Friedrich-Alexander-Universität
Technische Fakultät

Session_2_Presentation_3

Integrated Energy Systems Modeling Framework i7-AnyEnergy

Peter Bazan, Reinhard German

ABM4Energy, Freiburg, 21.03.2024

Agenda

Cellular Approach

Cellular Approach

Related work

General concept

- e.g., from German Association for Electrical, Electronic & Information Technologies (VDE), German project C/Sells
- similarly: local energy management, energy communities, energy hubs, P2P energy trading, fractal-structured energy systems, …

Algorithms

- **Market mechanism for load balancing in fractal-structured smart micro grid models (hierarchies)**
  Apperley, M.: Modelling fractal-structured smart microgrids: Exploring signals and protocols. In: Sultan, M.N..V. (ed.) Proceedings of ENERGY 2019, The Ninth International Conference on Smart Grids, Green Communications and IT Energyaware Technologies. p. 13–17. IARIA (2019)
- **Recursive algorithm for the matching of supply and demand in a power grid with an acyclic connected graph structure (hierarchies)**
  Hekkelman, B., La Poutr´e, H.: Fairness in power flow network congestion management with outer matching and principal notions of fair division. In: Proceedings of the Eleventh ACM International Conference on Future Energy Systems. p. 106–115. e-Energy ’20, Association for Computing Machinery, New York, NY, USA (Jun 2020). https://doi.org/10.1145/3396851.3397701
- **Distributed algorithm for the demand-side management in smart grids with cyclic connected graph structures (neighborhoods)**
  Dong, Y., Zhao, T., Ding, Z.: Demand-side management using a distributed initialisation-free optimisation in a smart grid. IET Renewable Power Generation 13(9), 1533–1543 (Apr 2019). https://doi.org/https://doi.org/10.1049/ietrpg.2018.5858
- **Recursive algorithm for graph structures with hierarchies and neighborhoods (developed with i7-AnyEnergy framework)**
  Dengler, G., Bazan, P. & German, R. Simulation of a Cellular Energy System including hierarchies and neighborhoods. Energy Inform 5 (Suppl 4), 51 (2022). https://doi.org/10.1186/s42162-022-00243-2

Cellular Approach

Energy cell

atomic energy cell (green)

– for demand, generation, storage …
  (with cell controller)

aggregated energy cell (blue)

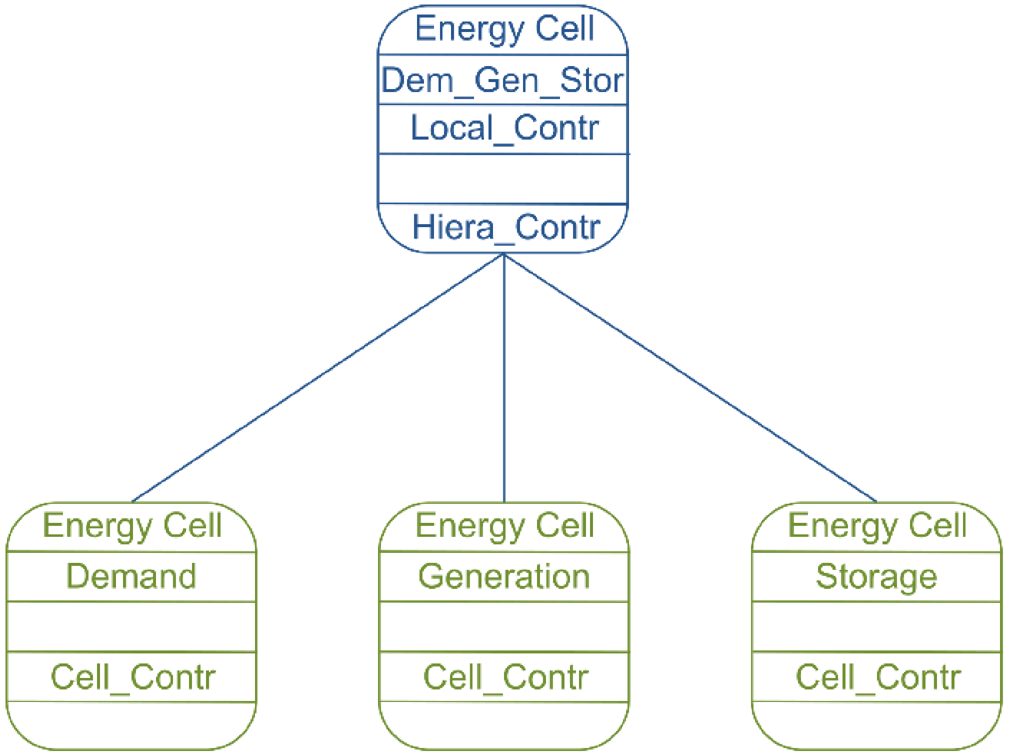
– for combining atomic
  and aggregated ECs

hierarchical controller

– for energy exchange with **subordinated** ECs
  (with a selected strategy)

local controller

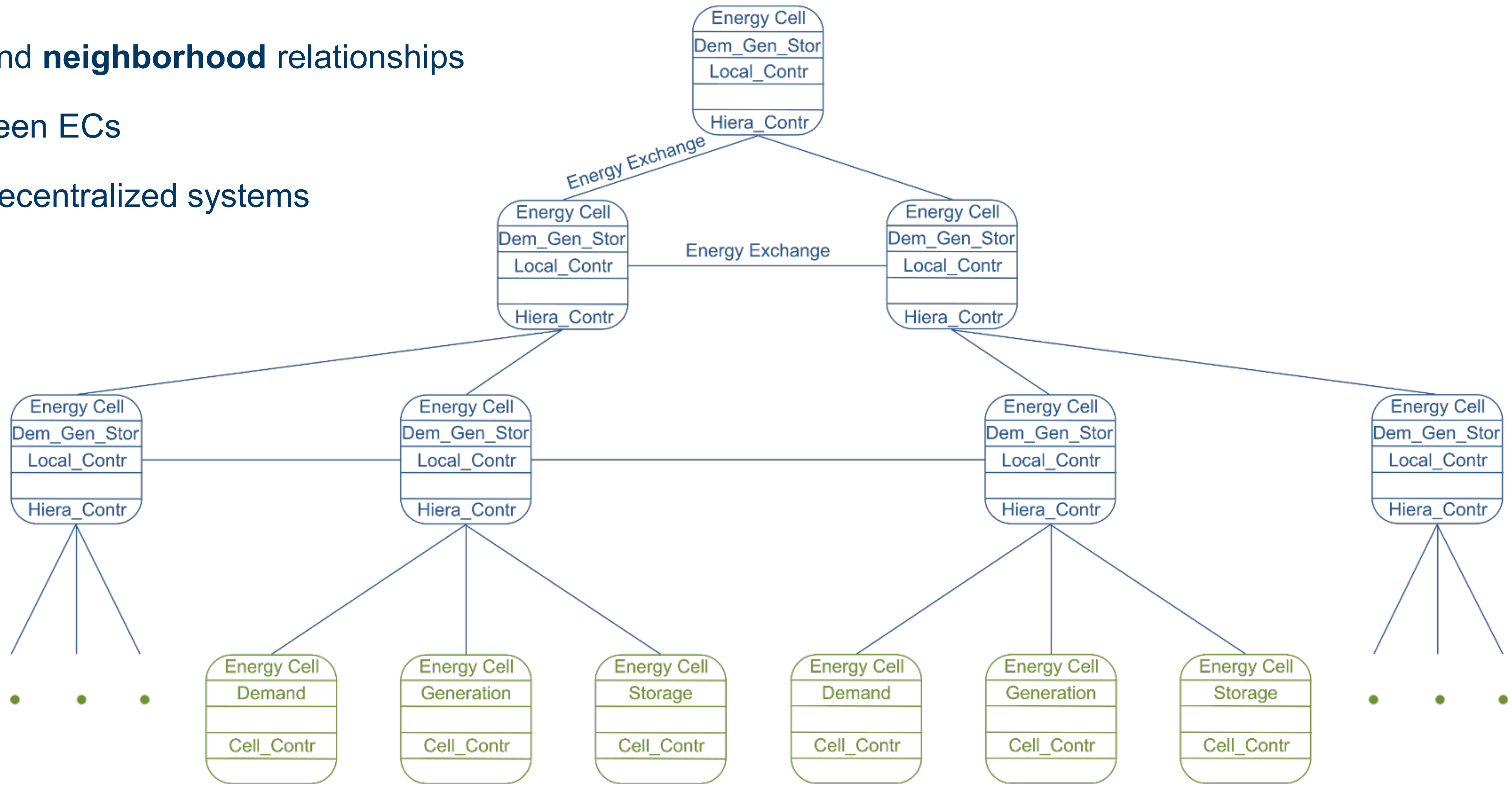
– for energy exchange with **neighbor** ECs
  (with a selected strategy)



Cellular Approach

Hierarchies and neighborhoods

- **hierarchical** structure and **neighborhood** relationships
- **energy exchange** between ECs
- **control strategies** for decentralized systems

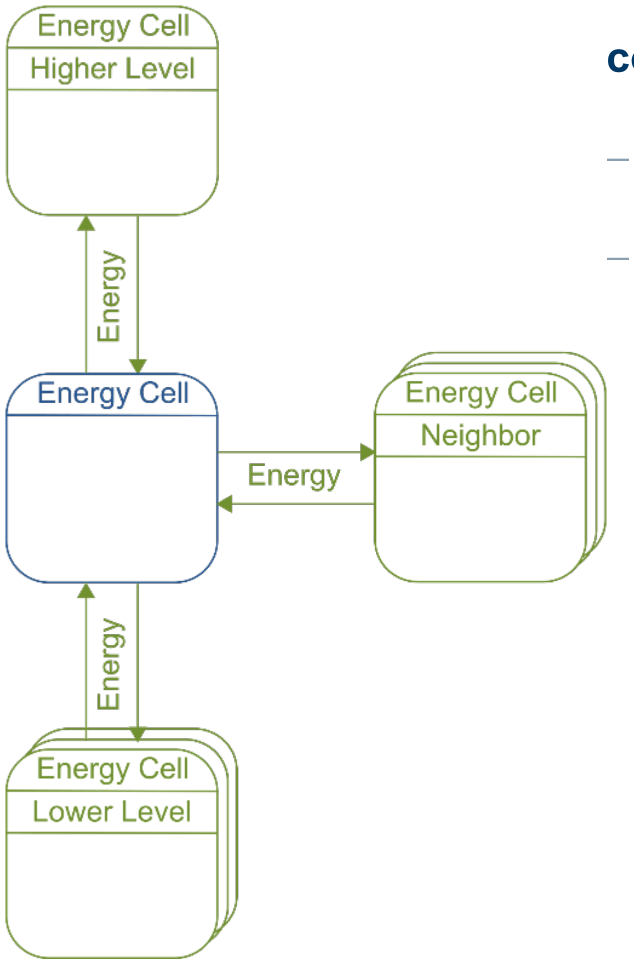


Cellular Approach

Recursive, decentralized control strategy

energy flows between EC and

- lower level EC
  (managed by hierarchical controller)
- neighbor EC
  (managed by local controller)
- higher level EC
  (managed by hierarchical controller of higher level EC)



control strategies for energy flows

- can be set arbitrarily
- e.g., **local load compensation on all levels**
  - self consumption if possible
  - compensation of additional demand and excess by batteries
  - remaining balance via neighbor and higher level ECs
  - recursively on all levels
  - controls charging and discharging of all batteries in the system

Cellular Approach

Generalization for integrated energy systems

Energy carrier of a cell can be of type

- electricity
- heat
- natural gas, hydrogen

Demand, generation and storage cells can also be used for

- cost flows
- material flows

Hierarchical structures can be the

- technical perspective
- political perspective
- stakeholder perspective

Integrated energy systems

- multiple cell types
- multiple hierarchical structures
- additional sub models for
  - transport
  - production processes
  - …

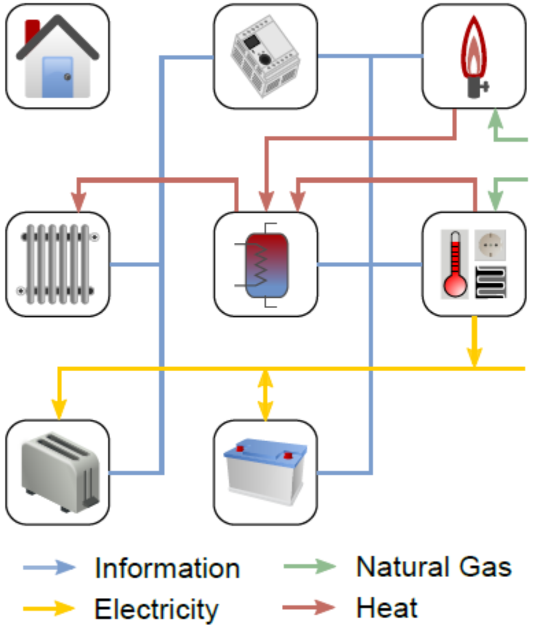
i7-AnyEnergy Framework

i7-AnyEnergy Framework

Concepts

R. German, P. Bazan, “Rapid Prototyping with i7-AnyEnergy and Detailed Co-Simulation with SGsim”, 7th D-A-CH+ Energy Informatics Conference, Oldenburg, 2018.

- reusable and replaceable **agents** (demand, generation, PV, battery, heat, control, networks, ...)
- **multiple energy carriers** (electricity, heat, hydrogen, ...)
- **technical** and **economic** analyses
- **interface objects** for flexible and efficient access to all model parts
- **cellular approach** with **hierarchies** and **neighborhoods**
- configuration with **drag and drop**, **text files** or **databases**
- **visualization** and **animation**
- **open source**
  - → https://github.com/cs7org/i7-AnyEnergy

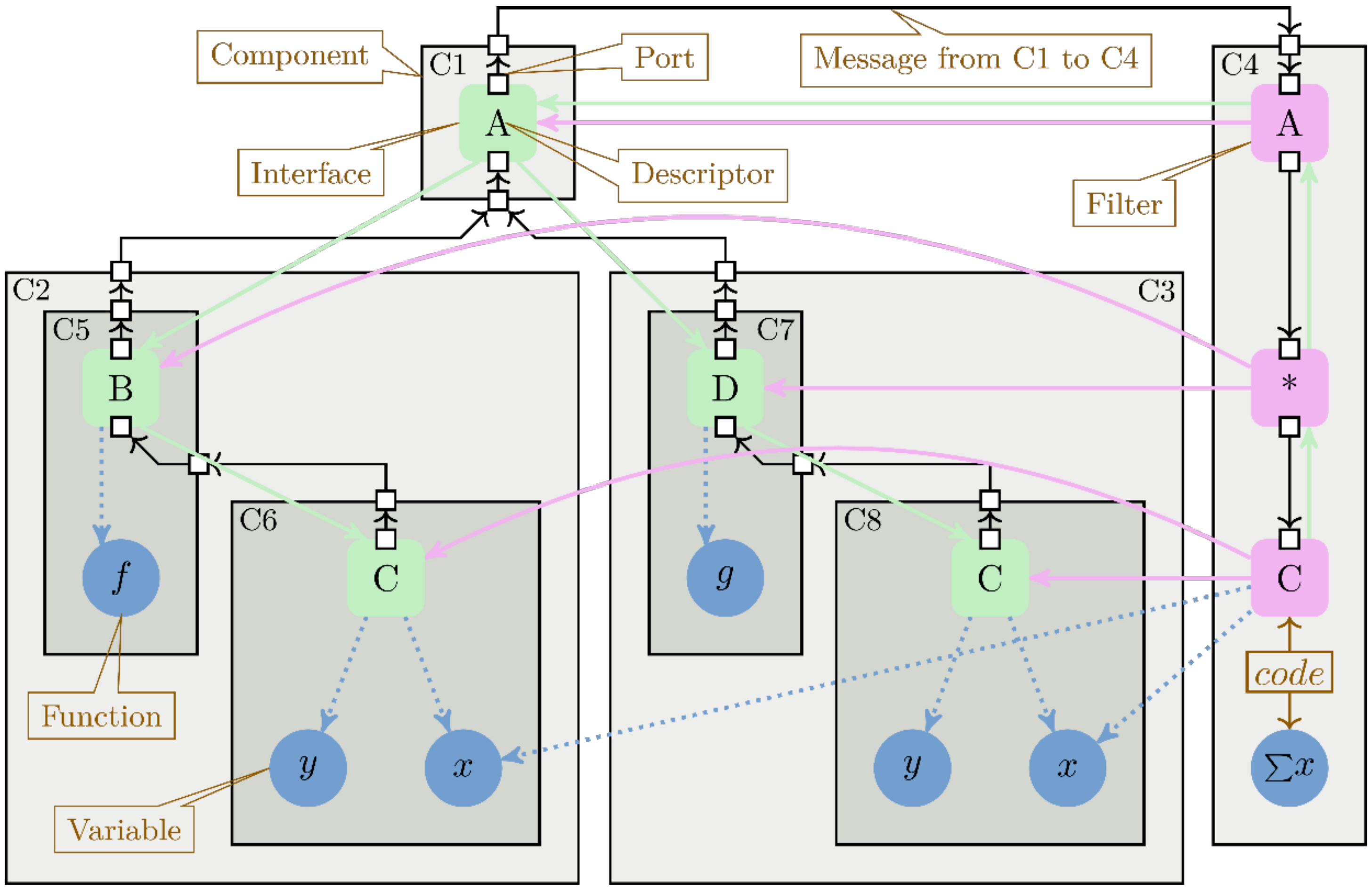


i7-AnyEnergy Framework

Interface/filter concept

R. German, P. Bazan, “Rapid Prototyping with i7-AnyEnergy and Detailed Co-Simulation with SGsim”, 7th D-A-CH+ Energy Informatics Conference, Oldenburg, 2018.

- interfaces for variables and functions, can be aggregated
- other components use filters for access, can also be aggregated
- easy rearrangement of components
- established automatically at initialization time
- efficient direct access at run-time, modeler defined *code*
- configuration and transformation of model structure



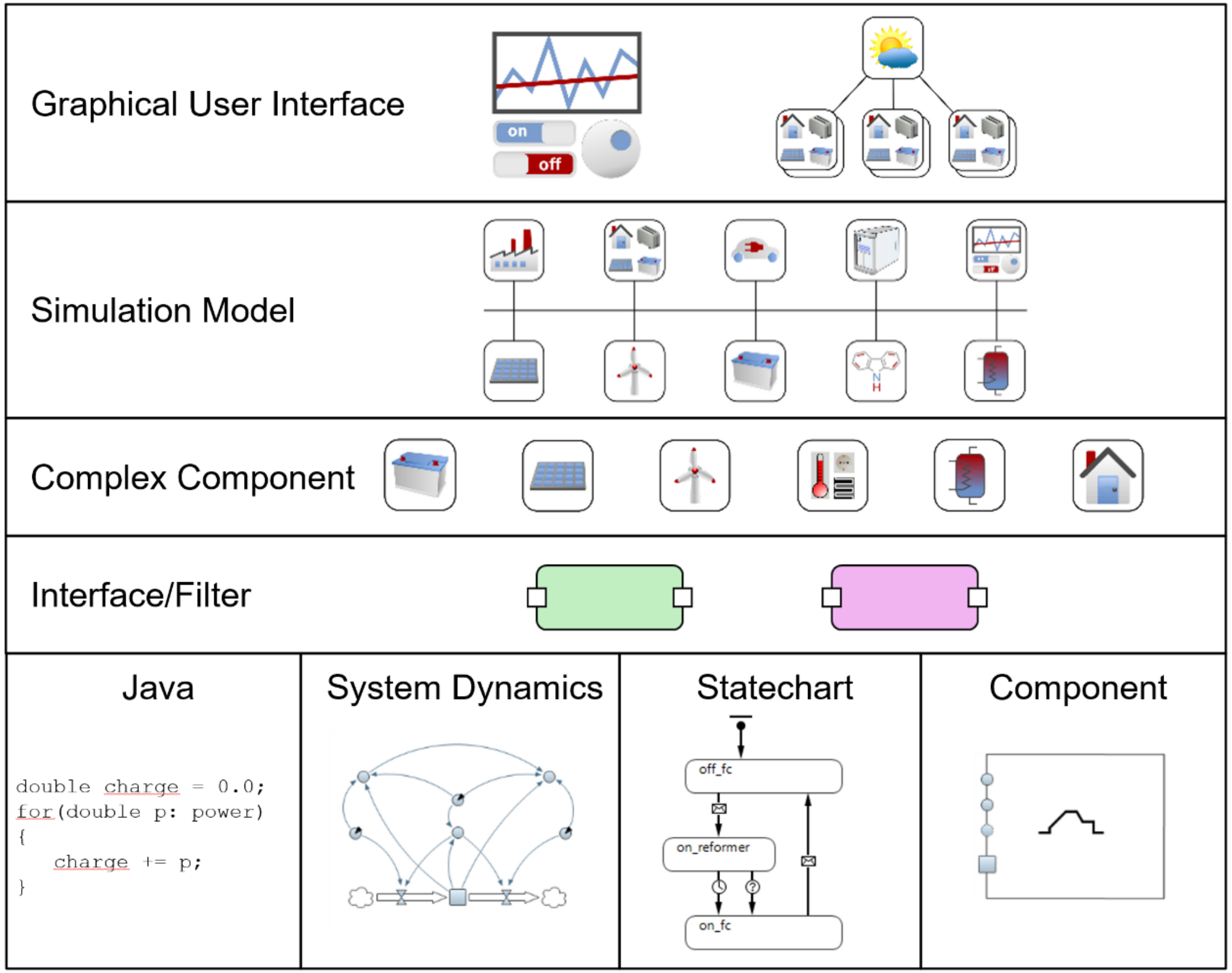
i7-AnyEnergy Framework

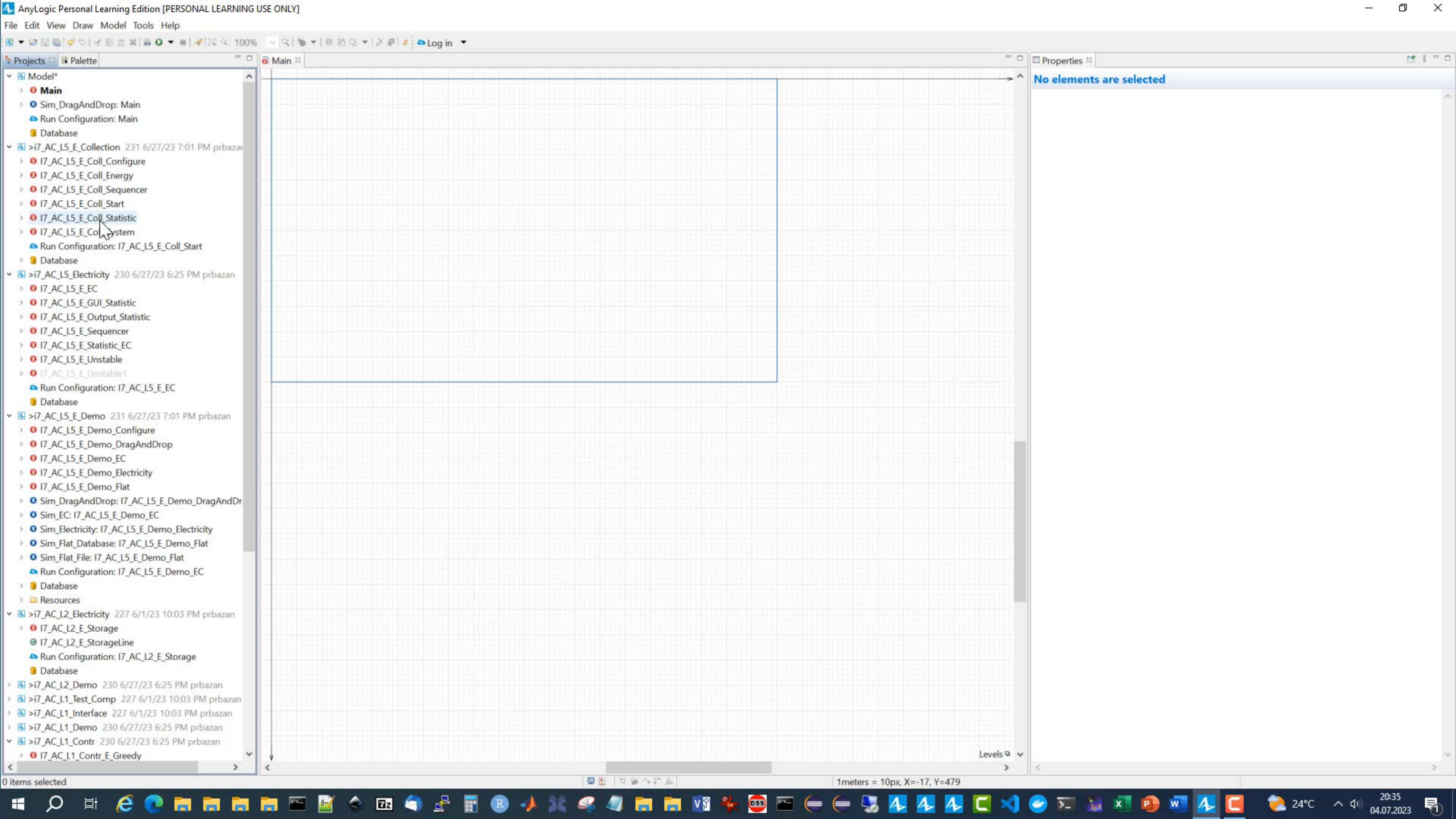
Agent-Based Modeling architecture

R. German, P. Bazan, “Rapid Prototyping with i7-AnyEnergy and Detailed Co-Simulation with SGsim”, 7th D-A-CH+ Energy Informatics Conference, Oldenburg, 2018.

- **AnyLogic**
  agents, ports, state charts, system dynamics, Java, …
- **component-based**
  agents are connected through ports
- **interfaces**
  interface objects
- **filters**
  access objects
- **infrastructure**
  registration, read/write, configuration files, timer, traces, optimization …
- **conventions**
  naming, energy flows, …
- **energy components**
  demand, PV, battery, …

→ **Rapid modeling of energy systems**

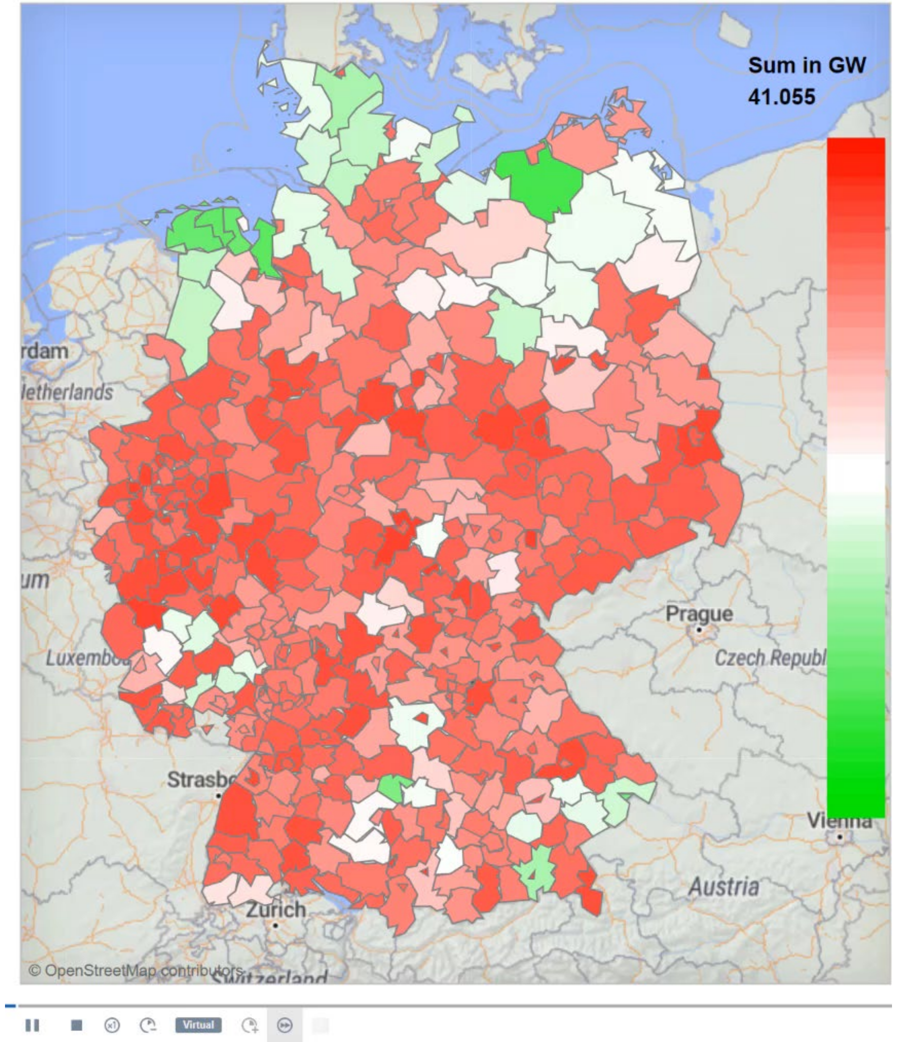



AnyLogic Personal Learning Edition [PERSONAL LEARNING USE ONLY]
File Edit View Draw Model Tools Help
100%
Log in
Projects
Palette
Model*
Main
Sim_DragAndDrop: Main
Run Configuration: Main
Database
>i7_AC_L5_E_Collection 231 6/27/23 7:01 PM prbazan
I7_AC_L5_E_Coll_Configure
I7_AC_L5_E_Coll_Energy
I7_AC_L5_E_Coll_Sequencer
I7_AC_L5_E_Coll_Start
I7_AC_L5_E_Coll_Statistic
Run Configuration: I7_AC_L5_E_Coll_Start
Database
>i7_AC_L5_Electricity 230 6/27/23 6:25 PM prbazan
I7_AC_L5_E_EC
I7_AC_L5_E_GUI_Statistic
I7_AC_L5_E_Output_Statistic
I7_AC_L5_E_Sequencer
I7_AC_L5_E_Statistic_EC
I7_AC_L5_E_Unstable
I7_AC_L5_E_Unstable1
Run Configuration: I7_AC_L5_E_EC
Database
>i7_AC_L5_E_Demo 231 6/27/23 7:01 PM prbazan
I7_AC_L5_E_Demo_Configure
I7_AC_L5_E_Demo_DragAndDrop
I7_AC_L5_E_Demo_EC
I7_AC_L5_E_Demo_Electricity
I7_AC_L5_E_Demo_Flat
Sim_DragAndDrop: I7_AC_L5_E_Demo_DragAndDr
Sim_EC: I7_AC_L5_E_Demo_EC
Sim_Electricity: I7_AC_L5_E_Demo_Electricity
Sim_Flat_Database: I7_AC_L5_E_Demo_Flat
Sim_Flat_File: I7_AC_L5_E_Demo_Flat
Run Configuration: I7_AC_L5_E_Demo_EC
Database
Resources
>i7_AC_L2_Electricity 227 6/1/23 10:03 PM prbazan
I7_AC_L2_E_Storage
I7_AC_L2_E_StorageLine
Run Configuration: I7_AC_L2_E_Storage
Database
>i7_AC_L2_Demo 230 6/27/23 6:25 PM prbazan
>i7_AC_L1_Test_Comp 227 6/1/23 10:03 PM prbazan
>i7_AC_L1_Interface 227 6/1/23 10:03 PM prbazan
>i7_AC_L1_Demo 230 6/27/23 6:25 PM prbazan
>i7_AC_L1_Contr 230 6/27/23 6:25 PM prbazan
I7_AC_L1_Contr_E_Greedy
Main
Properties
No elements are selected
Levels
0 items selected
1meters = 10px, X=-17, Y=479
24°C
20:35
04.07.2023

i7-AnyEnergy Framework

Applications

- **Houses, neighborhoods:** house with PV, battery, heating; virtual battery storage with primary control power (SWARM, N-ERGIE, Caterva, Siemens); flexibility with Blockchain (ZD.B); thermal storage for renewable energy (EnCN)
- **Regional and national level:** Germany's electrical energy system (KOSiNeK, BMWi); sector coupling of electricity, gas, heat, mobility in Bayreuth (ESM-Regio, BMWK); Monash Microgrid (Monash Univ.); hydrogen potential in the EMN (City of Nuremberg), transition paths for the EMN energy system (Climate Protection 2030+, BMBF)
- **Mobility related:** system services with electric fleets (ZD.B); e-bus port (N-Ergie, VAG); mobility on demand with robot taxis (Audi); multimodal employee mobility at Munich Airport (Munich Airport, Fraunhofer IIS); alternative drives for heavy commercial vehicles
- **Other:** Cement plant with renewables (ThyssenKrupp); data centers (noris networks); battery technologies (Siemens), real-time communication in smart grids (with Univ. Oldenburg, DFG); National Research Data Infrastructure for Energy (NFDI4Energy, DFG)



Simulation Model for the Hydrogen Potential in the European Metropolitan Region of Nuremberg (EMN)

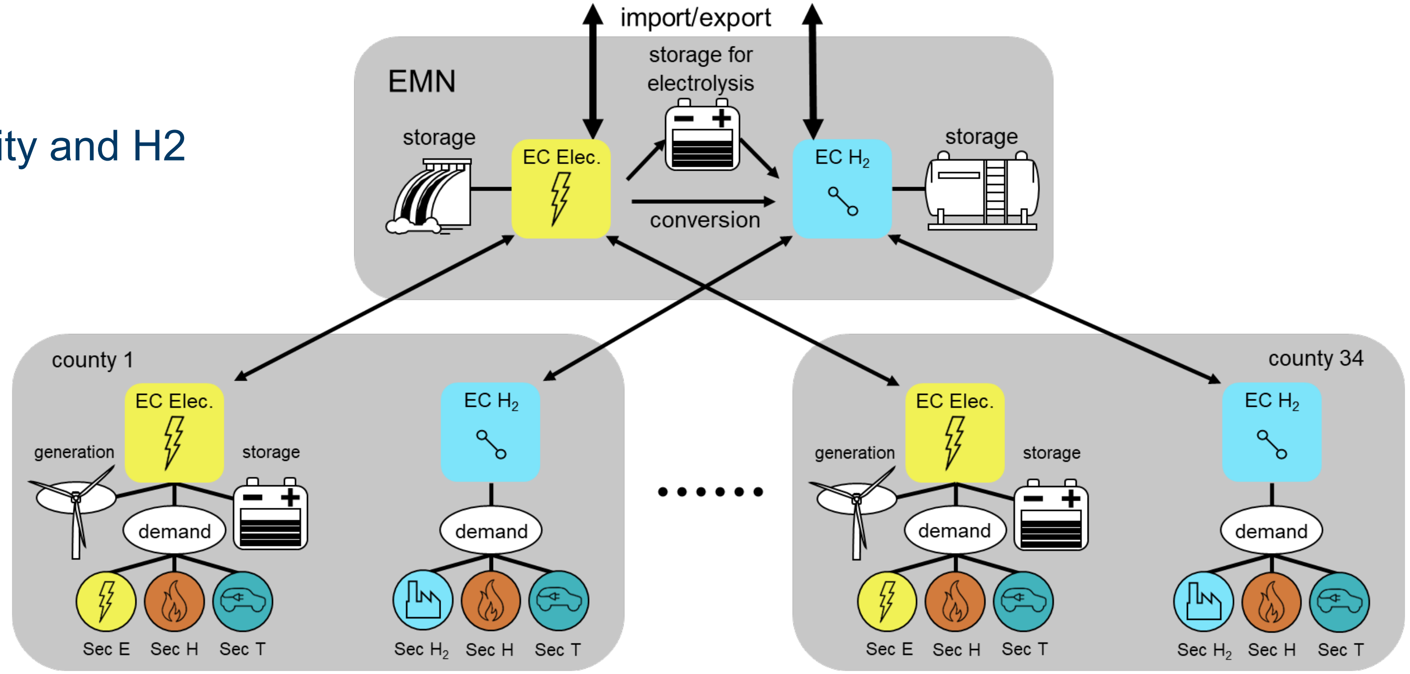
Study commissioned by the city of Nuremberg

https://www.encn.de/nachricht/encn-stellt-wasserstoffstudie-fuer-die-metropolregion-vor

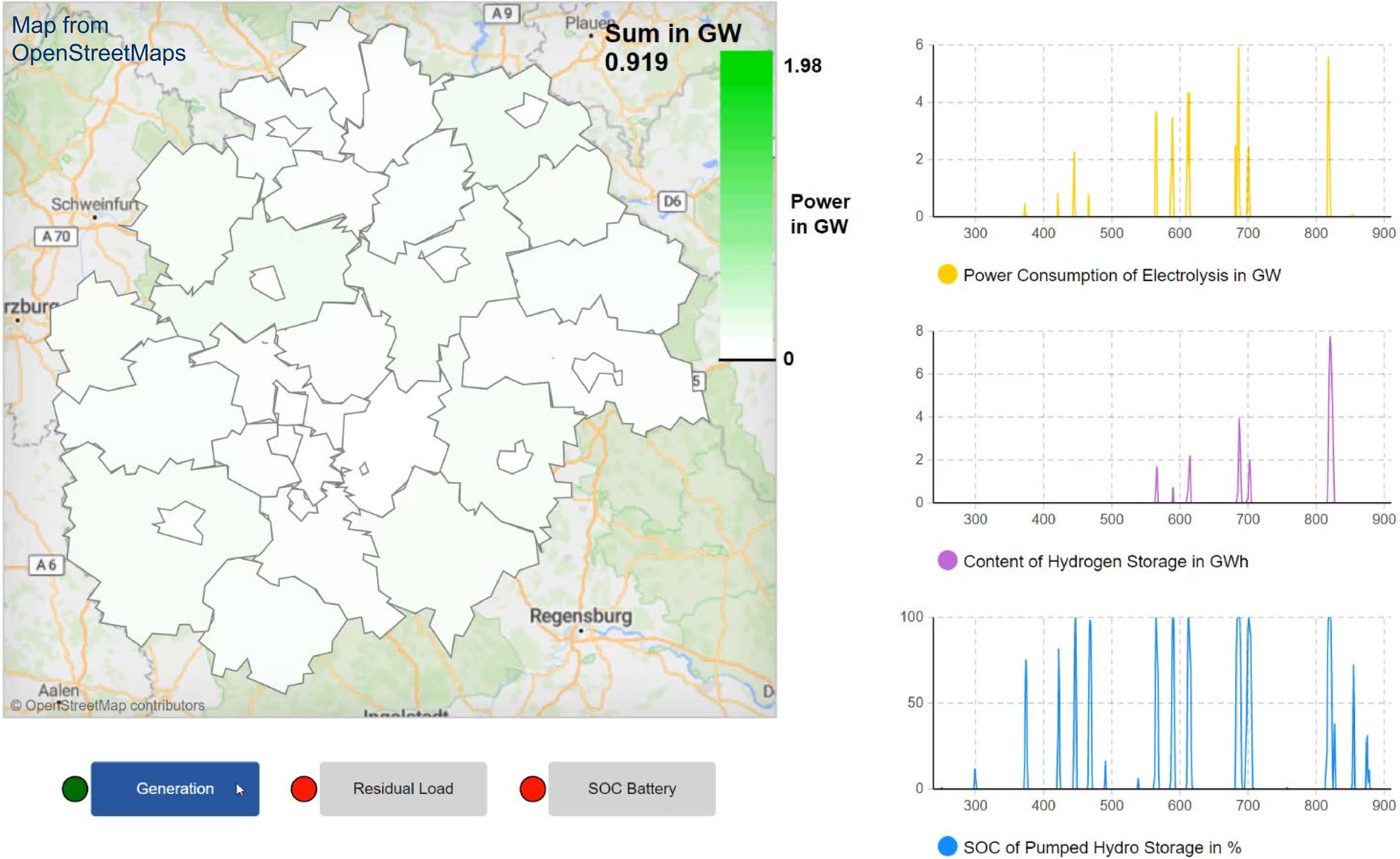
Hydrogen Potential in EMN

Model structure

– **34 counties as energy cells**
  – energy carrier electricity: renewable generation, demand (electricity, heat, transport), battery storage
  – energy carrier H2: demand (H2, heat, transport)
  – unlimited transport capacities in EMN for electricity and H2
– **EMN as energy cells**
  – pumped storage, H2 storage (unlimited)
  – Electrolysis to convert electricity → H2 (renewable surplus after filling all electrical storage units)



– **Scenario 3 (optimistic) from EMN's Energy Utilization Plan (ENP): Use all expansion potential**


Map from
OpenStreetMaps
Sum in GW
0.919
1.98
Power
in GW
0
Plauen
A9
D6
Schweinfurt
A 70
rzburg
A 6
Regensburg
Aalen
© OpenStreetMap contributors
Generation
Residual Load
SOC Battery
Power Consumption of Electrolysis in GW
Content of Hydrogen Storage in GWh
SOC of Pumped Hydro Storage in %

Hydrogen Potential in EMN

Results (scenario 2050)

power [GW]

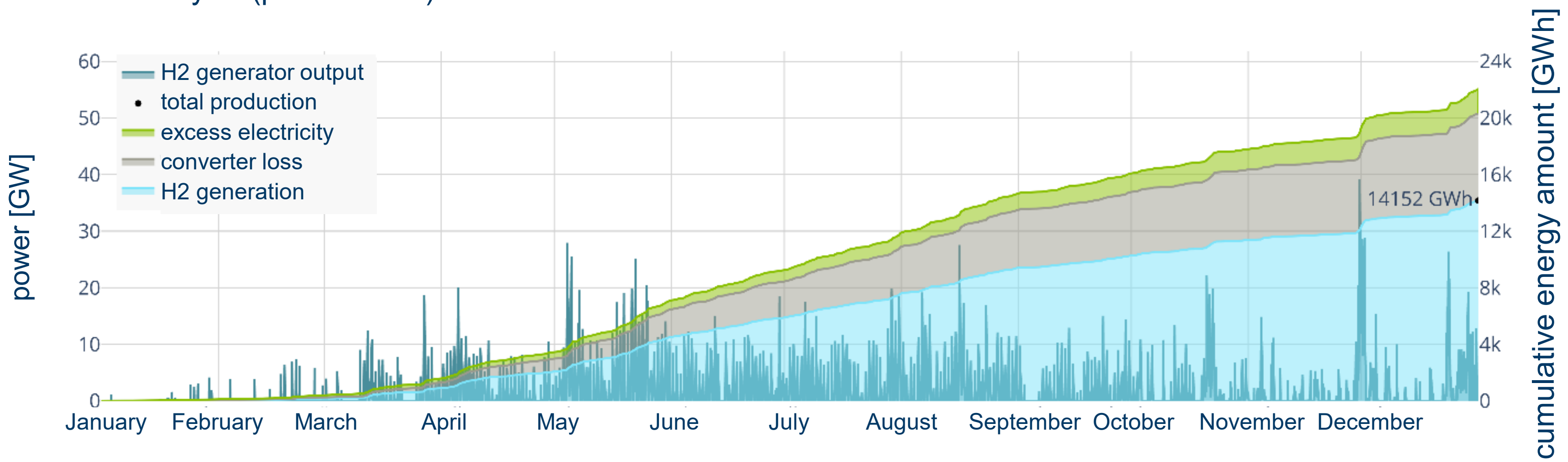
Electrolysis:

- annual H2 production approx. 14 TWh
- very high power peaks

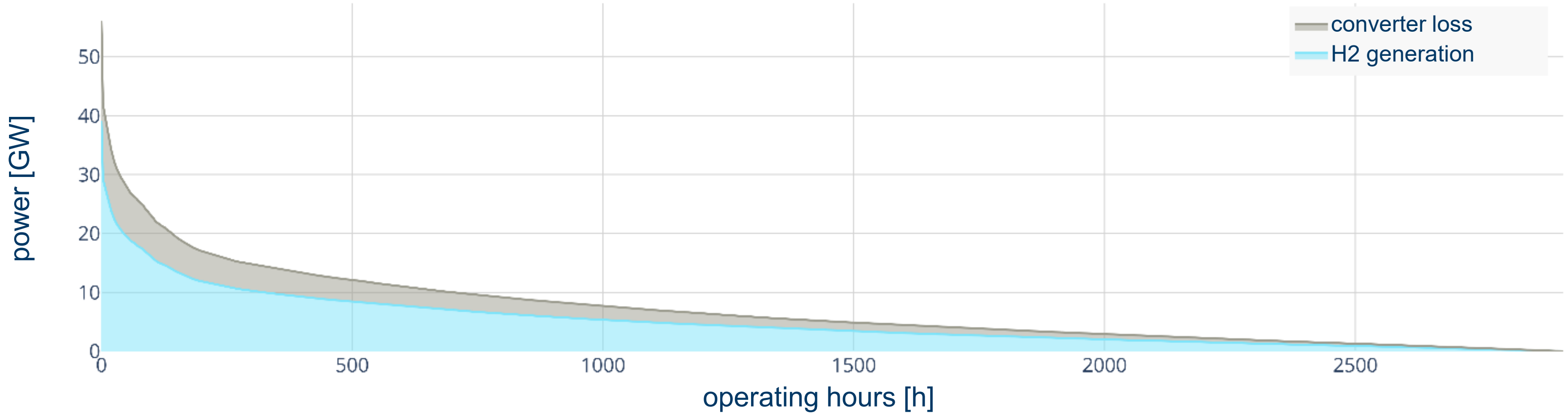
Distribution of generation output:

- only 1/3 year operation

Electrolysis (power to H2) scenario 2050



H2 generation distribution scenario 2050



Hydrogen Potential in EMN

Results (scenario 2050)

Expansion of renewables

- annual H2 production approx. 14 TWh, demand approx. 7 TWh, overall H2 self-sufficiency possible (ideal assumptions)
- high peak performance at low utilization: unrealistic system dimensioning
- even if there is an annual electricity surplus (approx. 11 TWh), electricity imports are required

Battery storage for electrolysis

- power limitation, smoothing, increase in utilization, advantages for smaller electrolysis outputs
- more realistic H2 production of 5 and 8 TWh
- for high electrolysis outputs, a utilization of 40% cannot be achieved, rather < 27%

Reconversion of hydrogen

- signs of electrolysis power of around 6 GW
- complete re-conversion of electricity enables EMN to achieve approx. 80% self-sufficiency
- requires storage volume of around 100 GWh

Conclusion

Conclusion

- **Cellular approach**
  - energy cells for electricity, heat, natural gas, hydrogen
  - simple demand, generation and storage cells can also be used for cost flows and material flows
- **i7-AnyEnergy framework supports modelling of**
  - energy, material and cost flow cells
  - hierarchical structures
  - centralized and decentralized control algorithms
  - integrated energy systems
- **Wide variety of applications**
  - e.g. Hydrogen Potential in EMN
    https://www.encn.de/nachricht/encn-stellt-wasserstoffstudie-fuer-die-metropolregion-vor
- **i7-AnyEnergy framework is open source**
  - https://github.com/cs7org/i7-AnyEnergy
  - MIT License
  - runs with AnyLogic (https://www.anylogic.com)