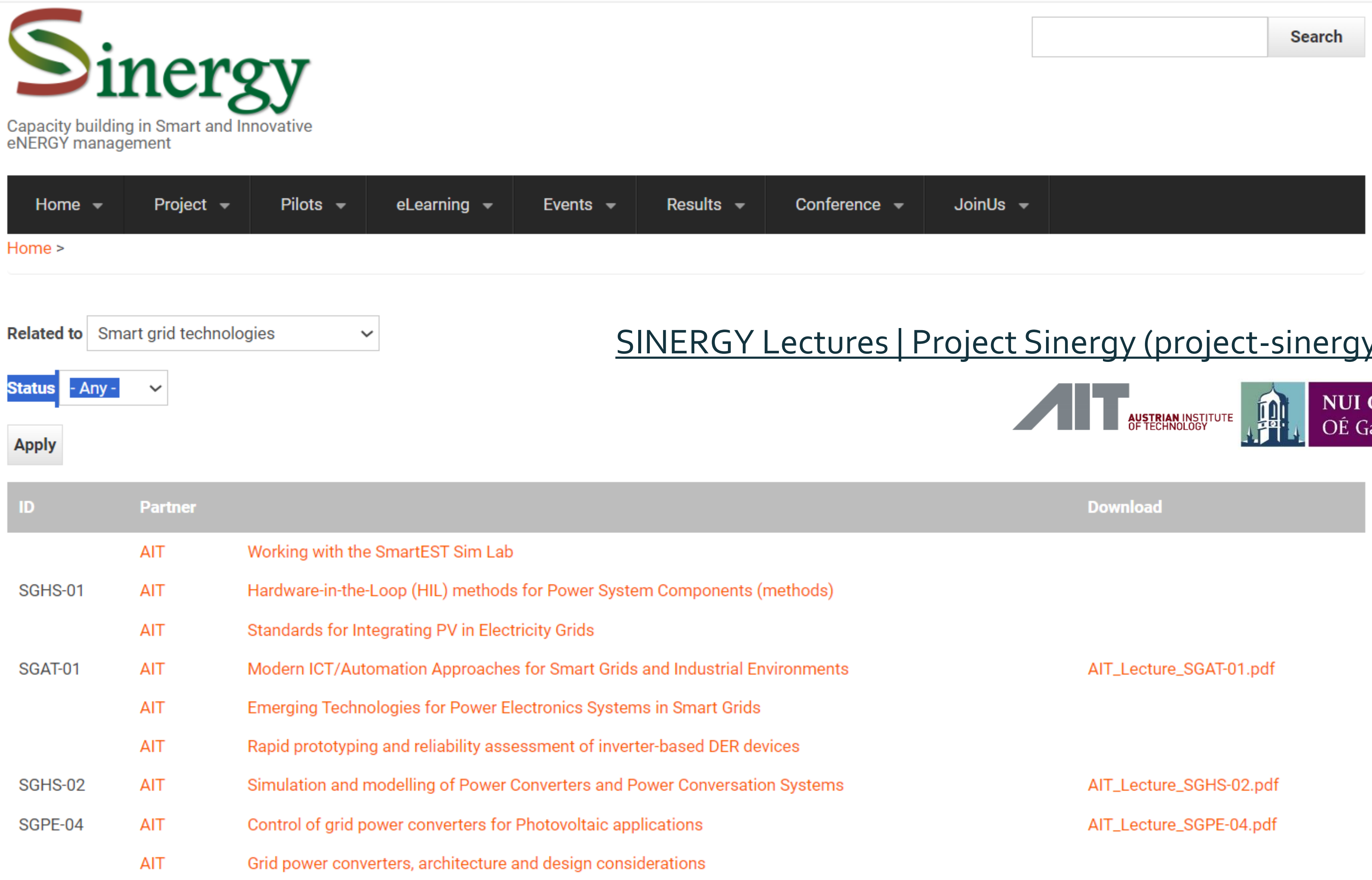
SINERGY Lectures | Project Sinergy (project-sinergy.org)



Related to: Smart grid technologies

Status: - Any -

ID	Partner		Download
	AIT	Working with the SmartEST Sim Lab	
SGHS-01	AIT	Hardware-in-the-Loop (HIL) methods for Power System Components (methods)	
	AIT	Standards for Integrating PV in Electricity Grids	
SGAT-01	AIT	Modern ICT/Automation Approaches for Smart Grids and Industrial Environments	AIT_Lecture_SGAT-01.pdf
	AIT	Emerging Technologies for Power Electronics Systems in Smart Grids	
	AIT	Rapid prototyping and reliability assessment of inverter-based DER devices	
SGHS-02	AIT	Simulation and modelling of Power Converters and Power Conversation Systems	AIT_Lecture_SGHS-02.pdf
SGPE-04	AIT	Control of grid power converters for Photovoltaic applications	AIT_Lecture_SGPE-04.pdf
	AIT	Grid power converters, architecture and design considerations	

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Technologies and Concepts for the Next-generation Integrated Energy Services

Institute Mihajlo Pupin, University of Belgrade, Serbia

Valentina Janev, Lazar Berbakov, Marko Jelić,

Dea Jelić, Marko Batić and Nikola Tomašević

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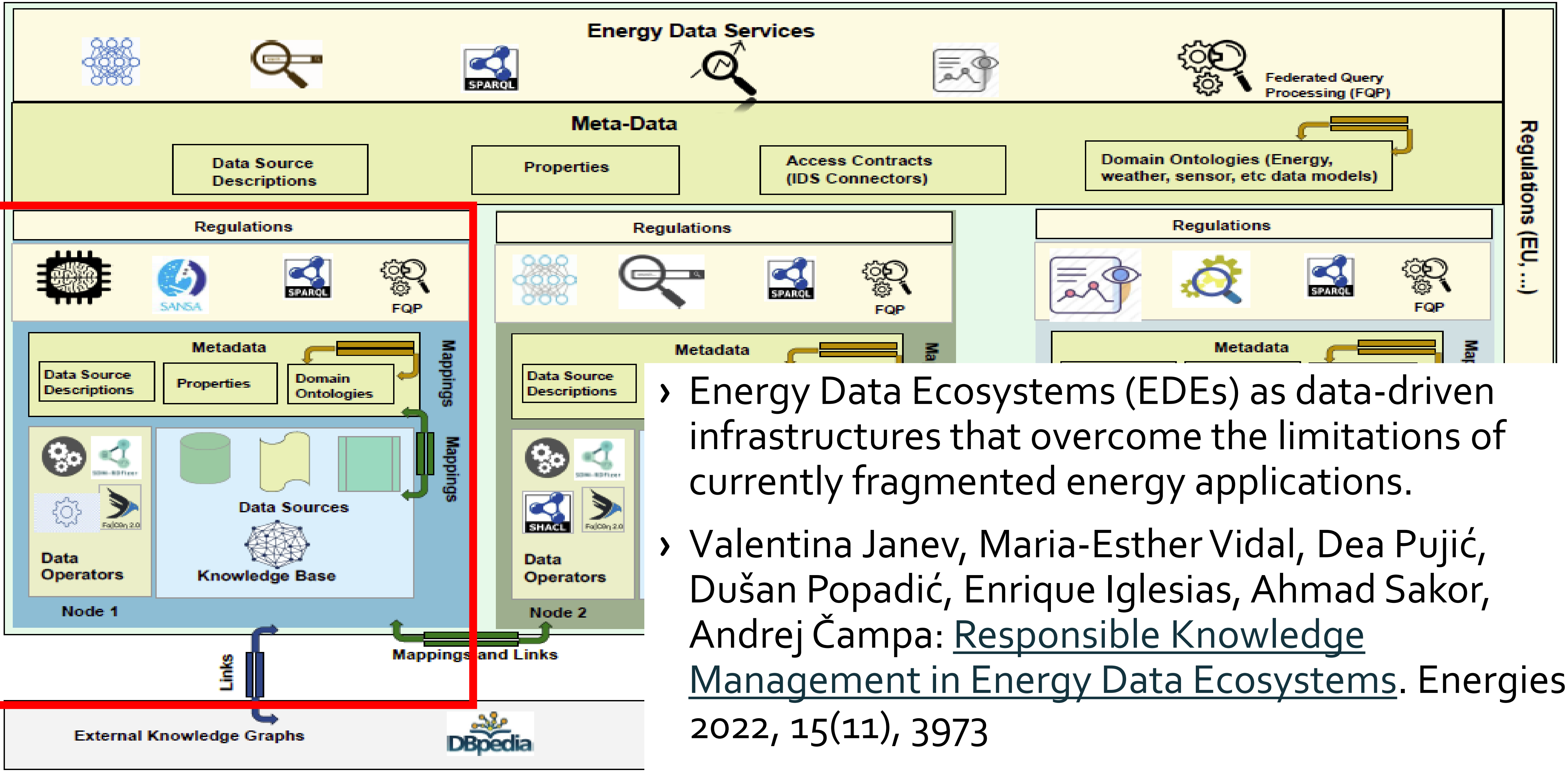
Energy Data Ecosystems



- › Energy Data Ecosystems (EDEs) as data-driven infrastructures that overcome the limitations of currently fragmented energy applications.
- › Valentina Janev, Maria-Esther Vidal, Dea Pujić, Dušan Popadić, Enrique Iglesias, Ahmad Sakor, Andrej Čampa: Responsible Knowledge Management in Energy Data Ecosystems. Energies 2022, 15(11), 3973

Platform requirements

- Integration of different data driven services and host the services
- Connecting to the physical energy assets
- Processing and data exchange between actors/software systems that are part of the CEC
- Platform design: cloud-based, service-oriented architectures, blockchain technology, flexibility and loosely coupling design, interoperability, security and privacy by design, and configuration management

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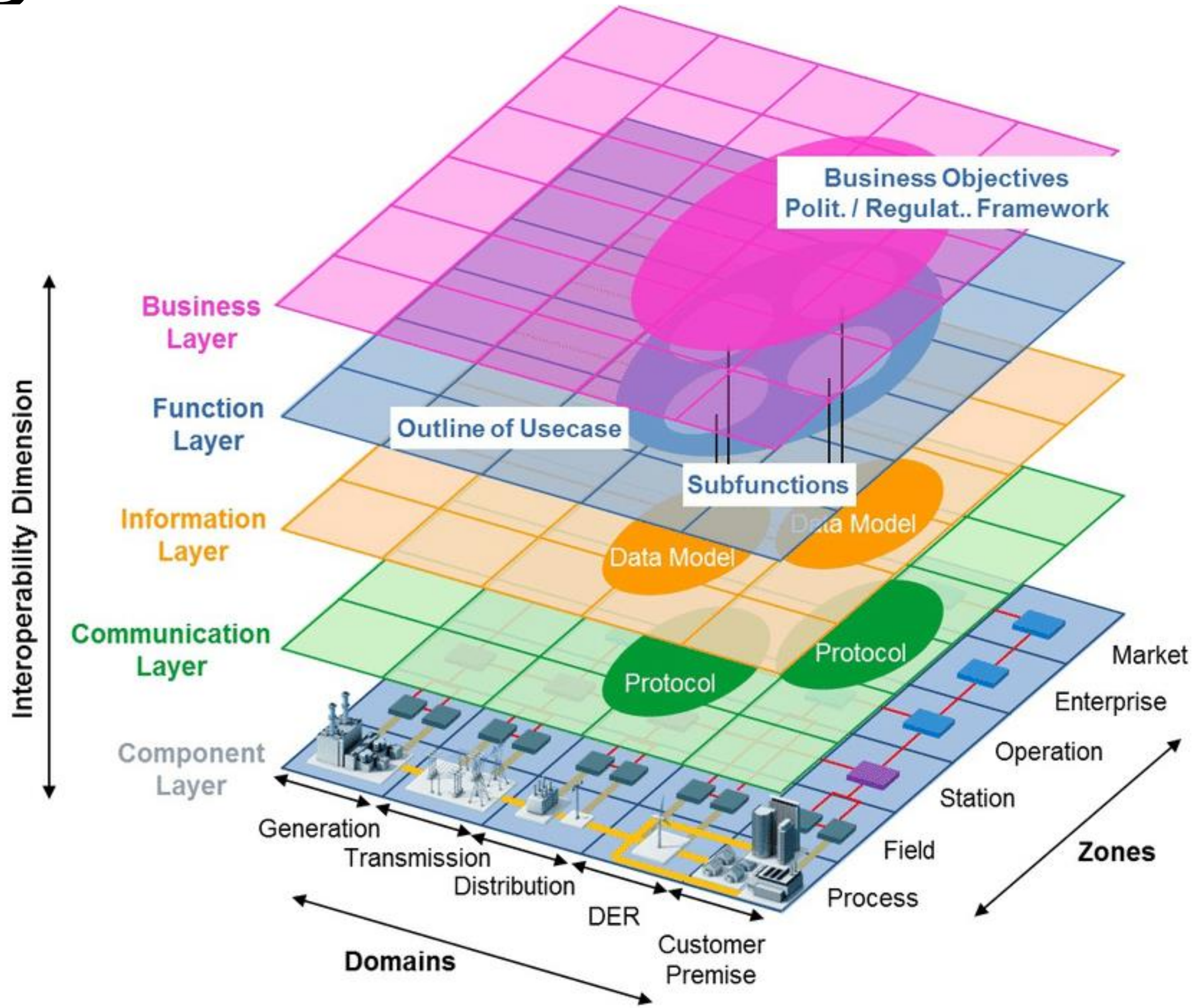
Platform design

Interoperability Dimension

Smart Grid Architecture Model (SGAM) that is a product of the standardization process in the EU Mandate M/490, the work of the CEN-CENELEC-ETSI Smart Grid Coordination Group



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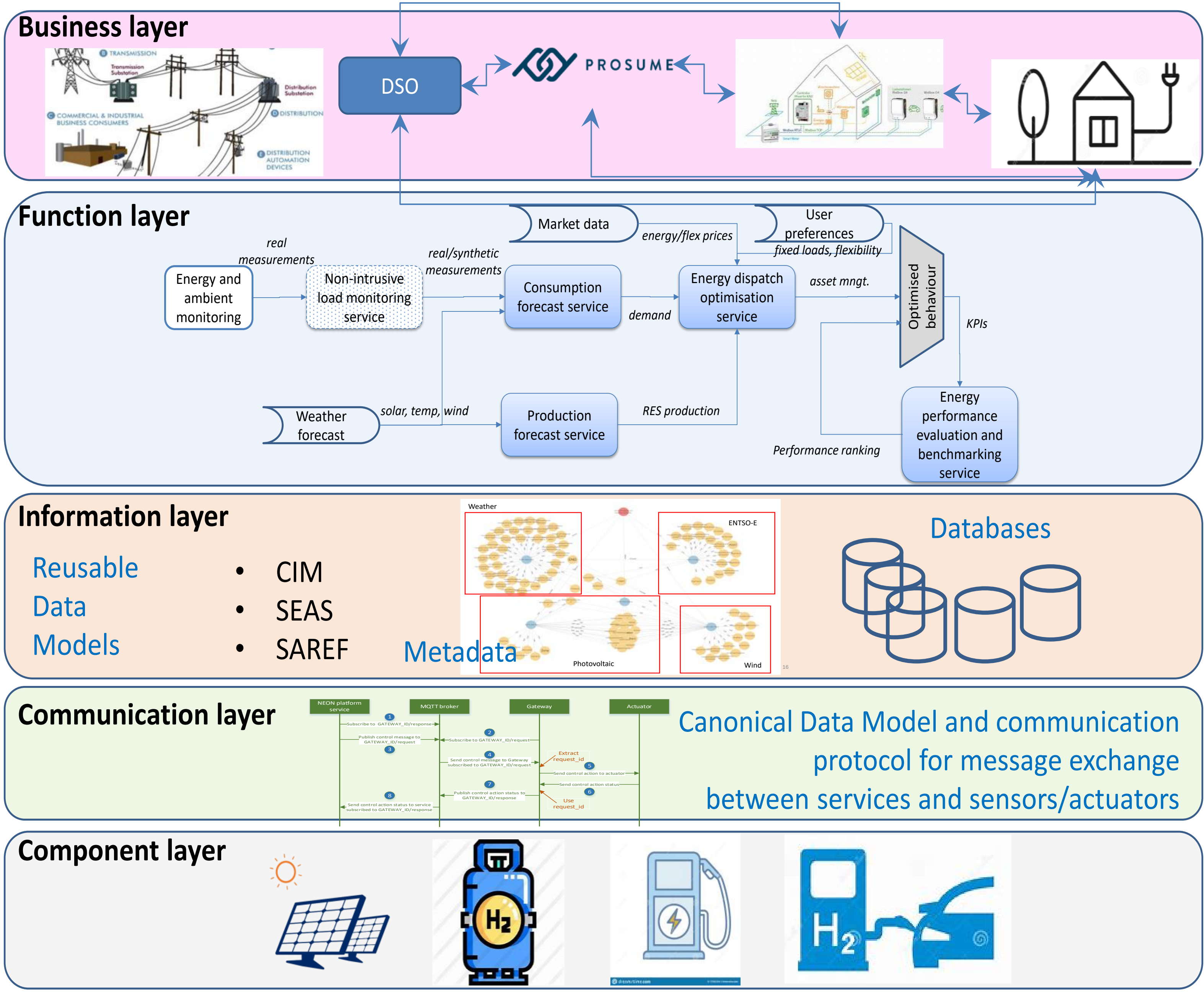
- Based on standard-enabling technologies and practices and recommendations from past EU projects
- Considers stakeholders along the energy value chain: consumers, energy managers, grid operators, service providers.



Business layer

Function layer

Energy and ambient monitoring
real measurements
Non-intrusive load monitoring service
real/synthetic measurements
Consumption forecast service
demand
Market data
energy/flex prices
User preferences
fixed loads, flexibility
Energy dispatch optimisation service
asset mngt.
Optimised behaviour
KPIs
Weather forecast
solar, temp, wind
Production forecast service
RES production
Performance ranking
Energy performance evaluation and benchmarking service

Information layer

Reusable
Data
Models

- CIM
- SEAS
- SAREF

Metadata

Databases

Communication layer

Canonical Data Model and communication protocol for message exchange between services and sensors/actuators

Component layer

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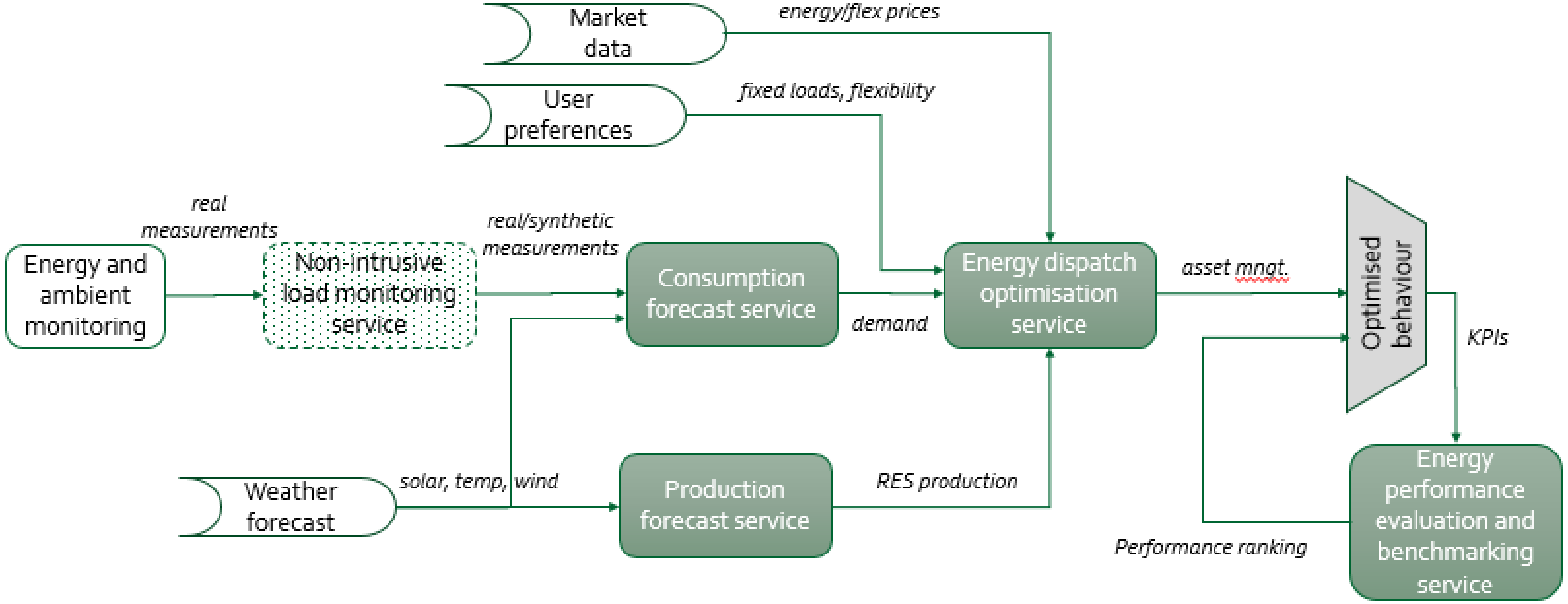
Available services

- Non-intrusive load monitoring
- Local and aggregated energy demand/consumption prediction
- Renewable energy sources (RES) generation forecasting
- Energy dispatch optimisation
- Energy performance evaluation and benchmarking

Sinergy workflow for energy services



[Innovative solutions | Project Sinergy (project-sinergy.org)](https://project-sinergy.org)

[Publications | Project Sinergy (project-sinergy.org)](https://project-sinergy.org)

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omega-x

Example 1 - PUPIN R&D Campus

Institute Mihajlo Pupin, University of Belgrade, Serbia

OMEGA-X – **O**rchestrating an interoperable sovereign federated **M**ulti-vector **E**nergy Data Space built on open standards and ready for **GA**ia-**X**

Focus – PUPIN R&D Campus

Size:

- 14,500 sq. meters indoor
- 17,500 sq. meters outdoor

Community:

- > 600 occupants
- 7 separate legal business in IMP and > 6 external SMEs

Total energy consumption:

- Electricity 1200 MWh/yr
- Heat 1700 MWth

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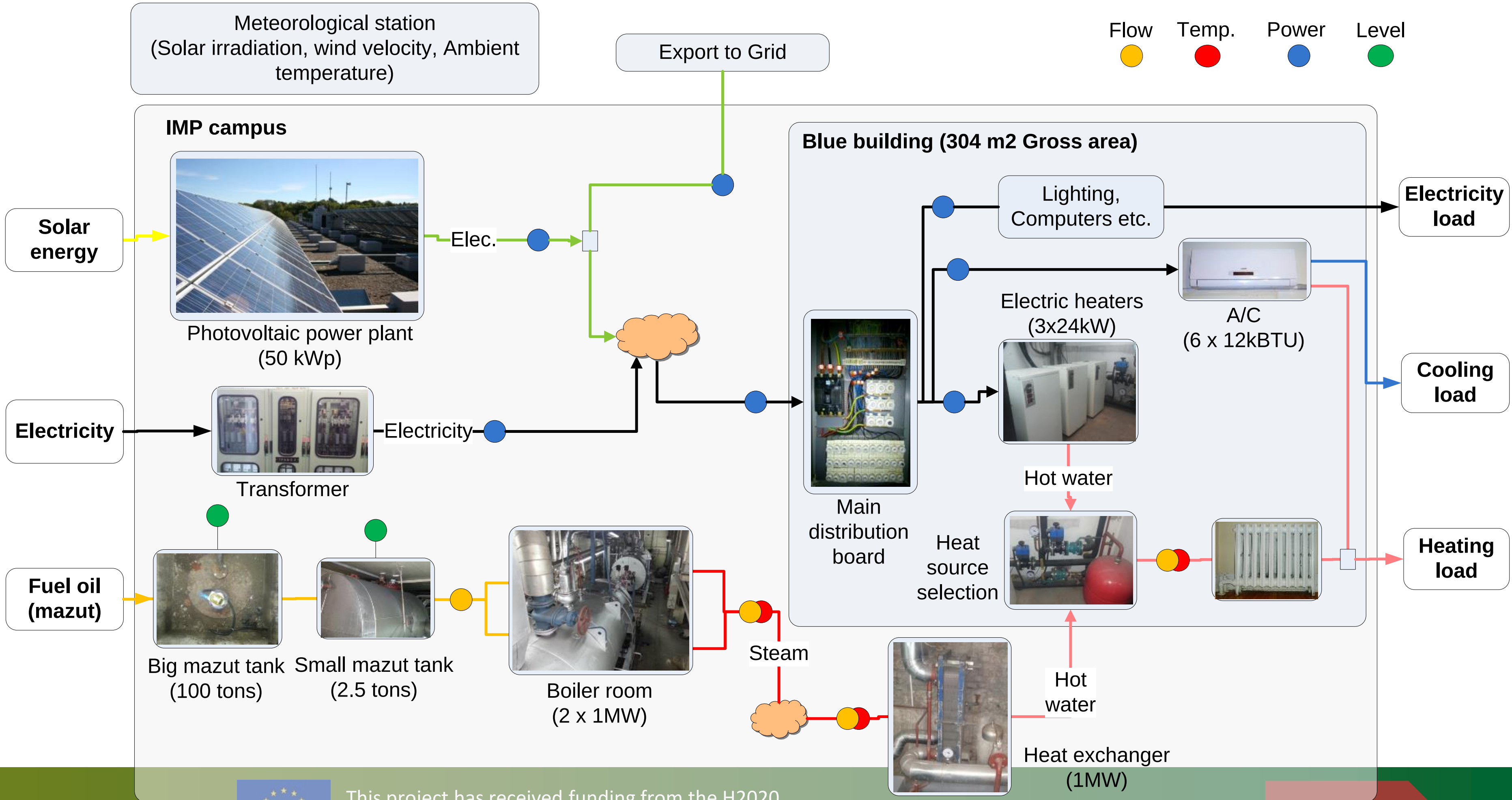
PUPIN R&D Campus

- Building, with offices, meeting room and a testing facility
- Three heating alternatives
    - Heating plant – using radiators running on hot water
    - Electric boilers – using radiators running on hot water
    - A/C – using electricity to heat the surrounding air
- Heat and electricity dispatching infrastructure
- Manual or automated control (SCADA)



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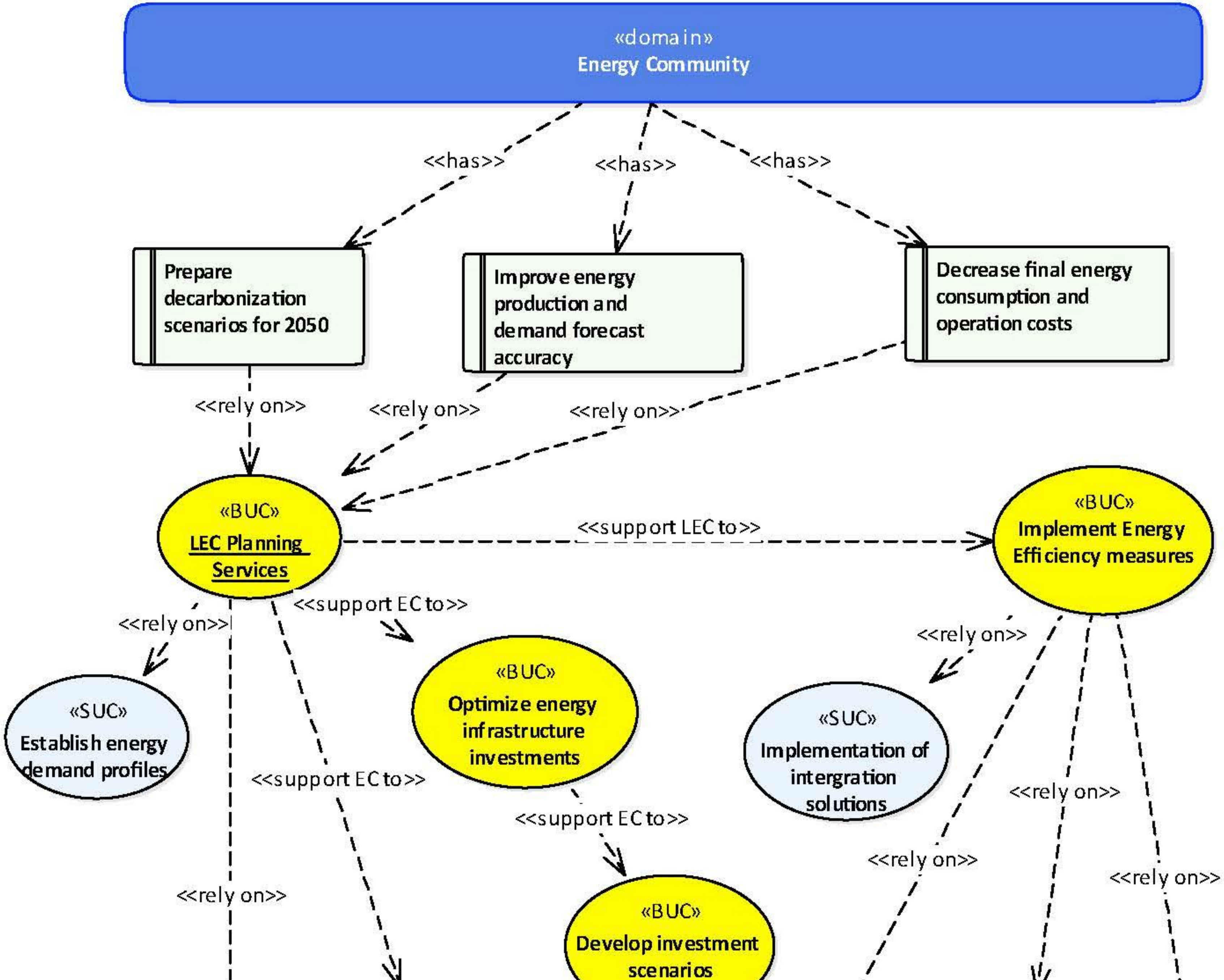
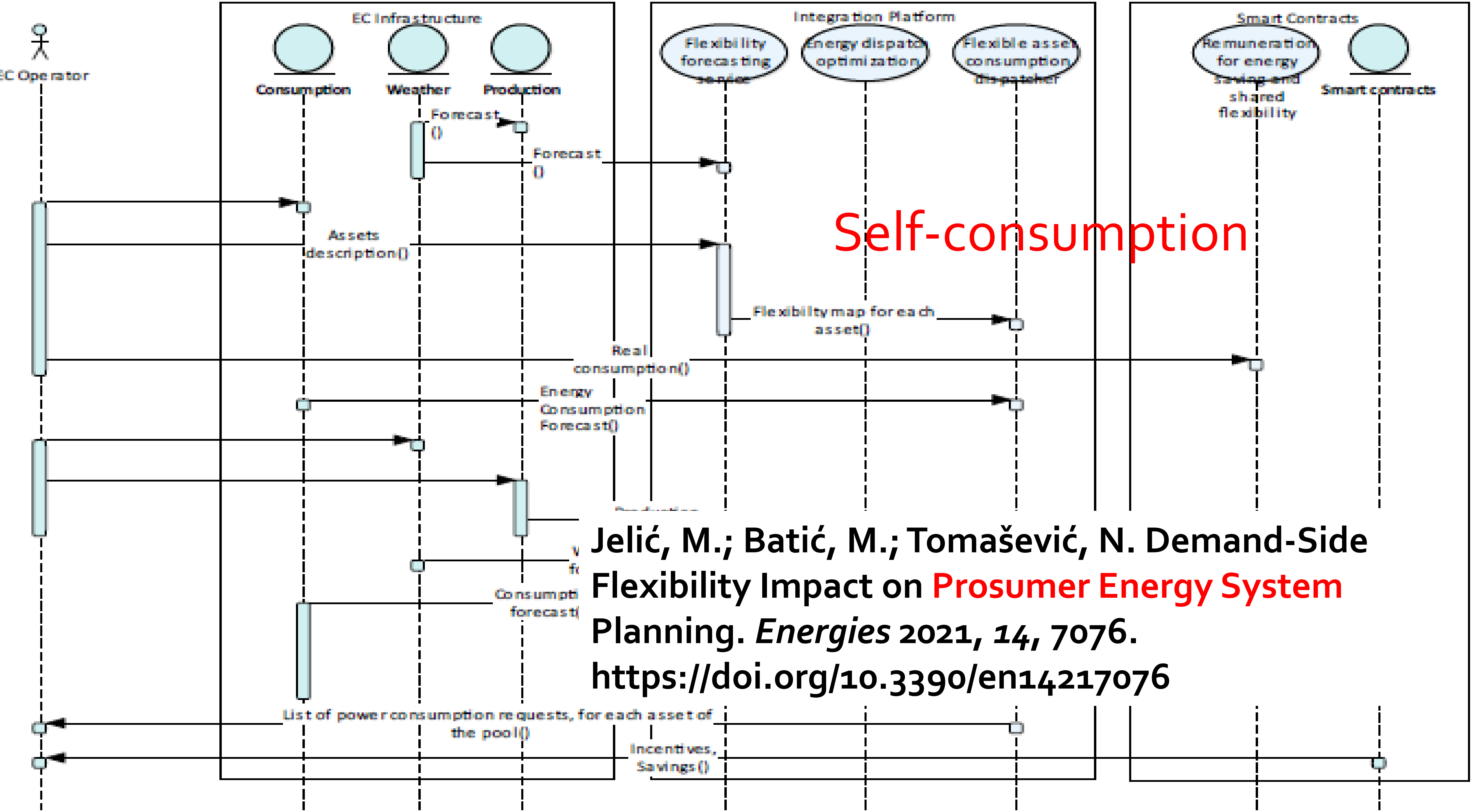
IEC 62559-2 Methodology





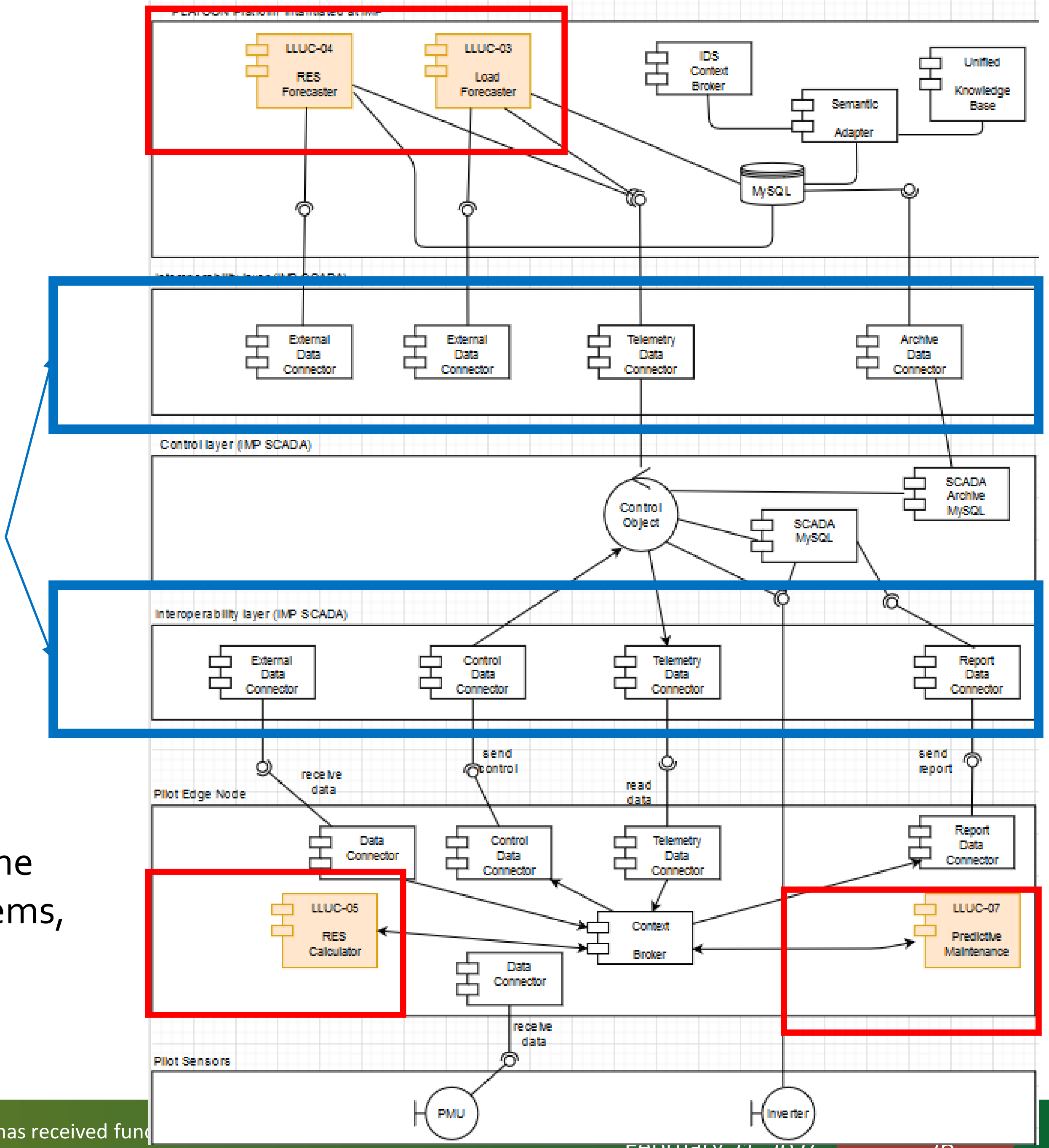
Self-consumption

Jelić, M.; Batić, M.; Tomašević, N. Demand-Side Flexibility Impact on Prosumer Energy System Planning. *Energies* 2021, *14*, 7076. https://doi.org/10.3390/en14217076

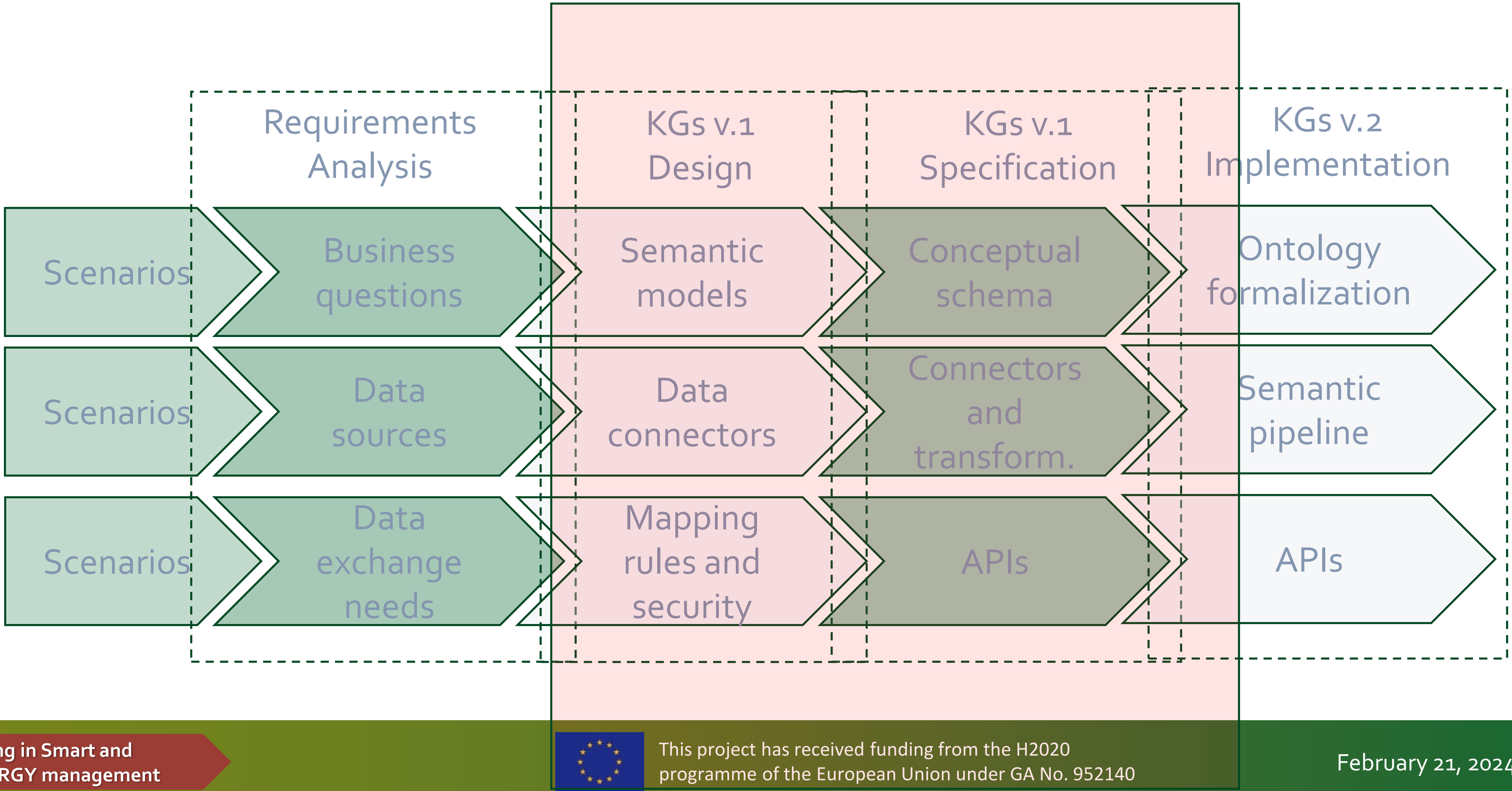
Analytical services

Communication layer – syntactic interoperability

Čampa, A., Hudomalj, M., Sodin, D., Gale, T., Janev; Lazar Berbakov; Marko Batić, M. (2023) Advanced Analytics at the Edge, Proc. Of the 30th International Conference on Systems, Signals and Image Processing (IWSSIP), DOI: 10.1109/iwssip58668.2023.10180252



Information layer – semantic interoperability



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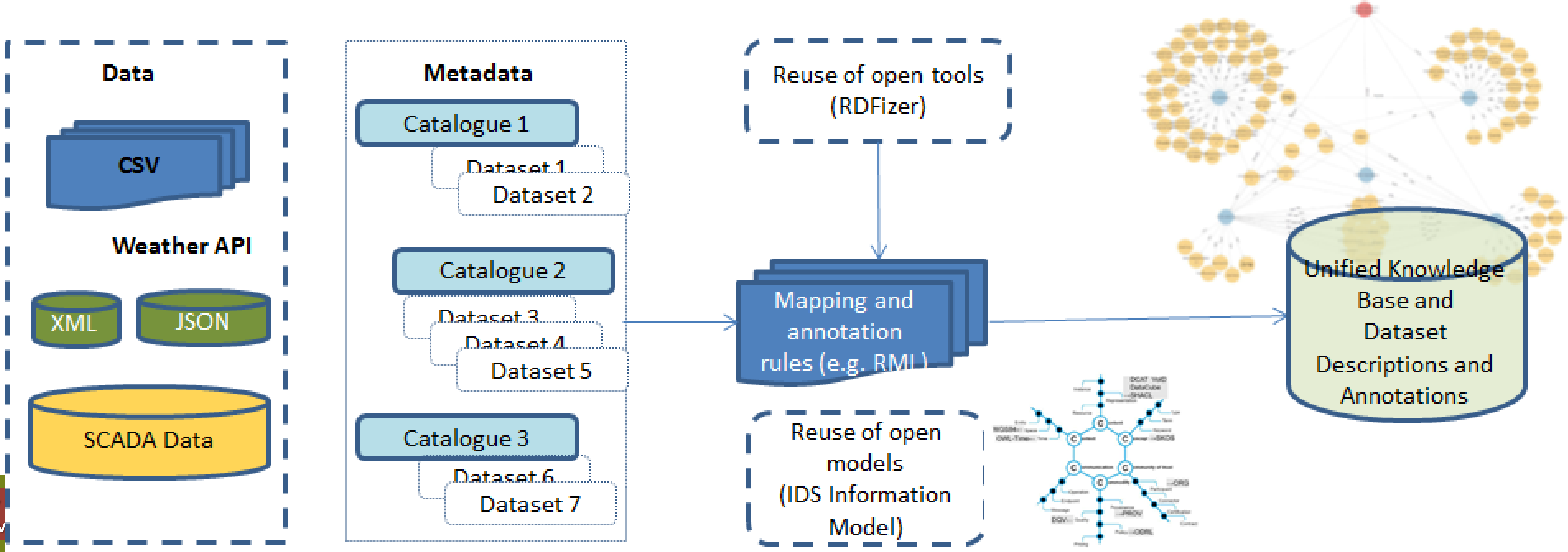
SEMANTIC PIPELINE

- Materialized Knowledge Graph Creation Process approach was followed to create a knowledge graph – data is loaded into an RDF format and stored in RDF triplestore



Data

CSV

Weather API

XML

JSON

SCADA Data

Metadata

Catalogue 1

Dataset 1

Dataset 2

Catalogue 2

Dataset 3

Dataset 4

Dataset 5

Catalogue 3

Dataset 6

Dataset 7

Reuse of open tools (RDFizer)

Mapping and annotation rules (e.g. RML)

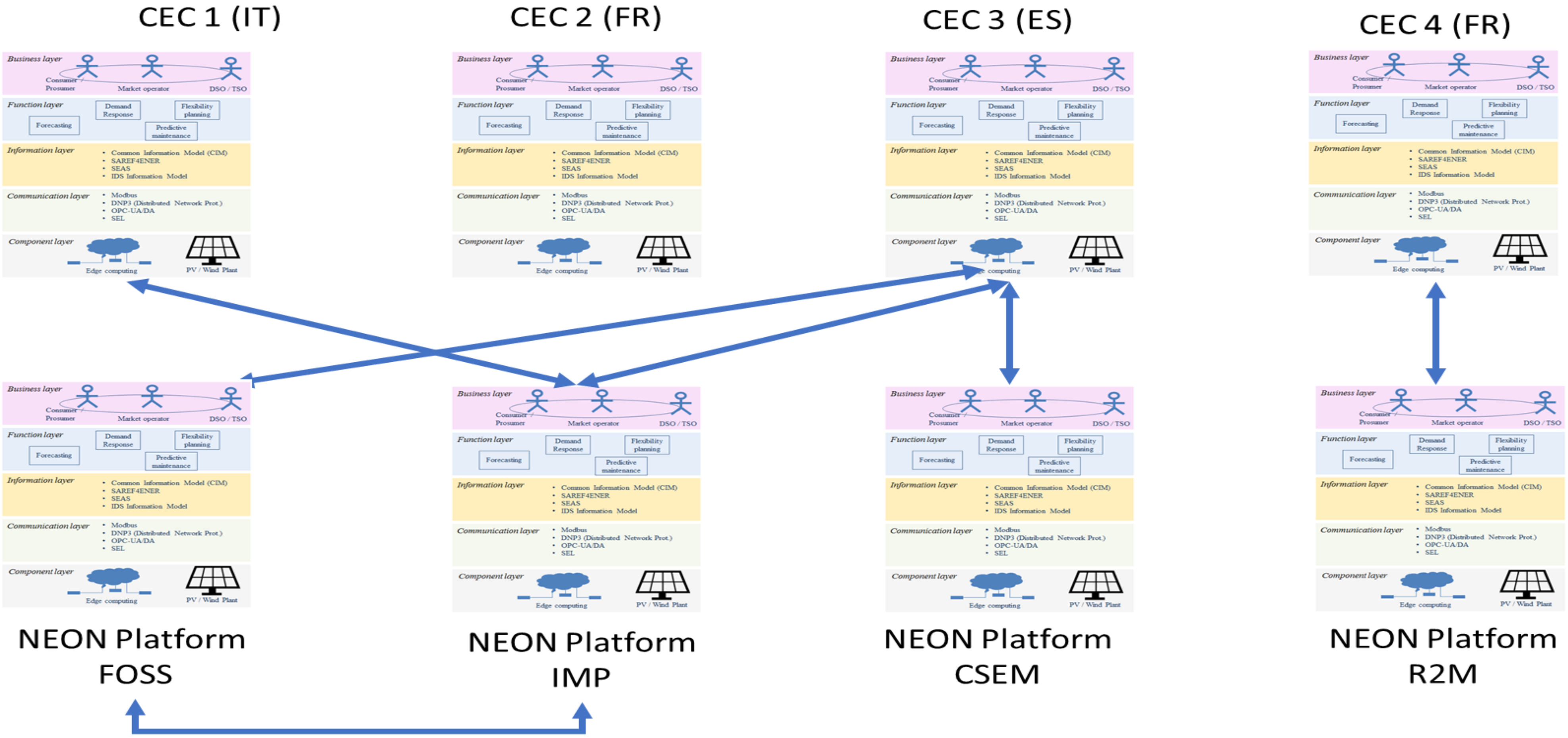
Reuse of open models (IDS Information Model)

Unified Knowledge Base and Dataset Descriptions and Annotations

Example 2 – NEON Project

NEON – **N**ext-Generation Integrated **E**nergy Services f**O**r Citizen Energy Commu**N**ities

Next-generation Integrated Energy Services



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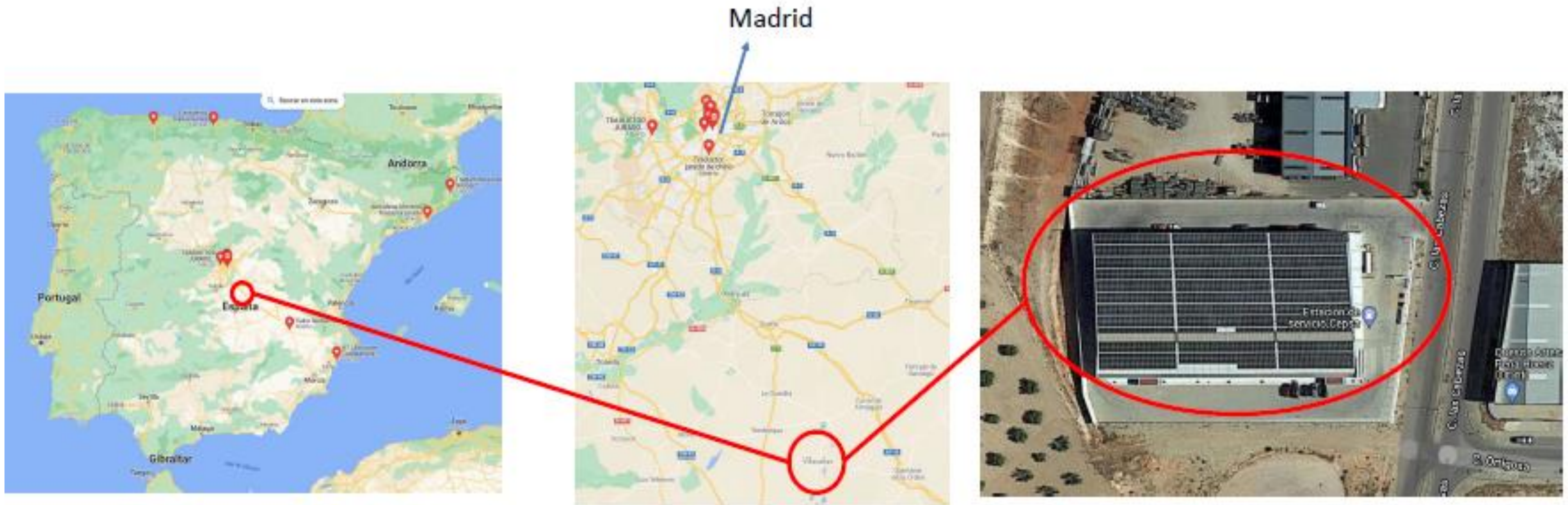
DEMO – Example CEC

LOCATION: CALLE LAS CABEZAS 16.
45860 VILLACAÑAS (TOLEDO - SPAIN)



Five industrial facilities/buildings of the industrial park Las Cabezas and ten preselected residential houses compose the citizen energy community.

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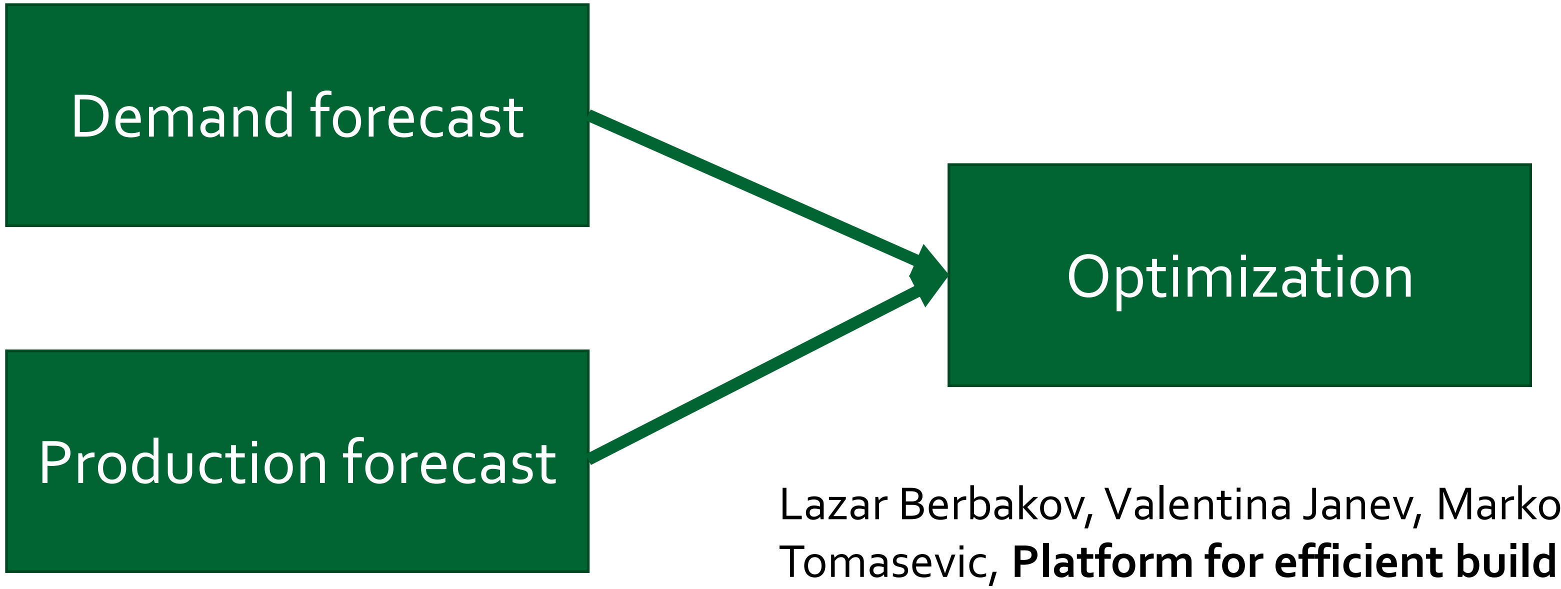
Service integration for CEC3 (Spain)

FOSS
Research Centre for
Sustainable Energy



Demand forecast

Production forecast

Optimization

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Lazar Berbakov, Valentina Janev, Marko Jelic, Nikola Tomasevic, **Platform for efficient building operation and Demand Response flexibility provision**. In: Zdravković, M., Trajanović, M., Konjović, Z. (Eds.) ICIST 2023 Proceedings, Springer, 2023.

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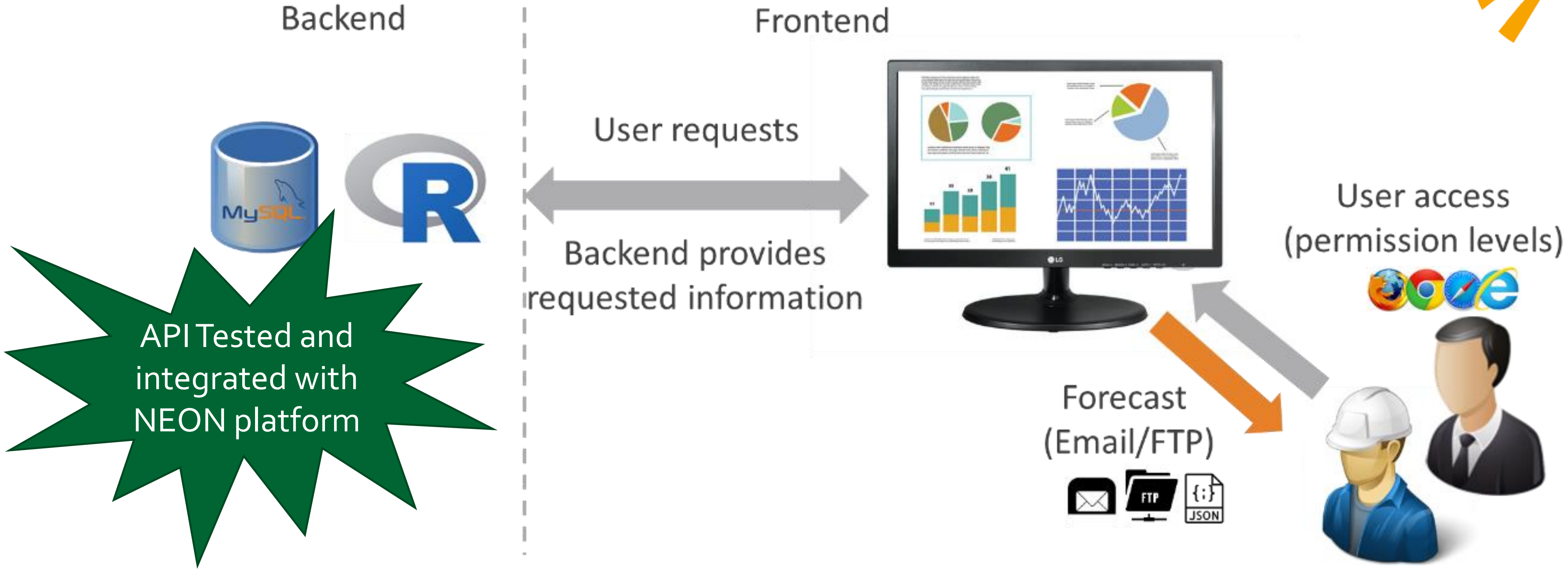
Production / Demand forecast

FOSS
Research Centre for Sustainable Energy



API Tested and integrated with NEON platform

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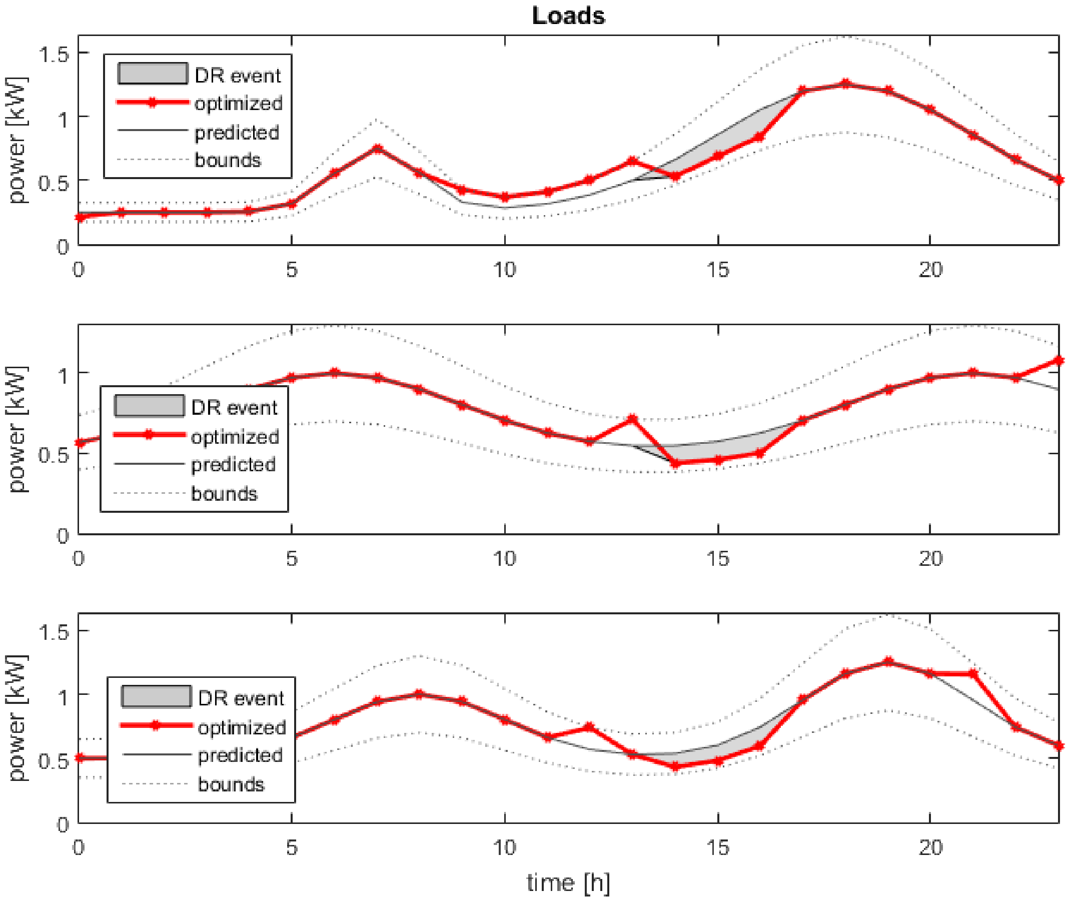
Energy dispatch optimisation

Objective:

- Optimal dispatch of energy flows in multi-source/storage environment with variable pricing and flexible demand

Challenges:

- Integrated supply and demand optimisation (optimal source selection + DSM)
- Demand Side Management (DSM) and Demand Response (DR) optimisation
- Individual asset management



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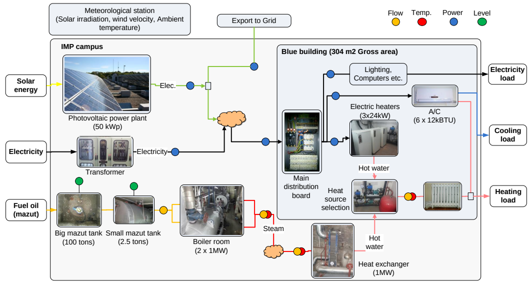
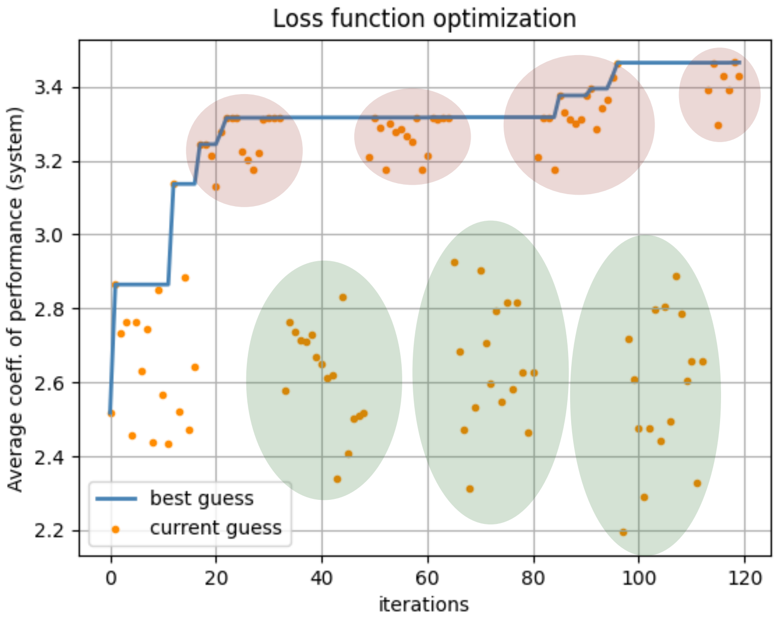
Energy dispatch optimisation

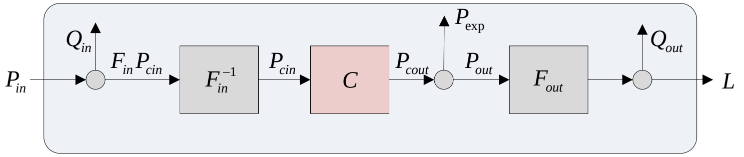
Solution:

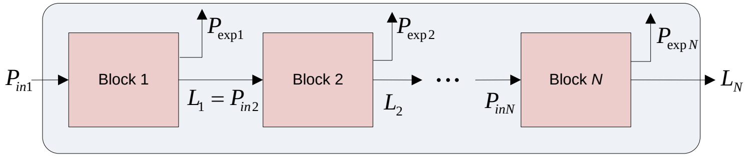


- › Energy Hub approach
- › Mixed-integer linear/non-linear programming
  - › Margin-based load optimization
  - › Window-based DSM optimization
- › Heuristic optimization

Operation strategy	Baseline	EH only	DSM only	EH&DSM
Cost [c€]	358.82	328.48	355.96	319.96
Saved [%]	0.00	8.46	0.80	10.83







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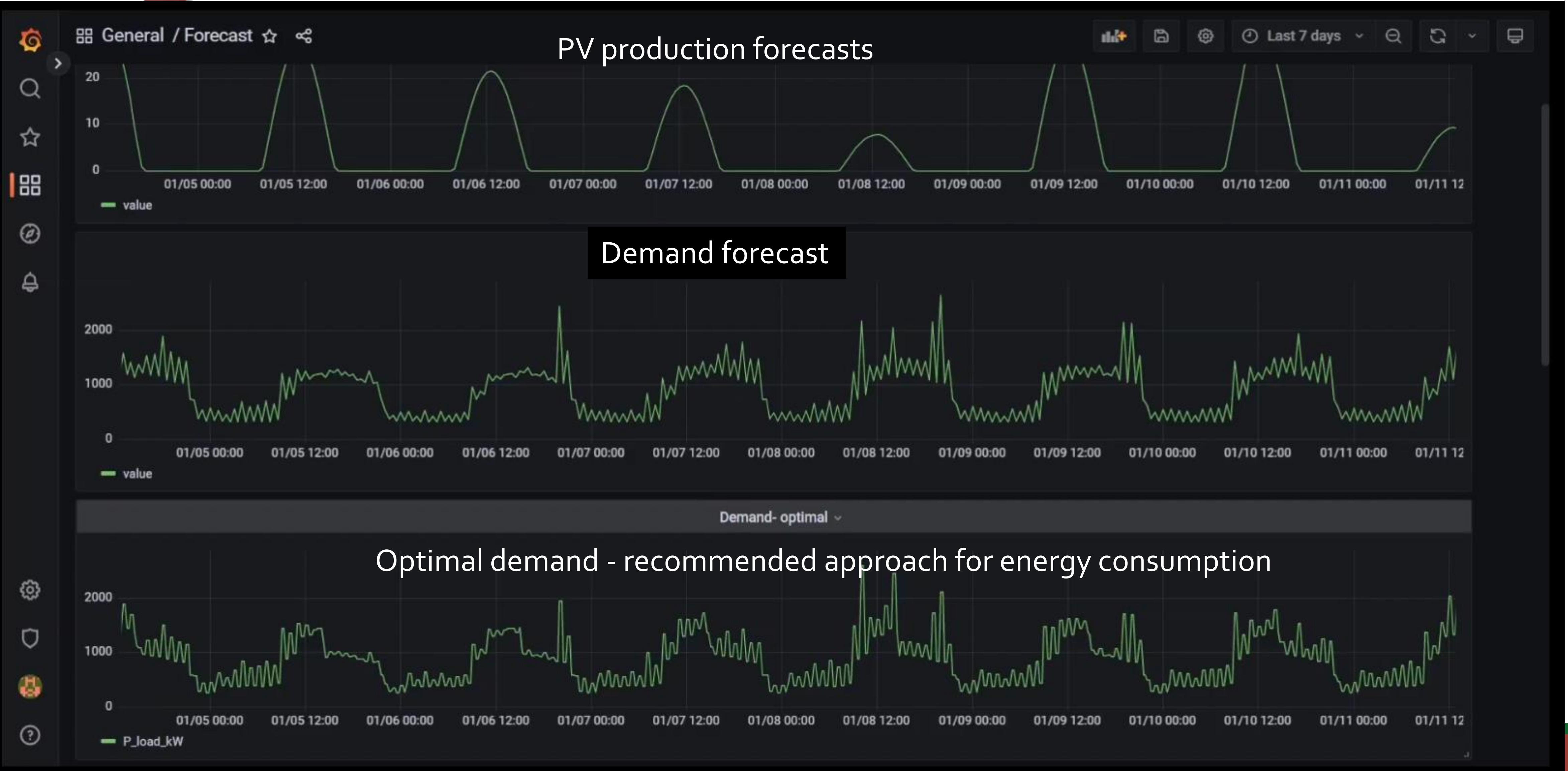
Demo – optimization



PV production forecasts

Demand forecast

Optimal demand - recommended approach for energy consumption

Validation Framework

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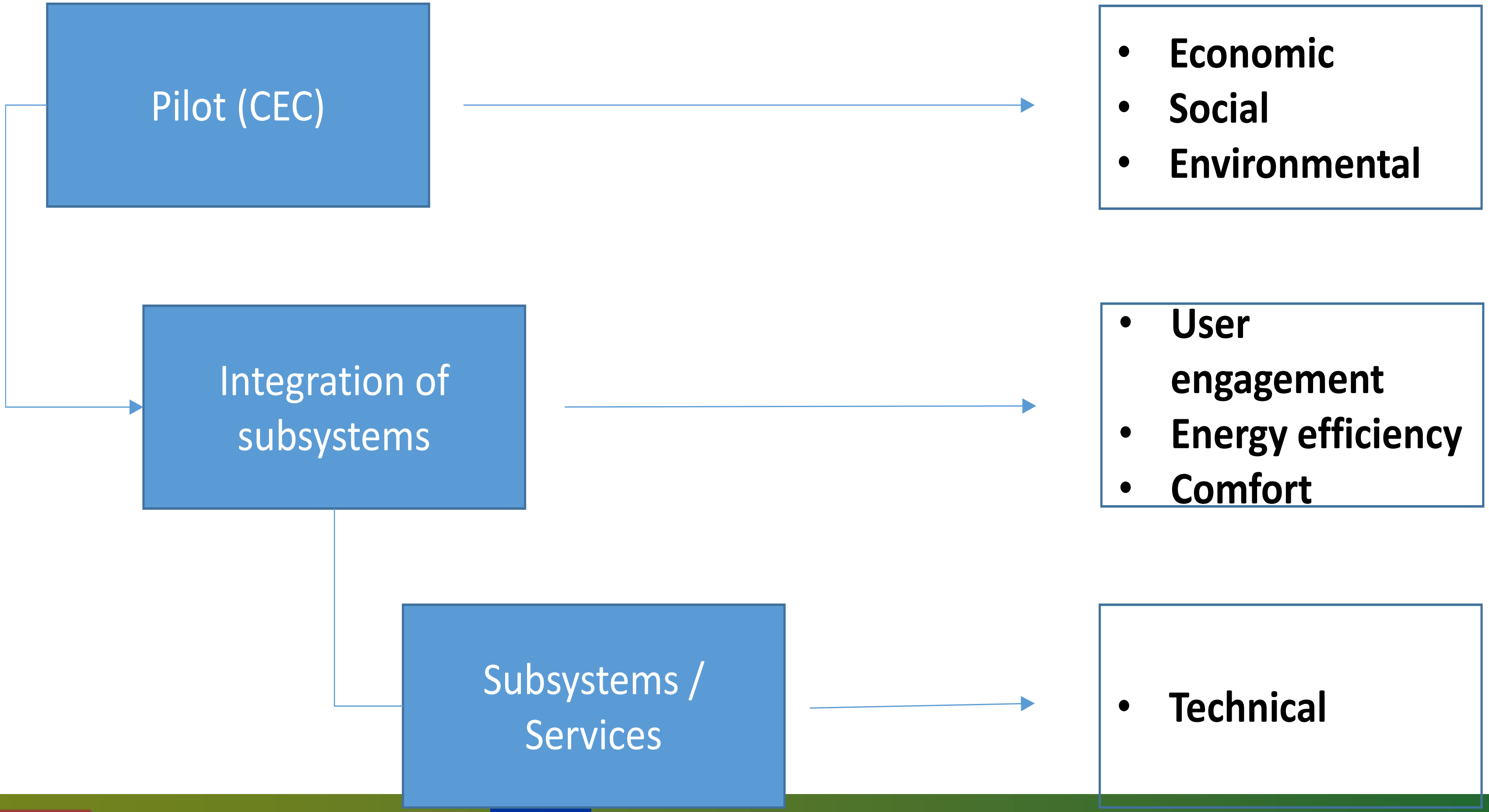
Valentina Janev, Lazar Berbakov, Marko Jelić, Dea Pujić and Nikola Tomašević

Categorization of KPIs



Pilot (CEC)

- **Economic**
- **Social**
- **Environmental**

Integration of subsystems

- **User engagement**
- **Energy efficiency**
- **Comfort**

Subsystems / Services

- **Technical**

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Categorization of KPIs

- **Economic** - to evaluate the **economic savings** that come as a result of changing user behaviour with respect to their engagement and energy usage following the CEC services and platform recommendations.
- **Social** – to explore how the required levels of flexibility intersect with social norms and everyday practices (routines, family life), as well as effects on health and well-being
- **Environmental** - to evaluate the impact of NEON solutions on the local environment.
- **Energy efficiency** - to account for the benefit in terms of optimizing users' energy usage by exploiting the demand flexibility of and energy efficiency of multi-carrier opportunities at the supply side under the holistic cooperative DR strategy.
- **User engagement** - to describe user's behaviour with respect to their interaction with CEC services and NEON platform.
- **Comfort –** to evaluate the benefits for end users in indoor environment.
- **Technical** - to evaluate different technical characteristics of the CEC services / systems.

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KPIs - Examples

- **User engagement:** Percentage of users involved in DR; Energy generation / consumption ratio (RES Generation / Utilization / Self-consumption percentage); Number of Community Transactions (Ask/Bid orders)..
- **Energy efficiency:** Total energy consumption, Reduction of CO_2 emissions, RES energy generated, Peak load/demand reduction, Energy cost per year, …
- **Comfort:** Instantaneous thermal comfort level, Thermal discomfort duration, Indoor air quality

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Conclusion & Future work

- The platform for Citizens Energy Community (lab settings at PUPIN, Demonstrated in CEC pilot in Spain) can be used by service providers to schedule a **cost-effective energy trading** (e.g. reduce energy import from grid by at least 20%).
  - **Economic savings** are result of energy savings achieved via optimised control (optimal energy dispatching across multiple energy vectors) and unlocked flexibility across systems (e.g. via variable tariffing).
  - **Cost savings** can be achieved by improved RES and excess/waste heat (E/WH) sources exploitation.
- **Improved interoperability and integration** of different data driven services (sector coupling solutions – electricity, heat, mobility) regardless of the equipment providers (the connected physical energy assets).
- **Scientific and Comercial Exploitation:** Adoption for pilots in EU taking into consideration the national and EU legislation.

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Thank you for your attention!
Questions?

Machine learning applied for RES production forecasting

Dea Jelic - Institute Mihajlo Pupin, University of Belgrade, Serbia

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Overview

- Introduction and motivation for RES production forecasting
- PV power production forecaster:
  - Introduction
  - Data exploration
  - Employed methodologies
  - Results
- Wind power production forecaster:
  - Introduction
  - Framework presentation
  - Results

This project has received funding from the H2020 programme of the European Union under GA No. 952140

Introduction

- RES penetration on the energy production side increases due to various ecological interest
- Increase of RES share might cause grid instability
- In order to maintain stable grid careful planning is required
- Necessity of RES production forecaster
- The most common RES production forecaster developed for PV and wind power plants

This project has received funding from the H2020 programme of the European Union under GA No. 952140

PV power production forecaster

- Within this research focus was put on day ahead forecasting of photo-voltaic (PV) panels production depending on the meteorological parameters – short to mid-term forecasting
- For (ultra) short forecasting ARMAX-like models are common
- In case of longer horizon, utilization of machine learning models was more successful, especially neural networks:
    - numerous architectures explored – CNN, RNN, LSTM, etc.
    - **hybrid architectures** were proven to be the most performable (e.g., combination of CNN and LSTM)
    - utilizing ANN in **ensemble** approach

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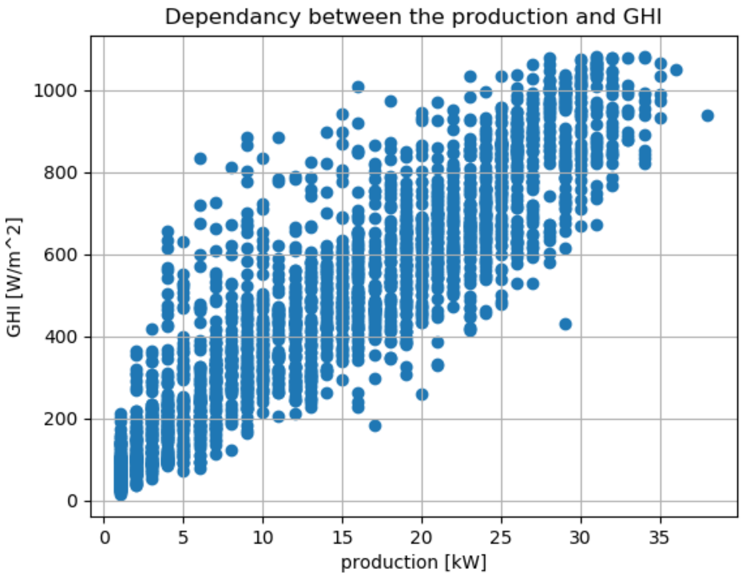
Data exploration

- For the modeling purposes real-world data was considered – data from Adeje town in Tenerife
- Production data – a year-long hourly production data from the PV plant with the capacity of 40kWp, with special resolution 1kW
- Meteorological data – plant did not have accompanying meteo-station, so data was obtained from **Solcast** web service; the data contained various meteorological parameters – air temperature, azimuth angle, cloud opacity, irradiations (DHI, DNI, GHI), etc.



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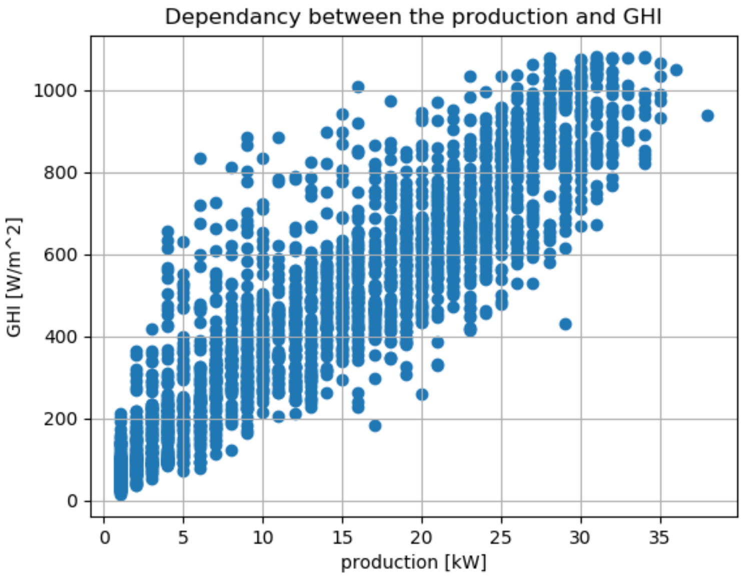
Data exploration

- For training and testing purposes only periods with radiation (production) were considered
- Outliers were removed by analysis of joint distribution between production and GHI
- Data has been separated into training, validation and test set:

January, February, March, April, May, June, July, August, September, October, November, December



Employed methodologies

- Existing methodologies:
  - ensemble ANN approach
  - hybrid neural network
- Proposed approach was combination of the existing once – an ensemble of hybrid neural networks
- Idea was to exploit more powerful architecture as a weak learner so that complex dependences could be detected, and to exploit ensemble method for performance improvement on the testing/validation data

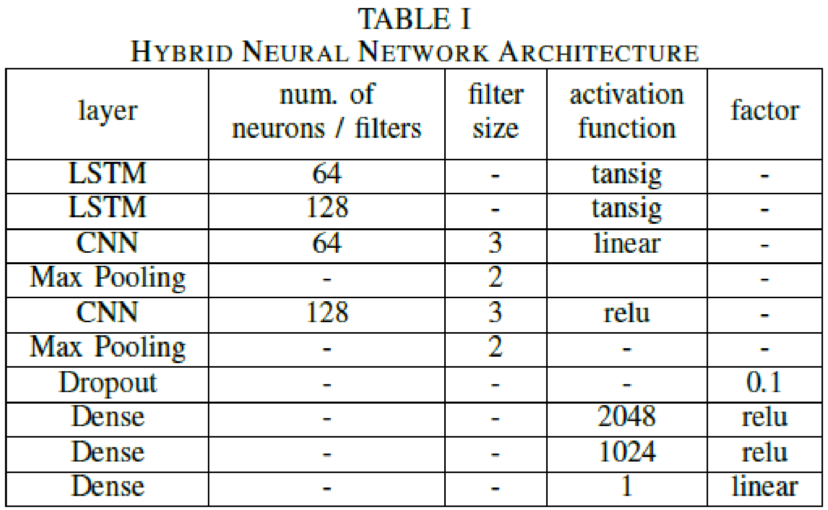


TABLE I
HYBRID NEURAL NETWORK ARCHITECTURE

layer	num. of neurons / filters	filter size	activation function	factor
LSTM	64	-	tansig	-
LSTM	128	-	tansig	-
CNN	64	3	linear	-
Max Pooling	-	2		-
CNN	128	3	relu	-
Max Pooling	-	2	-	-
Dropout	-	-	-	0.1
Dense	-	-	2048	relu
Dense	-	-	1024	relu
Dense	-	-	1	linear

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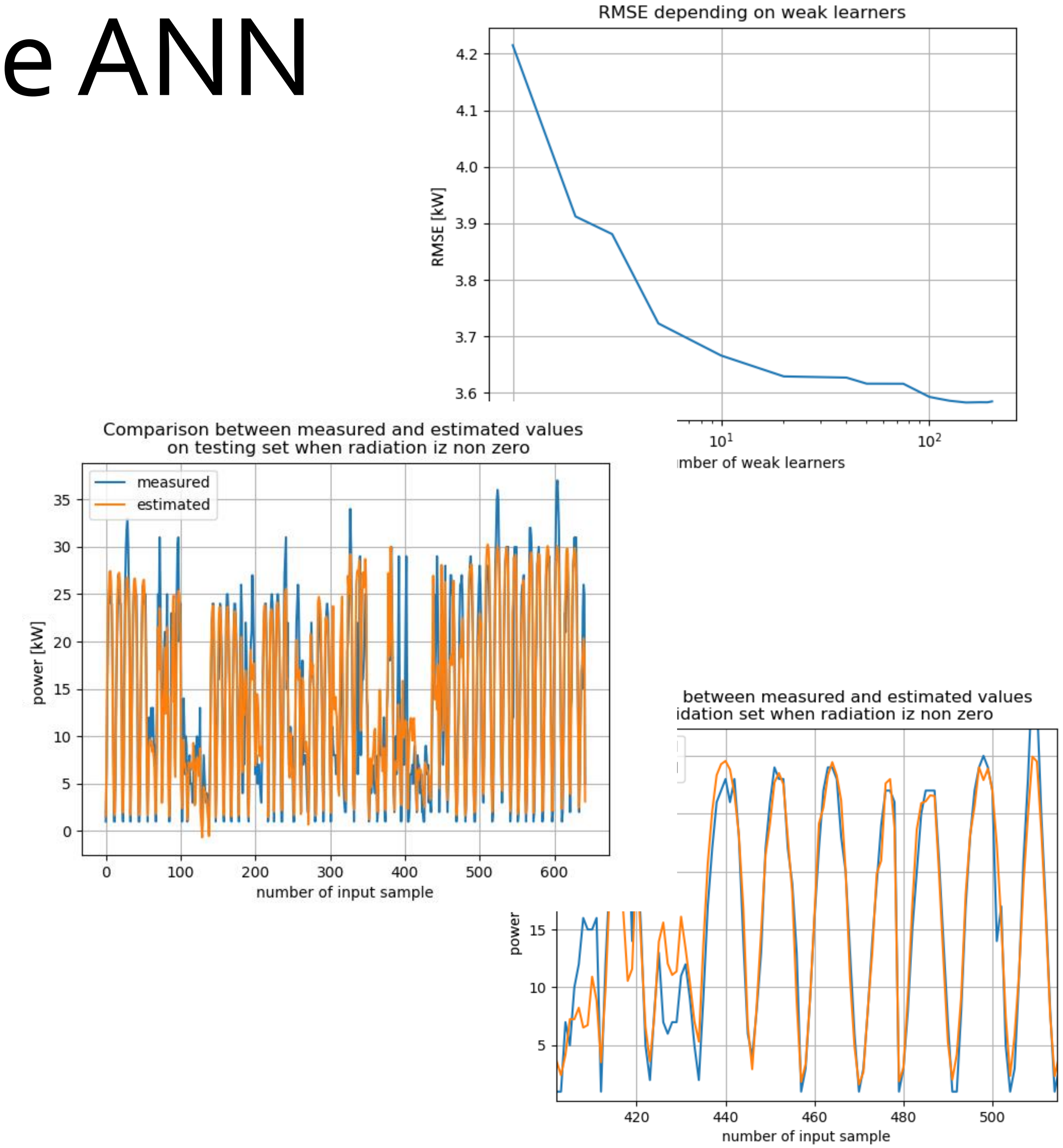
Results – ensemble ANN approach

- **200** weak learners were trained (ANNs) using random 80% (overlapping) of training data
- all learners have been trained under the **same conditions** (the same optimization engine (ADAM), 50 epochs, etc.)
- Optimal number of weak learners **150** was determined by observing **RMSE** on **validation** data
- Optimal model achieved RMSEs **3.11kW, 3.82kW and 3.58kW** (train, val, test)



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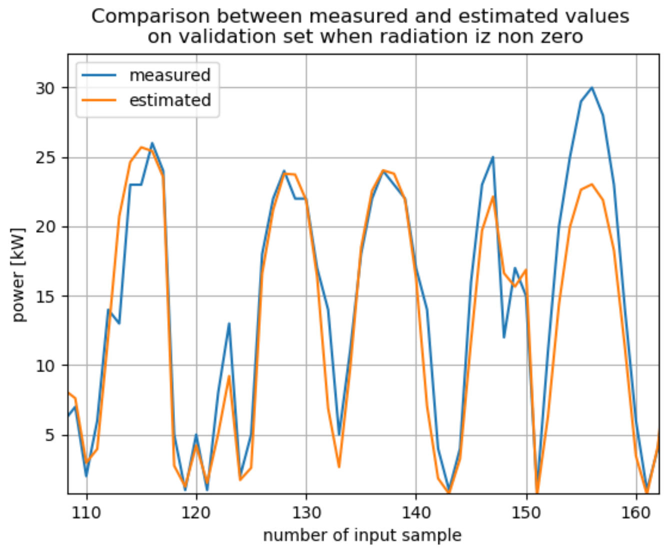
Results – hybrid neural network

- Network has been trained using the same data as the previous approach (but full training set) and the same optimization engine
- This model resulted in RMSE for training, validation and testing set of **3.58kW, 3.76kW and 3.49kW**
- The performance on testing and validation

data was slightly improved



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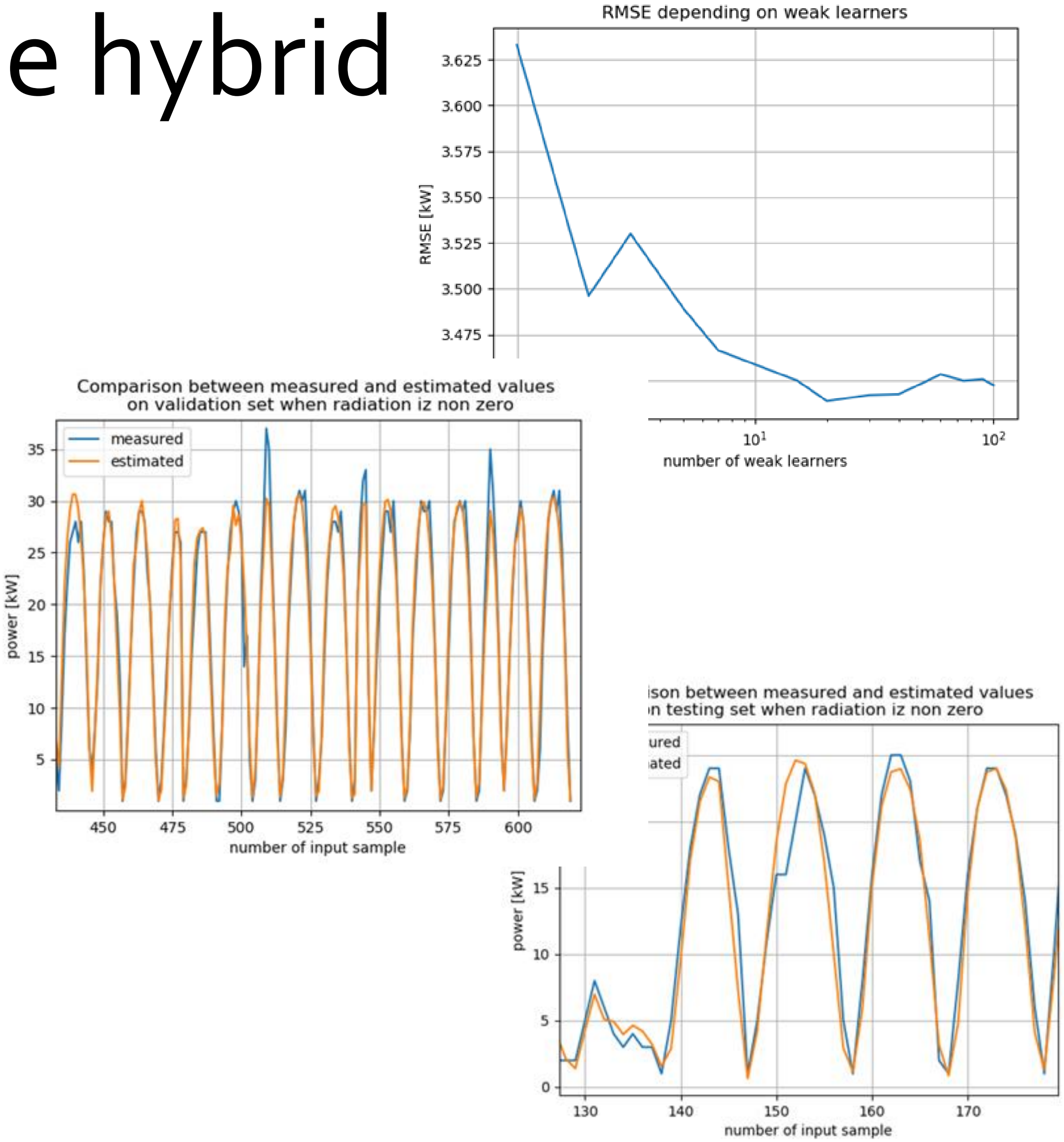
Results – ensemble hybrid approach

- **200** weak learners were trained (hybrid neural network) using random 80% (overlapping) of training data
- Minimal RMSE on validation data was achieved for 20 learners
- Optimal model achieved RMSEs **3.40kW, 3.70kW and 3.43kW** on training, validation and testing data respectively
- Improvement could be noticed both from RMSE and performance example – the most noticeable improvement is the solid estimations in all production ranges



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*D. Pujić and N. Tomašević, "Hybrid ensemble neural network approach for photovoltaic production forecast," 2021 29th Telecommunications Forum (TELFOR), Belgrade, Serbia, 2021, pp. 1-4, doi: 10.1109/TELFOR52709.2021.9653369.

Results summary

- Two existing and one improved approach have been analyzed
- It was shown that proposed solution improved PV forecasting performances for 60W to 150W in comparison with the existing methodologies
- Even though proposed solution shown the lowest performance on the training data, it showed the highest generalization performance, and lowest validation and testing RMSE
- The most notable improvement could be seen in periods with maximal and minimal production

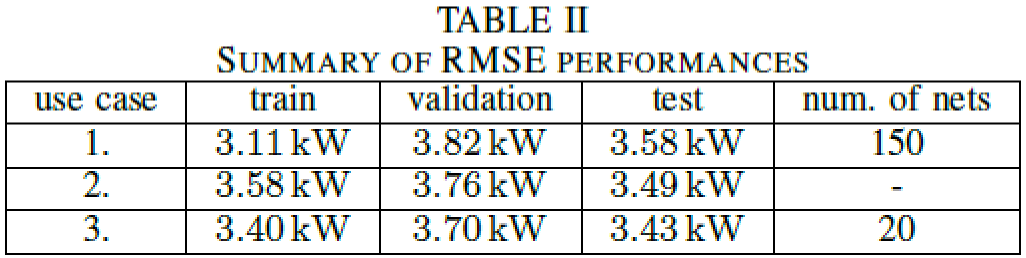
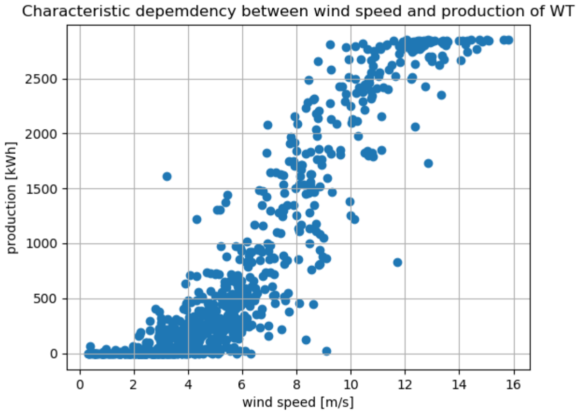


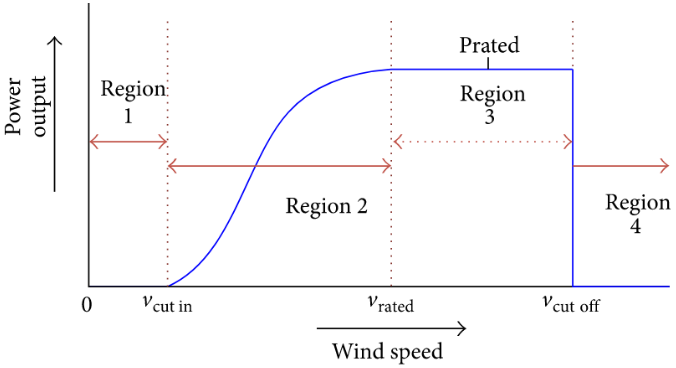
TABLE II
SUMMARY OF RMSE PERFORMANCES

use case	train	validation	test	num. of nets
1.	3.11 kW	3.82 kW	3.58 kW	150
2.	3.58 kW	3.76 kW	3.49 kW	-
3.	3.40 kW	3.70 kW	3.43 kW	20

Wind power plant production forecaster

- Krnovo wind power plant was focus of this research (Montenegro)
  - 26 wind turbines with different capacities
  - total capacity 71.5 MW
- Data exploration for a single wind turbine
  - Meteorological data aggregation
  - Production and meteorological data pre-processing
    - Missing values
    - Outliers detection – based on the data distribution
  - Correlation analysis





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Optimizing NN architecture

- Neural networks chosen to be used as modeling approach, due to their high performance precision
- Developed framework for optimizing NN architecture for wind production forecasting
- Parameters that were optimized:
  - **number of hidden layers**
  - **type of hidden layers** (LSTM, convolutional, dense, dropout)
  - **number of training epochs**
  - **learning rate**

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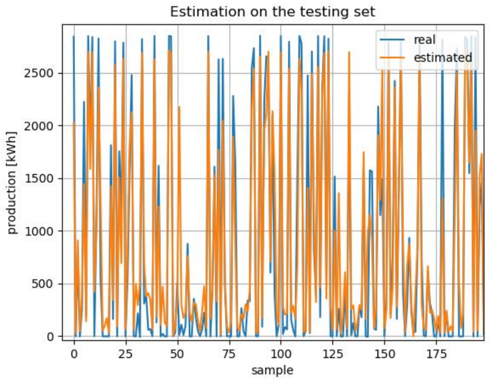
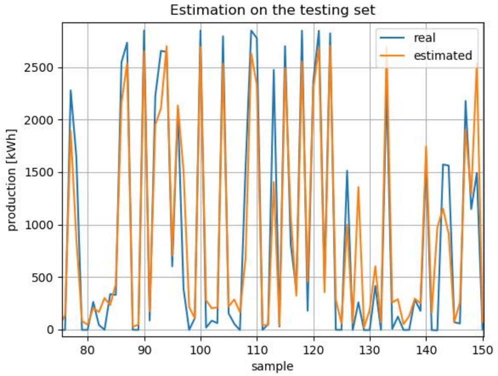
Results*

*Pujić, D., Janev, V. (2024). Framework for Optimizing Neural Network Hyper Parameters for Accurate Wind Production Forecasting. In: Trajanovic, M., Filipovic, N., Zdravkovic, M. (eds) Disruptive Information Technologies for a Smart Society. ICIST 2023. Lecture Notes in Networks and Systems, vol 872. Springer, Cham. https://doi.org/10.1007/978-3-031-50755-7_36

- In total, 250 NN models were trained, and final model was chosen in accordance with the minimal RMSE on validation data set
- Presumptions for reducing search space:
  - the same activation functions due to output saturation
  - predefined rules when to include dropout layers
  - ADAM optimization engine was used for training of all models
- Optimal model specifics:
  - model had 5 hidden layers (2 LSTM, 1 CNN and 5 dense)
  - model was trained for 500 epochs
  - learning rate equaled 1e-4
- Optimal model performances – RMSE performances **0.142 MW, 0.154 MW** and **0.159 MW** on training, validation and testing data respectively





Thank you for your attention!
Questions?

Cyber Security Issues of Cloud-based Dynamic Line Rating

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Overview

- Introduction
- Dynamic Line Rating
- Cloud Computing for DLR
- Cybersecurity in DLR
  - Objectives and issuess
  - Attacks and security countermeasures
- Hybrid Cloud-Based DLR
- Conclusion

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Introduction - Modern power grid

- Reliable and secure electricity and power infrastructure -> Intelligent electric power (EE) system
- Enhanced use of digital information and control data, for improving:
  - Security
  - Availability
  - Reliability
  - Efficiency
  - Costs reduction
- Combination of the traditional energy systems and the Future Internet (FIN): Cloud Computing, Internet of Things (IoT), Big Data analytics, etc.

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Dynamic Line Rating – DLR (1)

Data collection and analysis: calculation of the transmission line's allowed current load and of the dynamic increase of power capacity

- Proper utilization of transmission line capacity for: energy optimization, prevention from the conductor overheating, and enhancement of power system's security, availability and reliability
- Real-time estimation of the allowed ampacity and the management of the overhead transmission lines uses large data volumes:

  –> significant computer resources –> cloud computing
- Power generation: highly dependable on weather and operating conditions due to increased number of renewable energy sources (wind farms, solar panels)

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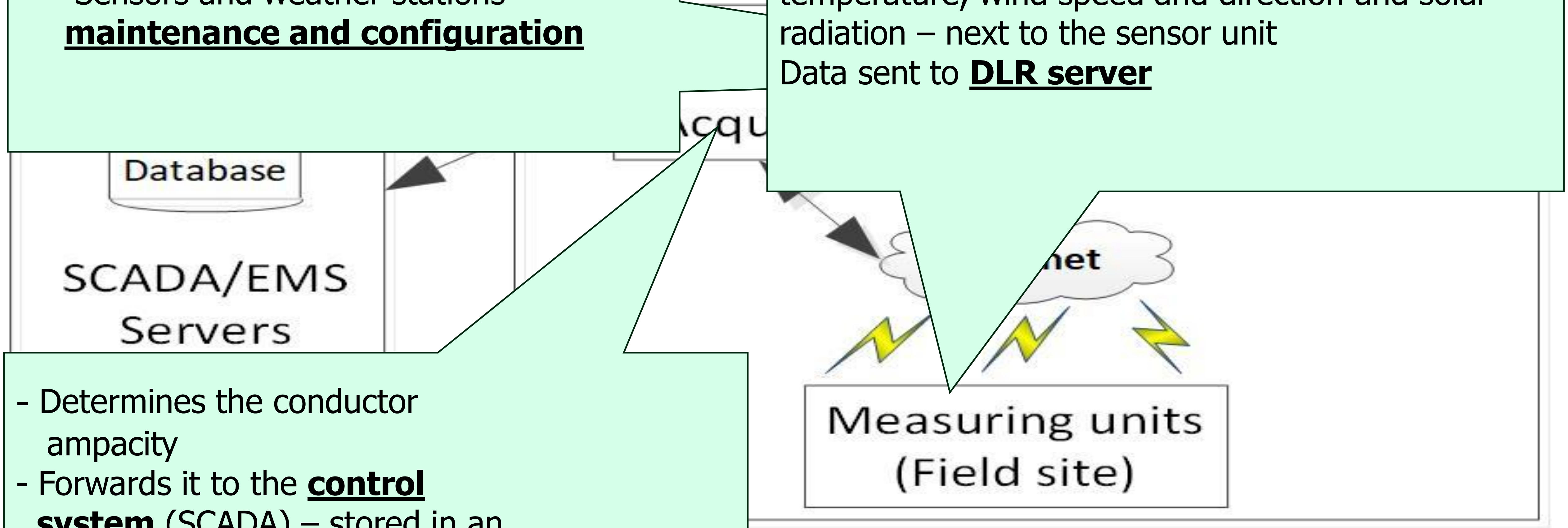
Line

- Real time **monitoring** of transmission line‘s **temperature** and **ampacity**
- Sensors and weather stations **maintenance and configuration**

Sensor unit – measures conductor’s temperature, tension and/or sag – on the transmission line.
Weather station – measures air temperature, wind speed and direction and solar radiation – next to the sensor unit
Data sent to **DLR server**



- Determines the conductor ampacity
- Forwards it to the **control system** (SCADA) – stored in an appropriate **database**.

Dynamic Line Rating – DLR (3)

Main benefits:

- Increase of the transmission system efficiency, i.e., more efficient utilization of transmission line's load;
- Operational flexibility of the transmission system;
- Improved utilization of the existing assets, which decreases overall costs;
- Greenhouse gas emissions reduction, through integration of renewable energy resources;
- Improvement of the security of power grid's operation in normal operating conditions

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Cloud Computing (1)

Big Data processing, high-performance computing resources, large memory capacities -> **otherwise extremely expensive!**

Web hosted computer and storage resources. No direct and/or active management by the user. **Access**: web browsers or applications; data and applications remain on cloud servers

Cloud computing **risks** –> cyber security, availability and reliability

Public: 3rd party Internet providers, free or subscription-based

Private: organization’s infrastructure, data center on-premises or 3rd party

Hybrid: combination of public and private, taking the benefits of both. Connected by a standard or proprietary technology allowing data and applications portability.

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Cloud Computing in electric power industry

- Information management and distributed energy management
- Several benefits for smart grid applications:
  - hardware and software resources needed to support big data analytics
  - scalability and elasticity of cloud computing services – continuity and accuracy of dynamic smart grid operations such as prediction, load management, as well as optimization of demand and consumption
- Electrical distribution systems:
  - web-based cloud platforms provide consumers the real-time information about energy usage and cost of energy
  - helps residents to organize their energy consumption and reduce bills – to select an optimal tariff plan according to their consumer profile

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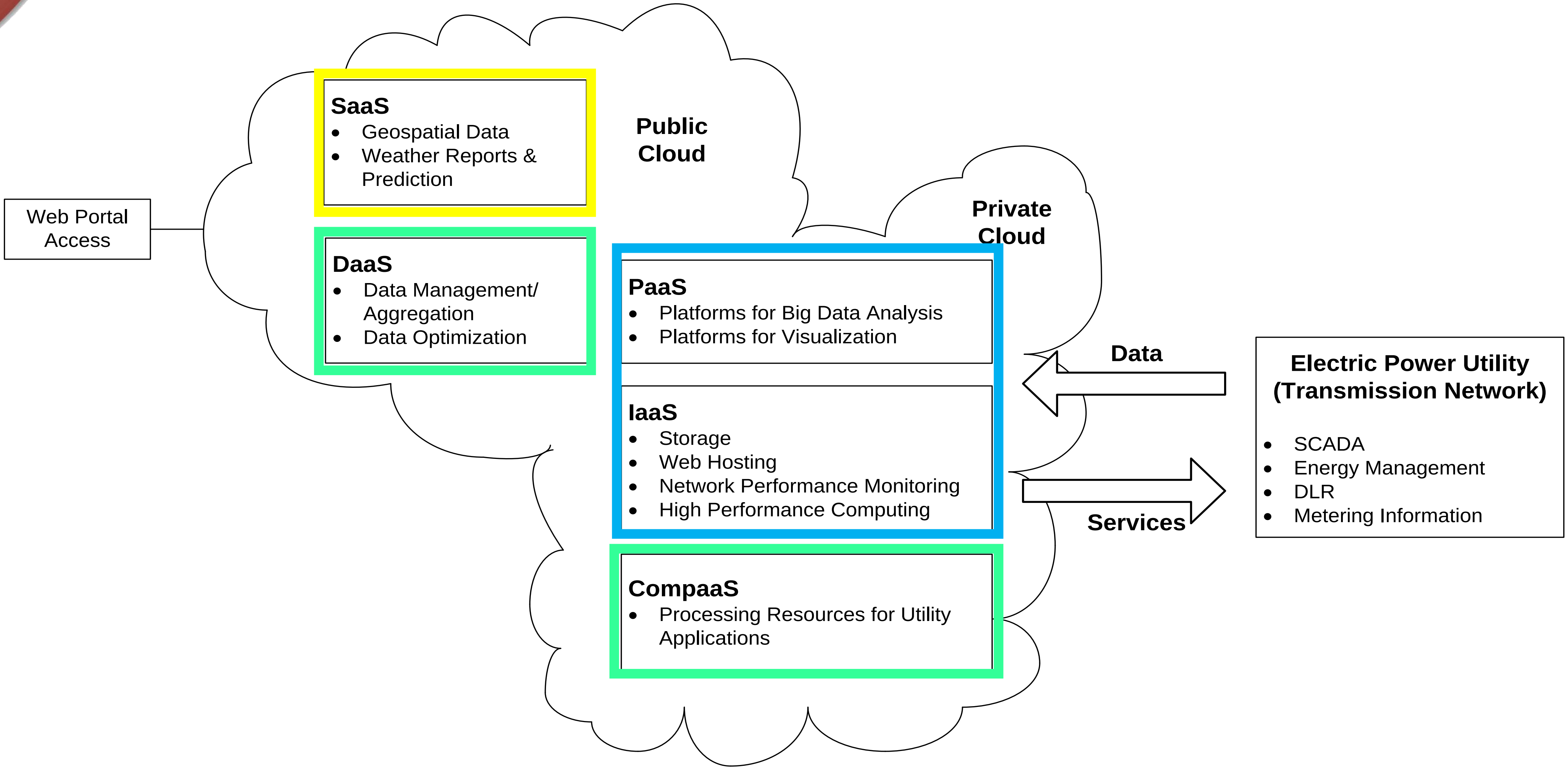
Cloud Services and Infrastructures Applicable to DLR Systems



Web Portal Access

Public Cloud

SaaS
- Geospatial Data
- Weather Reports & Prediction

DaaS
- Data Management/ Aggregation
- Data Optimization

Private Cloud

PaaS
- Platforms for Big Data Analysis
- Platforms for Visualization

IaaS
- Storage
- Web Hosting
- Network Performance Monitoring
- High Performance Computing

CompaaS
- Processing Resources for Utility Applications

Data

Services

Electric Power Utility (Transmission Network)
- SCADA
- Energy Management
- DLR
- Metering Information

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The main cybersecurity objectives

Availability: ensuring timely and reliable access to and use of information, which is available to authorized users when it is needed.

Integrity: The certainty that the data/configuration has not been subject to unauthorized modification, either intentional or unintentional. A message delivered to the receiver node should not be altered by any intruder. The receiver node should be able to verify whether the received data is corrupted or legitimate.

Confidentiality: preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information. Data or infrastructure is accessed only by an authorized user.

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Cyberattacks

Availability	*Integrity*	*Confidentiality*
- Wormhole - Flooding - DoS/DDoS - Jamming - Buffer overflow	- Wormhole - Replay - Spoofing - Data injection - Time synchronization - Data modification	- Man in the Middle - Spoofing - Unauthorized access - Traffic analysis - Eavesdropping

Passive attacks:

› Analyze data searching for system configuration, architecture, normal behavior

› Not changing the data -> **Hard to detect!**

› Influence data **confidentiality**

Active attacks:

- Modify transmitted data, thus affecting the operation of EE system
- Mostly influence the **availability** and **integrity**

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Cybersecurity issues in DLR

Cloud-based DLRs - more **vulnerable** when public cloud services are used:

- Insecure network connections between DLR system and cloud
- Use of commercial off-the-shelf solutions
- Denial of Service (DoS), Distributed DoS, man-in-the-middle (MITM)

Securing cloud data, applications, and infrastructure: implementation of policies, controls, procedures and advanced smart technologies

Categories of data security issues:

- **C**onfidentiality, **I**ntegrity and **A**vailability
- Authentication and access control
- Broken authentication, session and access control
- Minor data-related security issues due to data location, multi-tenancy, backup in the cloud

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Cybersecurity countermeasures in DLR

Ensuring data confidentiality, integrity and availability

- Some input data is publicly available, output information (estimated ampacity) is strictly confidential –> encryption algorithms (confidentiality)
- Input and output data should be unchanged and obtainable in a real-time (availability and integrity), since the maximum transmission line's load is estimated based on the input data, while the output data is sent to SCADA
  - Classification of the data: identification of sensitive data, defining security policies and appropriate access methods for different types of data
  - Identification which data can be shared
  - Predefined corrective action plan in case of data corruption

Authentication and access control

- Necessary for persons and equipment: username and password, Mobile Trusted Module (MTM), multifactor, Public Key Infrastructure, single sign-on, biometric authentication, etc.
- Firewalls and IDPS solutions at different network and cloud layers

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Cybersecurity countermeasures in DLR

Prevention of breaking authentication, session and access control:

- Implementation of a strong authentication and session management controls, examining access from unknown or untrusted sources

Other security measures:

- Intelligent **data segregation** techniques for isolation of data from different users.
- Strong **encryption** techniques for backup of data to stop data leakage

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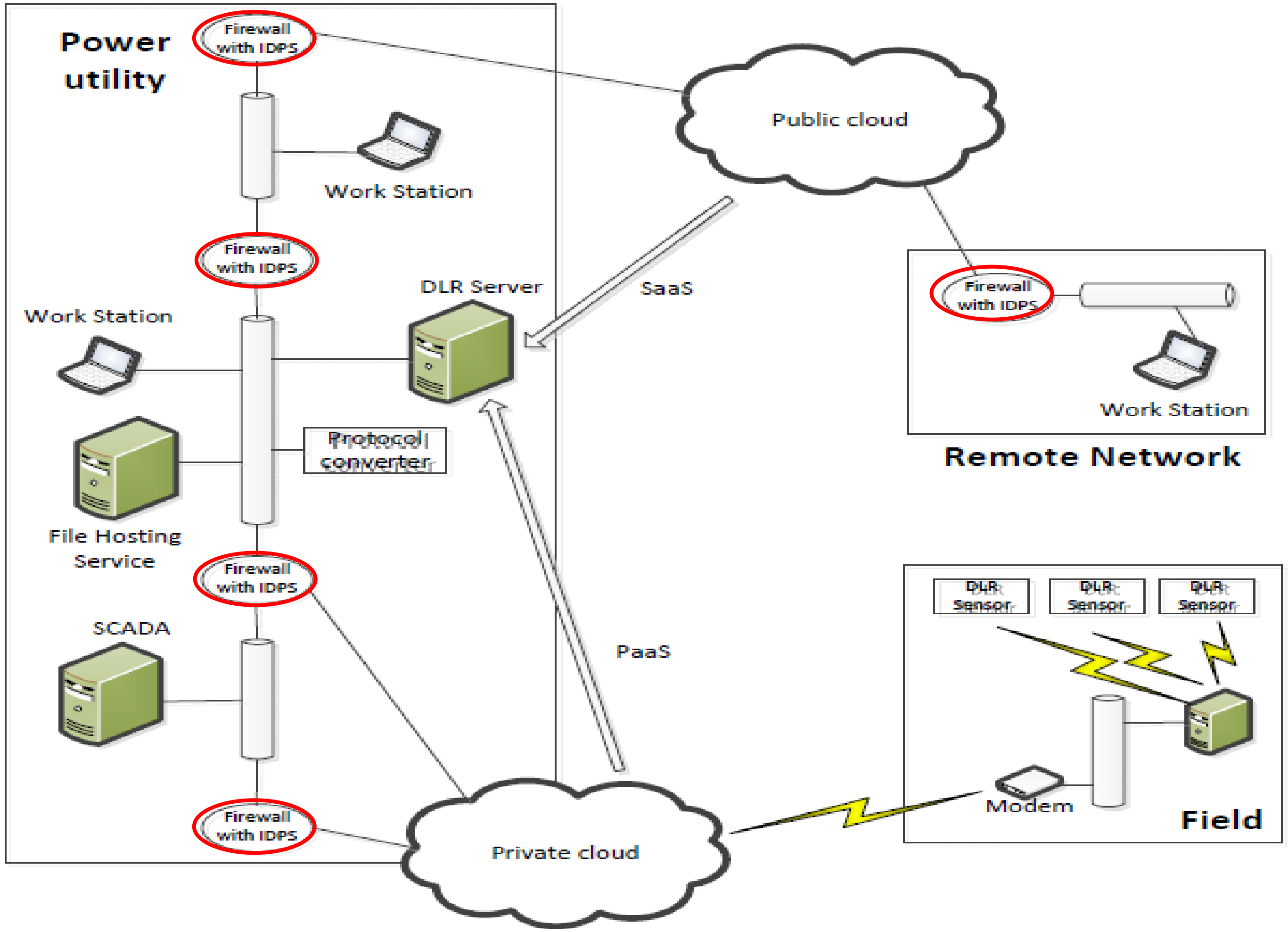
Proposed DLR cloud-based architecture

- IDPSs (collocated with firewalls):
  - Monitoring the traffic and examining the activities of the network -> identification and prevention of suspicious activities
  - Installed at network's vulnerability points
  - Logging events information;
  - Notification of important events
  - Reporting

- PaaS:
  - gathering the data (transmission line's parameters) from sensor units;
  - data aggregation, storage and management;
  - processing of the gathered data using algorithms for short and long term prediction of the ampacity;
  - sending the processed data to the control system (SCADA)
- SaaS:
  - The publicly available information (weather reporting and forecasting)

- The communication between the DLR and control systems is achieved with a protocol converter
- Benefits of hybrid cloud infrastructure are cost efficiency of public cloud services and the high level of security of the private cloud



Conclusion

- Cloud computing services in power utility systems: profound analysis and assessment of the benefits and risks trade-offs
- DLR system is an important part of the power system, contributes to the optimization of electric power distribution, providing an efficient power grid's load management
- Real time collecting and processing of large data volumes
- Cloud computing provides necessary computing and memory resources
- **Promising solution** -> Hybrid cloud infrastructure: cost efficiency and high level of security for critical applications (executed in the private cloud)
- DLR system migration to the cloud –> protect data and infrastructure
- Development of new solutions adapted to the control environment

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