Decision Support Tools for Control Rooms

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KU Leuven / EnergyVille

Power system structure and control centres

Keeping the balance between supply and demand

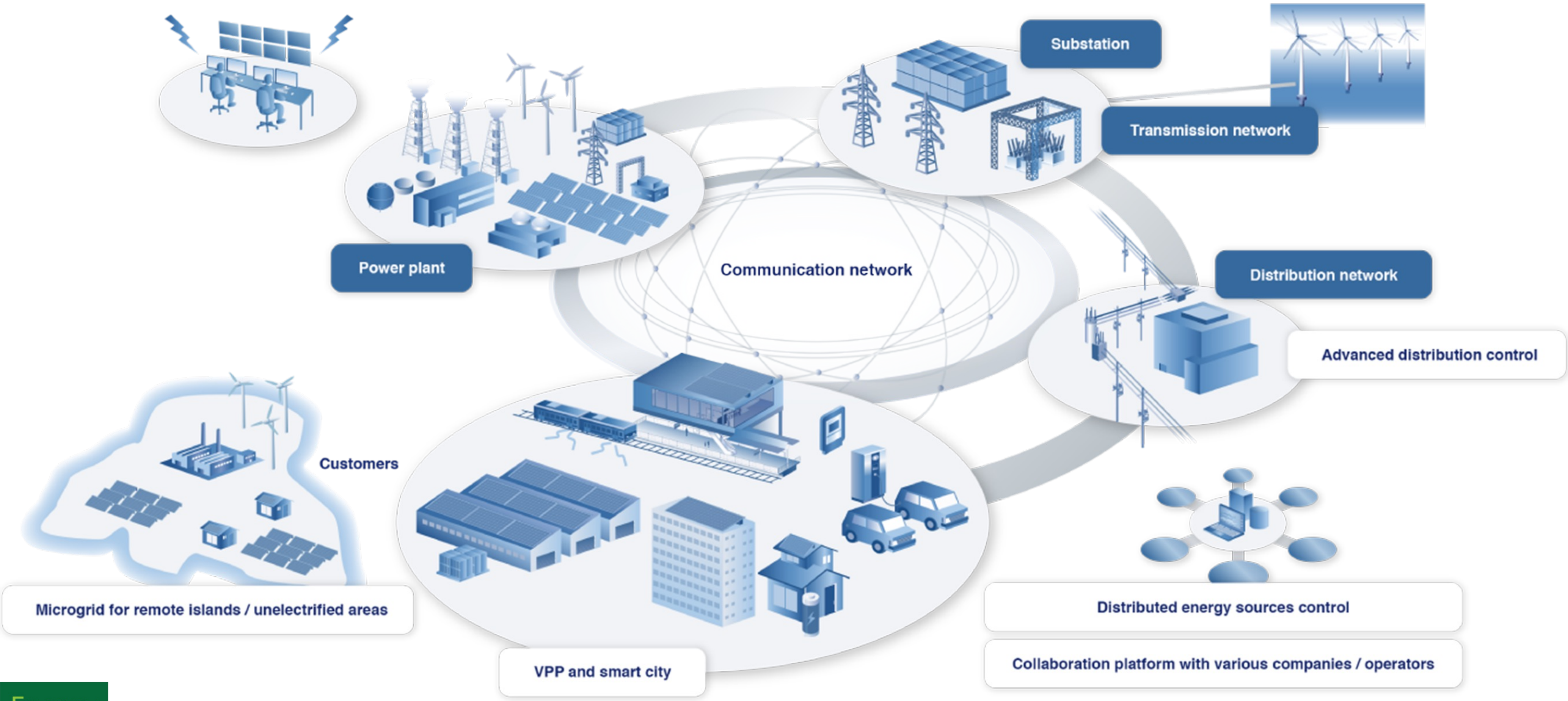


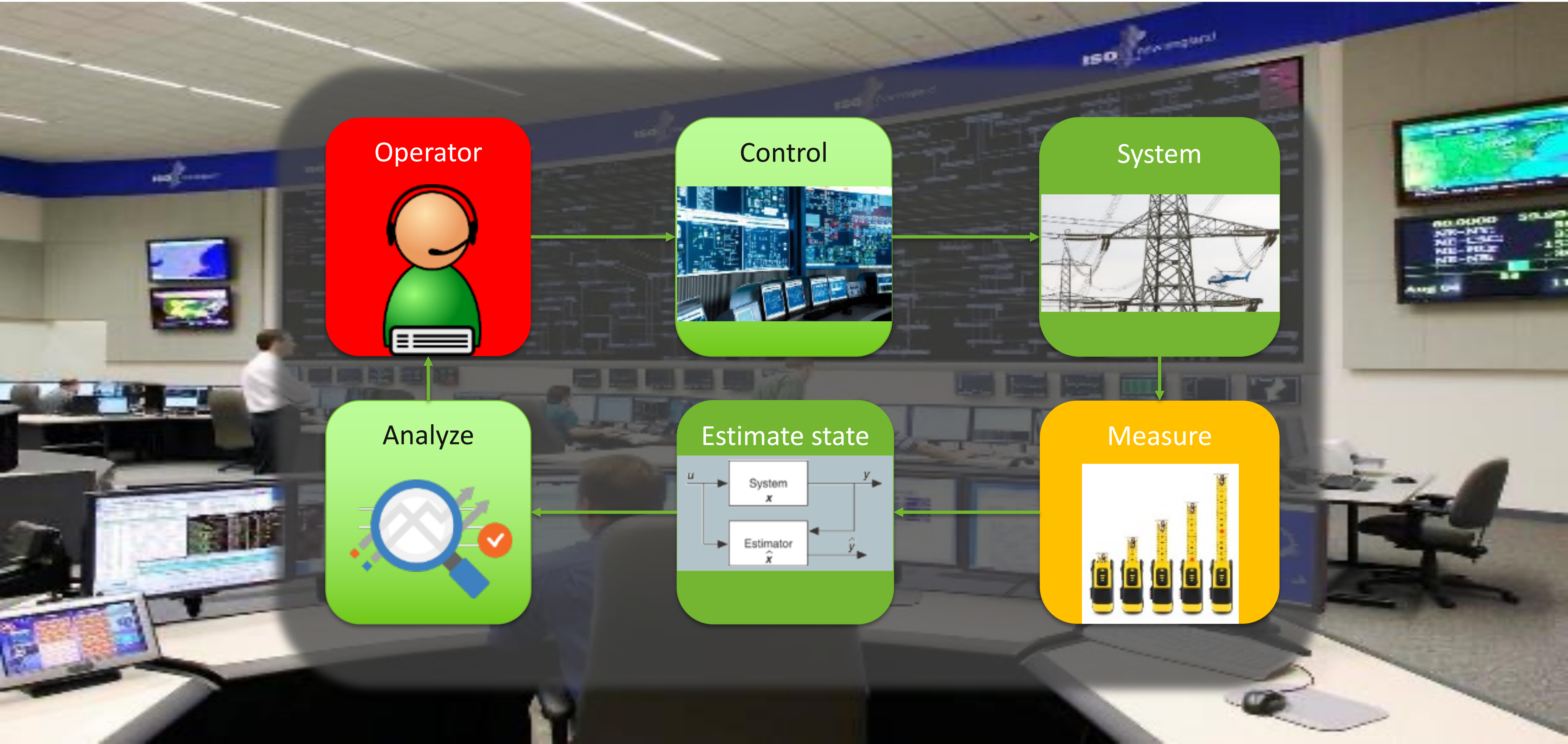
Image source: https://www.mitsubishielectric.com/eig/energysystems/overview/overview/

Main responsibilities of the control room operator

- Ensuring a balanced system
- Monitoring and enacting interchange activities with neighbouring control areas for congestion management or during incidents
- Monitoring of line loadings, voltages and performing transmission switching actions in case of need

Image source: https://www.elia.be/en/grid-data/transmission

Power system operation today



Energy management systems

- The energy management system carries out multiple functionalities
  - (Optimal) Power Flow calculations
  - State-estimation
  - Switching sequence validation
  - Short – circuit analysis
  - Sensitivity analysis
  - Short – term generation and demand forecasting
  - Interchange scheduling
- Generation control actions are automated processes, for frequency and voltage control in the short run
- Actions for re-dispatching, e.g. in 15 min time frame are usually not automated

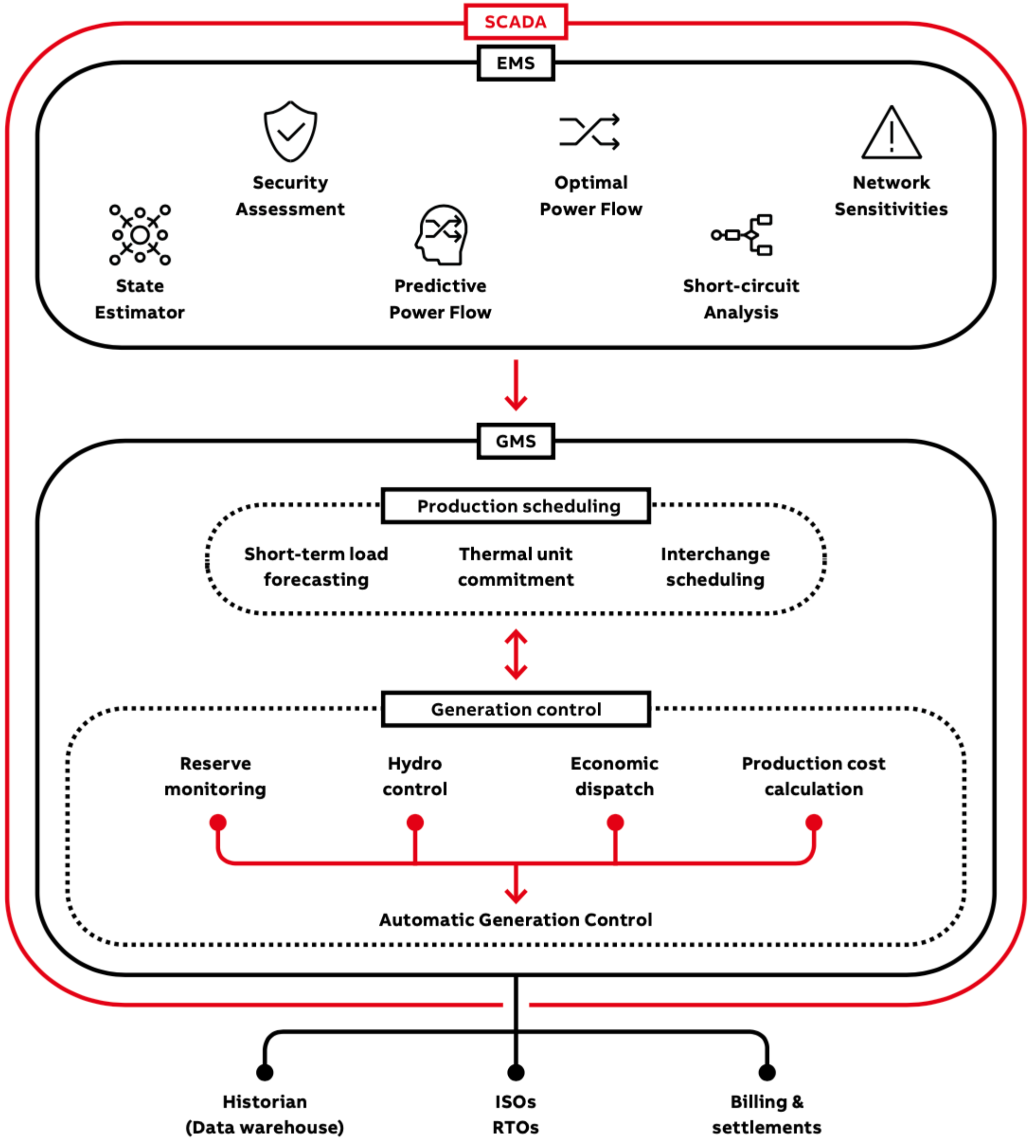


Image source: ABB Network Manager

Building blocks – “Micro services”

- State – estimation
  - Measurement based, “real-time” service
  - Provides the actual state of the system, deals with imperfect information, such as non-synchronised measurements or missing measurement data (especially important in distribution systems)
- Power flow analysis
  - Calculation of the system state for a given generation and demand snapshot
  - Identification of potential congestions in the “near” future
  - Analysis of the impact of contingencies, e.g. N-1 security analysis
- Optimal power flow analysis
  - The first step of decision support
  - Techno-economic optimisation of the control actions
  - Examples: Minimizing system losses, improving voltage profile of the network, minimising re-dispatch costs, choosing optimal generation control actions in case of contingencies, ….

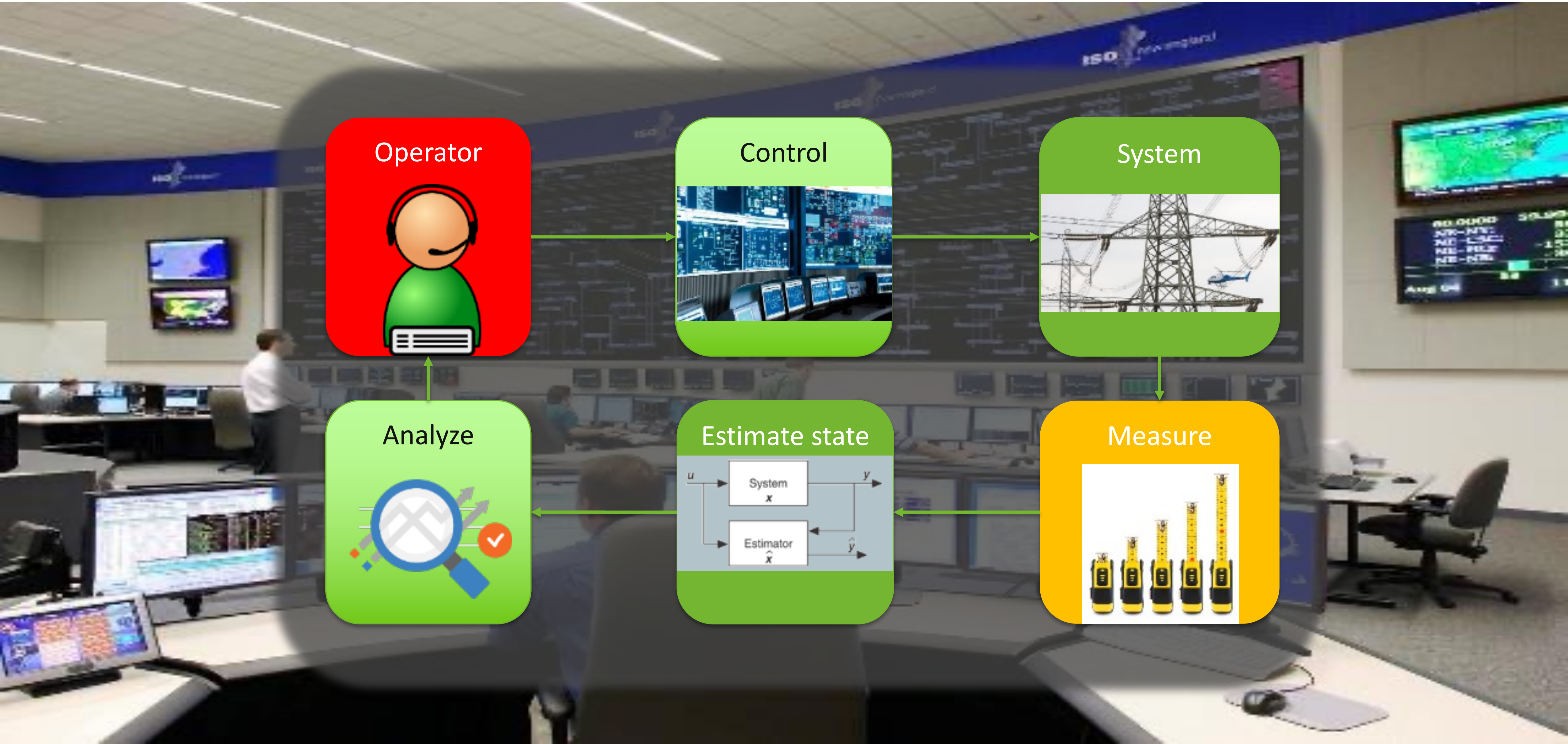
Building blocks – "Micro services"

- Switching sequence validation
  - Assisting the operator during switching event
  - Making sure that no unwanted short-circuits, or interruptions occur
- Short – term generation and demand forecasting
  - Usually combined with weather data services
  - Essential for short term operation and balancing
- Interchange scheduling
  - Time ahead scheduling of active and reactive power interchange with neighbouring networks
  - Coupled to day-ahead, intraday and reserve market operations

Services which can be connected to the EMS

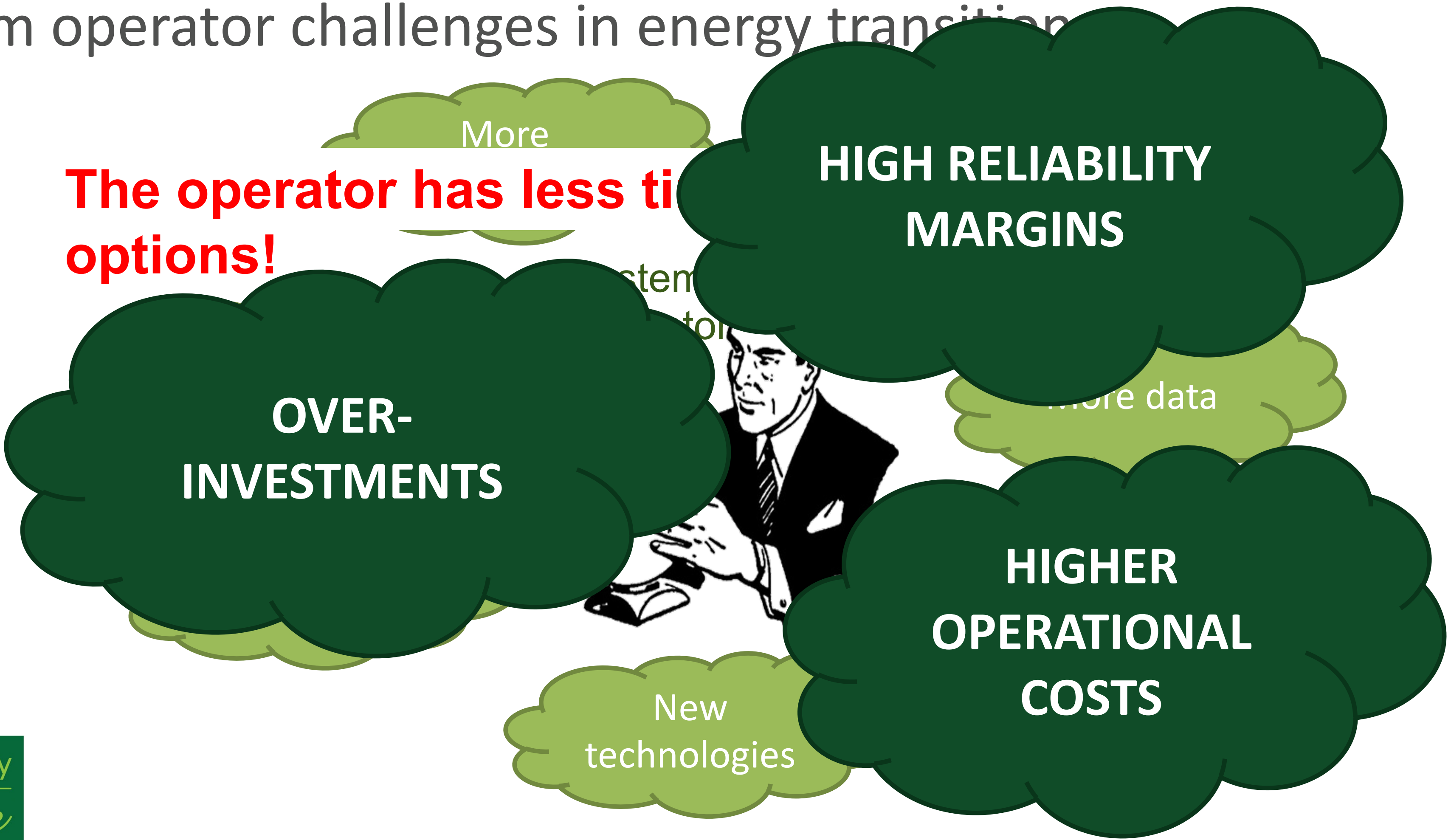
- Geographic information system (GIS)
- Weather data services
- Fault location detection
- Workforce management
- Billing services
- Market platforms

Bottle neck: Human in the loop



Desicion Support Tools for Grid Operators

- System operator challenges in energy transition



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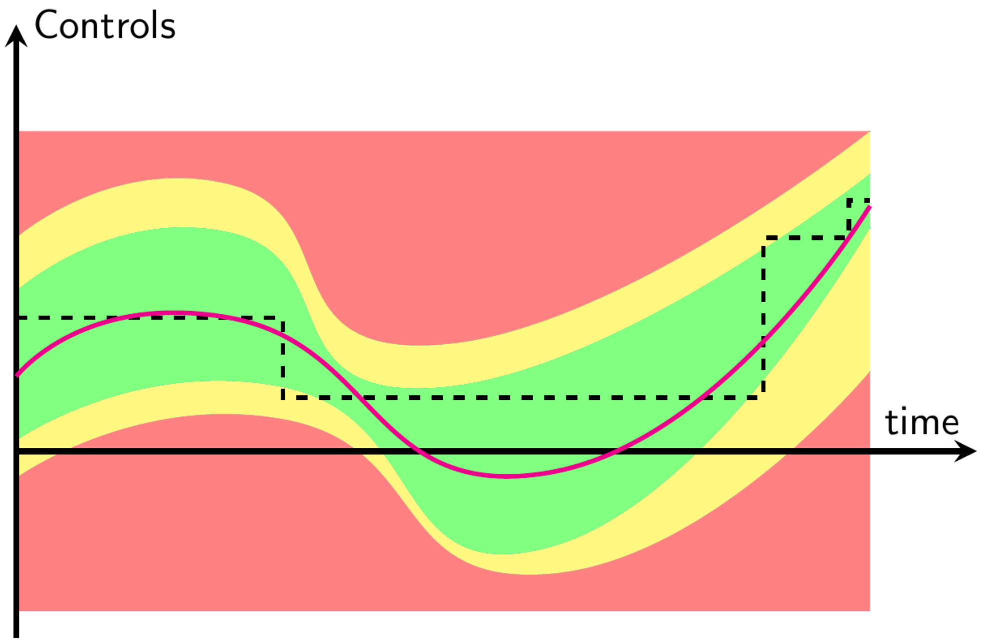
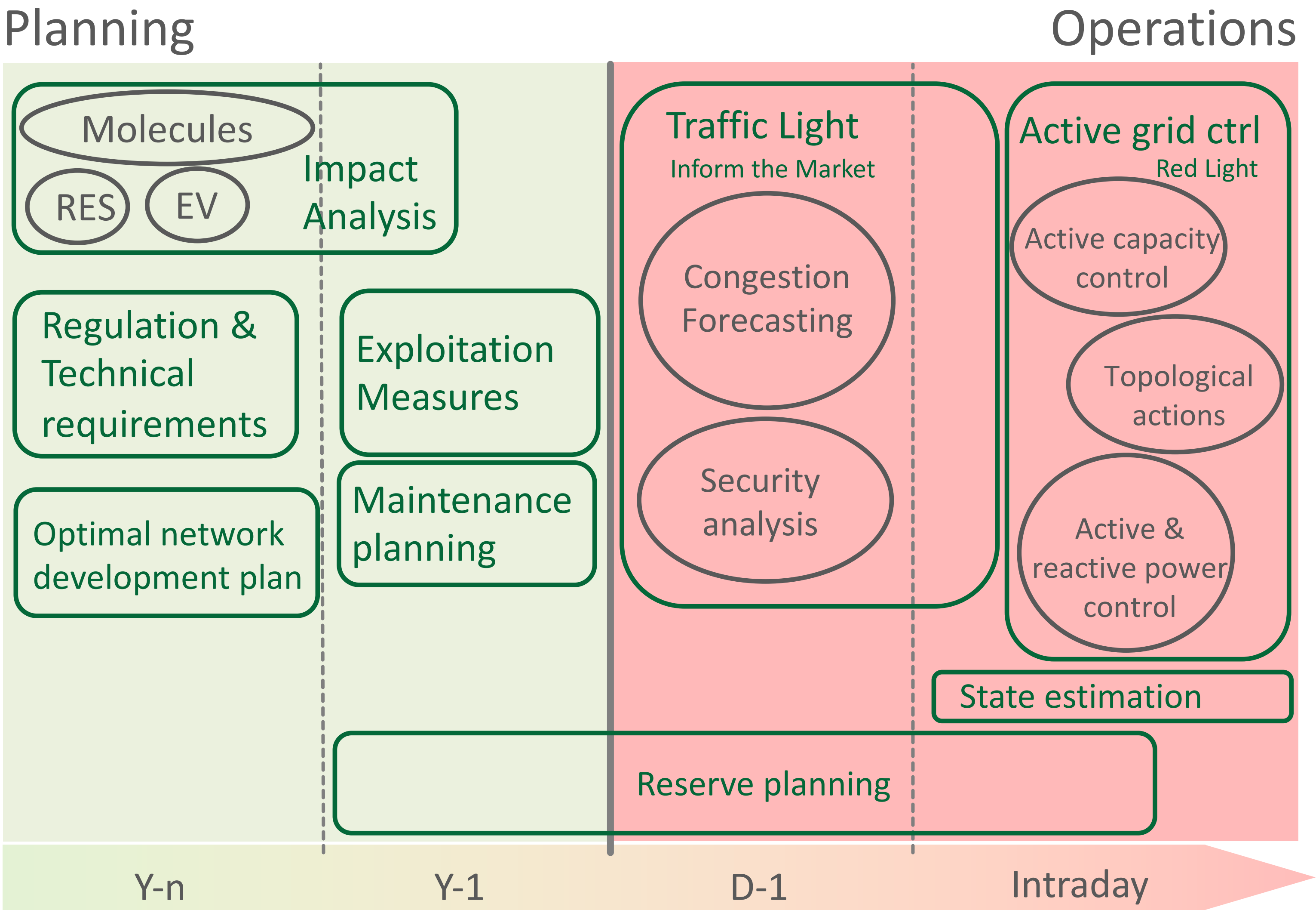
In the future, operators will have supervisory roles *and* interface with many stakeholders all the time

The challenge: system operator process must adapt under new paradigm

TODAY	FUTURE
What is happening now?	What will happen next?
Observing current state	Predicting states & risks
Providing problem alerts	Providing problem assessment
Operator making reactive decisions	Proactive decision support for operator
Predefined control actions	Continuous real-time optimal control actions



Making use of better information
Making use of more flexibility
➔ Choices
➔ Reliable, secure and sustainable!
➔ What is the objective?



Decision support for grid operators

Maximize the grid utilization

Automated grid operation – Analogy to automated driving

Driving	Description	Description
Level 0: No automation	Driver carries out all functions, e.g. steering, accelerating,…	Grid operator initiates all control actions based on measurements. System provides observability and remote control possibility
Level 1: Assisted driving	Provision of warnings for speed, line-assistant, …	Constant or requested provision of situational awareness and decision support
Level 2: Partly-automated	Automation of line assistance, cruise control,…	Certain control actions are taken autonomously after activation by the operator
Level 3: Condition-automation	Vehicle can change lanes, use indicators and so on. Driver only supervises.	Certain control actions are taken autonomously based on predefined event - triggers
Level 4: Highly-automated	Vehicle carries out most driving tasks and gives highly specialised tasks to driver	Daily network operation is handled by system, also during contingencies. Operator only required for highly specialised tasks
Level 5: Full-automation	Vehicle performs all driving tasks. Driver only sets destination.	No more operator is needed. The supervisor only provides target values for the system.

Today's situation

Source: Martin Braun, Heinrich Hoppe-Oehl, Julia Koenig, Andreas Kubis, Inga Loeser, Christian Rehtanz, Robert Schwerdfeger, Wolfram Wellssow, **Systematisierung der Autonomie- stufen in der Netzbetriebsführung, VDE Impuls**

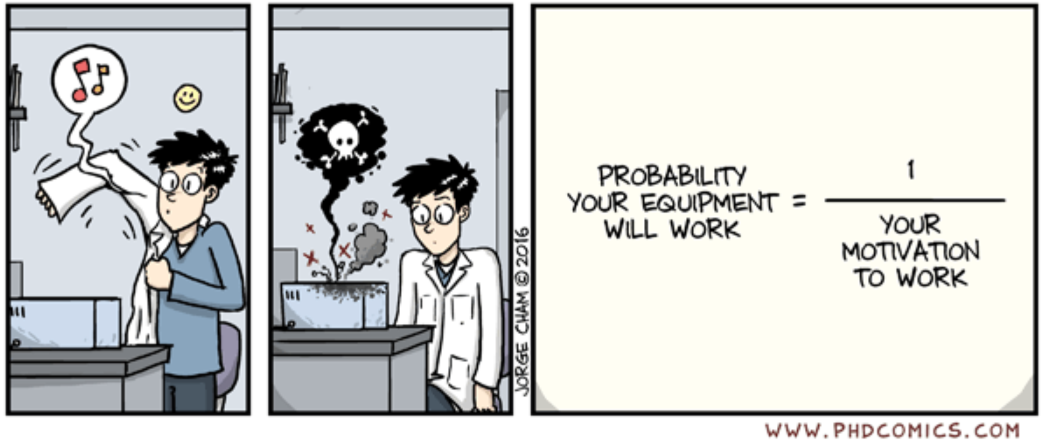
Examples of decision support provision

Mathematical models

Probabilistic reliability criteria

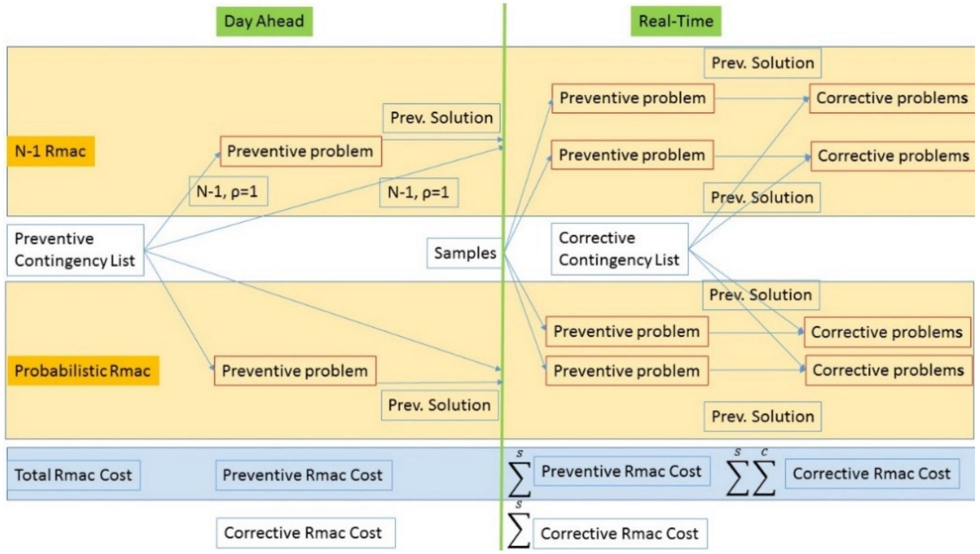
- N-1 is an edge case of probabilistic reliability
  - All N – 1 contingencies have the same probability
  - Two contingencies do not occur at the same time
  - The impact of all contingencies is equal

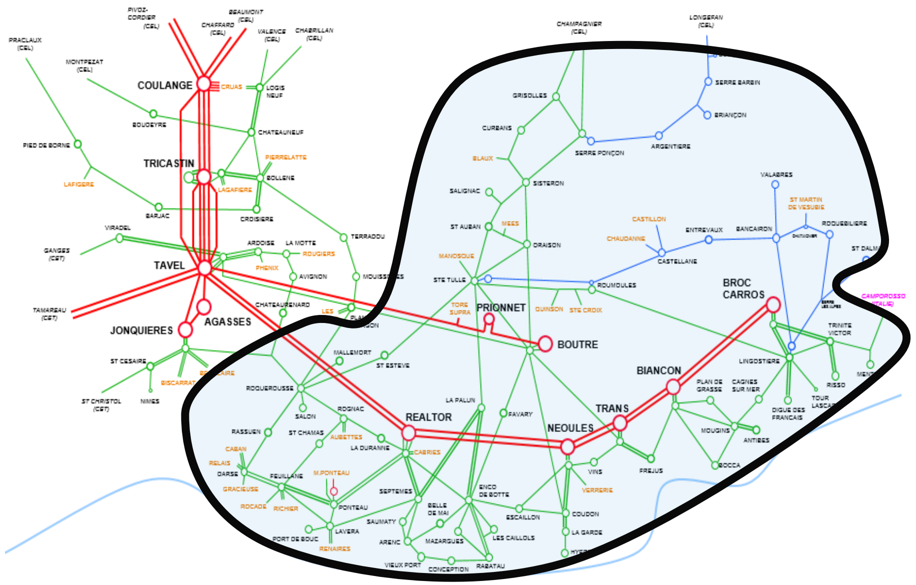
- In reality, the definition is still not unique
  - What is considered as N – 1?
    - E.g. transmission tower vs. circuit
    - Substations
      - Substation as a whole?
      - Bus bars, breakers, transformers differently?
  - By defining a contingency set, TSOs inherently make a reliability assessment!
- ***Comparison of probabilistic reliability criteria is challenging!***



Application to real network

- Development of the Garpur Quantification Platform (GQP) to perform cost benefit analysis of different reliability criteria
  - Consider TSO reliability control actions
  - Evaluate the cost-benefit of the reliability criterion based on detailed real-world test cases (RTE pilot)
  - Objective considers weighted cost of preventive and corrective actions as well as possible blackout
    - That way, low probability high impact events can be analyzed
    - Allows also to quantify failure of corrective actions
  - Multi – stage decision process
    - Preventive, post – contingency short term and corrective actions
  - Security constrained optimal power flow, MISOCP formulation
    - Allowing generator dispatch, corrective load shedding, PST actions, topological changes
    - Using NF, DC and LPAC formulation to approximate AC power flow
    - AC initialization and post optimization check
  - Real life demonstration
    - Pilot test on the South – France transmission network
    - 600+ buses, 1000+ branches, …
  - CIM converter for efficient data exchange to Matlab

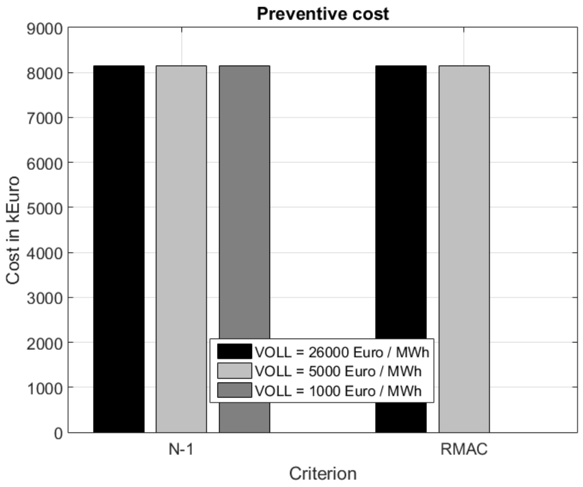


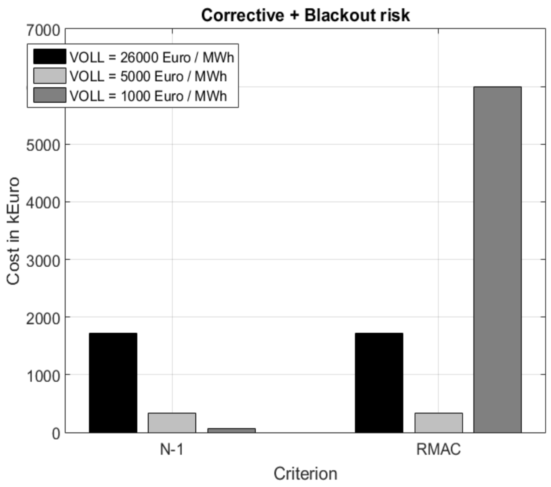


F Geth, H Ergun, D van Hertem, E Heylen, IB Sperstad, GARPUR D7. 3-A broader comparison of different reliability criteria through the GARPUR quantification platform, 2017

Comparison of reliability criteria and sensitivities

- Most sensitive parameter is the choice of the value of lost load (VOLL)
- The choice of VOLL determines the trade-off between preventive security and curative actions
- For high values of the VOLL, the probabilistic security converges to deterministic N-1





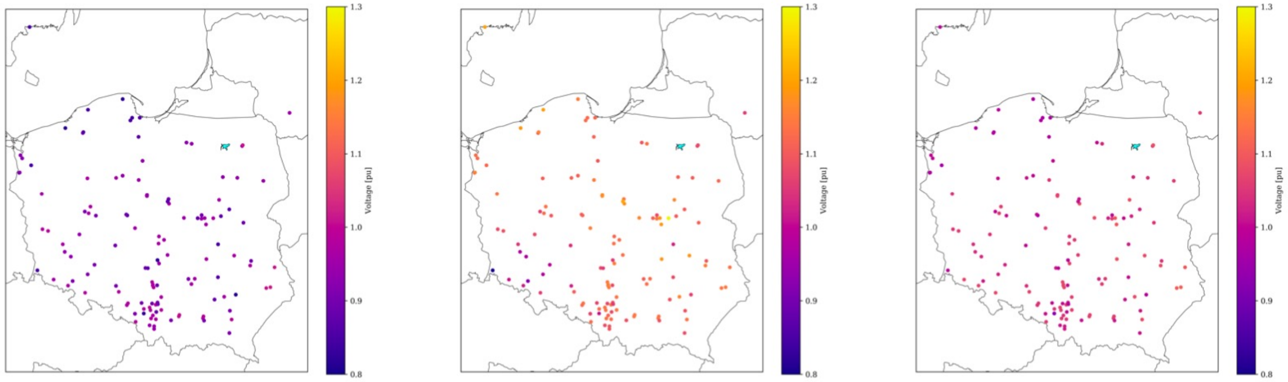
	N-1			RMAC		
VOLL	Preventive cost in €	Corrective + Blackout risk in €	Total risk in €	Preventive cost in €	Corrective + Blackout risk in €	Total risk in €
26 000 €/MWh	8155	1716	9871	8155	1716	9871
5000 €/MWh	8155	330	8485	8155	330	8485
1000 €/MWh	8155	66	8221	0	6001	6001

F Geth, H Ergun, D van Hertem, E Heylen, IB Sperstad, GARPUR D7. 3-A broader comparison of different reliability criteria through the GARPUR quantification platform, 2017

Reactive power management and optimal PST set point determination under contingencies

- Using a (security constrained) optimal power flow approach
- Optimal reactive power dispatch of generators and compensation equipment under contingencies
- Optimal PSTs set point changes under contingencies
- Nonlinear, relaxed and linearized power flow formulations
  - Tractable formulation to include discrete actions, such as switching or PST taps
  - Tractable formulation to deal with nonlinearities, e.g. PST impedance change
  - Evaluation of different objectives
- Used as benchmark for the PSE training system

Reactive Power Management: Comparison of Expert-based and Optimization-based approaches for dispatcher training



(a) TS1 (b) TS2 (c) TS3

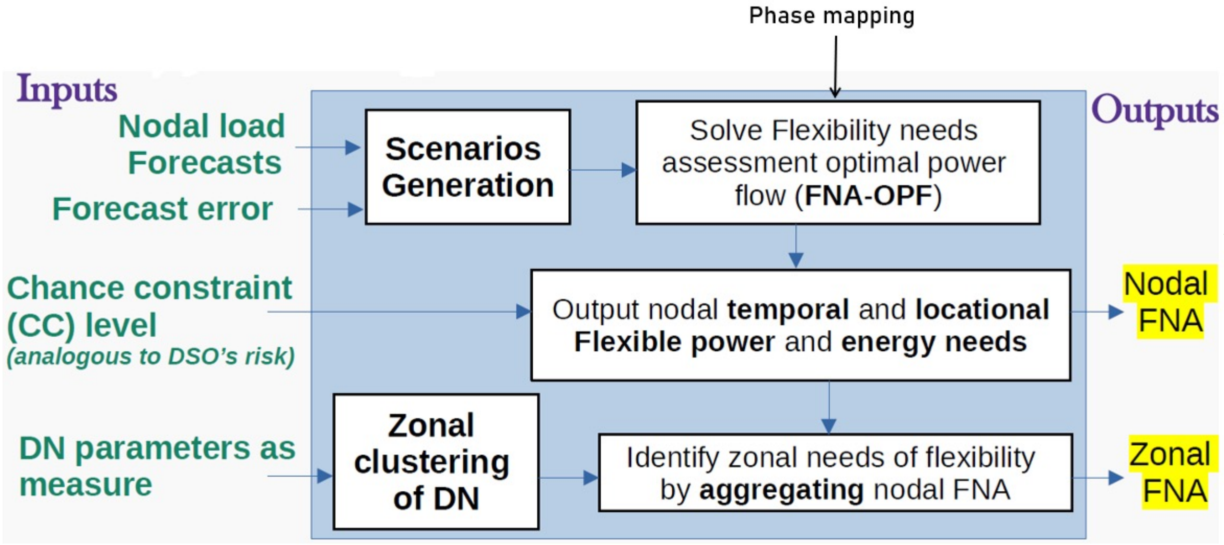
Figure 2: Nodal voltages for reference contingency without generator redispatch

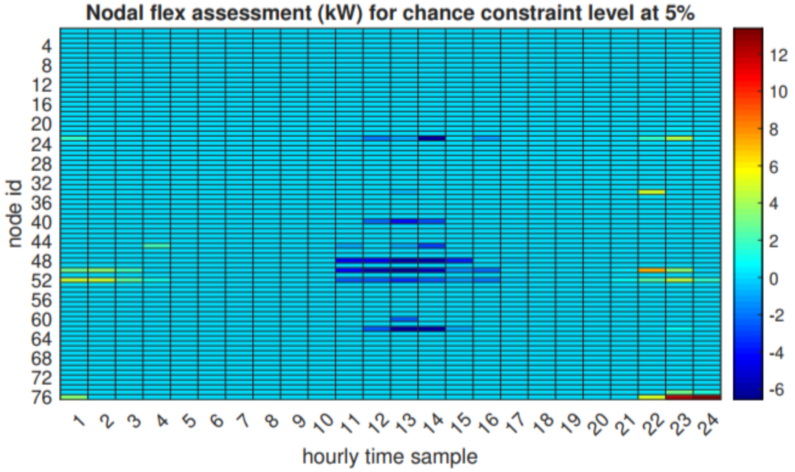
Timestamp	TS1			TS1			TS1		
Approach	OBA	EA	Difference	OBA	EA	Difference	OBA	EA	Difference
Redispatch cost [€]	378408	447549	69141	343043	391638	48595	287075	366109	79034

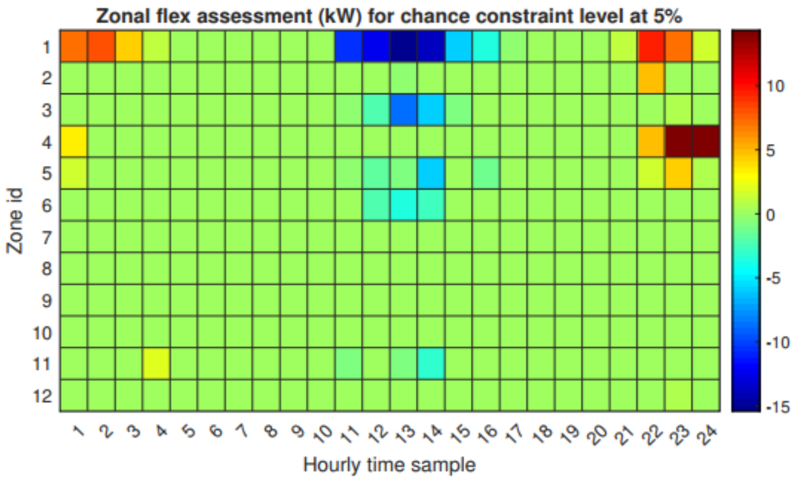
Table 4
Redispatch cost for reactive power management

Flexibility needs assessment – EUniversal project

- Flexibility needs assessment using chance constraints for risk-based operation,
- Provision of zonal flexibility needs to reduces computational needs,
- Derivation a network state-driven flexibility activation signal,
- Consideration of the effect of reactive power flexibility activation with distribution network load power factor.

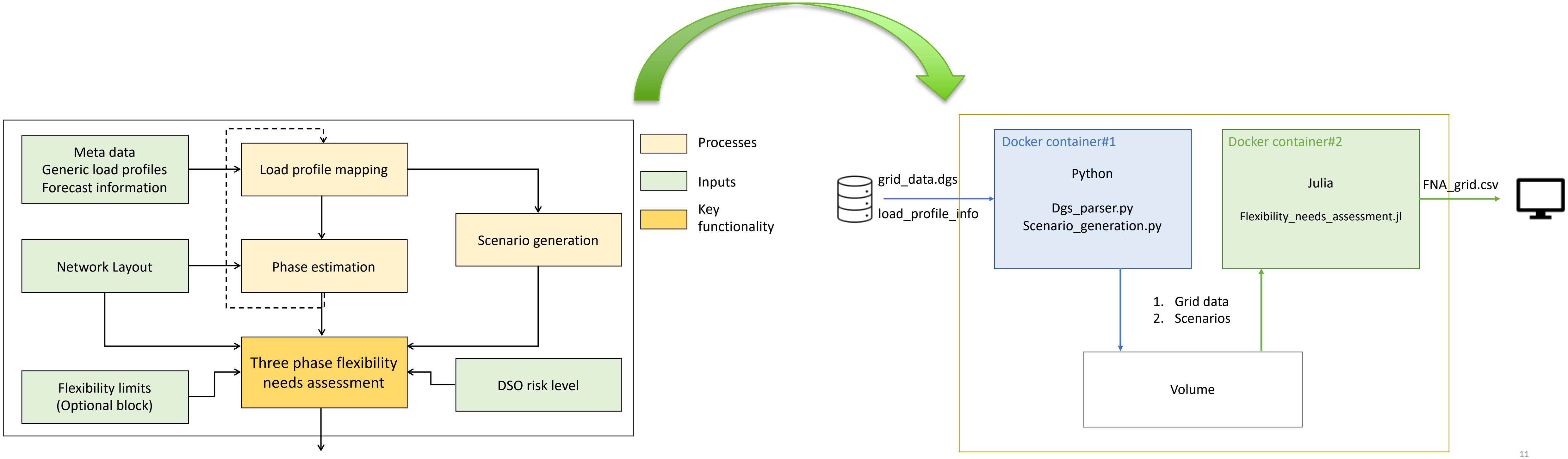






Flexibility activation signal tool set-up

Integration in the German demo



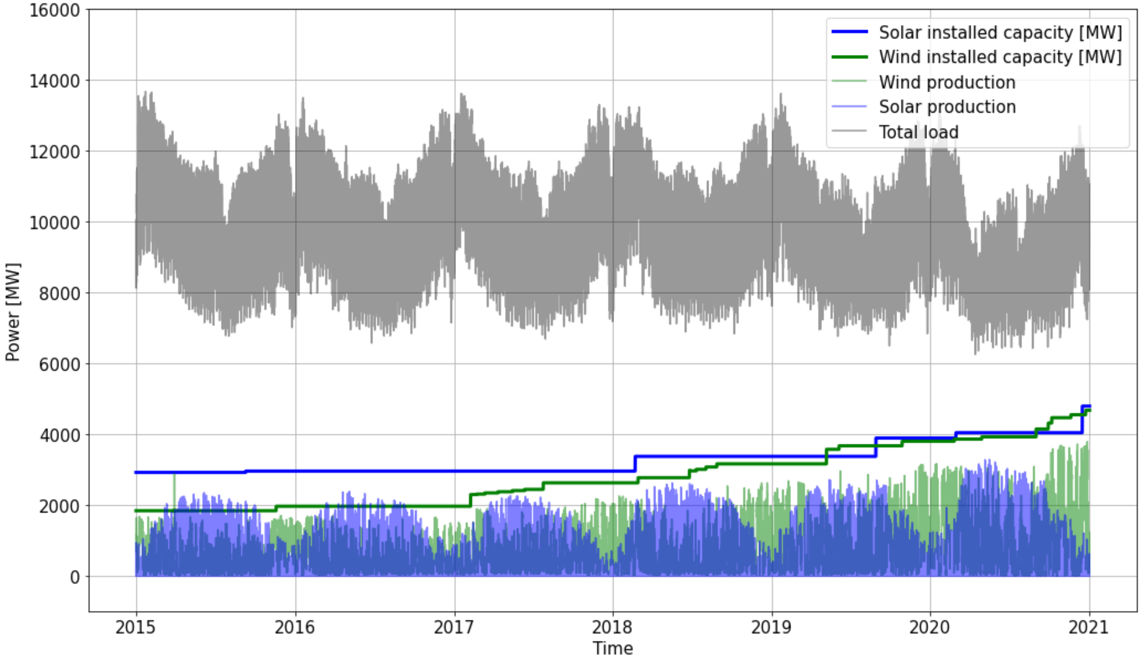
Hashmi, M.U., Koirala, A., Ergun, H., Van Hertem, D. (2022). Flexible and curtailable resource activation in three-phase unbalanced distribution networks. *Electric Power Systems Research*, *212*, Art.No. 108608. doi: 10.1016/j.epsr.2022.108608

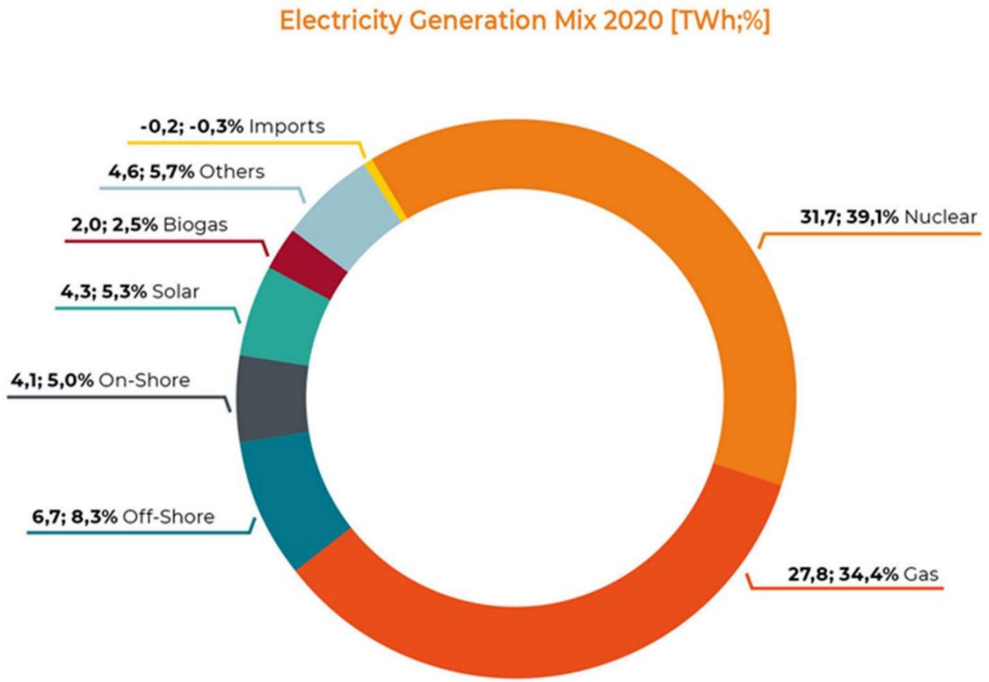
Hashmi, M.U., Koirala, A., Ergun, H., Van Hertem, D. (2021). Flexible and curtailable resource activation in a distribution network using nodal sensitivities. Presented at the 2021 International Conference on Smart Energy Systems and Technologies (SEST), Vaasa, Finland, 06 Sep 2021-08 Sep 2021. ISBN: 978-1-7281-7660-4. doi: 10.1109/SEST50973.2021.9543215 Open Access

Examples of decision support provision

AI based models

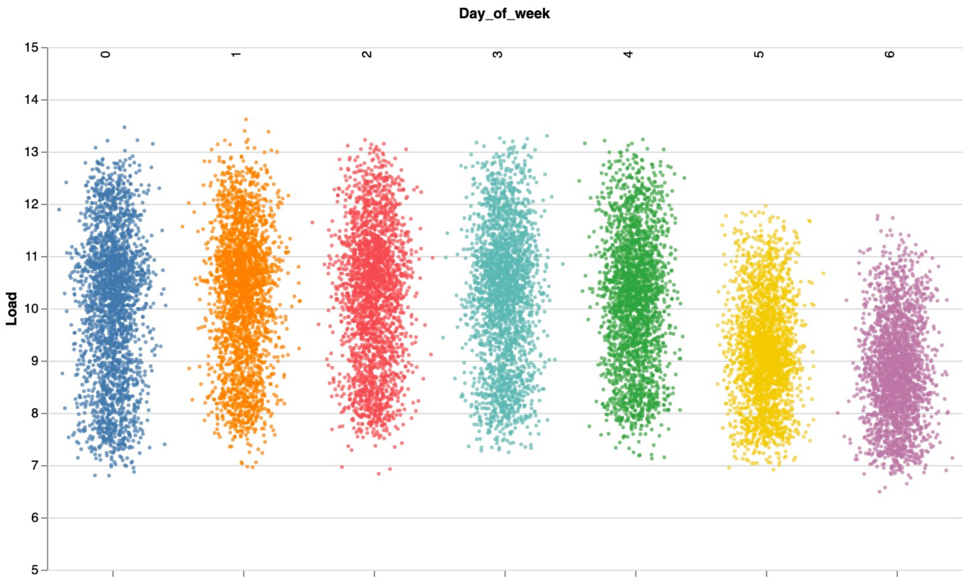
Belgian electricity system – a bird's eye view

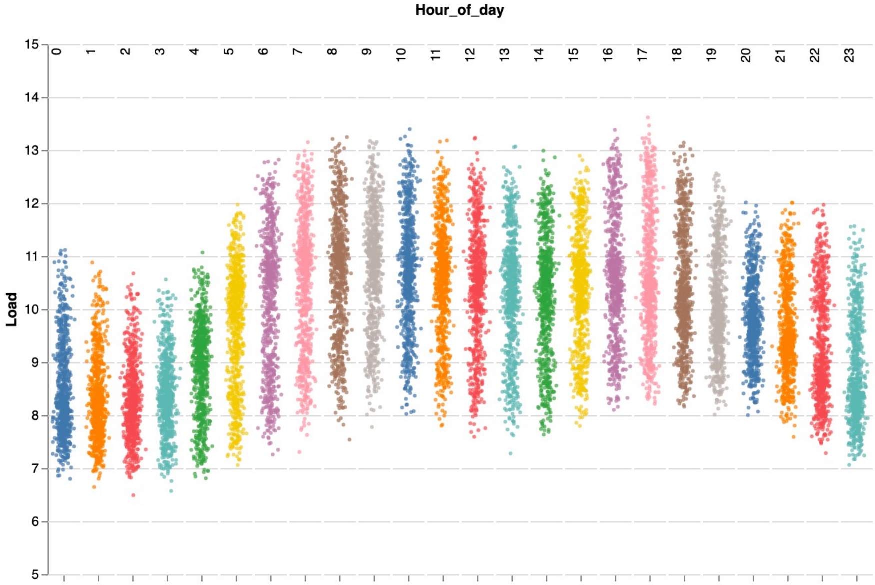


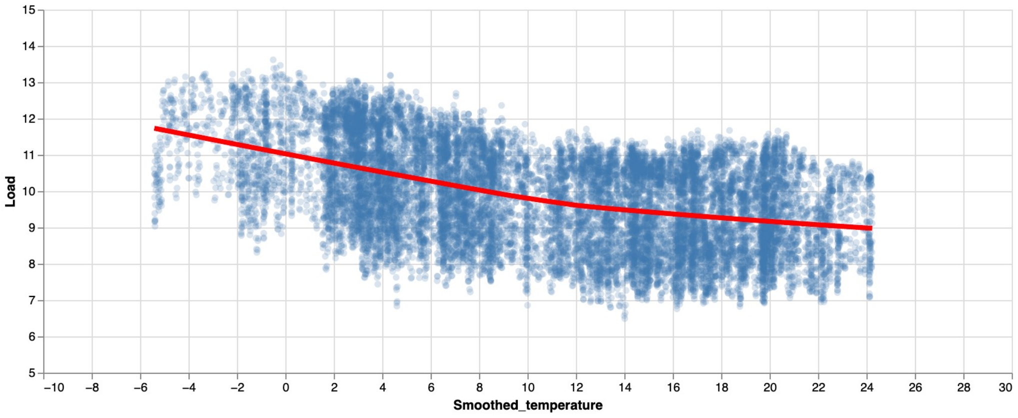


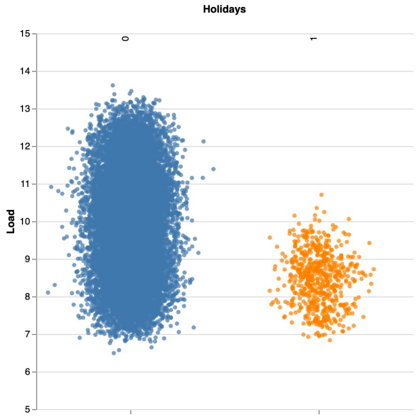
Source: Elia

The demand side

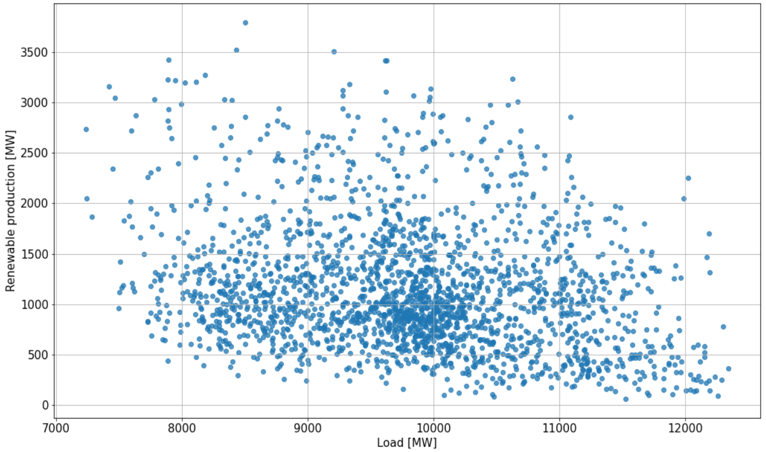




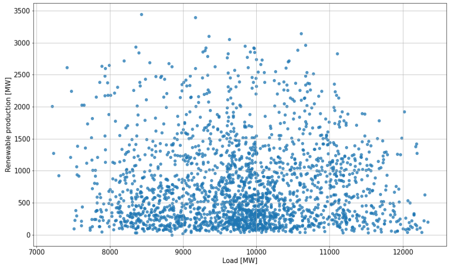




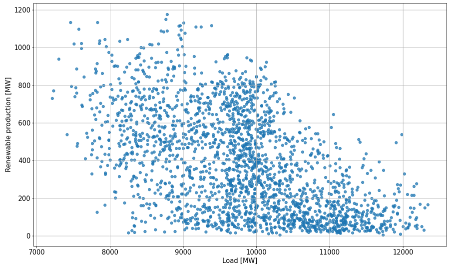
The renewable generation side

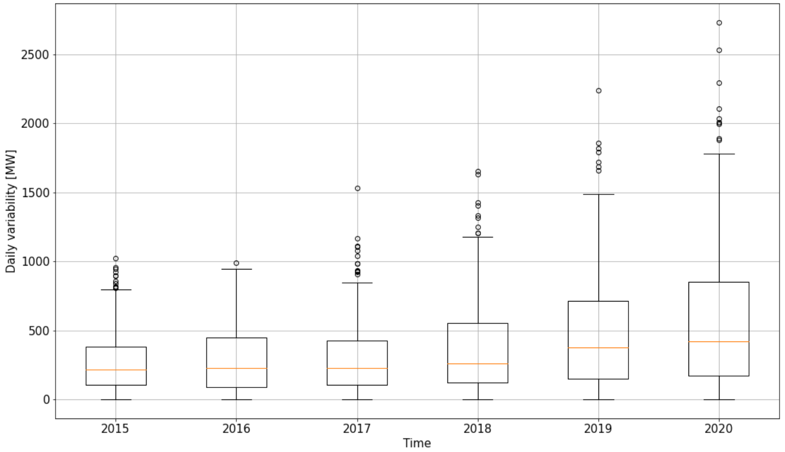


Wind



Solar





Short-term load forecasts at the TSO

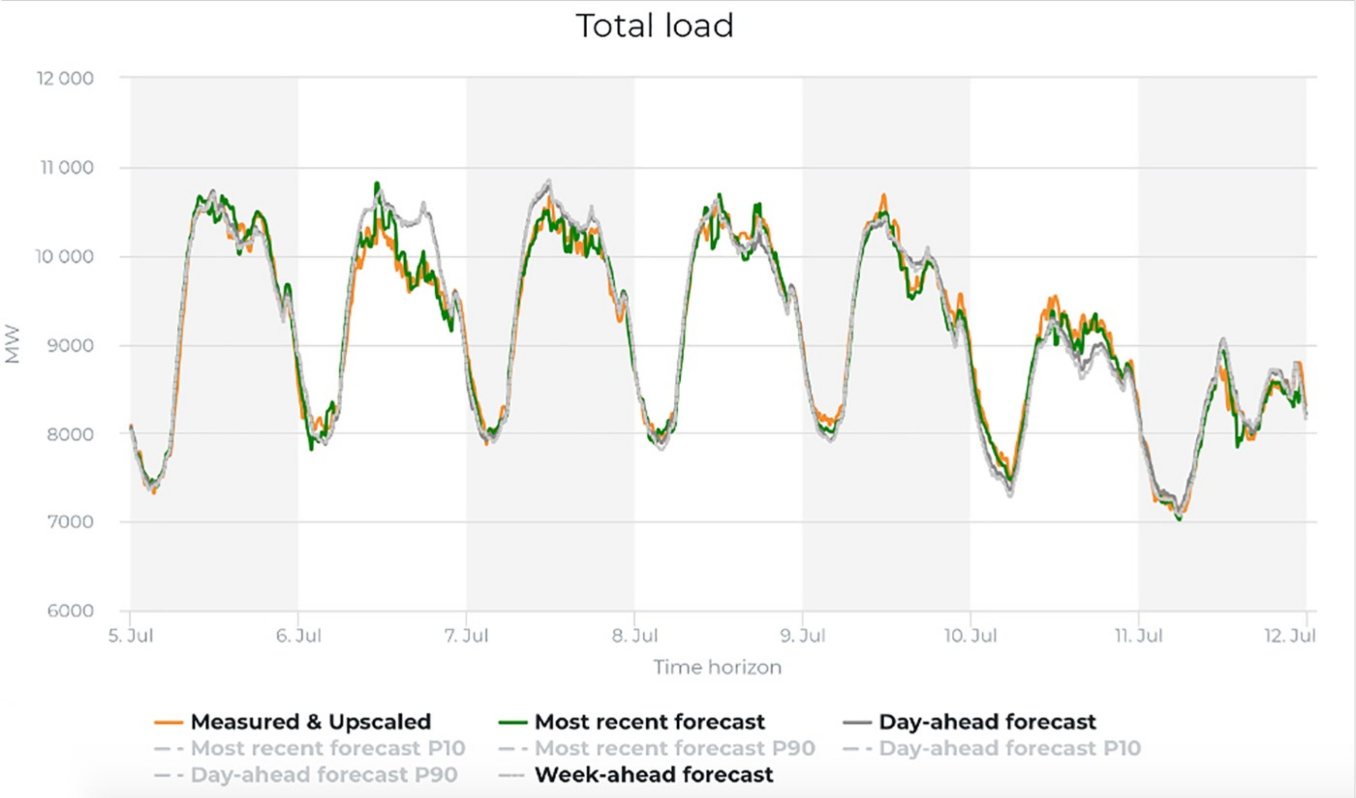


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Image source: Elia

Incorporating uncertainties

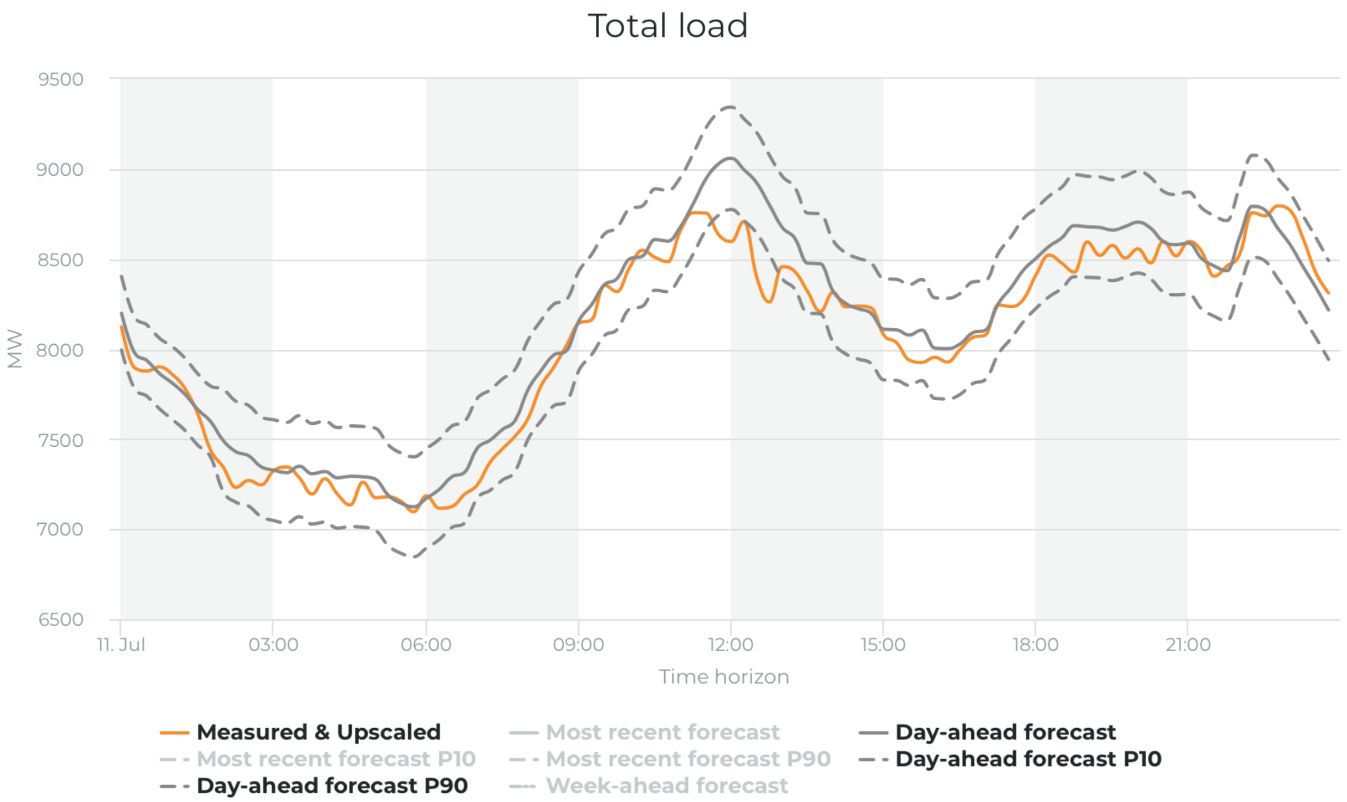
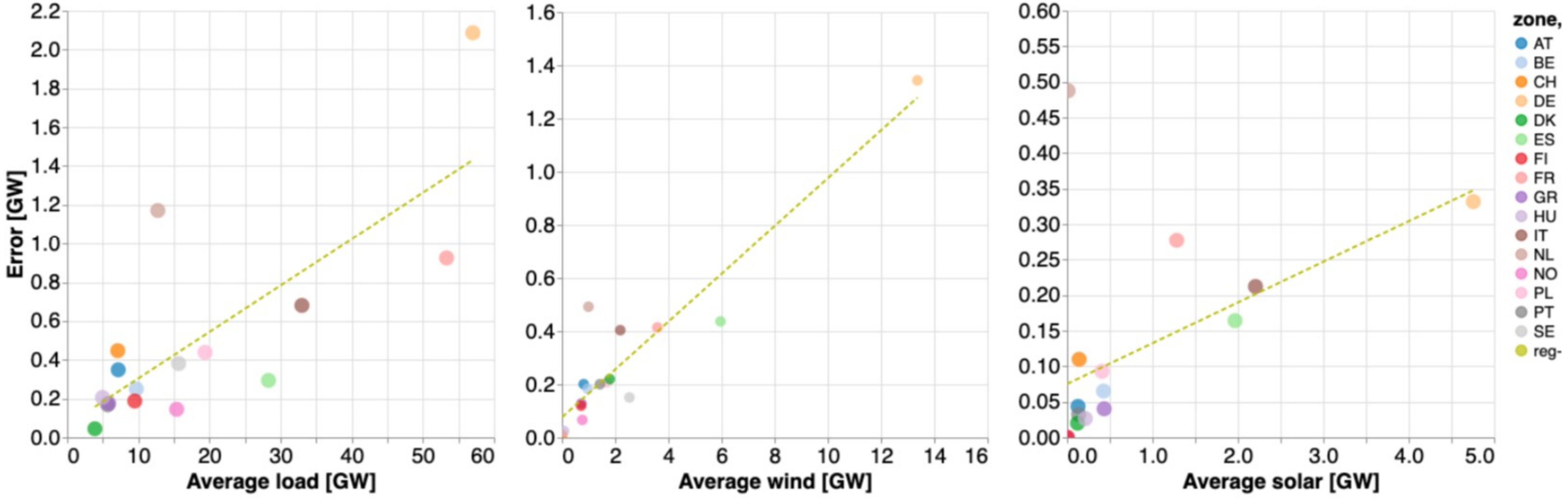


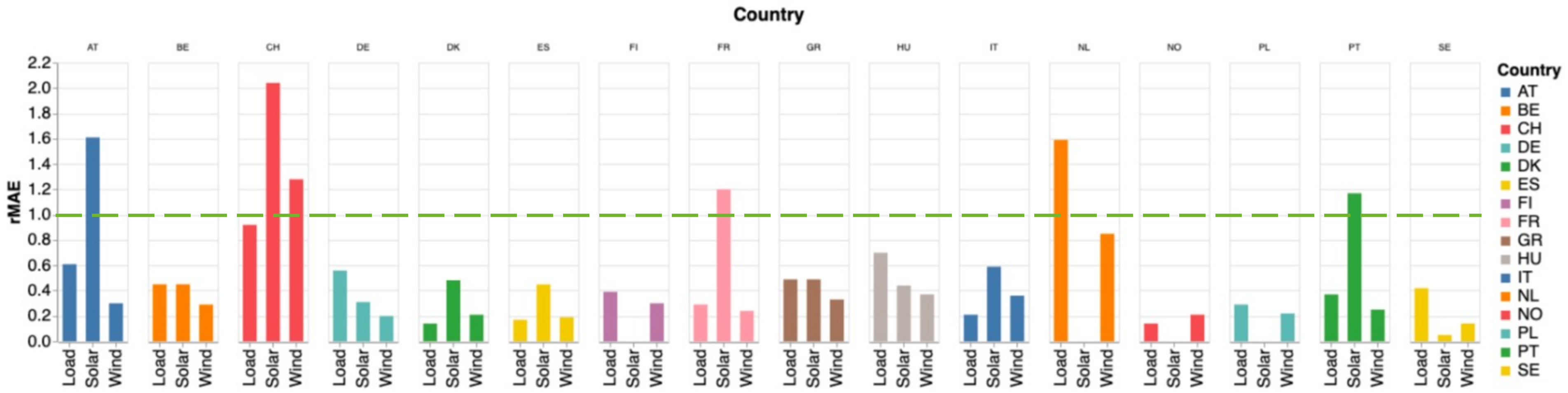
Image source: Elia

Performance of TSO forecasts (1)



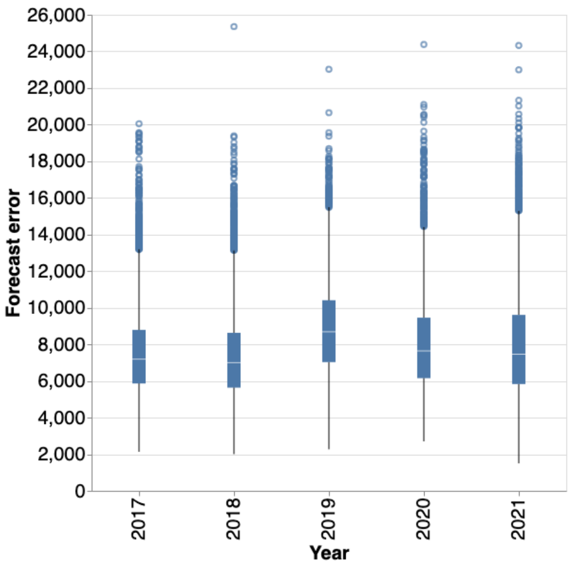
Kazmi, H., & Tao, Z. (2022). How good are TSO load and renewable generation forecasts: Learning curves, challenges, and the road ahead. *Applied Energy*, *323*, 119565.

Performance of TSO forecasts (2)

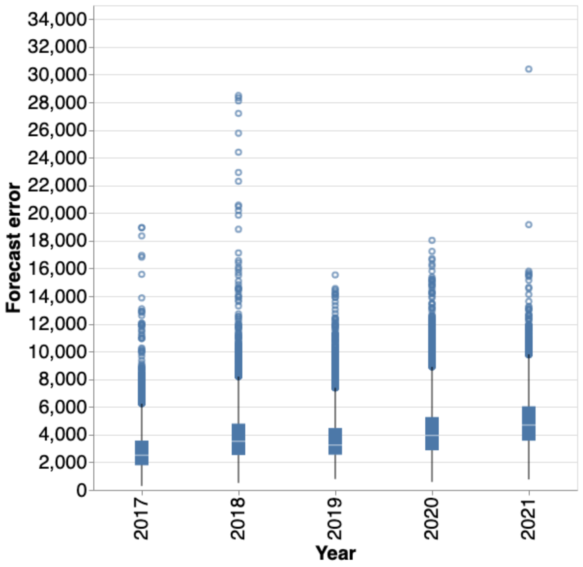


Kazmi, H., & Tao, Z. (2022). How good are TSO load and renewable generation forecasts: Learning curves, challenges, and the road ahead. *Applied Energy*, *323*, 119565.

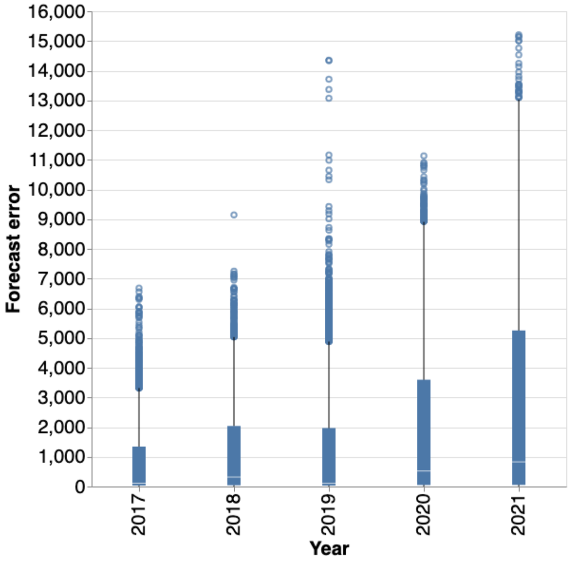
The temporal aspect



Load



Wind



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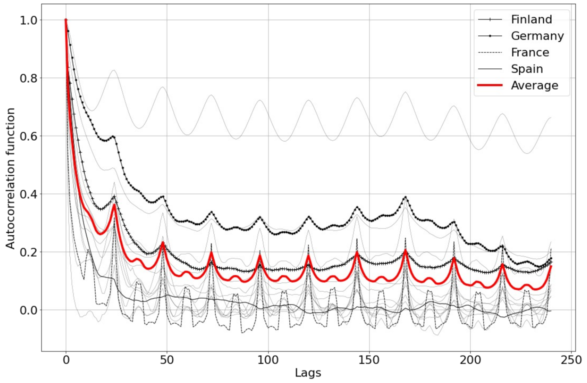
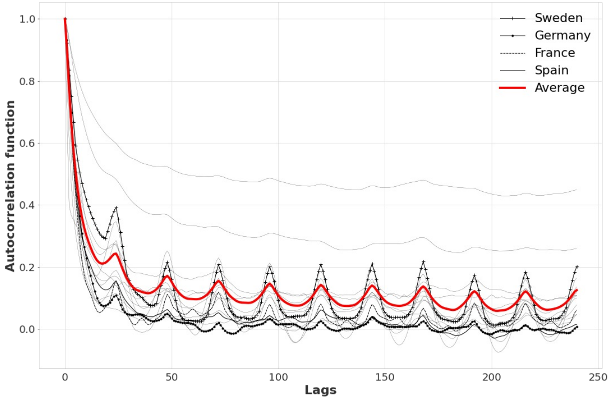
Can we improve existing forecasts?



Load



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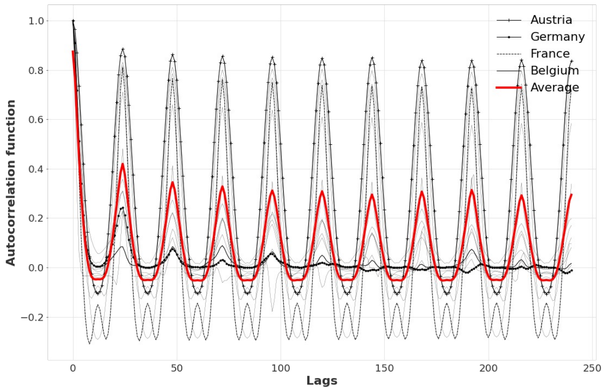

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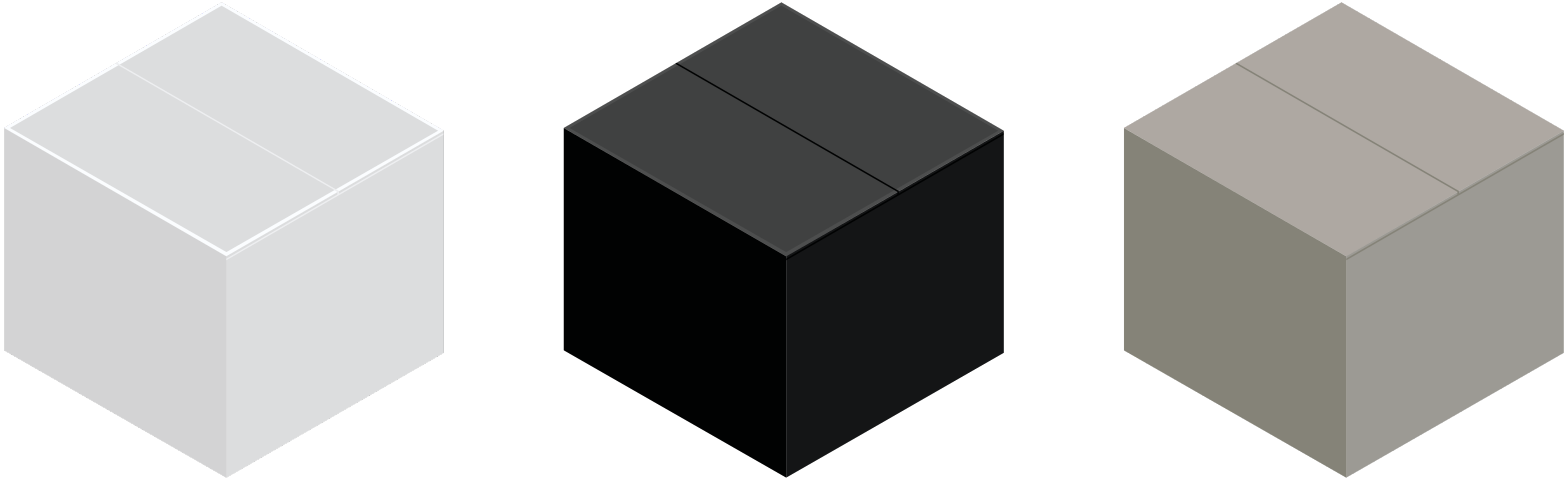
Challenges with this vision

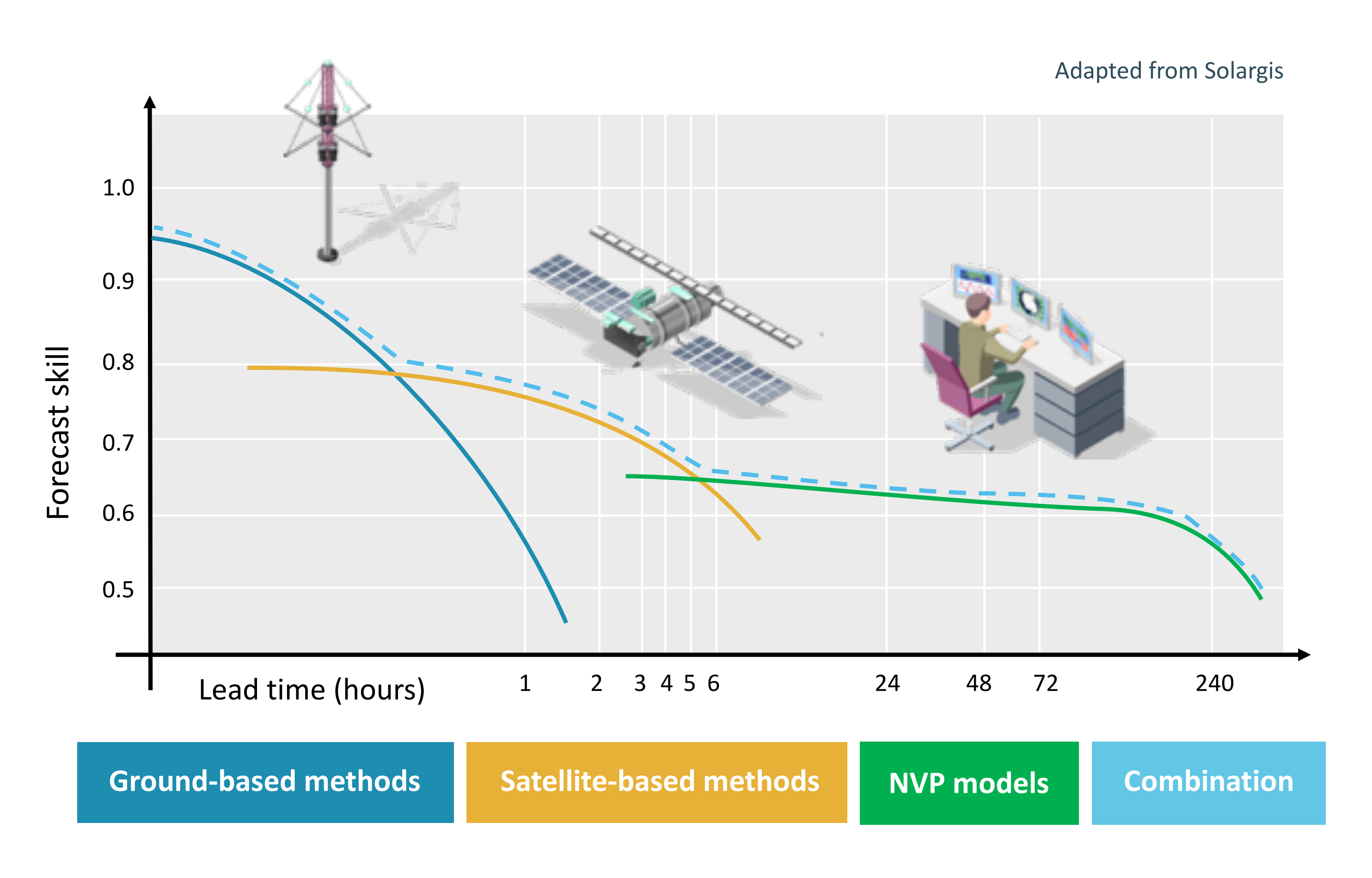
- Black-boxes galore
- Lack of expertise and knowledge
- Lack of required data (often in the right format)
- Different challenges for different spatial and temporal scales
- Non-stationarities (Covid-19, electrification, RES, climate change)
  - Fit-and-forget does not scale well

Real world complexity – model selection and combination (1)

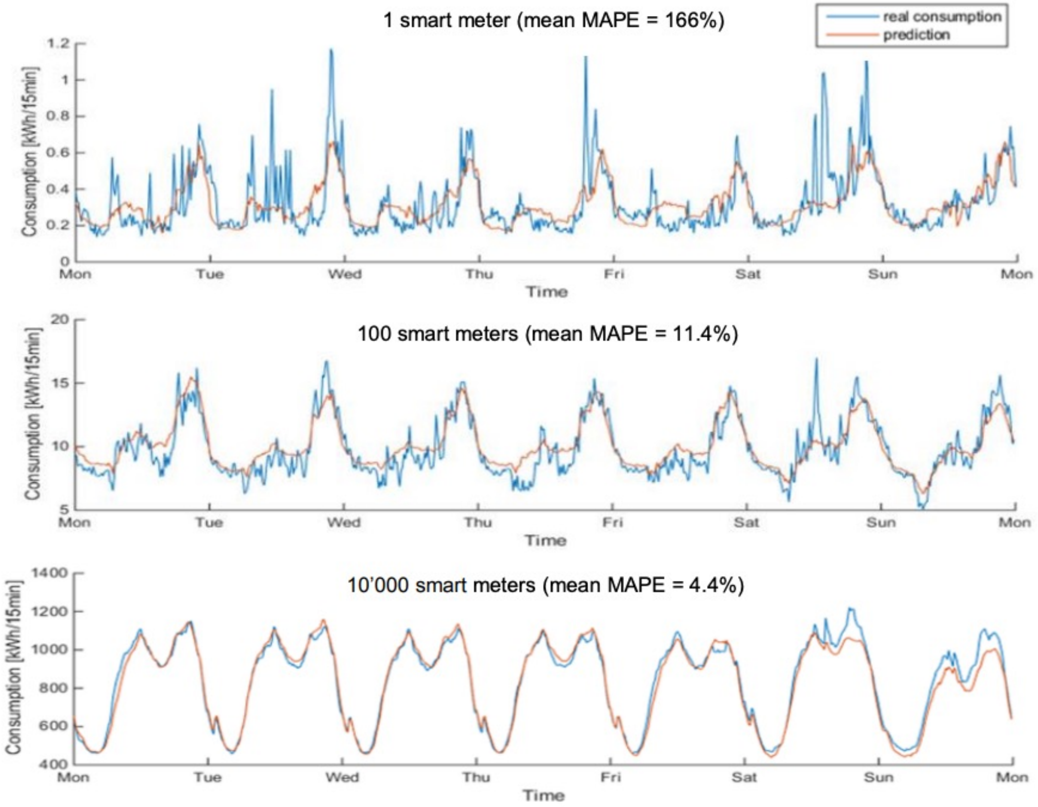
White-box models | **Black-box models** | **Grey-box models**



Real world complexity – model selection and combination (2)

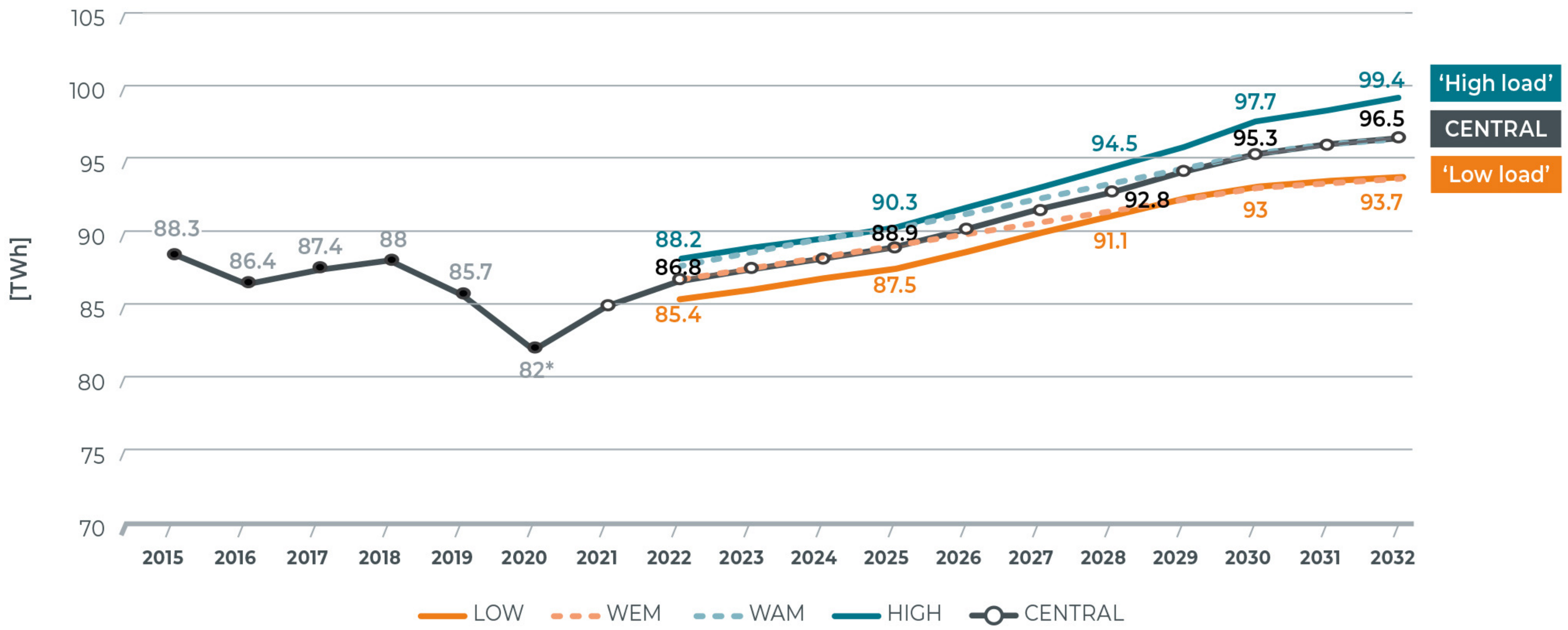


Accuracy does not solely depend on better algorithms



Zufferey, T., Ulbig, A., Koch, S., & Hug, G. (2016, September). Forecasting of smart meter time series based on neural networks. In *International workshop on data analytics for renewable energy integration* (pp. 10-21). Springer, Cham.

How do you even test certain long-term forecasts?



* the 2020 value is an estimation

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Adapted from Elia Report 2021

Emerging challenges (1)

- How to activate distributed flexibility with millions of DERs
  - Robustness guarantees
  - Incomplete and missing information
- How to determine counterfactuals in flexible mode operation?
  - A/B testing
  - Model-driven approaches
- How to keep trigger-happy data scientists in check?
  - Occam's razer
  - Deep / reinforcement learning is not always the answer

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Emerging challenges (2)

- Operationalizing ML
  - Code is often versioned, but data, models, experiments and predictions are not
  - Ensemble models win competitions but create operational nightmares
  - *Torch. manual_seed (3407) is all you need*

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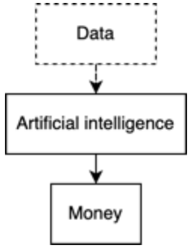
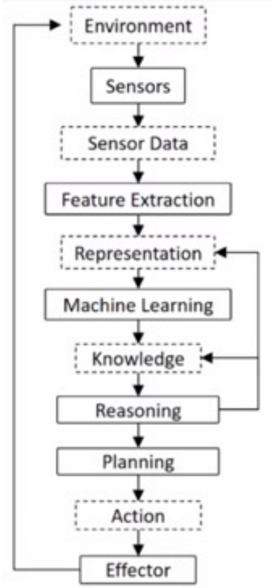
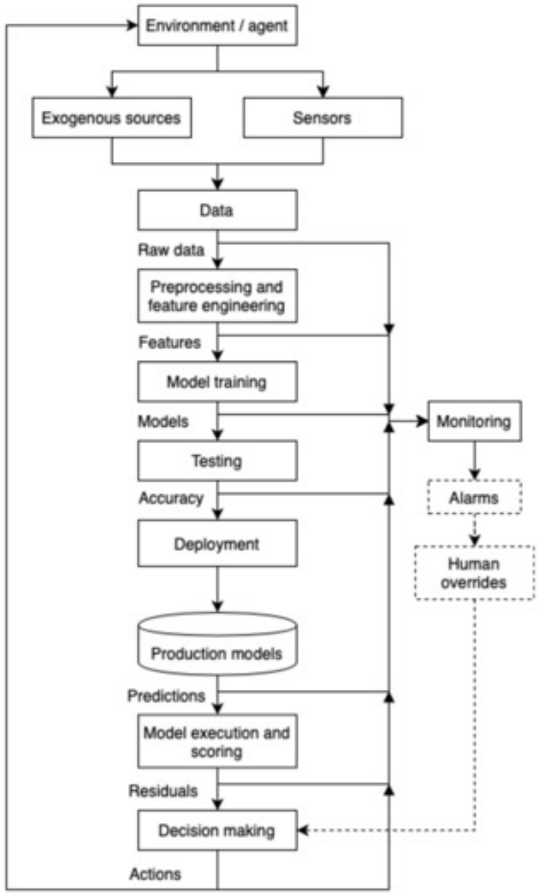
From data to insights and decisions: machine learning



Expectation

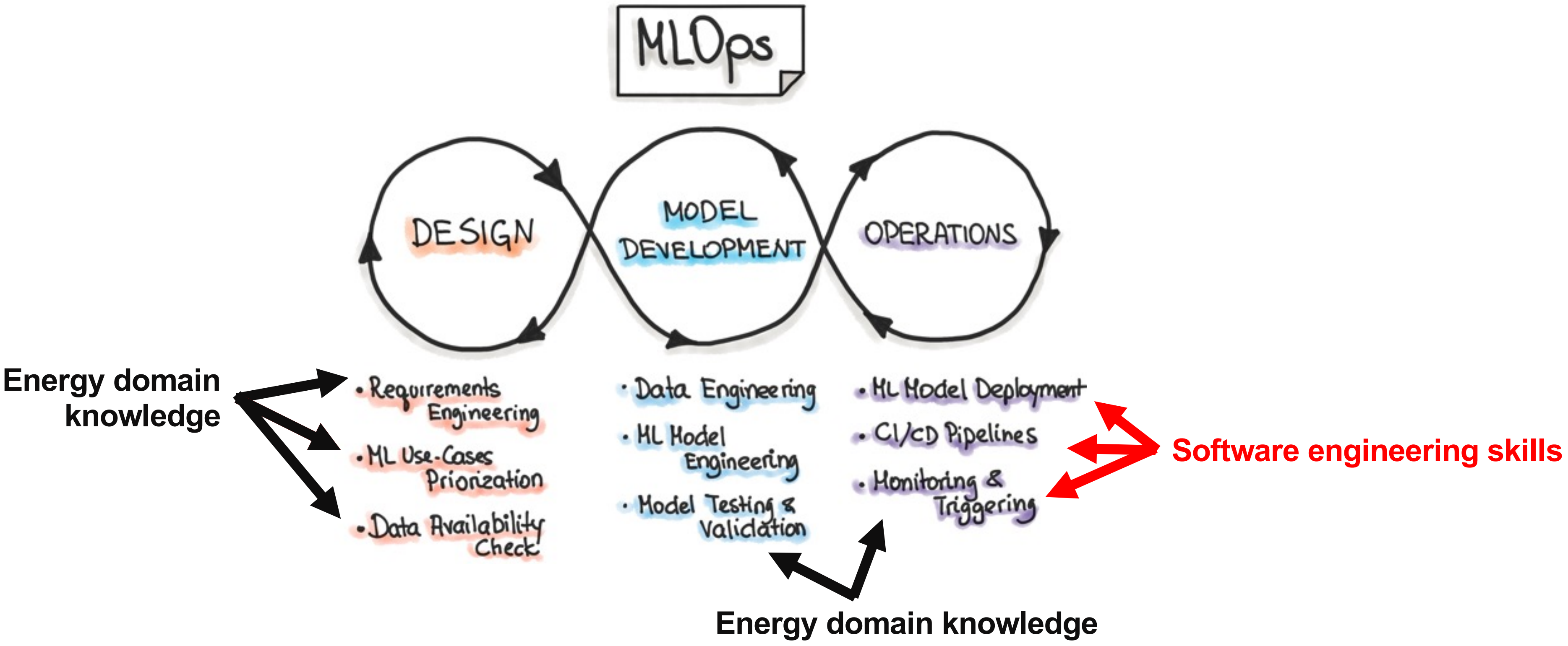


Text books



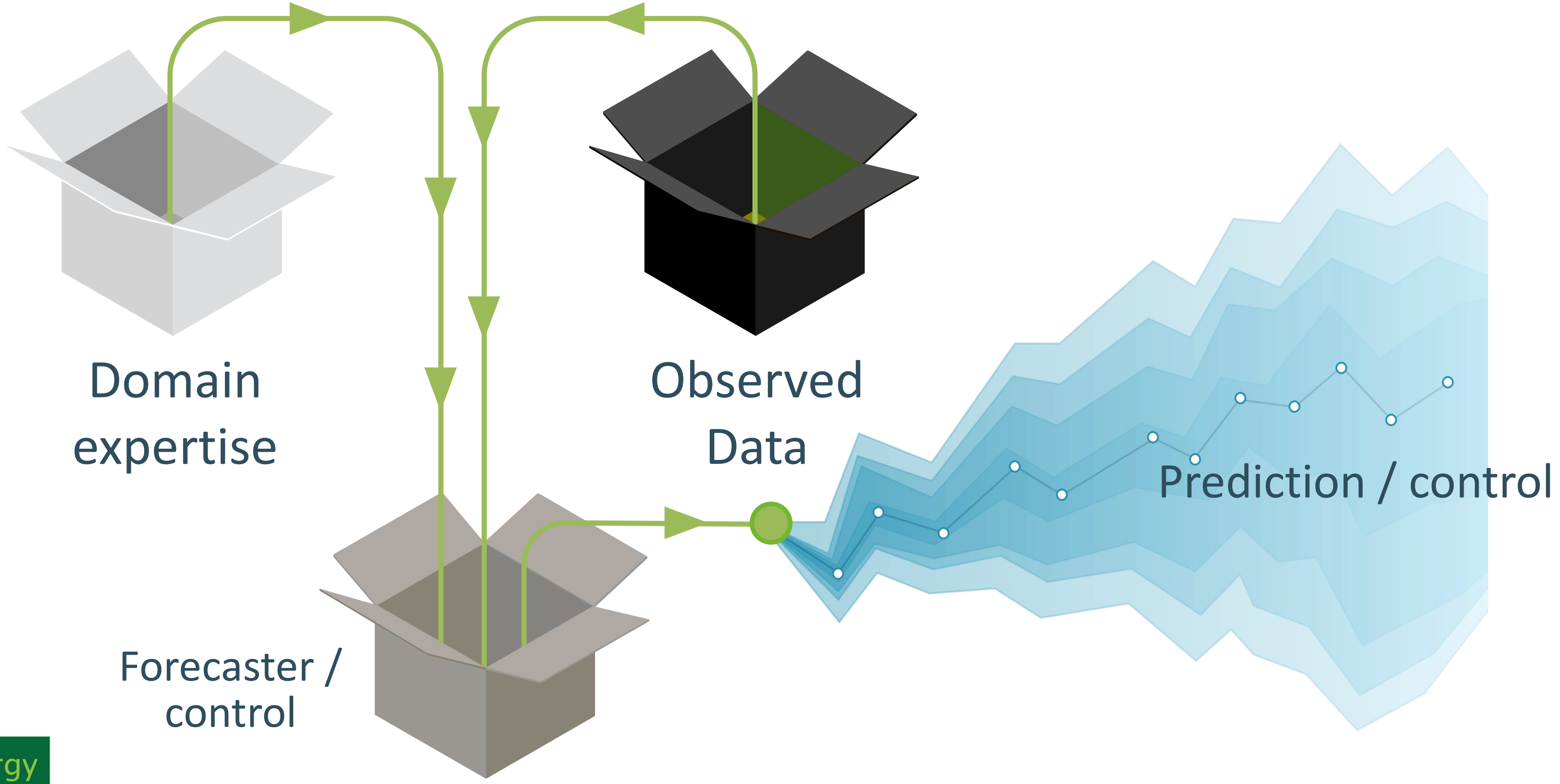
Real world

The future control room requires integration of many skills

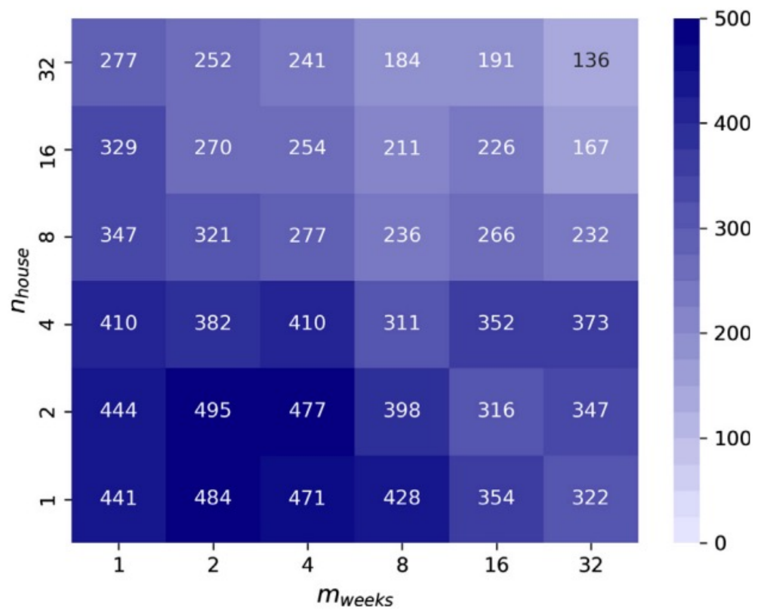


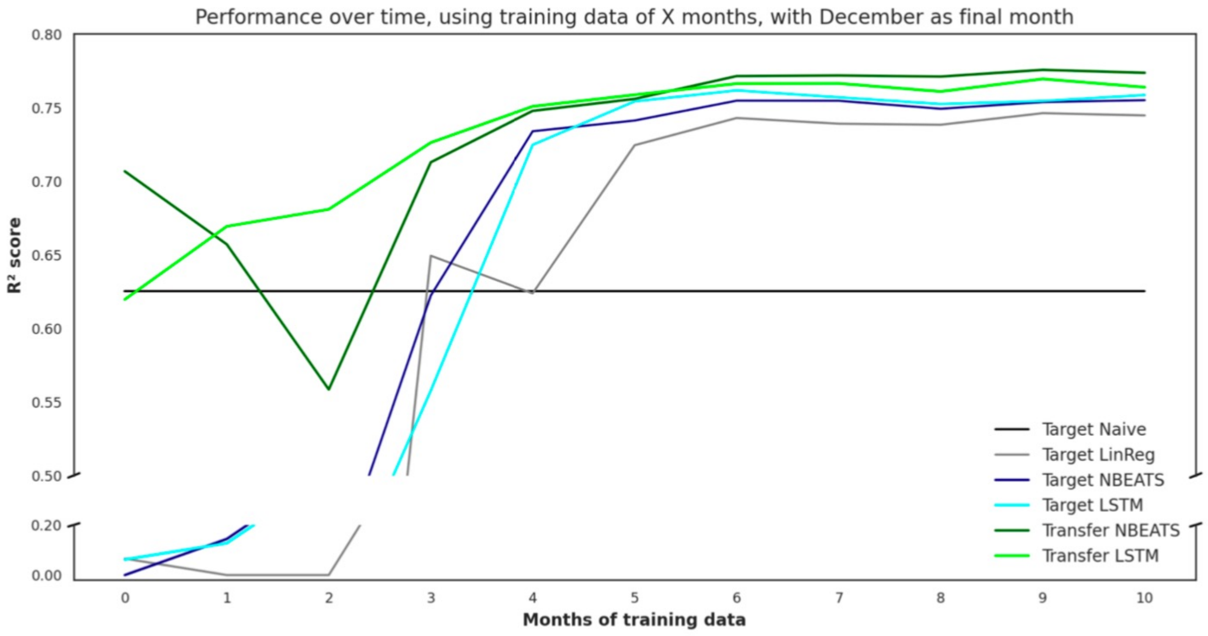
Valohai, MLOPs, 2021

Fusing domain expertise with ML



Collaborative and transfer learning





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Kazmi, H., Suykens, J., Balint, A., & Driesen, J. (2019). Multi-agent reinforcement learning for modeling and control of thermostatically controlled loads. *Applied energy*, *238*, 1022-1035.

The road ahead

Feature stores and the rise of service providers (FaaS, Caas, …)

Privacy aware learning and control techniques (fed. Learning, diff. privacy, …)

Value oriented forecasting

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Future needs for decision support tools

- Develop tractable methods, which are sufficiently accurate
- Choice of steady state operational points considering system dynamics
- Dealing with uncertainty: How to find control actions, which are robust with respect to many operational scenarios?
- Risk-based operation of the power system: Finding trade-offs between preventive and corrective actions based probability of system states, contingencies, and their impact
- Visualisation: How to convert data in useful information?

Thank you for your attention!

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List of open source EnergyVille toolboxes

- *PowerModelsACDC.jl*
  - A hybrid AC/DC OPF package based on PowerModels.jl
  - *https://github.com/Electa-Git/PowerModelsACDC.jl*
- *OptimalTransmissionRouting.jl*
  - *https://github.com/Electa-Git/OptimalTransmissionRouting.jl*
- *PowerModelsDistributionStateEstimation.jl*
  - A Julia Package for Power System State Estimation
  - *https://github.com/Electa-Git/PowerModelsDistributionStateEstimation.jl*
- *FlexPlan.jl*
  - An open-source Julia tool for transmission and distribution expansion planning considering storage and demand flexibility
  - *https://github.com/Electa-Git/FlexPlan.jl*
- *StochasticPowerModels.jl*
  - An extension package of PowerModels.jl for Stochastic (Optimal) Power Flow
  - https://github.com/timmyfaraday/StochasticPowerModels.jl

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