Challenges in Cyber-Physical Energy Systems

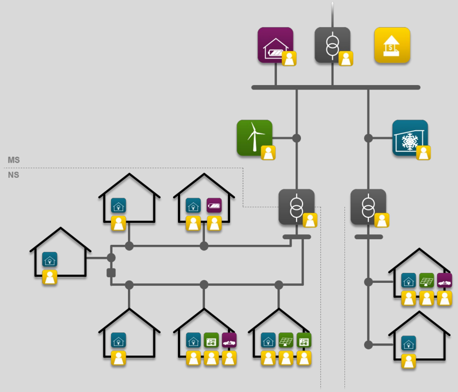
- of agents and data -

Astrid Nieße| Uni Oldenburg & OFFIS

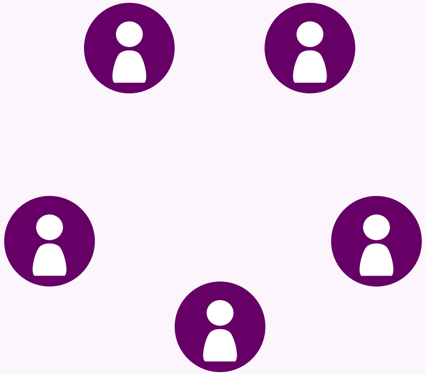
Digitalisierte Energiesysteme

Challenges in Cyber-Physical Energy Systems

- of agents and data -



CPES



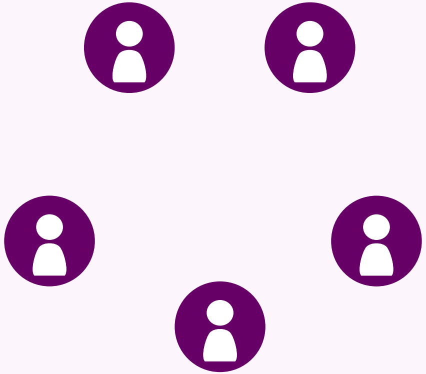
multi-agent systems

data

Challenges in Cyber-Physical Energy Systems

- of agents and data -

buzzwords & bosses



multi-agent systems

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Challenges in Cyber-Physical Energy Systems

- of agents and data -

buzzwords & bosses

visions & excitement

data

Challenges in Cyber-Physical Energy Systems

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buzzwords & bosses

visions & excitement

pain

Cyber-physical energy systems

On the power of buzzwords

Once upon a time …

Cyber-physical energy systems

New challenges

Energy systems are critical infrastructures (CRITIS)

Phenomena and instabilities can spread in short time

- Connected systems on both information and electro-technical system layer
- Instabilities might cascade in real-time
- Cross-sectoral effects

Digitalization comes with new challenges

- Security
- Complexity
- Regulation

Multi-criteria optimization means conflicting goals

- Monetory, technical, political, …

Just in the middle of a fundamental transformation ...

Handle Complexity

Adaptive Control
Flexibility Potential

Transformation
Innovation

Cyber-physical energy systems

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Cyber-physical energy systems

New challenges: Handle complexity

Restruct: Integration, segregation und substitution of system componentes

Scalability

Security

Safety

Relocation of functionality

Integration with existing SCADA-systems

Compatibity

Real-time requirements

Data analytics

Constraints and effects across sectors

Cyber-physical energy systems

New challenges

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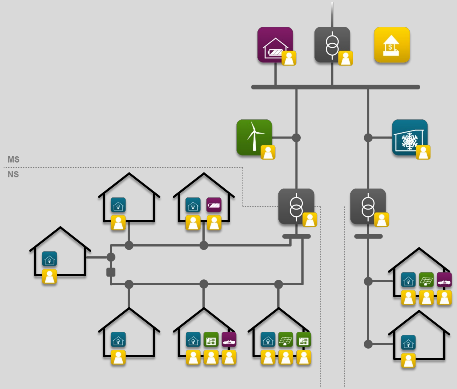
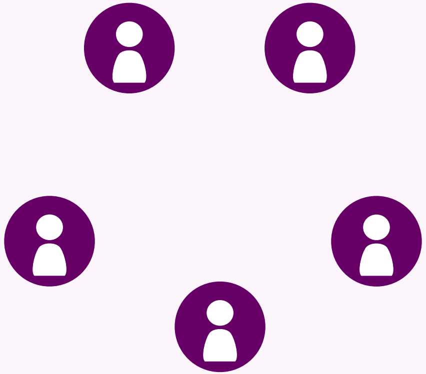
Challenges



buzzwords & bosses
CPES

Adaptive Control Flexibility Potential



multi-agent systems

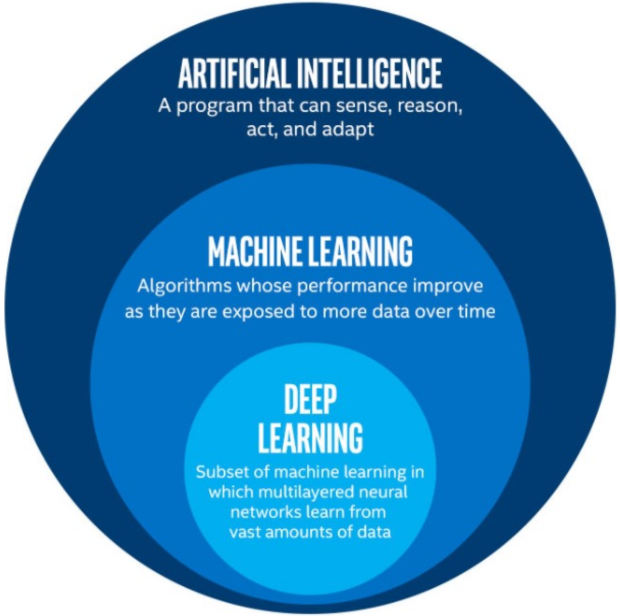
Transformation Innovation

data

Controlled Self-organization & Artificial Intelligence

*"Artificial Intelligence is the science of making **machines** do things that would require **intelligence*** *if done by* ***men***."

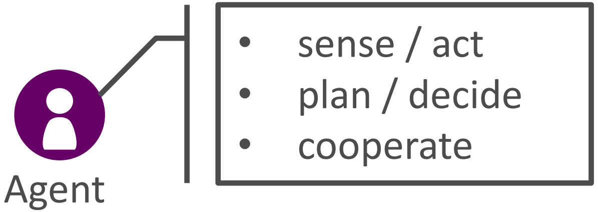
- Marvin Minsky, 1966



Distributed Artificial Intelligence

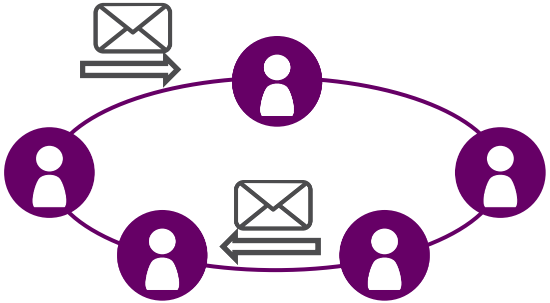
For controlled self-organisation

Distributed AI is a part of AI research dealing with the development of **distributed solutions** for complex and / or large scale problems.



Technical basis: Multi-agent systems

> Software agents = intelligent, autonomous software
>
> Multi-agent systems = communicating and interacting agents with special characteristics
>
> Includes learning / trained models



Simple agents, complex systems

Nature-inspired coordination and emergence

Emergence in MAS

- Reduced complexity by simple agents
- Complex system response as emergence from interacting agents

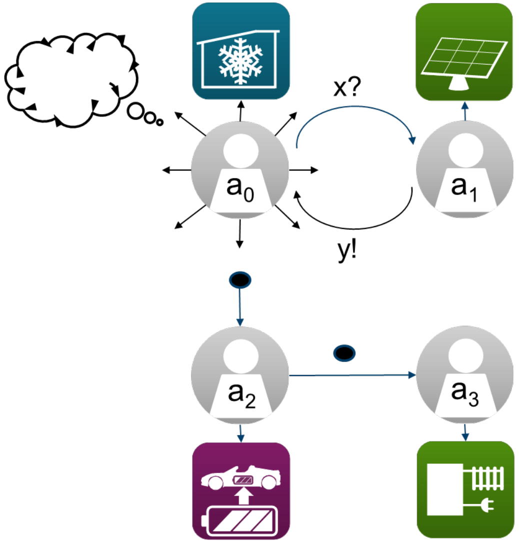
Self-organization

- Avoid Single-Point-of-Failure problems by distributing control

Quelle: Touahmi, Yaniss & Burlutskiy, Nikolay & Lee, Kongwoo & Lee, Beom. (2012). Congestion Avoidance for Multiple Micro-Robots Using the Behaviour of Fish Schools. International Journal of Advanced Robotic Systems. 9. 10.5772/51190.

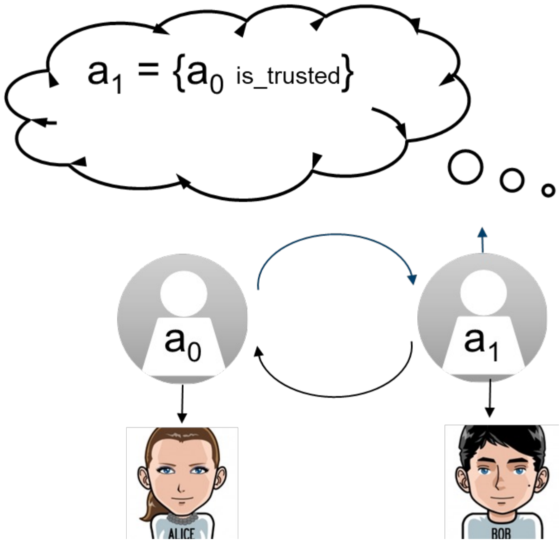
Agent-based control and agent-based simulation

Agent-based control



> Control components in the field

Agent-based simulation



> Understand interactions

> Design systems

Agent-based control

Plants, Network, Markets

Self-X-agent systems for the use of decentralized flexibilities

- Self-optimizing multi-purpose operation management in a swarm
- Self-organizing flexibility for decentralized redispatch
- Self-healing, blackstart-capable digitized distribution grids

Challenges addressed so far:

- *Algorithmic challenges:* Distributed Optimization Algorithms (COHDA, WINZENT)
- *Implementation challenges:* Appropriate agent framework – from design phase to the field (ongoing: mango)
- *Co-simulation challenges:* Modeling of the communication infrastructure (OMNET, mosaik-coupled)
- *Transfer to the field challenges:* Agent-based simulation & co-simulation to lab testing to hybrid testing to the field (battery storage swarm in field test)

Time warp …

2012 Research project Smart Nord: Dynamic Virtual Power Plants

2015 Foundation of a start-up for flexibility placement on energy markets based on dynVPPs

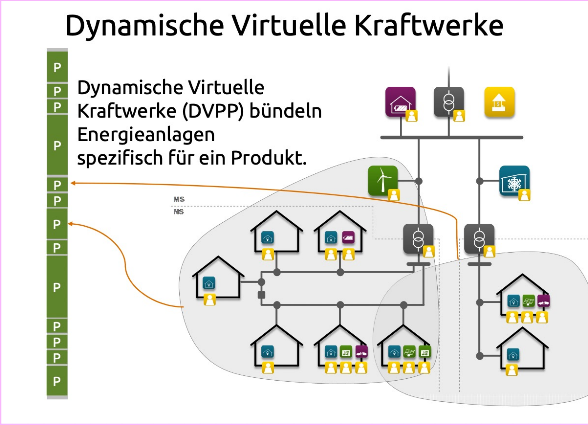
Stopped start-up and reintegrated tool in research activities

Developed OSS aiomas → later: mango for agent-based control

2018 Extended view on system operation and resilience

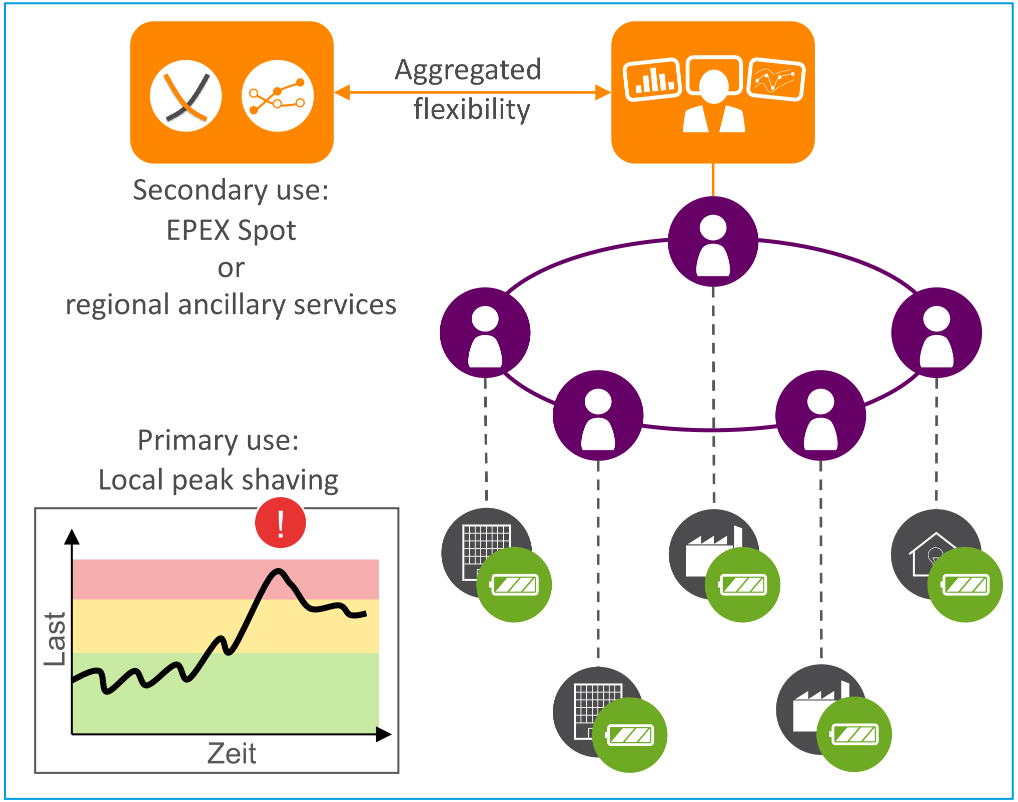
Began to answer industry requirements “we need agents!“

2022 Field trial for FCR successfully finished, products at industry partners



Agent-based control of a swarm of batteries

A project done with be.storaged GmbH



Battery storage as crucial components for energy system transformation

- Primary use: Peak load control in industry
- Use remaining flexibility for grid and market purposes

Distributed battery swarm

- Software agents with autonoumous characteristics
- Fast and robust optimization

Pilot project tested in the field

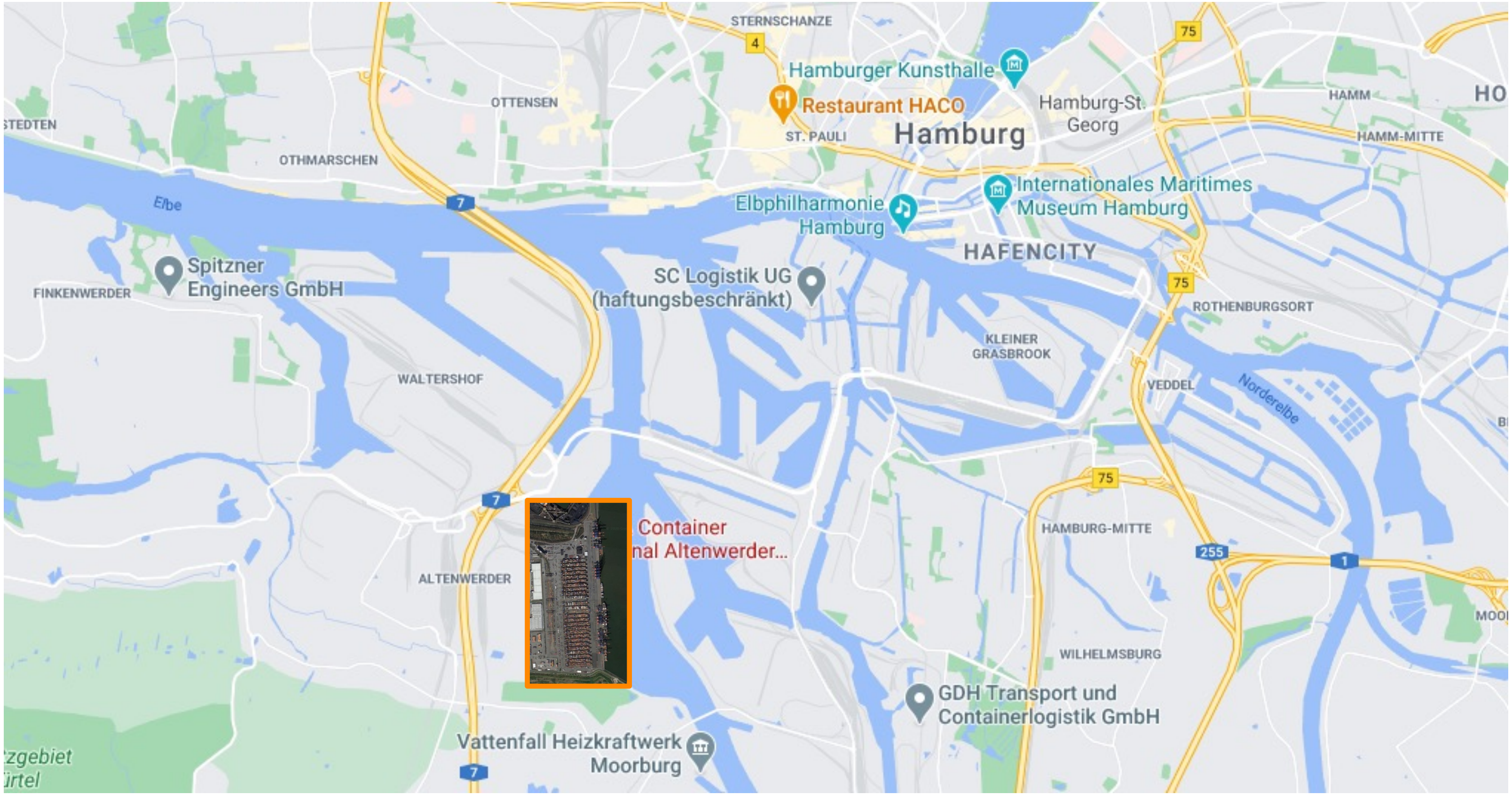
- be.storaged as lead partner

Flexibility Management and Provision of Balancing Services with Battery-Electric Automated Guided Vehicles in the Hamburg Container Terminal Altenwerder

IKT FÜR ELEKTROMOBILITÄT

Container Terminal Altenwerder (CTA)

Setting the scene



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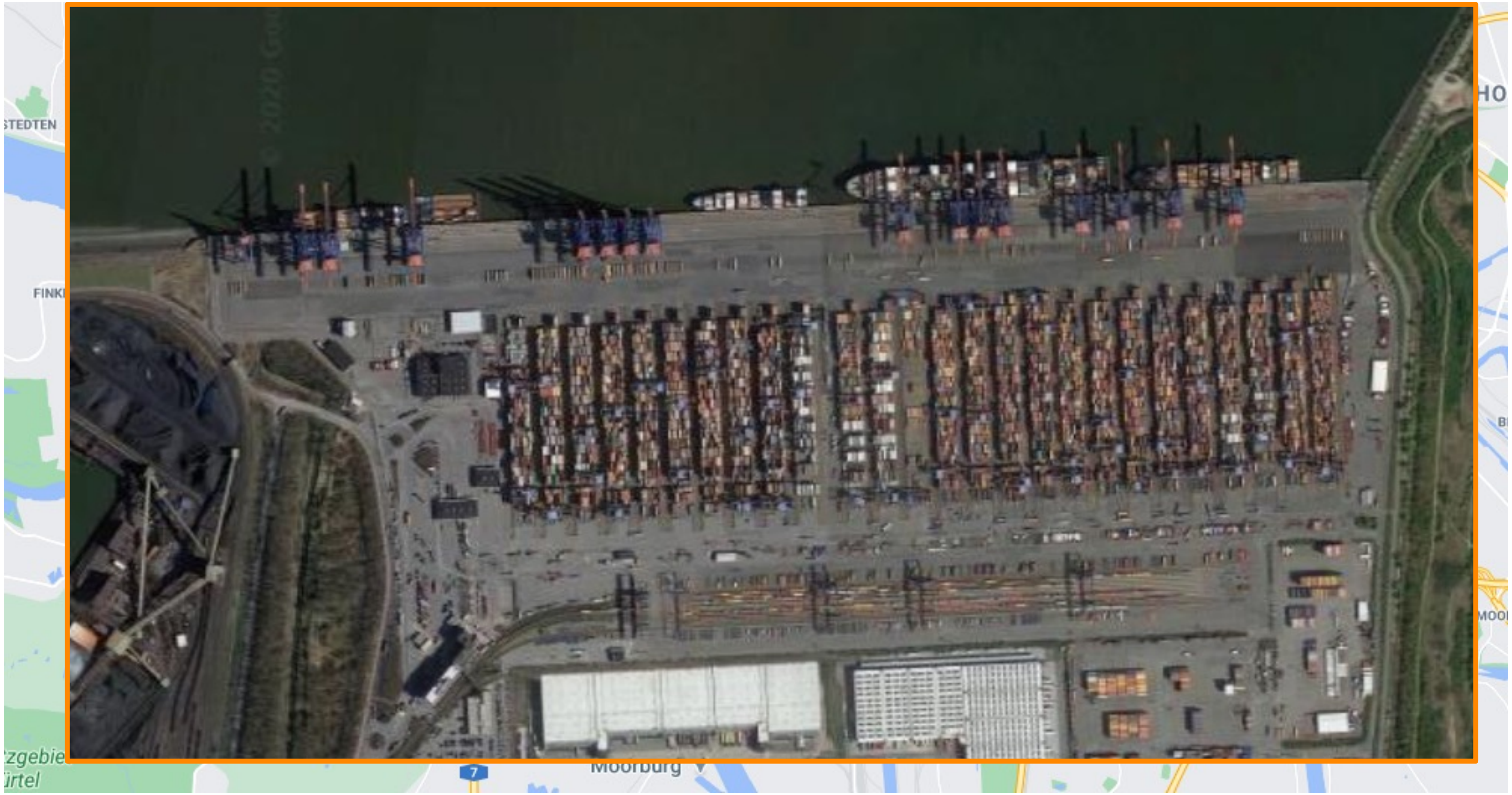
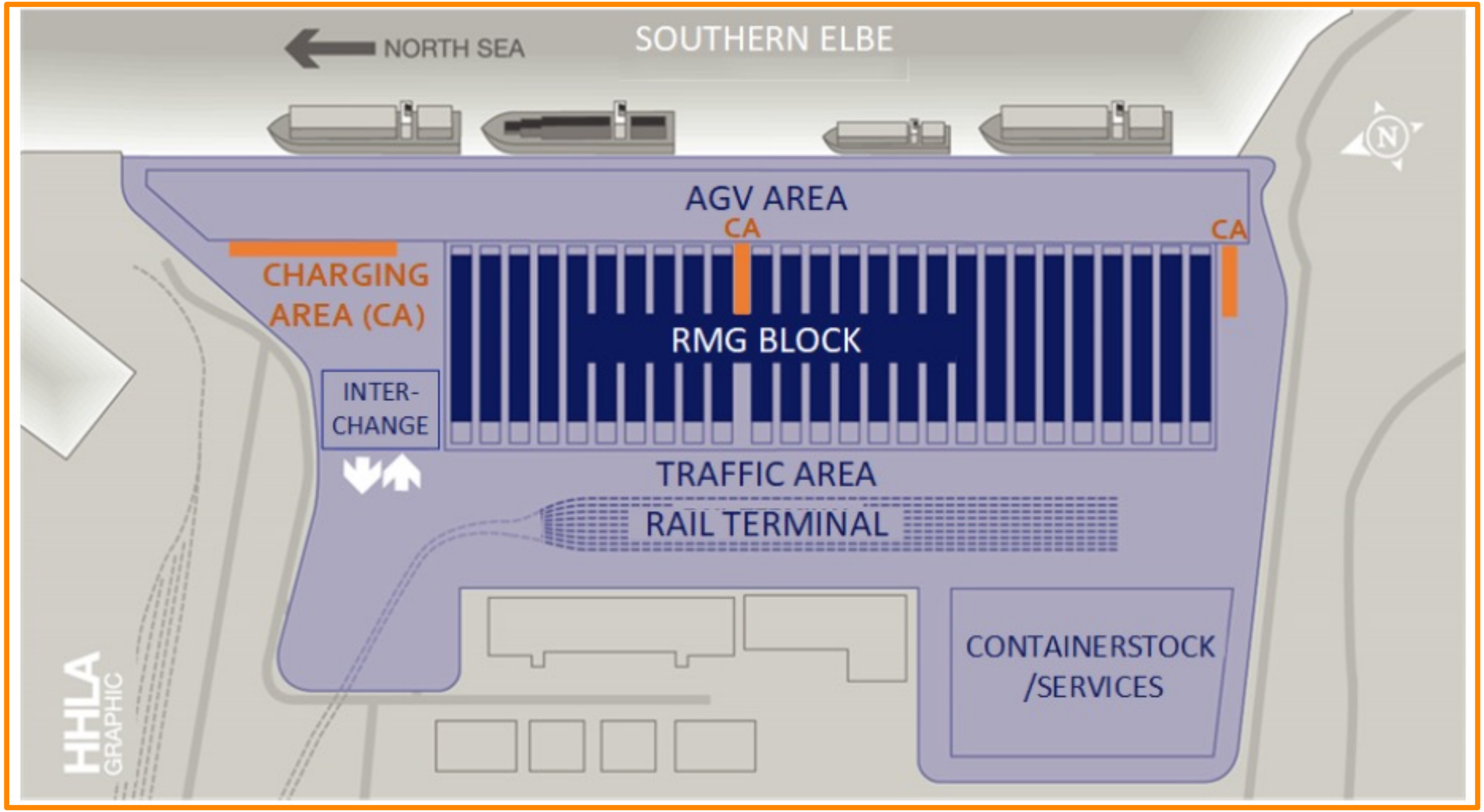
Container Terminal Altenwerder (CTA)

Setting the scene



Container Terminal Altenwerder (CTA)

Schematic layout



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Battery-electric Automated Guided Vehicles (AGVs)

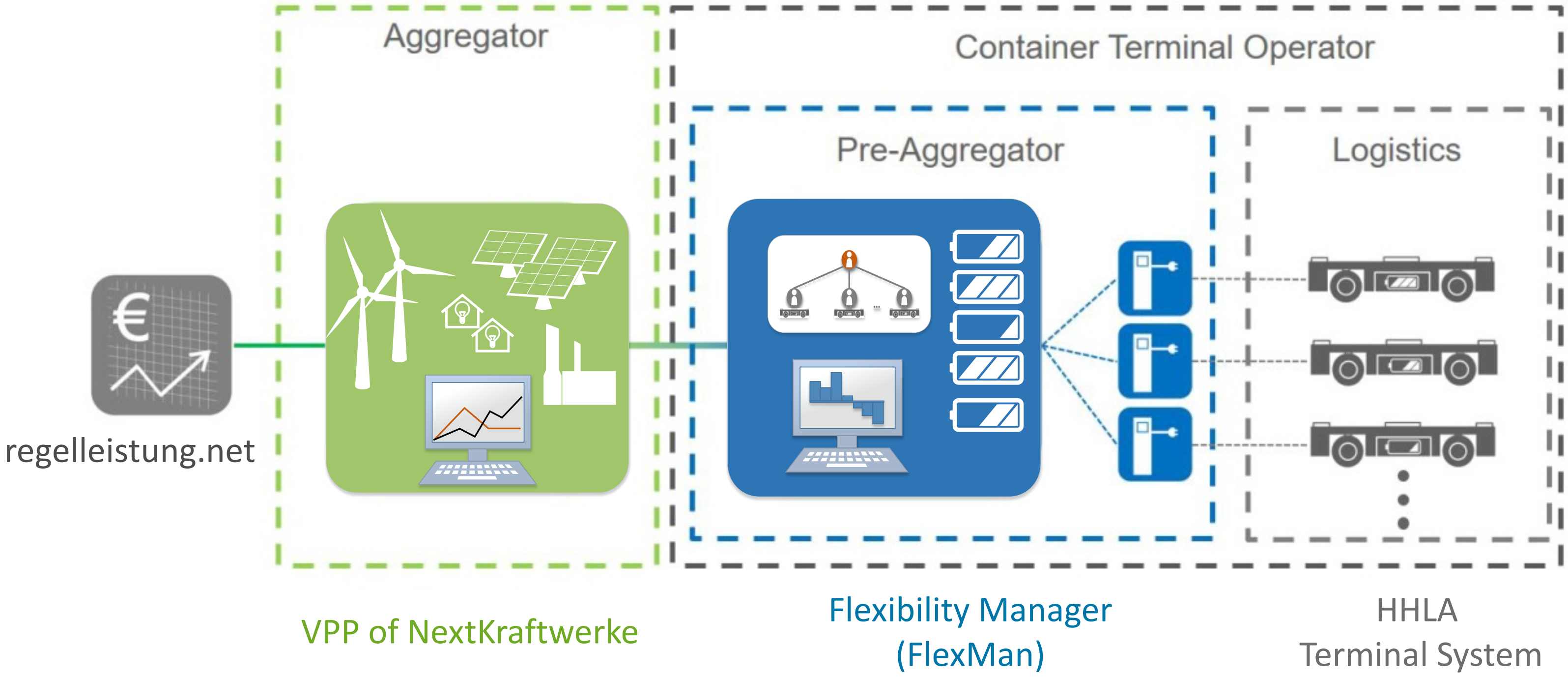
Electrification (Li-Ion) of formerly diesel-electric AGV fleet

Images provided by and copyright with HHLA.

90 battery-electric AGVs + 18 Automated Charging Stations ≈ 4 MW symmetrical flexibility

Provision of Frequency Containment Reserve

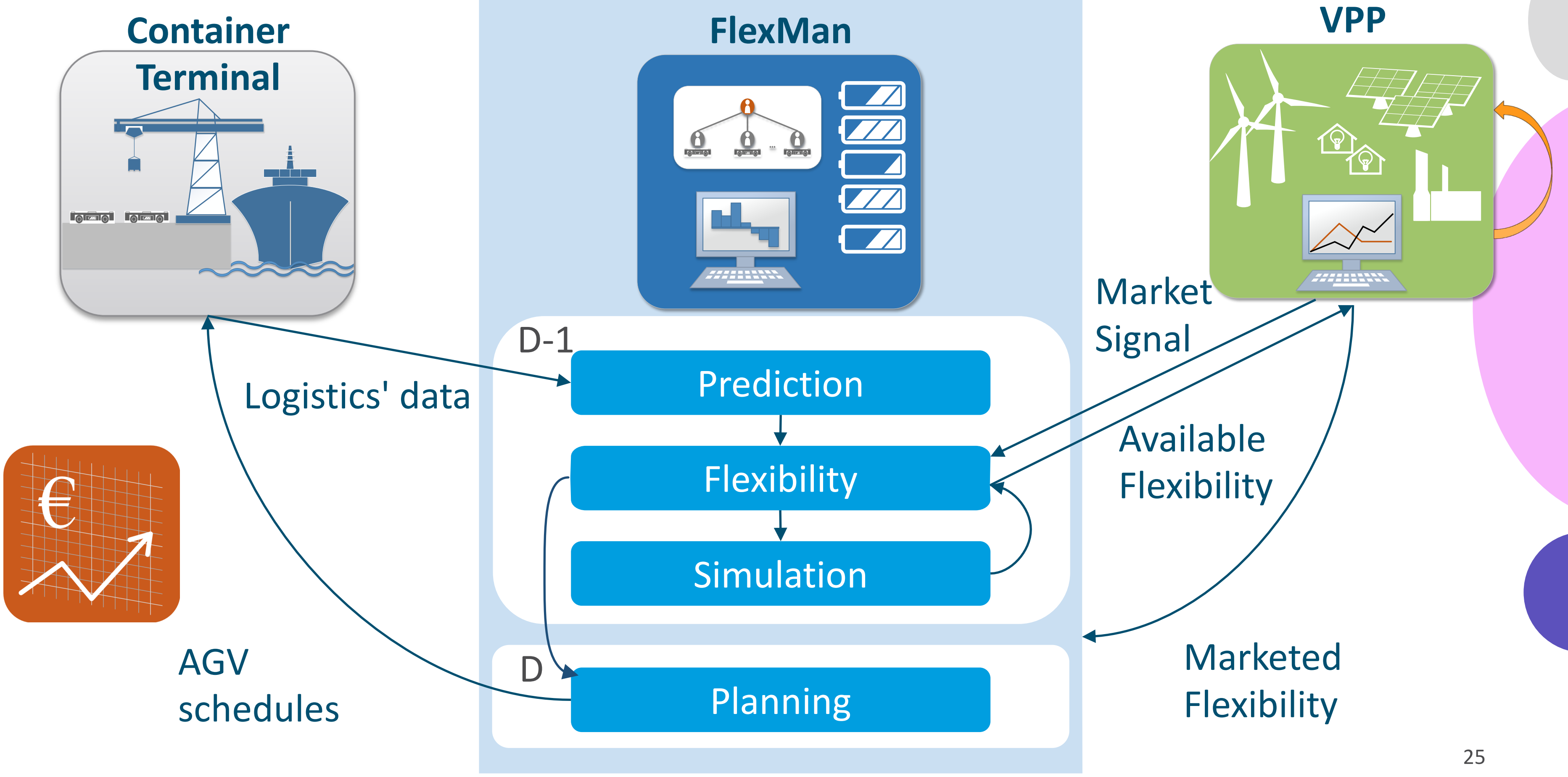
Schematic system overview



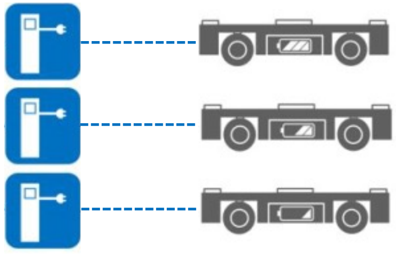
Challenge: Reliably providing flexibility without disturbing the logistical processes.

Provision of Frequency Containment Reserve

Process



What is flexibility?

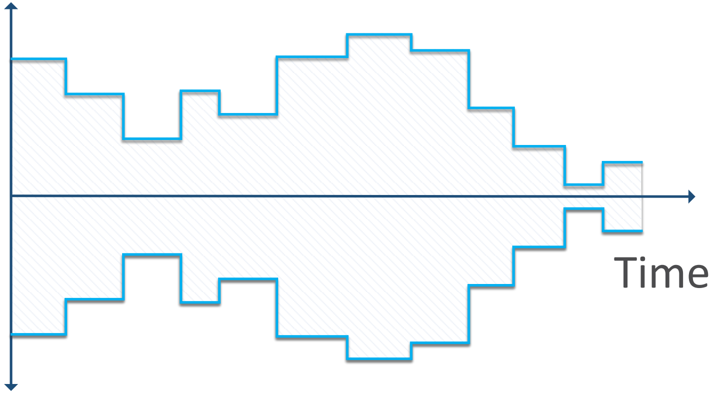


Number of AGV and ACS per time interval that can be removed from the logistics process without impairing it

Marketable symmetric flexibility

Power (kW)

0



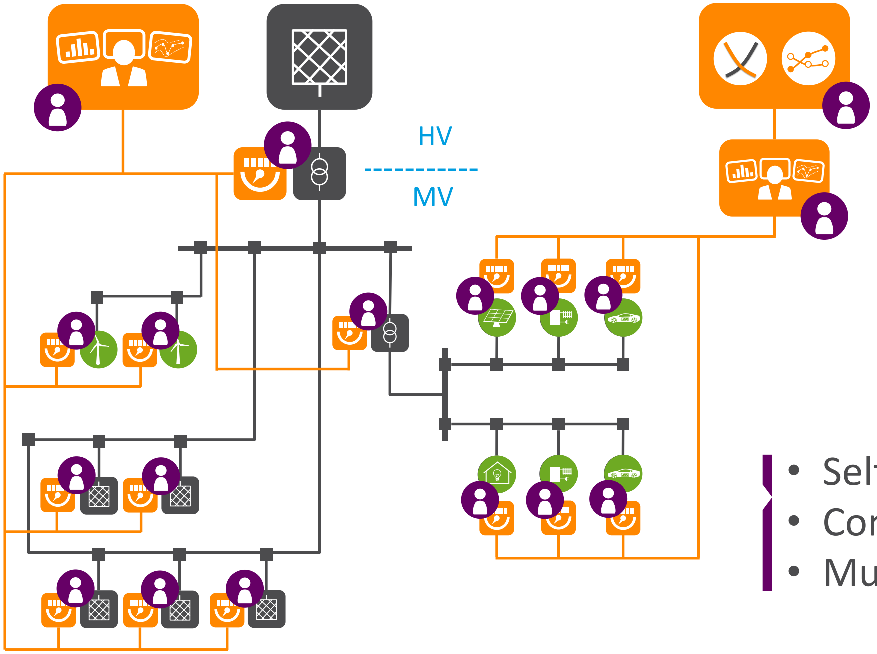
Time (15-minute blocks)

Vision: AI-empowered Energy Systems

Decentralized, decarbonized, efficient and resilient CPES operation

- State estimation
- Anomaly detection
- Learn cyber-resilience strategies

- Learn constraints & operation
- Distributed ancillary service provision



- Forecasting
- Learned & algorithmic trading

- Self-organized aggregation
- Contractable behavior
- Multi-modal optimization

Agents: Towards Controlled Self-Organization in the Field

Wrap up & Lessons Learned

(1) Understand energy systems as self-organizing systems

> Use software agents as abstraction model

(2) Use observer/controller paradigm

> Tap potential of distributed systems in critical infrastructures

(3) Use the full range of distributed control and distributed algorithms

> Manage transformation to post-fossile energy systens

Bring some time & be humble

> Paradigms change not always in an interruptive manner
> System operation has to be guaranteed
> Understand regulatory constraints

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buzzwords & bosses

visions & excitement

data

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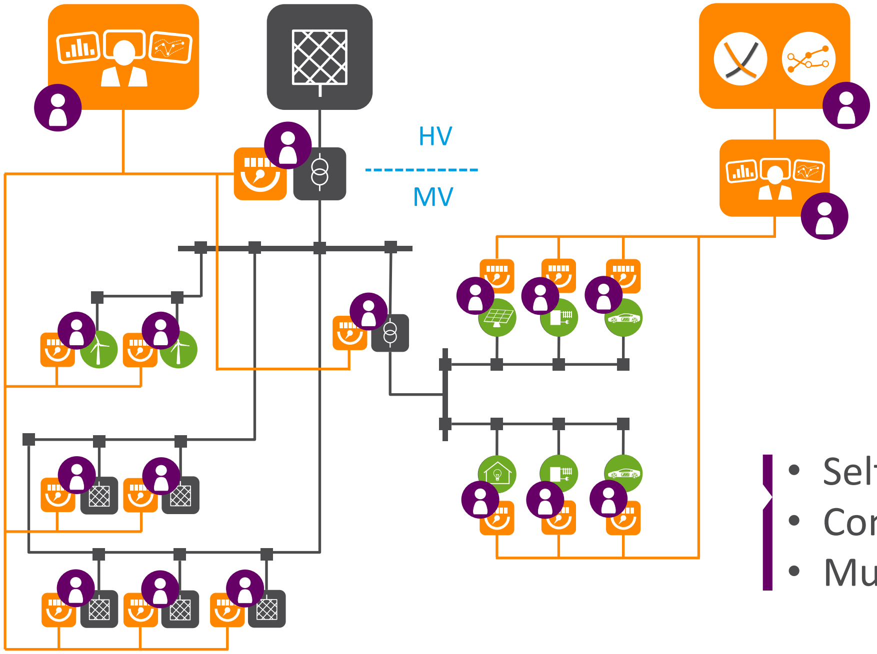
Learning is about data

- State estimation
- Anomaly detection
- **Learn** cyber-resilience strategies

- **Learn** constraints & operation
- Distributed ancillary service provision



- Forecasting
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Simulation is about data

- State estimation
- Anomaly detection
- **Learn** cyber-resilience strategies

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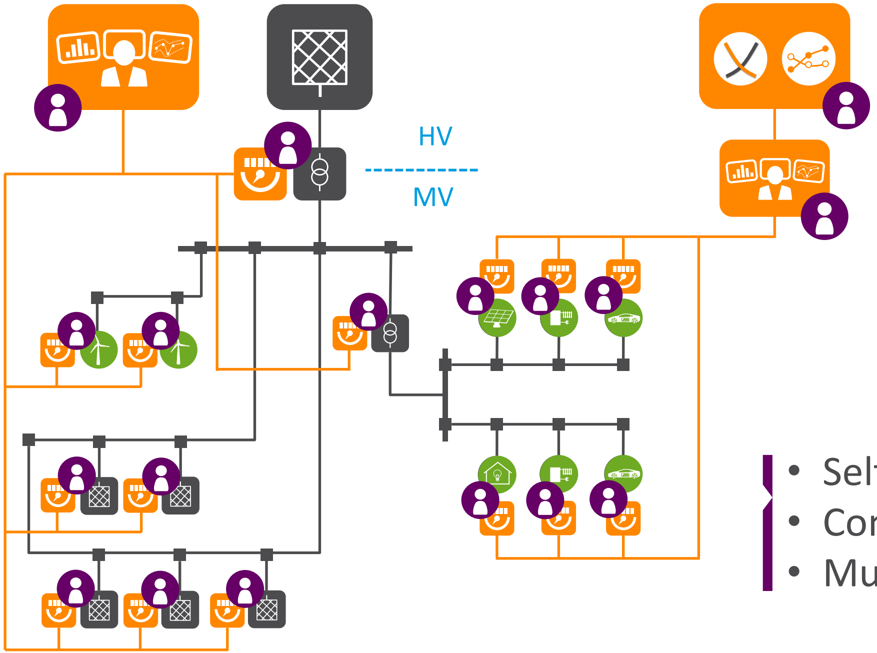

- Forecasting
- **Learned** & algorithmic trading

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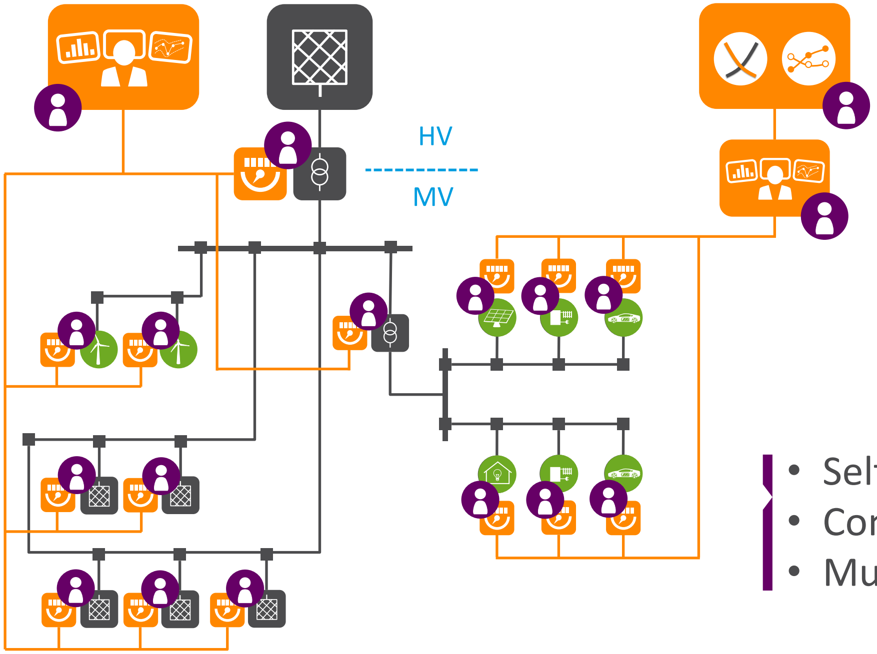
Preparation for field trials is about data

- State estimation
- Anomaly detection
- **Learn** cyber-resilience strategies

- **Learn** constraints & operation
- Distributed ancillary service provision



- Forecasting
- **Learned** & algorithmic trading

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Data – Digital Objects in Energy System Research

Still at the very beginning of a FAIR universe

Datasets

- Timeseries e.g. weather, power input (wind, solar…), demand
- Demographic data

Software

- Grid Computation Frameworks
- Co-Simulation Frameworks
- Agent-based sim. frameworks

Models

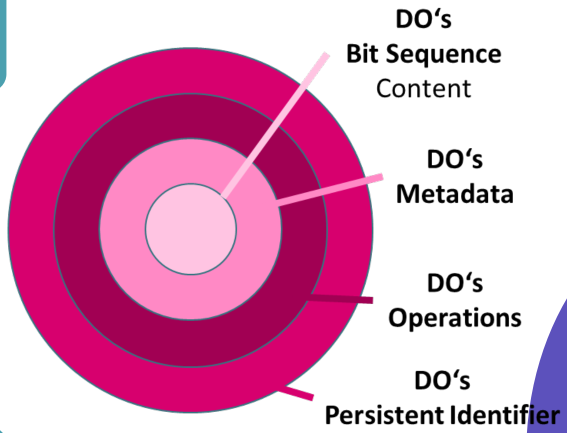
- Devices (Wind, PV, …)
- Networks, Operational models

Scenarios

- Energy system transformation long term / short term
- Benchmark grids and device configurations
- Benchmark/Reference scenarios
- User acceptance scenarios

Workflows

- Detailed simulation configuration
- Best practices for public involvement



Based on Wittenburg et al. 2019

Data in CPES research

FAIRness is still to come

> Findability
> Accessibility
> Interoperability
> Reusability

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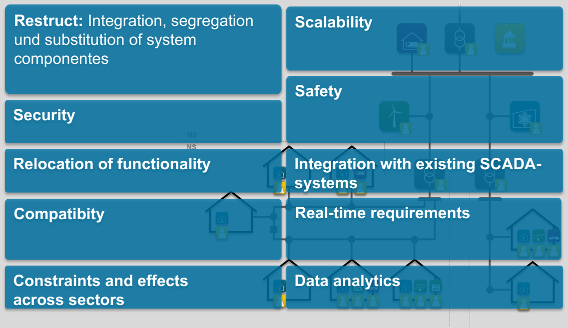
CPES

Handle Complexity



multi-agent systems

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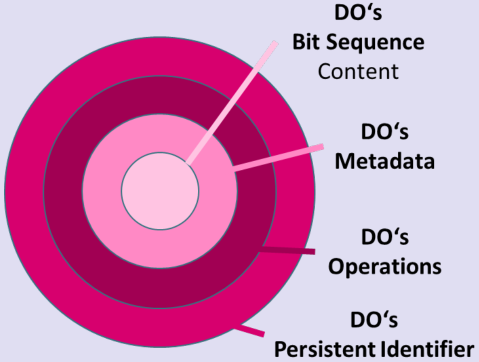

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