technische universität
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Institut für
Energiesysteme, Energieeffizienz
und Energiewirtschaft

SIMONA: Agent-based Discrete-Event Simulation Environment for Electric Power Distribution System Analysis

Energy Informatics - Vienna, 04.10.2023

Introduction and workshop agenda

Introduction and Overview

Introduction

Thomas Oberließen

- Industrial Engineer and
- PHD Candidate at ie3 institute since 2021
- Agent based simulation and ML-Application

Daniel Feismann

- Electrical Engineer and Industrial Engineer
- At ie3 institute as PhD Candidate since 2022 before at grid operator and utilities
- Research on grid planning approaches and congestion management

4-6 people + student assistants are working on SIMONA as of today

Introduction and Overview

Agenda

- Motivation and objective
- Core components and functional overview
- Concepts of Agents and their behaviour
- Coffee Break
- Excursion PowerSystemDataModel
- Flexibility and DMS
- SIMONA in research projects
- Wrap-up

Motivation and objective

SIMONA - Motivation and objective

Energy transition is massively changing electrical energy system

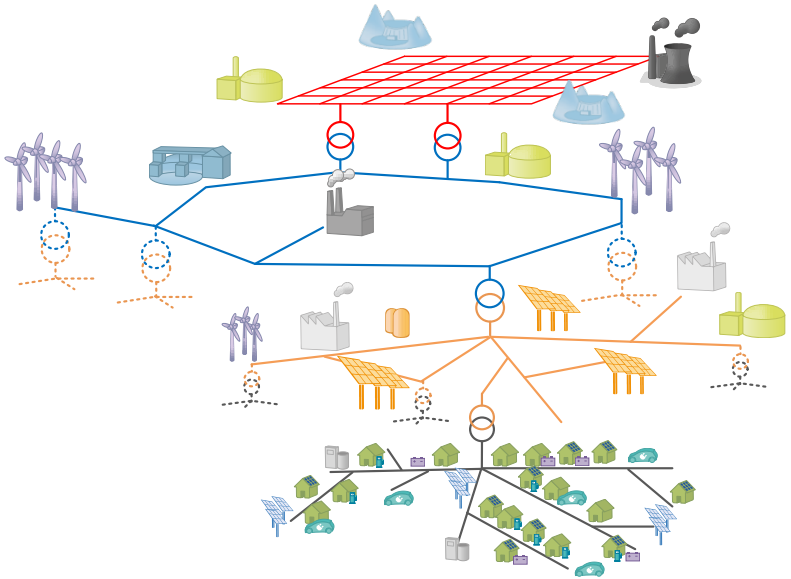
Change in supply task

- Conventional power plants ↘
- Renewable energies ↗
- Sector-coupling ↗
- Electric vehicles ↗

Effects on distribution grids

- Increasing system complexity
- Increasing volatility
- Network planning and operation are becoming more complex
- Increasing dependence between network planning and operation

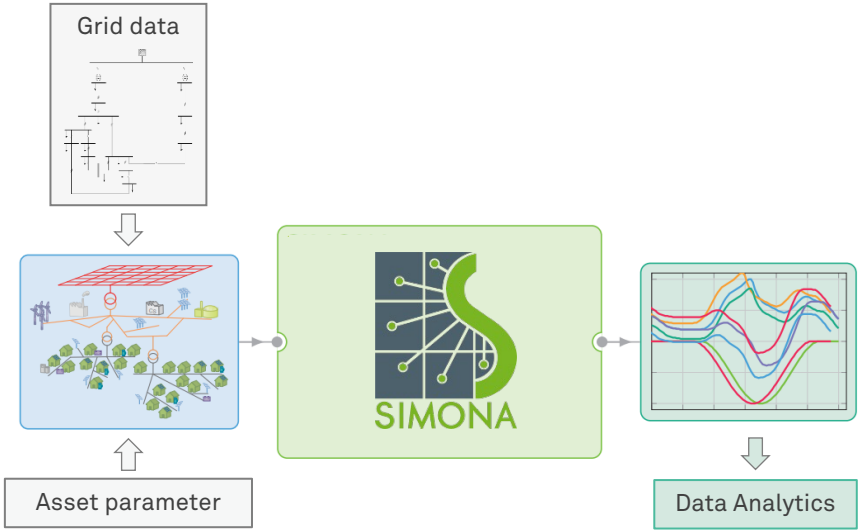
➢ Flexible models for system simulation for planning, operation and analysis purposes are needed



SIMONA - Motivation and objective

SIMONA is a digital representation of the energy system for simulation purposes

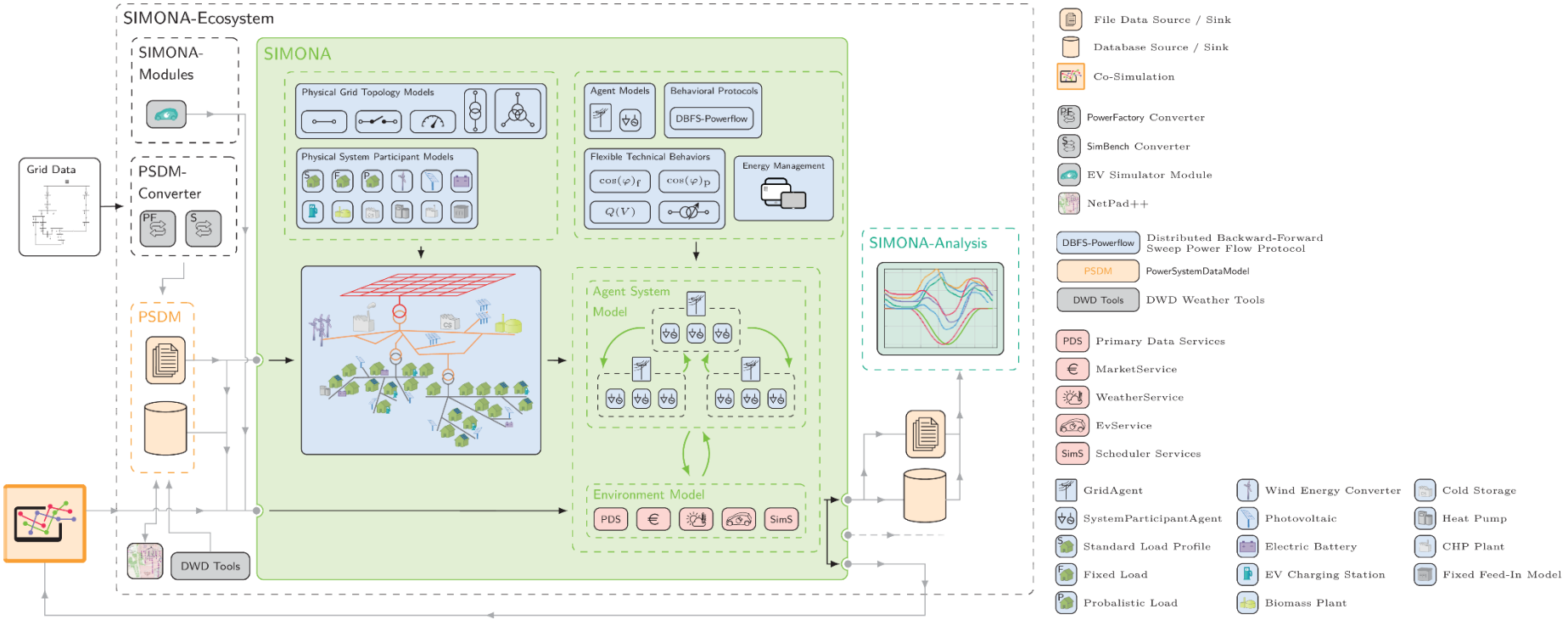
1. Feed-in and load simulation of plants
   - Physical operating behaviour
   - "User-centred" behaviour models
   - Flexible, controlled operation
2. Power flow calculation
   - Across voltage levels
   - Innovative, decentralized approach for large grids
   - Consideration of control systems
3. Time series generation
   - Quasi-dynamic with a resolution of up to 1 s
   - Feed-in and load time series
   - Grid utilization time series



Core components and functional overview

SIMONA – Core components and functional overview

SIMONA - The modular digital mapping of the energy system

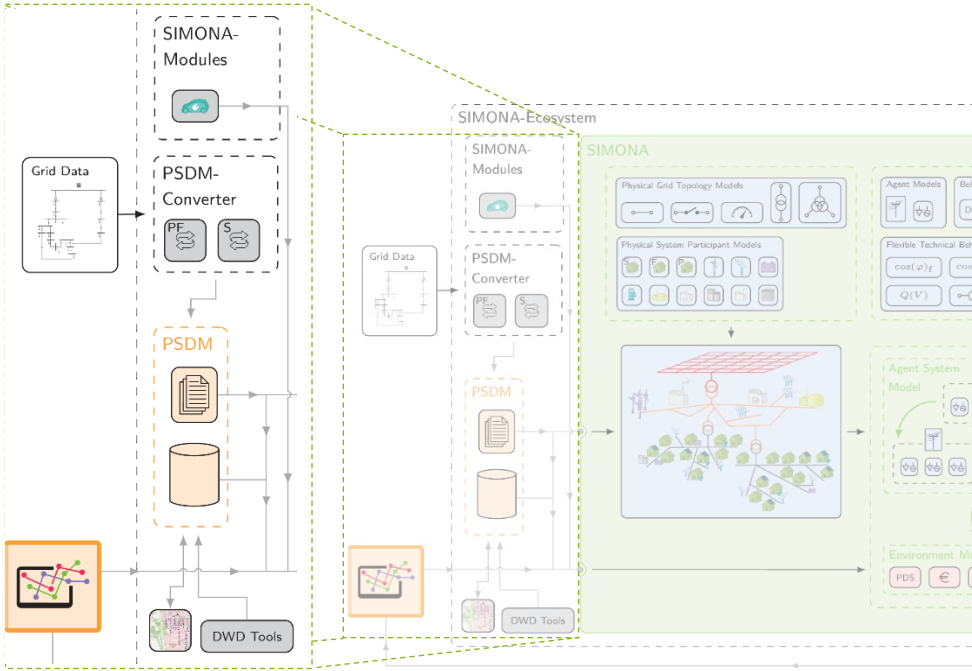


Based on: Hiry, J., *Agent-based discrete-event simulation environment for electric power distribution system analysis*. Düren: Shaker Verlag, 2021, ISBN: 978-3-8440-8462-7. DOI: 10. 17877/DE290R-22549.

SIMONA – Core components and functional overview

SIMONA is able to interface several input sources

- Grid converter to PowerSystemDataModel
- Mobility Simulation
- Weather Service interface (DWD)
- Time series interface for external time series data e.g. from smart meter



SIMONA – Core components and functional overview

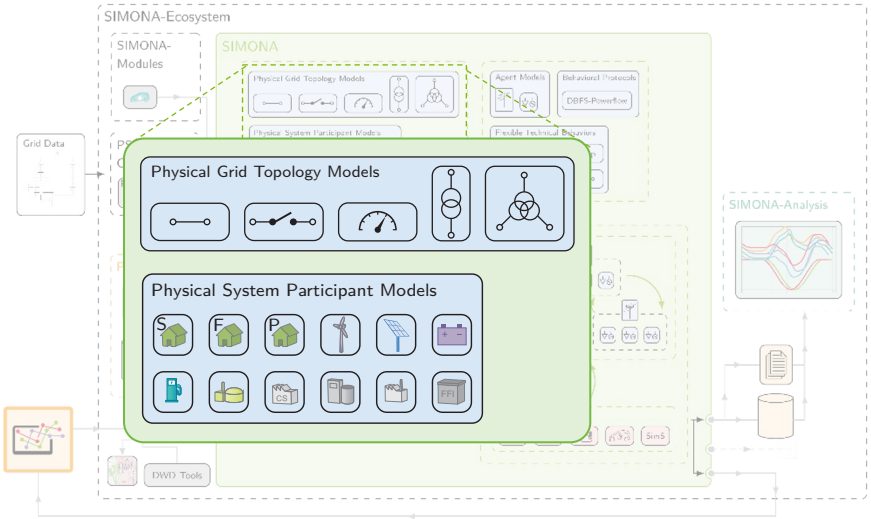
SIMONA includes all Grid Topology Models and several System Participants

System Participant Models

- Loads
  - Household load
  - Heat Pump, Storage and Thermal House Model
  - Electric Vehicle and Charging Station
- Renewable power generation (PV, Wind)
- Conventional power generation

Grid Topology Models

- Nodes, Lines, Transformers, …



SIMONA – Core components and functional overview

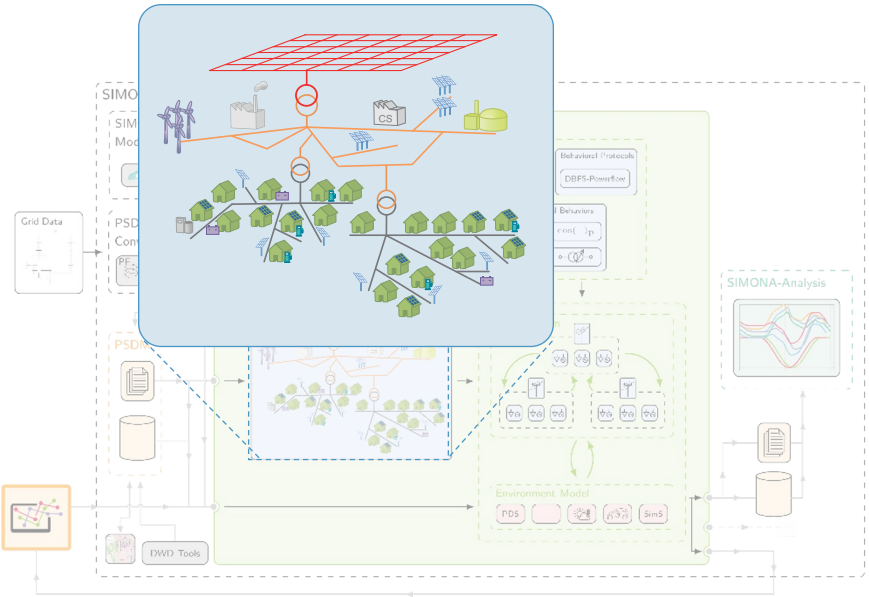
Grid and System Participant Assets form the electrical system

Resulting Power System Model

- Full technical description of the overall system
- Trade-Off between model specificity and ease of use

What's missing?

System Description → System Behavior → System Analysis



SIMONA – Core components and functional overview

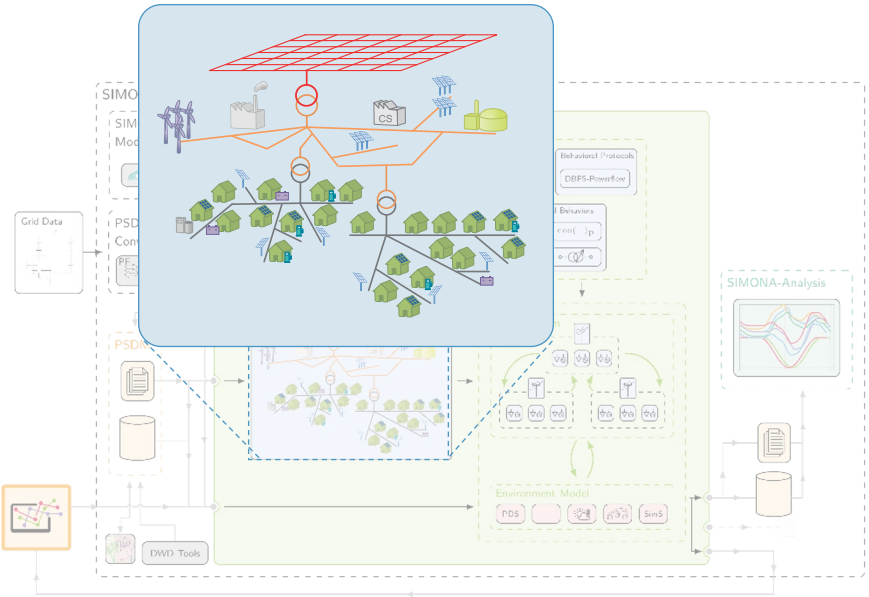
Grid and System Participant Assets form the electrical system

Input data + Grid Model = Grid analysis

- Enables time series-based system investigation
- Highly flexible and easy modelling
  - Topologies
  - Different scenarios
- Including detailed asset parameterization

Target:

Model grid and system participants according to requirements of analysis



Agents and their Behaviour

Agents and their Behaviour

What makes an Agent

Definition of an Agent

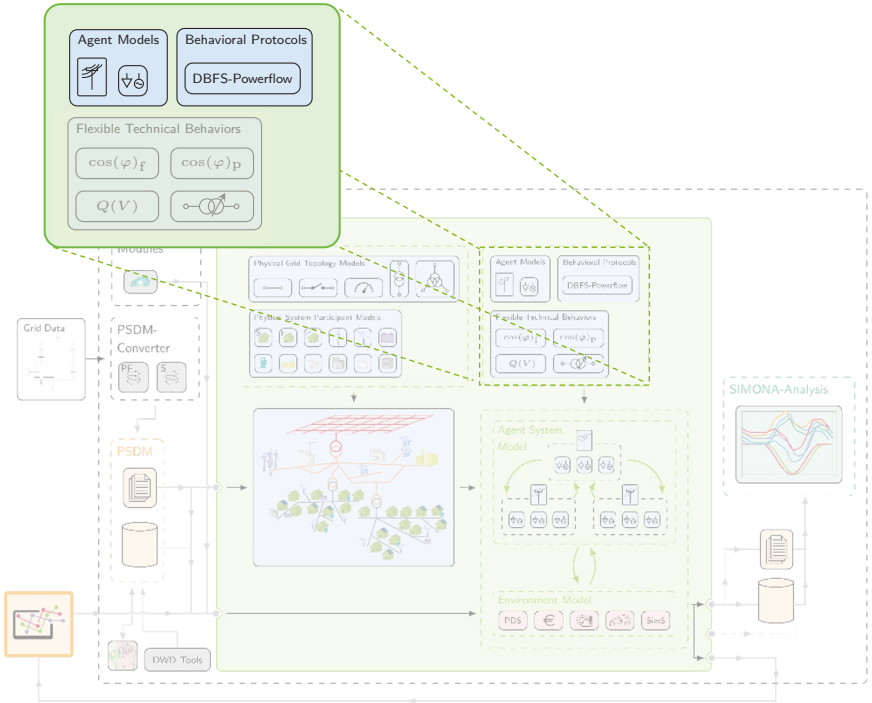
- .. depends on who you ask
- Communication, Autonomy, Negotiation

Decomposition Approach

- Every Agent is its own decoupled system
- “ Fear Less” concurrency
- Hides internal implementation details

Enables Internal Communication

- Agents can communicate with each other, and act based on their internal state and environment



Agents and their Behaviour

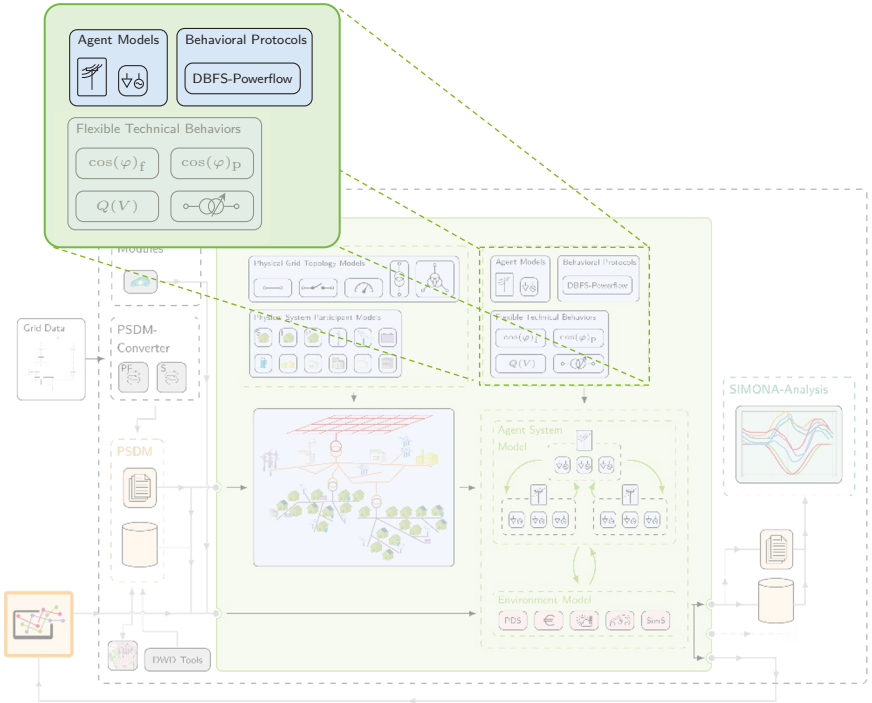
What makes an Agent

Agent Models

- Grid Agents
  - Represents the grid and communicates with agents connected to it's grid model
- System Participant Agents
  - System Participants of the system
  - E.g., PVs, Loads, EVs, ...

Behavioral Protocols

- Agent interaction is defined by behavioral protocols
- E.g., Power Flow communication



SIMONA – Core components and functional overview

The Simulation Environment Model

Like in real life, agents act in an Environment

- Encompasses information that can influence the agent's behaviour

The environment is described by services

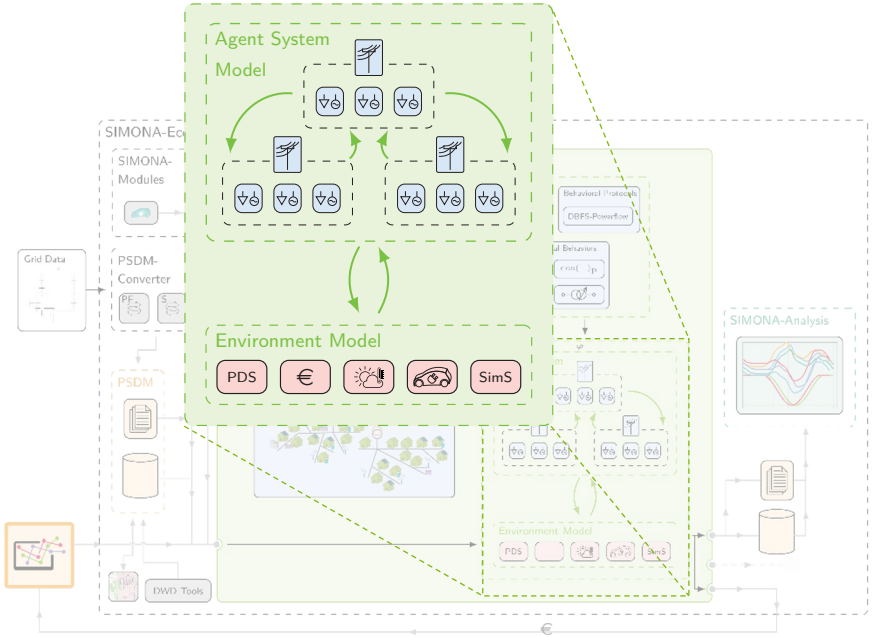
- Each service delivers the environment dependent data to each agent that needs it

Subscription based service

- Each agent that needs data from a service can subscribe to it

Implemented Services

- Weather Data
- Market Prices
- Primary Data



Excursion: Data Concepts & Flows

Data Services

Secondary Data

- Used for model calculations
- E.g., Weather Data

Primary Data

- Actual model behavior of a system
- E.g., active and reactive Power

Secondary Data Service

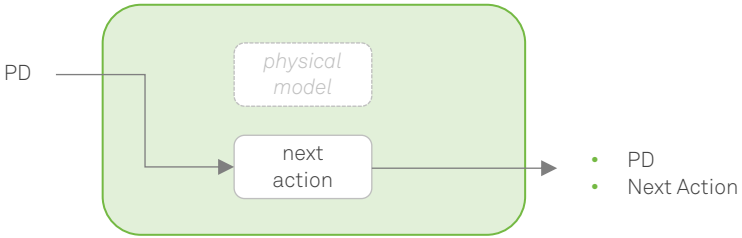
- Environment Agent that delivers Secondary Data
- E.g., Weather Service

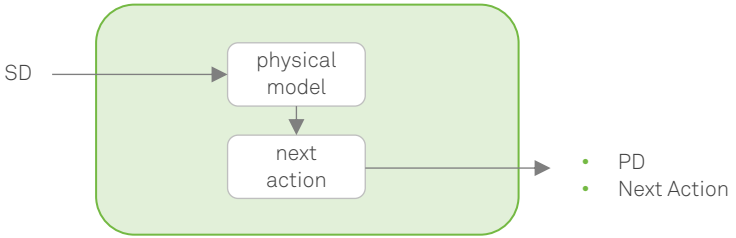
Primary Data Service

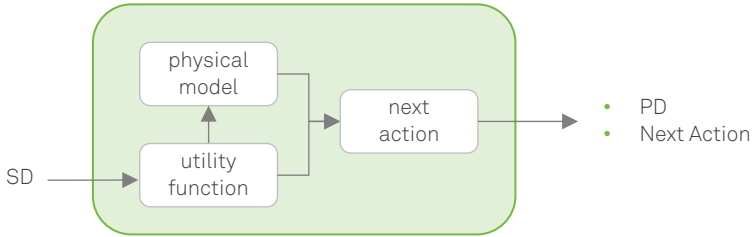
- Delivers precalculated primary data to system
- SIMONA agents replay the behavior

Agents and their Behaviour

Agent Types in SIMONA







Available Agent Types

- Simple Proxy Agent - Type 1 (top left)
- Physical Model Agent - Type 2 (bottom left)
- Physical Model Agent with UF - Type 3 (top right)

Agents and their Behaviour
Discrete-Event Scheduling and Time Advancement

Discrete-Event Approach

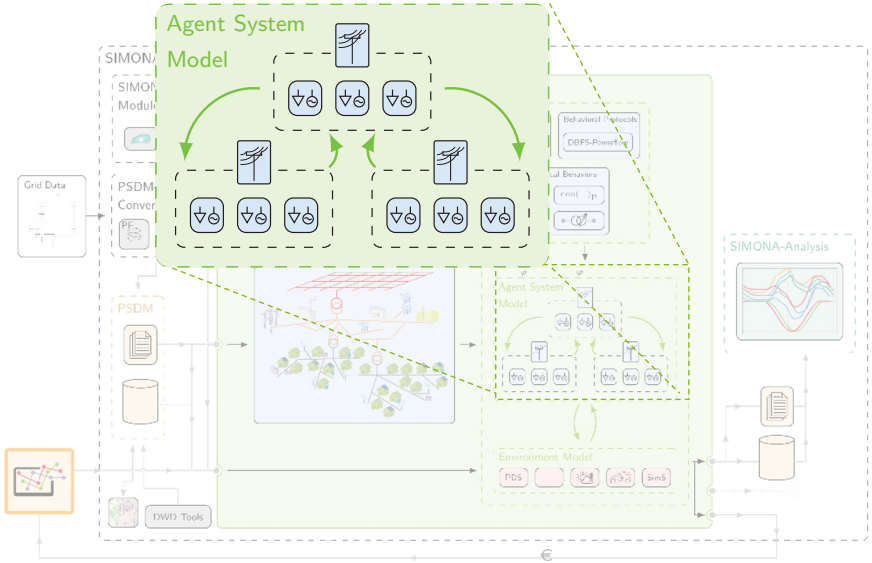
- The represented system only changes when an *event* takes place
- Conversely the system is in equilibrium between state changes

Scheduler

- State Changes are orchestrated by central system scheduler
  - Triggers the agent that registered a state change for current simulation tick

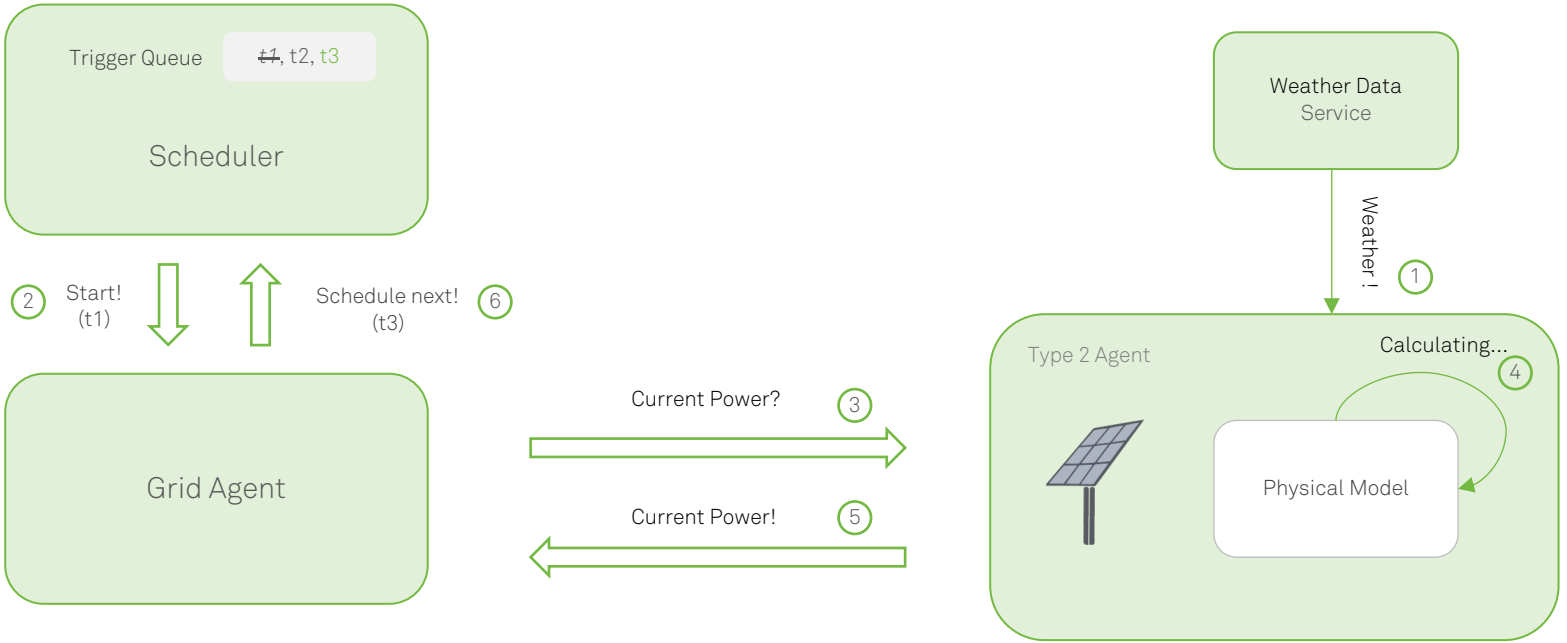
Agent Behaviour

- Registers state changes by sending an activation request for a defined tick to scheduler



Agents and their Behaviour

High Level Exemplary Agent Calculation



SIMONA – Core components and functional overview

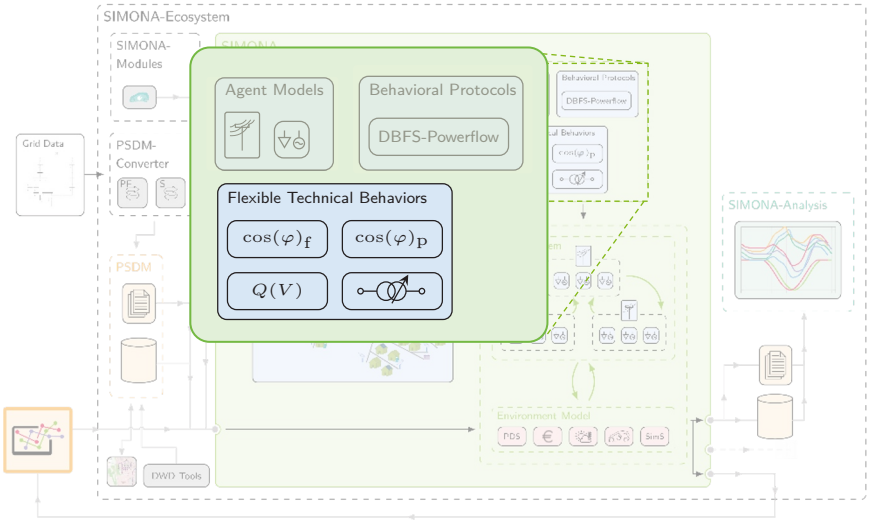
Several behavioural protocols including Energy Management can be simulated

Grid Behaviour

- Multi-voltage level distributed backward–forward sweep power flow algorithm
- On load tap changing
- Overhead line monitoring

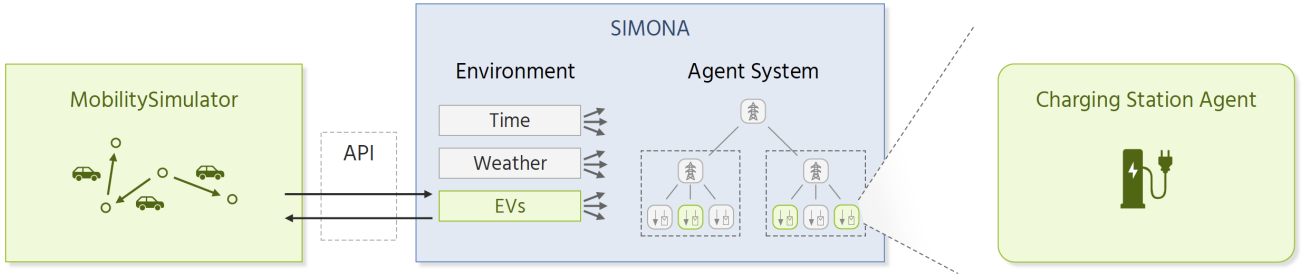
Participant Behaviour

- Active Power Dependent Power Factor
- Reactive Power as Function of Nodal Voltage Magnitude
- Energy Management on household and grid level



Agents and their Behaviour

Integration of Co-Simulations



Generation of Driving Behavior

- Generation of car trips with Markov-Chains
- Determines trip destination and trip distance depending on transition probabilities
- Parameterization of trip generation with largest german mobility study: „Mobilität in Deutschland“

Charging

- Charging Station Agent in SIMONA
- Allows implementation of flexible charging behavior..
  - .. Demand Side Management
  - .. Vehicle-to-home

SIMONA – Core components and functional overview

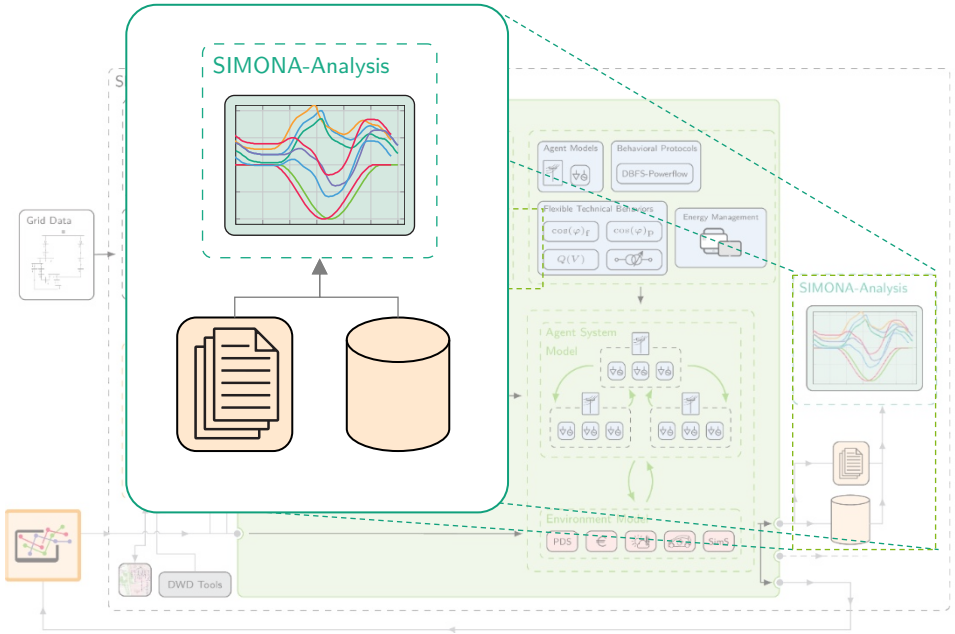
SIMONA – Core components and functional overview

Main outcome of SIMONA are time-series of all grid elements and participants

- Time step resolution as low as 1s

- PowerSystemDataModel
  - Results can be offered in various formats
    - CSV,
    - SQL,
    - Kafka

- Analysis can be performed multiple ways
  - ie³ psdm-analysis
  - Business Intelligence tools
  - Spreadsheet, Pandas



Coffee break?

System Analysis and Data Model

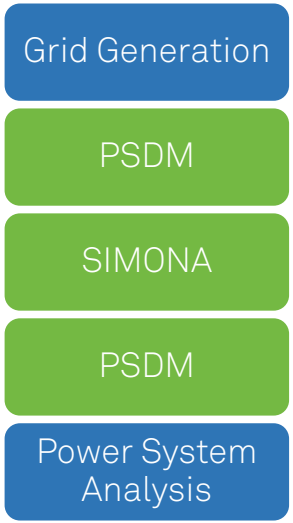
Data Model

The Value of a Distinct Data Model

- Defines a common interface

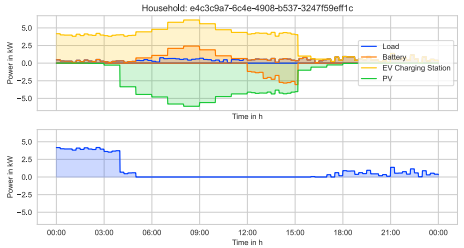
- Having a distinct Library
  - Can be incorporated in different projects
  - Interoperability due to same data format

- Building utilities surrounding the data Model
  - Grid model generation
  - Power System analysis
  - Plotting



Data Model
PSDM-Analysis

Grid Plots



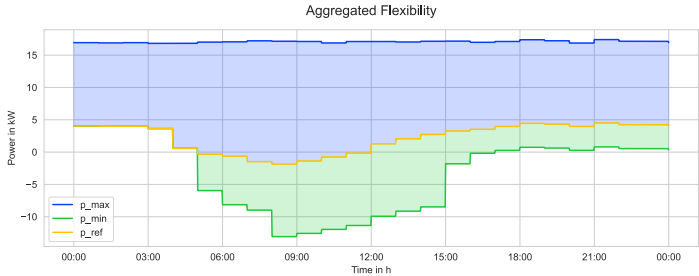
Time Series Plots

```
1    results.participants.sum()
[68] ✓ 1.2s                                    MagicPython

PQResult(entity_type=<SystemParticipantsEnum.PARTICIPANTS_SUM: 'part
time
2016-01-01 00:00:00  20.955151  6.319352
2016-01-01 01:00:00  17.661560  5.431222
2016-01-01 02:00:00  20.201289  6.046626
2016-01-01 03:00:00  18.878304  5.851889
2016-01-01 04:00:00  23.039660  6.966572
...                        ...       ...
2016-12-31 19:00:00  27.755942  8.597967
2016-12-31 20:00:00  28.306076  8.819135
2016-12-31 21:00:00  26.856426  8.285494
2016-12-31 22:00:00  23.750977  7.268426
2016-12-31 23:00:00  23.109840  7.382867

[8784 rows x 2 columns])
```

Time Series Calculation



Flexibilities and Energy management systems (EMS)

Flexibilities and EMS

Increasing demand and potentials of flexibility requires flexibility simulation

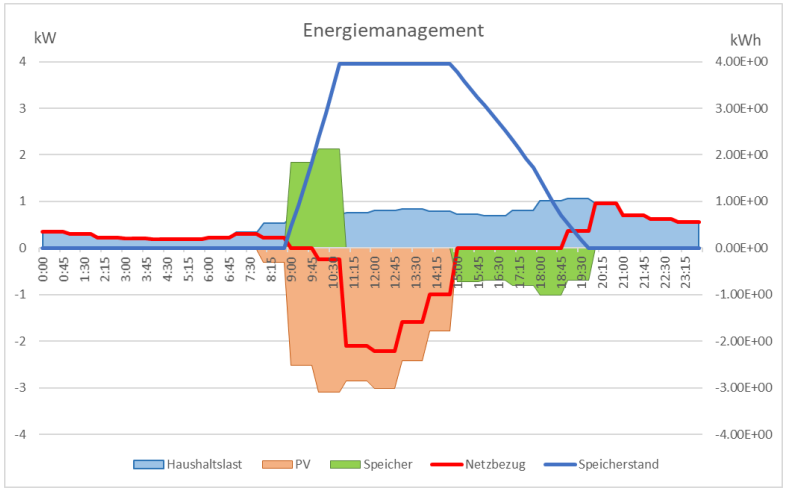
Motivation for including flexibility functions in an energy and power systems simulation

- Grid extension is lagging and expensive (at least marginal costs for peak power)
- Increasing amounts of system participants with flexibility potential
- Higher grid utilisation are beneficial
- Flexibility usage can have a high impact on grid utilisation
- Thus, simulation of flexibility will be a requirement in future.

Flexibilities and EMS

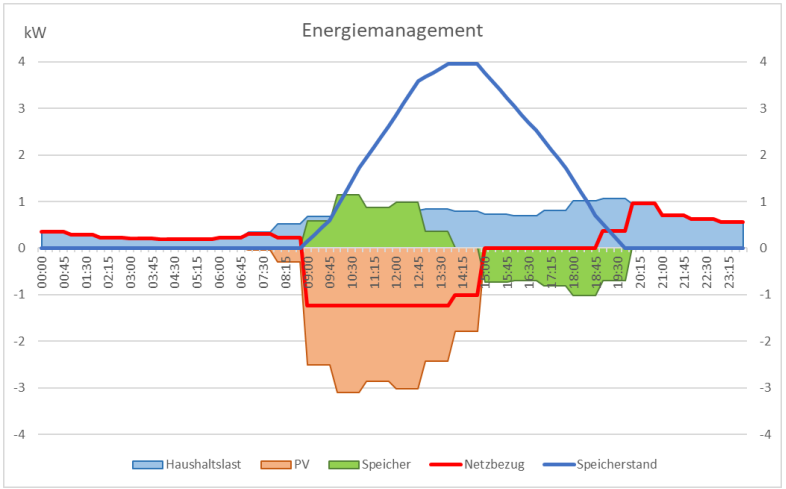
Flexibility usage has a significant influence on grid load

Minimize energy consumption from grid



Max: –2,2 kW Feed in

Minimize residual load on grid



Max: –1,2 kW Feed in

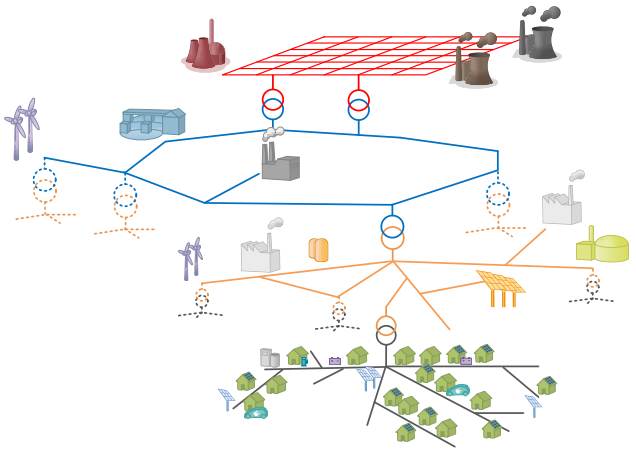
Assumption: Battery storage 4kWh / 3kW

Flexibilities and EMS

Goals and requirements for including Flexibilities into SIMONA

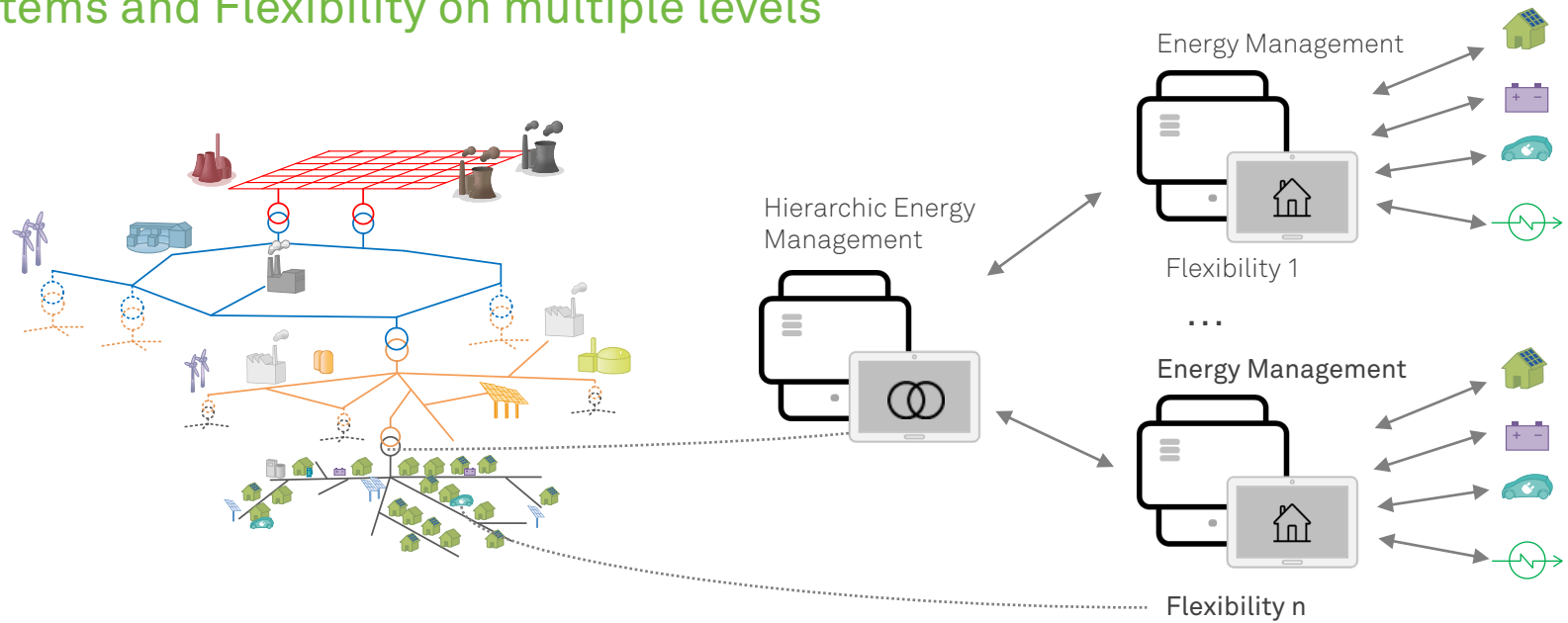
Goals

- Ability to simulate **flexibility options** and **demand** based on the agents information
- **Aggregation, Disaggregation** and **Call** of Flexibility
- Integration in **Power Flow**
- Flexible use at **all grid levels** (Household, Substations, etc.)
- Modelling of different **strategies**
  - Increase self consumption of renewables ✓
  - Grid friendly behaviour by limiting Power at Node ✓
  - Market behaviour by following price signals ⚙
- **Coordination** of flexibility



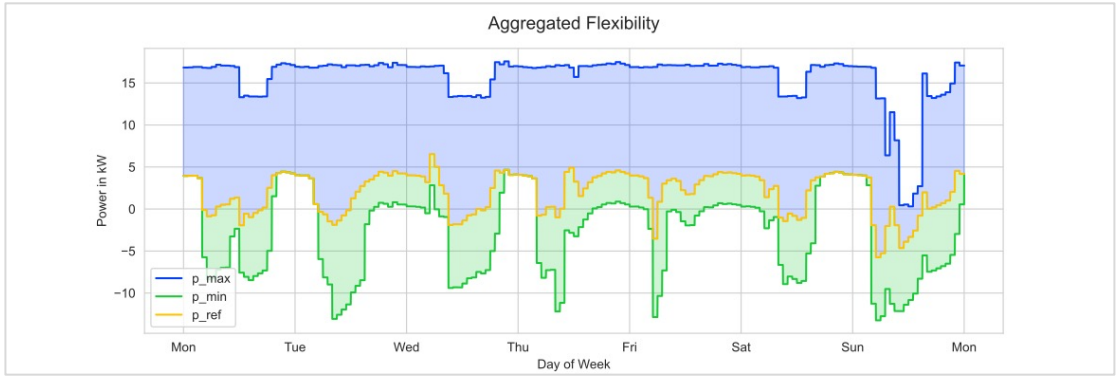
Flexibilities and EMS

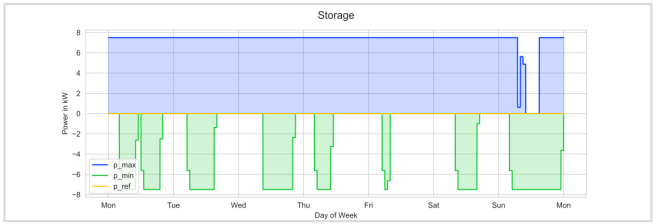
Generic Energy Management Agents enable simulation of Energy Management Systems and Flexibility on multiple levels

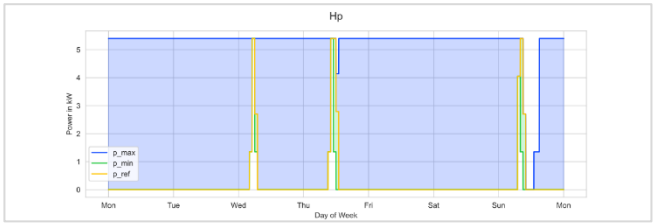


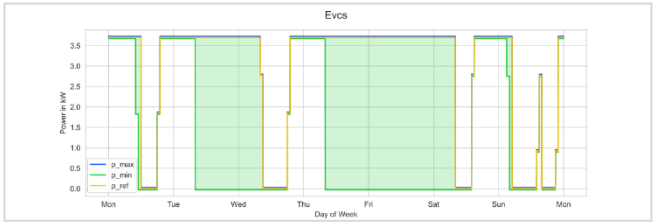
Flexibilities and EMS

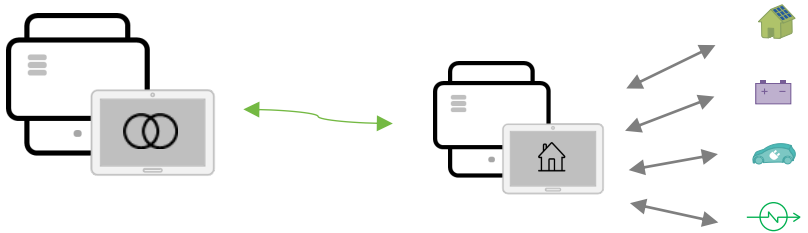
Energy Management Agent manage flexibilities of underlying agents











Flexibilities and EMS

Are there challenges? Yes, many! But one is working on these.

We don't have answers to all of them, but ...

... challenges fit to actual research questions and projects

Data? Does the user have all information on flexibility required? → Smart Meter rollout

Uncertainty? Parallel simulation of trajectories => computational power. → SIMONA is designed for parallel runs on distributed systems

Dependency? Do decisions interact with each other? (Yes, to do!) → A challenge but agent-based simulation fits quite good to this

Optimization? Just simulate the behaviour or change the behaviour? → SIMONA offers interface to Optimizers

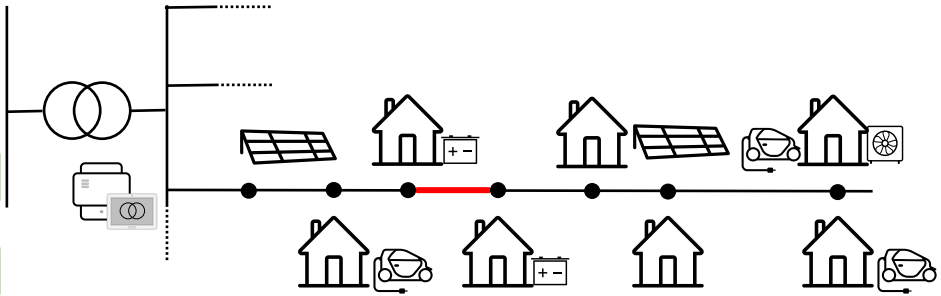
Redispatch 3.0

Flexibilities and EMS

EnWg 14a as Use Case for Energy Management

Goals

- State Estimation -> Identify congestion in Real-time
- Solve congestion by
  - A. Preventive Power Limit — 01.01.2024
  - B. Grid-oriented Control — 01.01.2029
    - Call flexibility to solve congestion
    - Max. 3 minutes from State Estimation



Status: 2. Konsultationsfassung 16.06.2023

SIMONA in research projects

Research projects

Wide-ranging use in ongoing research projects with further developments

AGENT.GRIDPLAN

DESIGNETZ
VERBUNDEN MIT KREATIVER ENERGIE

NOVAgent

TRANSENSE

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds
für regionale Entwicklung
EFRE.NRW
Investitionen in Wachstum
und Beschäftigung

SINTEG
SCHAUFENSTER INTELLIGENTE ENERGIE

DFG
Deutsche
Forschungsgemeinschaft

HoLa
Hochleistungsladen Lkw-Fernverkehr

DYNAFLEX®

MoMeEnT
Modellierung des sozio-technischen Mehrebenen-systems der Energie-versorgung und dessen Transfor-mation

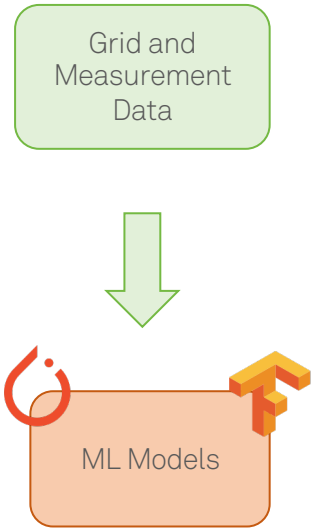
Redispatch 3.0

TRANSENSE

A Digital Twin as a Machine Learning Data Source

Situation

- We increasingly try to leverage data driven algorithms
  - DSSE, Time Series Forecasting, Optimal Powerflow, ...



TRANSENSE

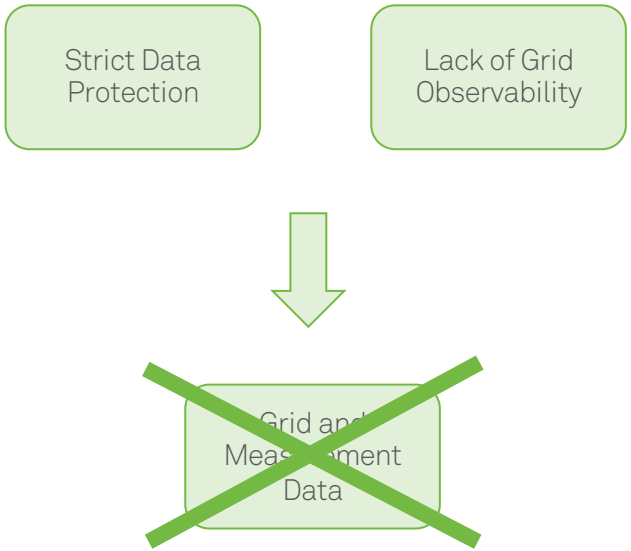
A Digital Twin as a Machine Learning Data Source

Situation

- We increasingly rely on data driven algorithms

Problem

- Necessary data is hard to come by
- Especially grid and corresponding measurement data
  - Strict data protection regulations



TRANSENSE

A Digital Twin as a Machine Learning Data Source

Situation

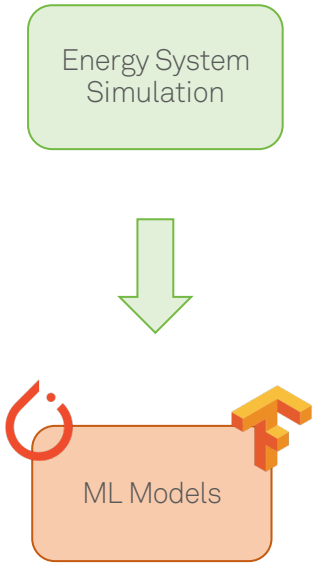
- We increasingly rely on data driven algorithms

Problem

- Necessary data is hard to come by
- Especially grid and corresponding measurement data
  - Strict data protection regulations

Solution (?)

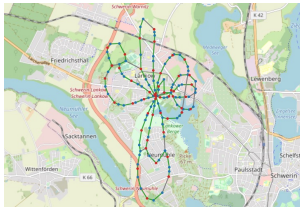
- Simulation environments can act as an artificial data source
- Open Questions:
  - Necessary level of detail
  - Robustness against ..
    - .. Underlying changes in data distribution
    - .. Lack of measurement synchronicity

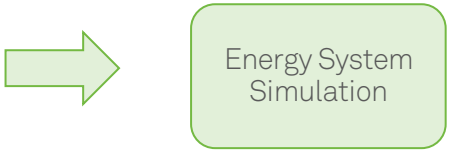


TRANSENSE

A Digital Twin as a Machine Learning Data Source

1. Translate a model of a real MV distribution grid
2. Generate a training data set
3. Train Model
4. Evaluate model performance with real measurement data

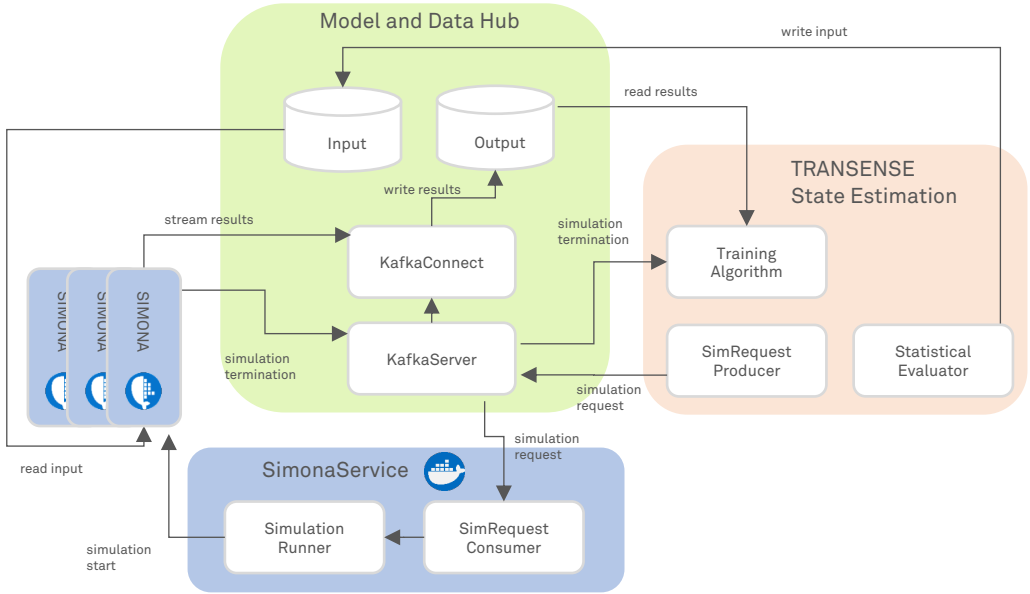




TRANSENSE

A Digital Twin as a Machine Learning Data Source

- Leverage energy system simulation for specific data sets
- Simulation-as-a-Service infrastructure
- Evaluate distribution of training data
  - Generate additional samples

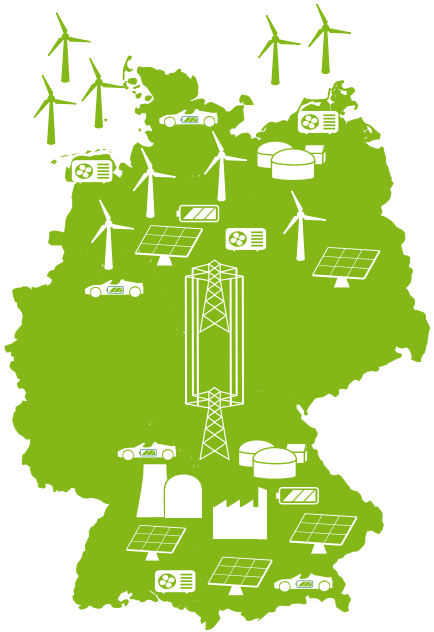


Research projects

Redispatch 3.0 – Congestion management

Redispatch	1.0	2.0	3.0
TSO	✓	✓	✓
DSO		✓	✓
Power plants > 10 MW	✓	✓	✓
Power plants < 10 MW		✓	✓
Renewables > 100 kW		✓	✓
Renewables < 100 kW			✓
Prosumer, batteries, heat pumps, electric vehicle, variable loads etc.			✓

Project duration: 2022 – 2024



ie³ contribution

- SIMONA for prognosis and power flow calculations
- Flexibility aggregation for preventive Redispatch
- Optimize flexibility usage for Preventive Redispatch Use Case

Funded by

Bundesministerium für Wirtschaft und Klimaschutz

Redispatch 3.0

Reliable, robust forecasts of load, feed-in and flexibility are elementary

Example:

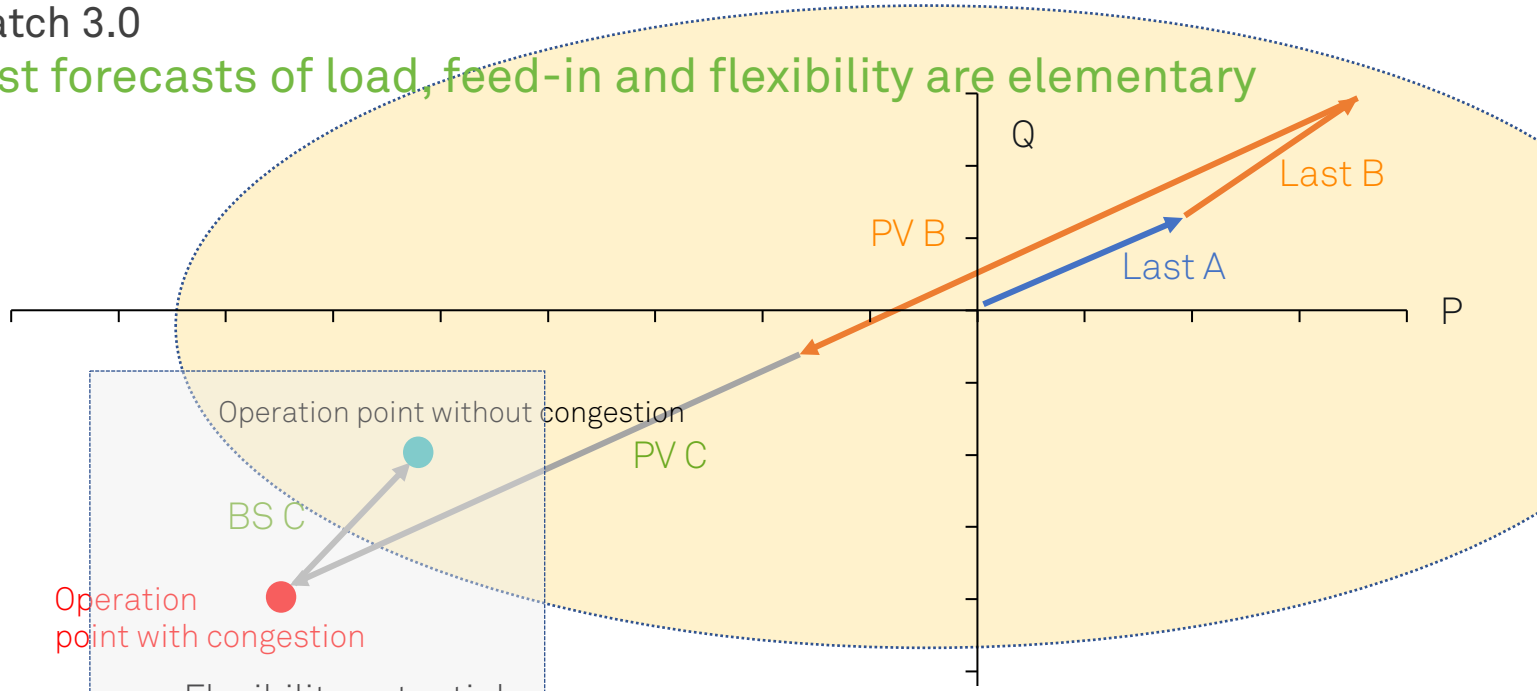

Load A


Load B


PV B


PV C

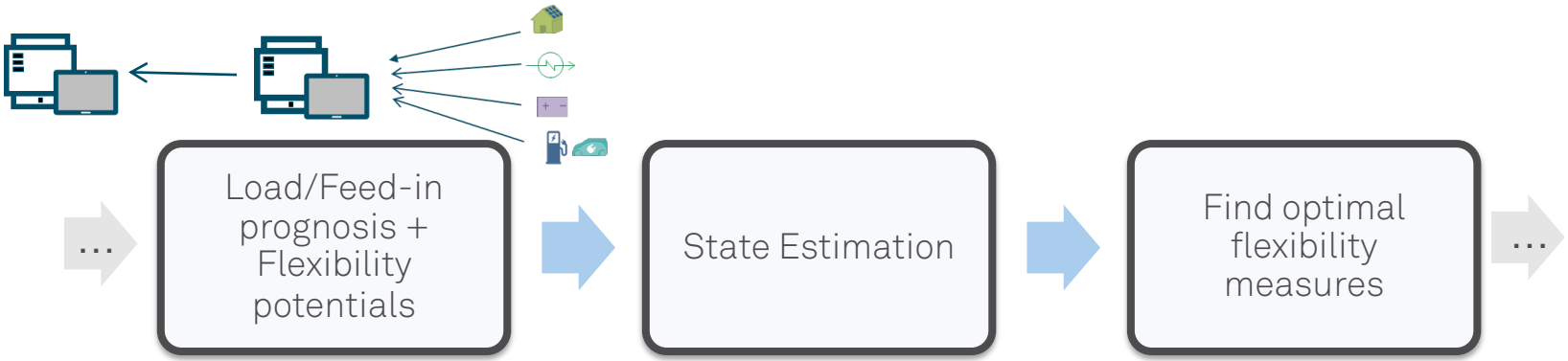

Battery C



Uncertainties lie in the flexibility potential as well as in load and feed-in forecasts

Redispatch 3.0

SIMONA uses EMS functionalities in RD3.0 for improving prognosis



Simplified extraction of RD3.0 process (AP1.2)

- Load / Feed-in prognosis in preventive RD
- Simulate possible flexibility offers / potentials

Open Source

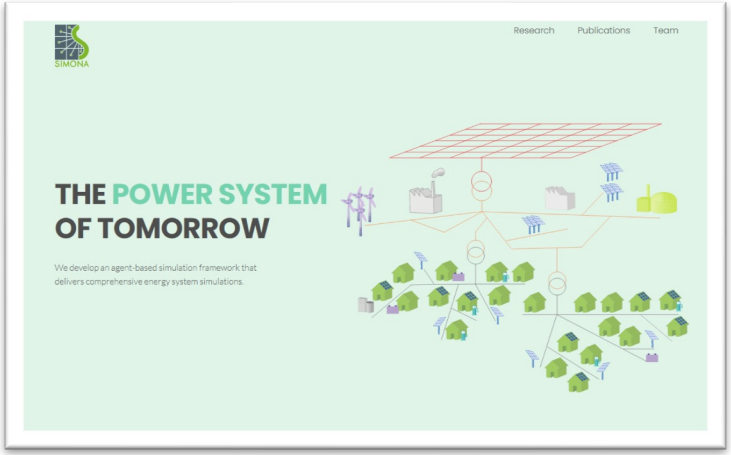
SIMONA is free and available Open Source

- For more information visit our website

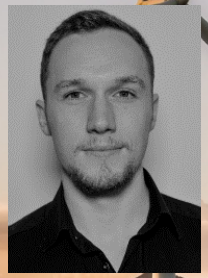
  https://simona.ie3.e-technik.tu-dortmund.de

- SIMONA Code is available on GitHub

  https://github.com/ie3-institute/simona



Thank you for your attention!



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