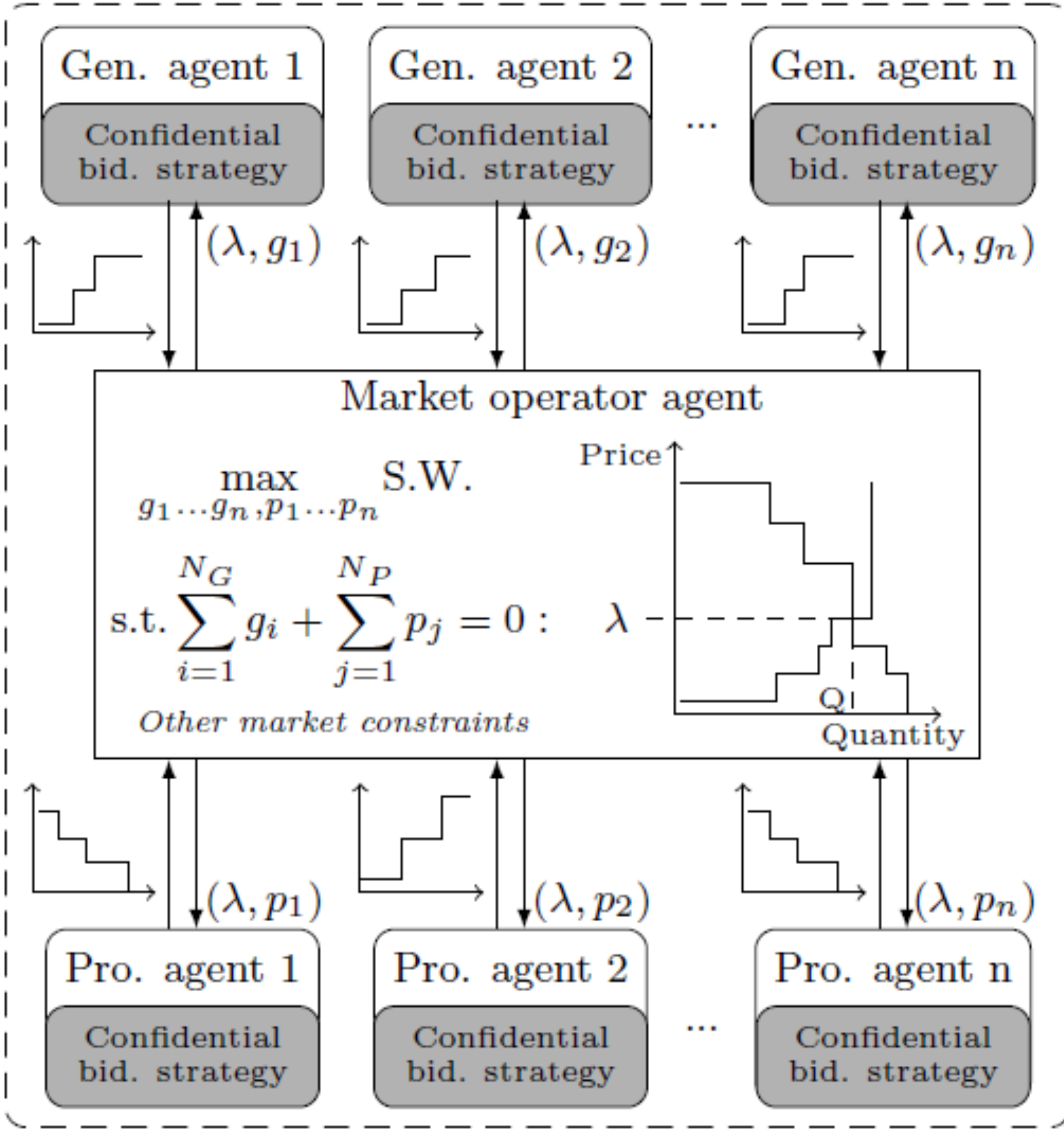
Coupling agent-based energy market models:

benefits and limitations

Laurens de Vries

TU Delft



My research question: how to design electricity markets?

How to set the right incentives to achieve public objectives?

Incentives:

- Market design, network tariffs, policies like the ETS, CRMs.
- Public objectives:
  - short-term economic efficiency, long-term economic efficiency, affordability
  - reliability, adequacy
  - CO_2 emissions, renewable energy

Strong focus on investment

- Energy transition
- Do markets provide system adequacy?

The role of ABMs

Modeling imperfections:

- In market design

- In behavior.

Three steps in model evoluation at TUDelft

(0: Unnamed model for my own dissertation, 2004)

1. EMLab
2. AMIRIS-EMLabPy
3. DEMOSES

Themes:

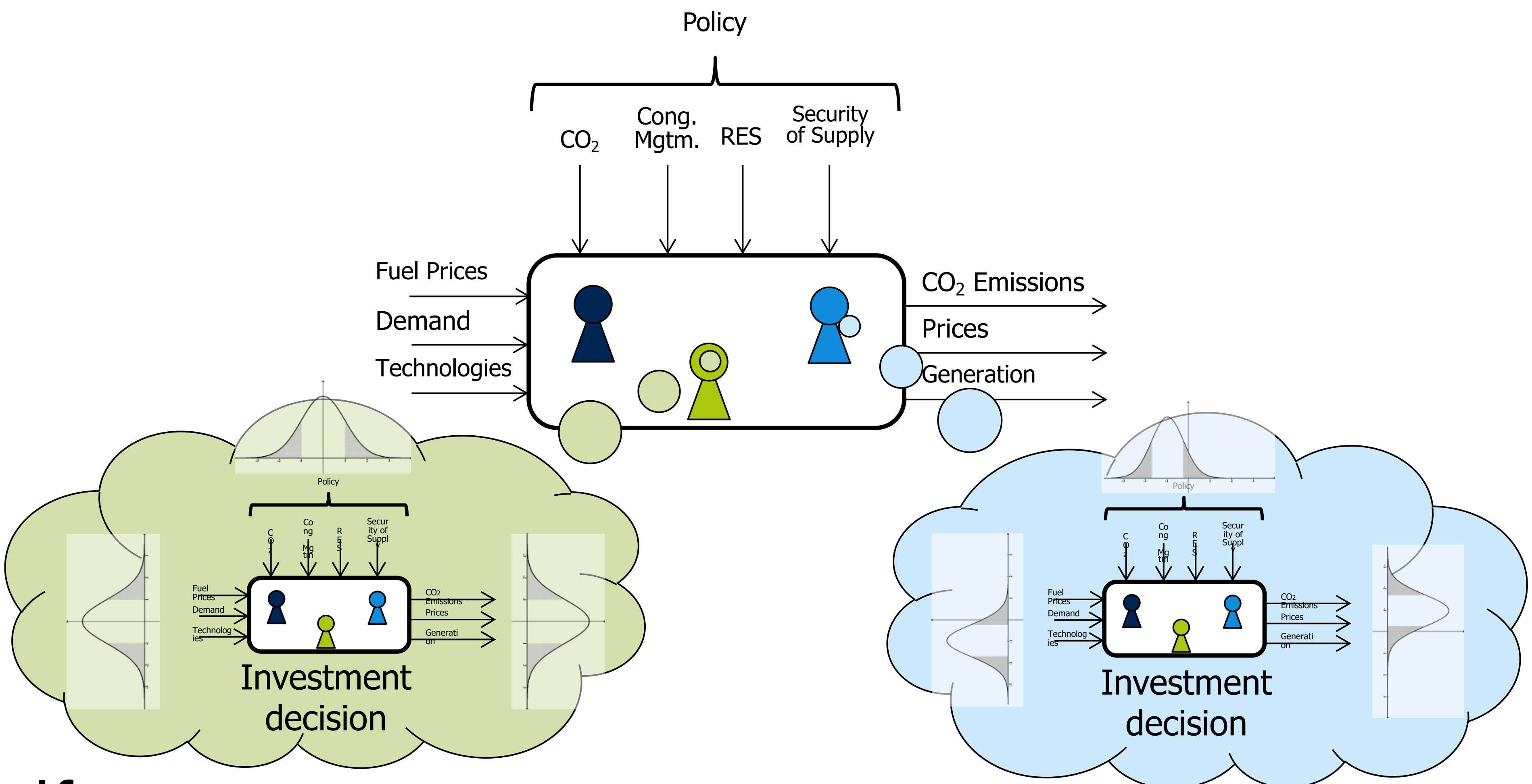
- System adequacy
- Modeling flexibility
- Model coupling

EM-Lab
Electricity Modeling Lab
2010s

Model developed at TU Delft by Emile Chappin, Jörn Richstein, Pradyumna Bhagwat and others

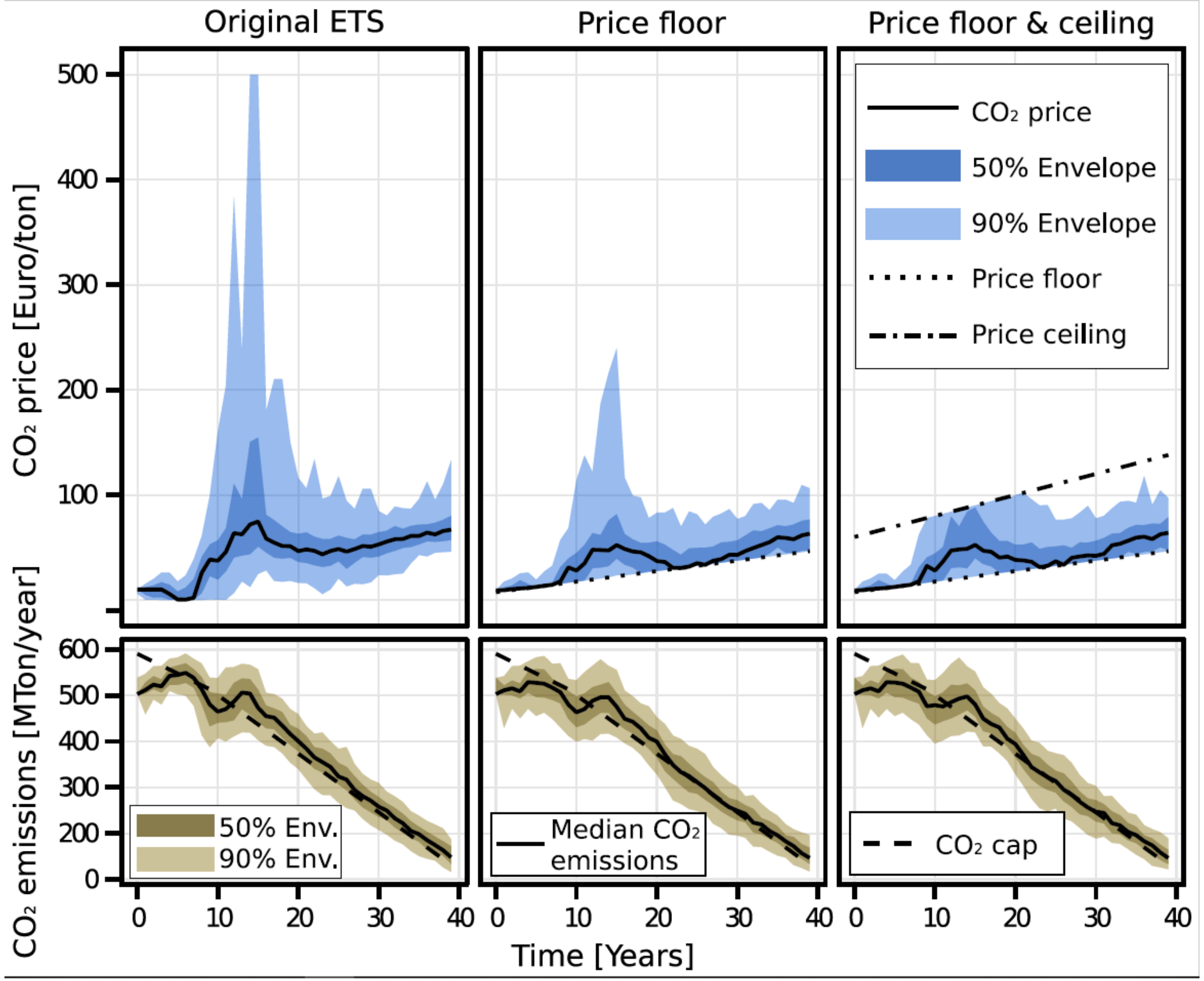
TU Delft

Example: EM-Lab: virtual ‘lab’ for testing energy policies



With thanks to Émile Chappin

EM-Lab results for CO_2 policy



With thanks to Jörn Richstein

TU Delft

EM-Lab: strengths and weaknesses

Strenths:

myopic investment.

CO_2 policy

CRMs

Shortcomings:

Time slice approach to limit computer time.

Lack of representation of flexibility, consumer participation.

EM-Lab selected references

Richstein, J.C., Chappin, E.J.L. and De Vries, L.J. (2014). "Cross-border electricity market effects due to price caps in an emission trading system: An agent-based approach." Energy Policy. Vol. 71., pp. 139–158.

Richstein, J. C., Chappin, É. J. L., & De Vries, L. J. (2015). The market (in-)stability reserve for EU carbon emission trading: Why it might fail and how to improve it. Utilities Policy 35, 1–18.

Richstein, J. C., Chappin, É. J., & De Vries, L. J. (2015). 'Adjusting the CO2 cap to subsidised RES generation: Can CO2 prices be decoupled from renewable policy?'. Applied Energy 156, 693-702.

Chappin, E.J.L., De Vries, L.J., Richstein, J.C., Bhagwat, P., Iychettira, K. and Khan, S. (2017). "Simulating climate and energy policy with agent-based modelling: The Energy Modelling Laboratory (EMLab)". Environmental Modelling & Software 96: 421-431.

Bhagwat, P.C., De Vries, L.J., Marcheselli, A., Richstein, J.C., & Chappin, E.J.L. (2017). 'An analysis of a forward capacity market with long-term contracts'. Energy Policy, 111(May), 255–267.

Pradyumna C. Bhagwat, Kaveri. K. Iychettira, Jörn C. Richstein, Emile J.L. Chappin and Laurens J. De Vries (2017). "The effectiveness of capacity markets in the presence of a high portfolio share of renewable energy sources". Utilities Policy 48:76-91.

Chappin, E.J.L., De Vries, L.J., Richstein, J.C., Bhagwat, P., Iychettira, K. and Khan, S. (2017). "Simulating climate and energy policy with agent-based modelling: The Energy Modelling Laboratory (EMLab)". Environmental Modelling & Software 96: 421-431.

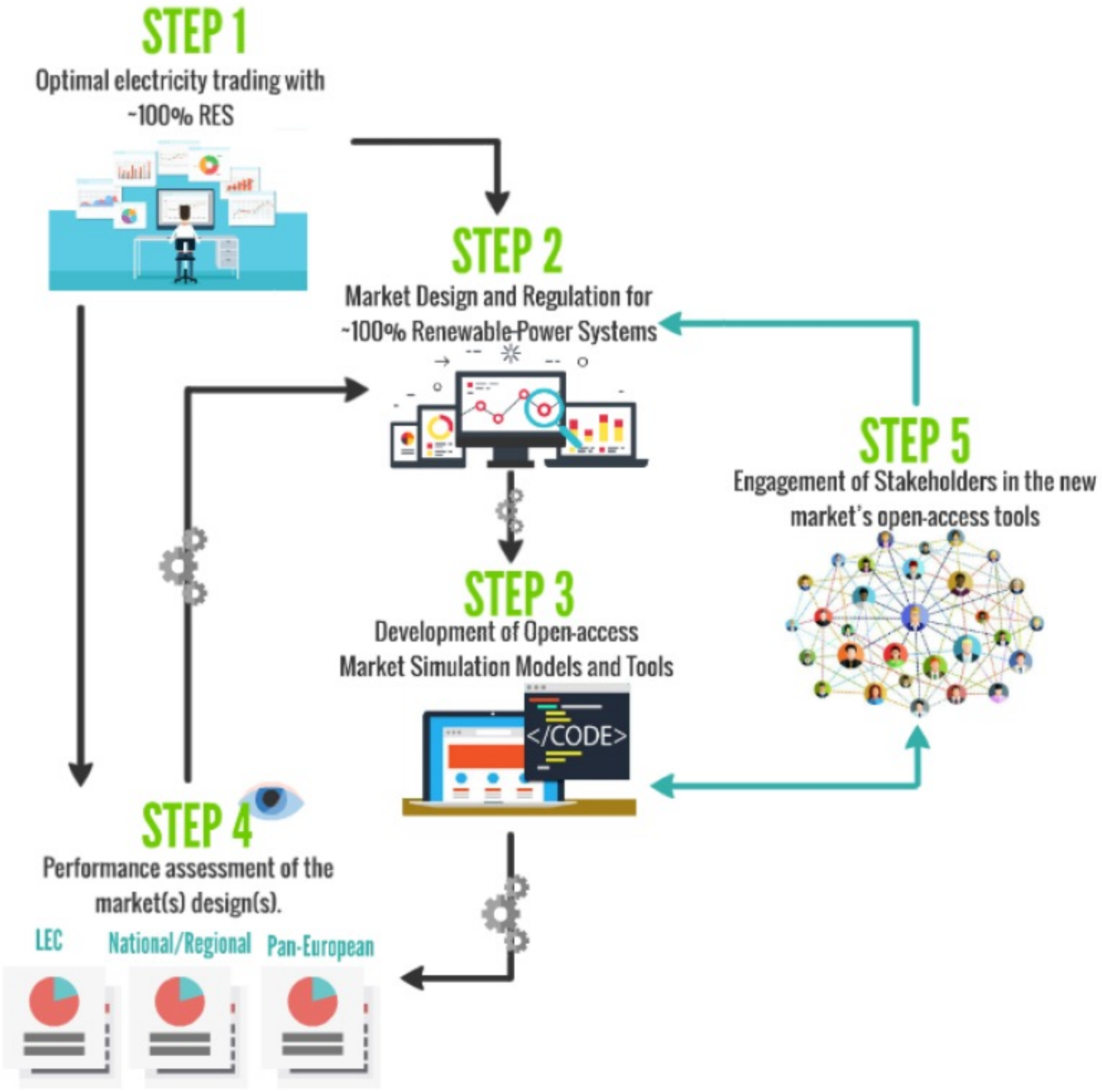
Pradyumna C. Bhagwat, Jörn C. Richstein, Emile J.L. Chappin, Kaveri. K. Iychettira, Laurens J. De Vries (2017). "Cross-border effects of capacity mechanisms in interconnected power systems". Utilities Policy (46): 33-47.

TradeRES
2020-2024

HEU Project, PI: Ana Estanqueiro, LNEG, Portugal

TU Delft

The TradeRES project approach



TU Delft

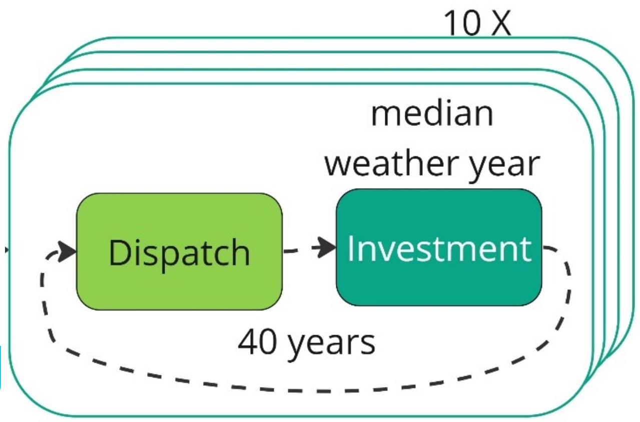
Agent-Based Model Co-simulation

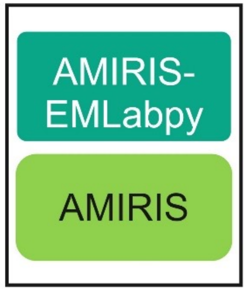
EMLabpy **TU Delft**

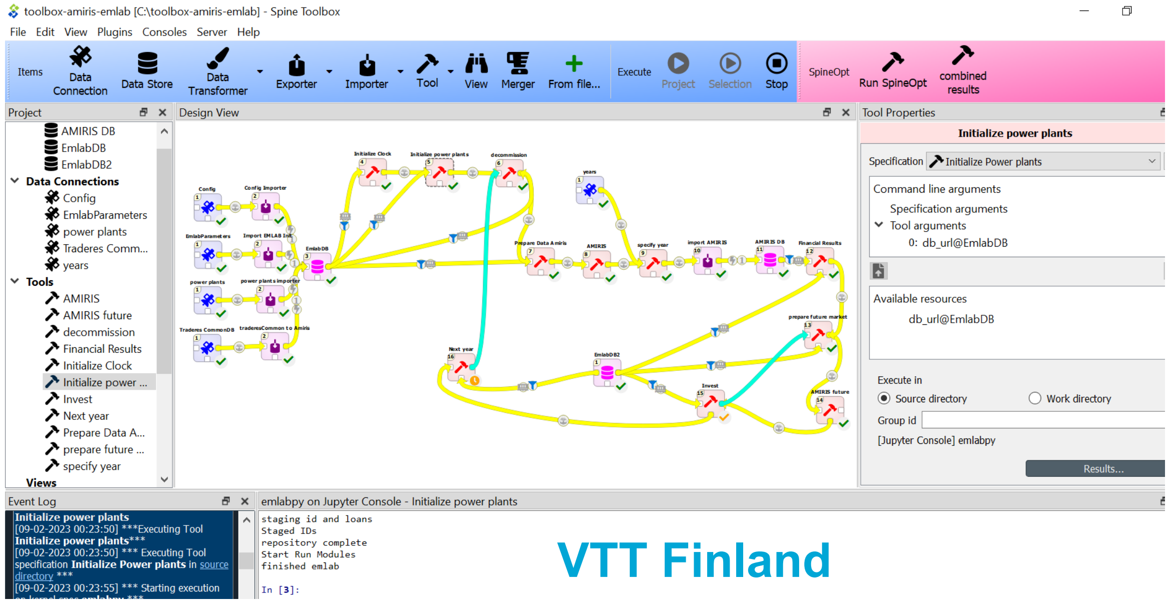
- Long term
- Investment and decommission
    - NPV > 0
    - Myopic
    - No equilibrium
- CRMs
- Limited flexibility

AMIRIS **DRL Stuttgart**

- Dispatch (hourly)
- More flexibility types
- vRES support policies
- No investment decisions

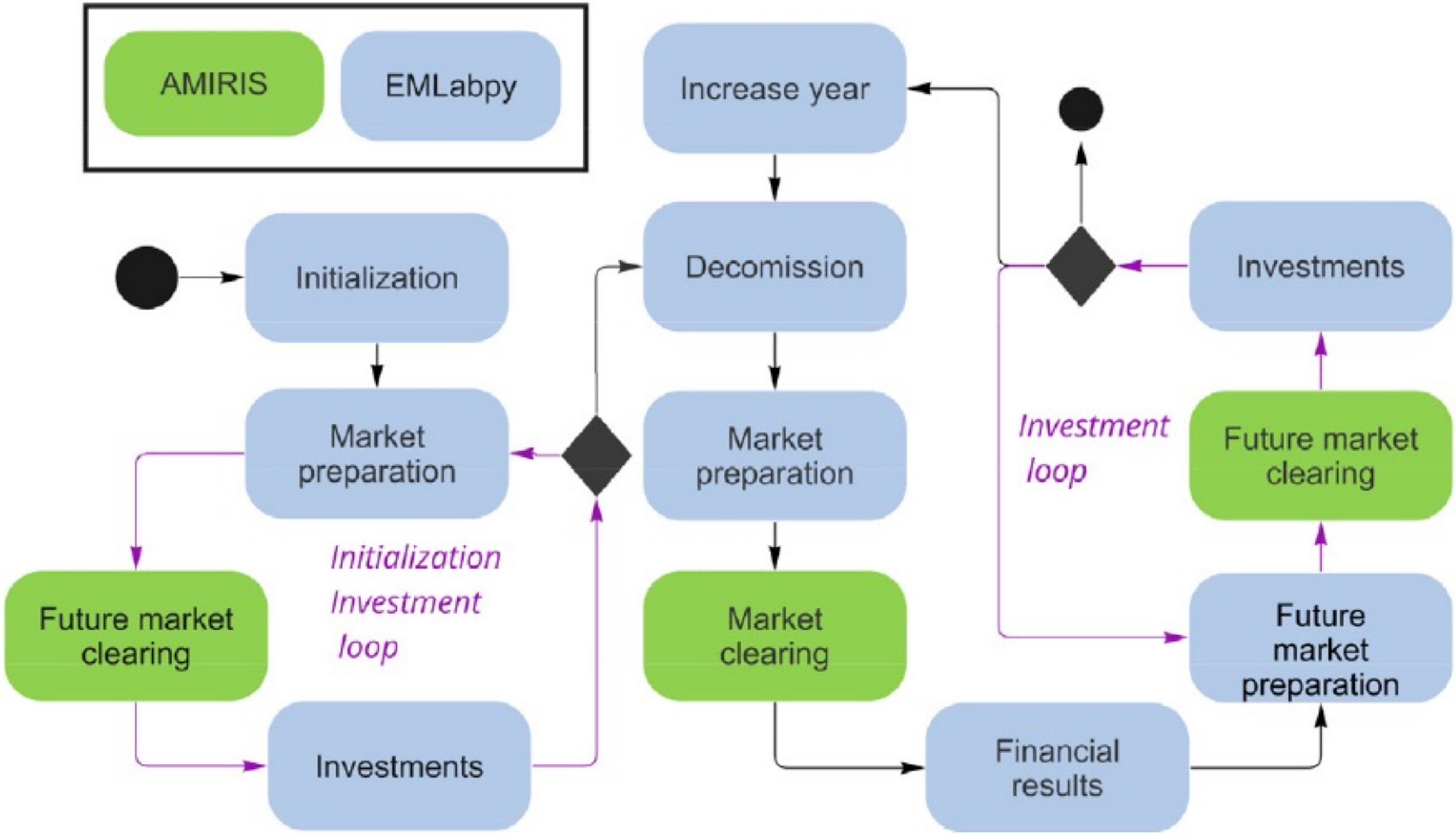






VTT Finland

Cosimulation AMIRIS - EMLabpy

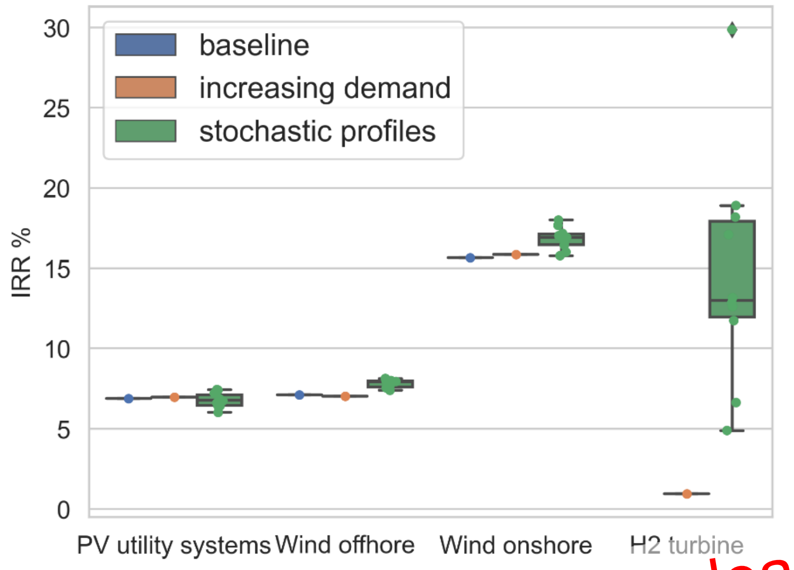


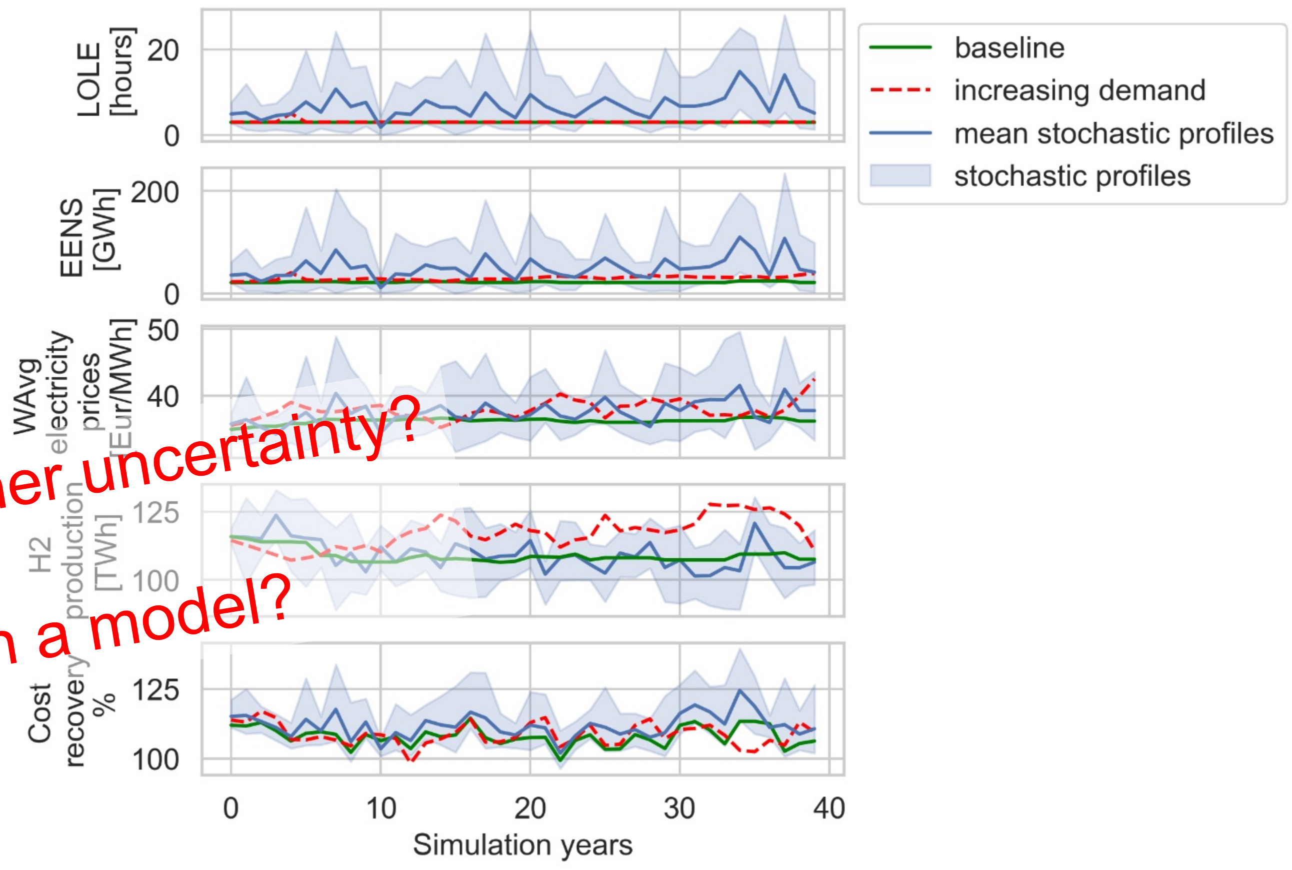
TradeRES: AMIRIS – EMLabPy insights

- New market dynamics. Demand may set the price a large part of the time in the future (especially hydrogen production).
- Due to weather uncertainty, energy-only markets are not likely to drive enough investment:
    - neither in RES
    - Nor in dispatchable power plant.
- CRMs: strategic reserve distorts the merit order. Capacity market more effective, but needs to be adjusted:
    - To provide efficient incentives for storage and demand flexibility
    - To deal with the dependence on hydrogen.

TU Delft

Modeling challenge: weather uncertainty





How do investors deal with weather uncertainty?

How to represent this behavior in a model?

TU Delft

TradeRES–AMIRIS: challenges

- Complexity
  - Combination of two models with different representations of power plants etc.
- How to schedule flexibility efficiently over a 5-10 day rolling time horizon?
  - The day-ahead market was designed to schedule thermal plant for the next day…
  - Real-life market design question and modeling question.
- Runtime
  - Agent-based investment decisions need to reflect agents' expected revenues in the future.
  - This requires a model loop over the operational model (AMIRIS)
- How to represent investors' behavior?
  - Regarding weather patterns
  - Regarding policy uncertainty
  - Regarding sector integration, network investment and consumer demand

Selected TradeRES references

Ingrid Sanchez-Jimenez, D. Ribó-Pérez, M. Cvetkovic, J. Kochems, C. Schimeczek, L.J. De Vries (2024). “Can an energy only market enable resource adequacy in a decarbonized power system? A co-simulation with two agent-based-models”. Applied Energy 360: 122695.

Ingrid Sanchez Jimenez, Kenneth Bruninx, Laurens de Vries (2024). “Capacity Remuneration Mechanisms for Decarbonized Power Systems”. Preprint.

Ingrid Sanchez Jimenez, Silke Johanndeiter, Laurens de Vries (2025). “Capacity Remuneration Mechanisms for Power Systems in Transition”. Preprint.

TU Delft

DEMOSES
Designing and Modeling Systems of Energy Systems
2022-2026

Funded by the Dutch Research Council

PI: Laurens de Vries

TU Delft

Project goals

1. To assess barriers to flexibility
2. To couple partner models so they can express their (expected) flexibility without sharing their confidential data

The underlying challenge is a chicken-and-egg problem:

- To model the future electricity system, we need to know the degree of flexibility of (large) consumers.
- To know how much to invest in flexibility, (large) consumers need to know future electricity prices.

Potential barriers to flexibility in electricity markets

	Electricity taxes	DSO network tariffs	TSO network tariffs	SDE++	Rooftop solar prosumer	Gas taxes	Carbon taxes
Applicability	All consumers	All consumers connected to distribution grid	All consumers connected to transmission grid	Consumers/ generators with RE or emission reduction technologies	Consumers with grid-connected rooftop solar systems	All consumers	Industrial consumers, waste incinerators, nitrous oxide emitters
Consumer categories	Categorisation based on end-use type, subcategorisation based on total annual consumption level	Categorisation based on consumer size, subcategorisation based on connection size or connected voltage	Categorisation based on connected voltage	Categorisation based on technology for RE generation or CO2 emission reduction	Categorisation based on retail price contract type	Categorisation based on total annual consumption level	Categorisation based on total emissions
Components	Variable	Transport dependent (variable), transport independent (fixed)	Transport dependent (variable), transport independent (fixed)	Base amount, correction amount, base energy price, base GHG amount	Static (FiT) or dynamic (market price) tariff (variable)	Variable	Variable
Accounting period	Annual	Annual, monthly, time of use (hourly)	Annual, monthly, weekly	Annual	Annual, hourly	Annual	Annual
Variable	Energy consumption (kWh)	Connection size (kW), Maximum withdrawal(kW), energy consumption (kWh)	Contracted capacity (kW), Maximum withdrawal(kW)	Energy generated (kWh), emissions avoided/reduced (tCO2)	Energy injected into the grid (kWh)	Gas consumption (m^3)	CO2 emission (tons)
Unit	€/kWh	€/kW, €/kWh	€/kW, €/kWh	€/kWh, €/ton CO2 reduction	€/kWh	€/m^3	€/ton cO2
Exceptions and special conditions	Subsidised rate for EV users, energy tax credit provided to each consumer	None	Very large users allowed to negotiate tariffs	Dedicated budget for 'molecule' related technologies	None	Reduced rate for hortiulture consumers	Large industrial consumers can have 'custom' agreements

Source: Sugandha Chauhan, TU Delft

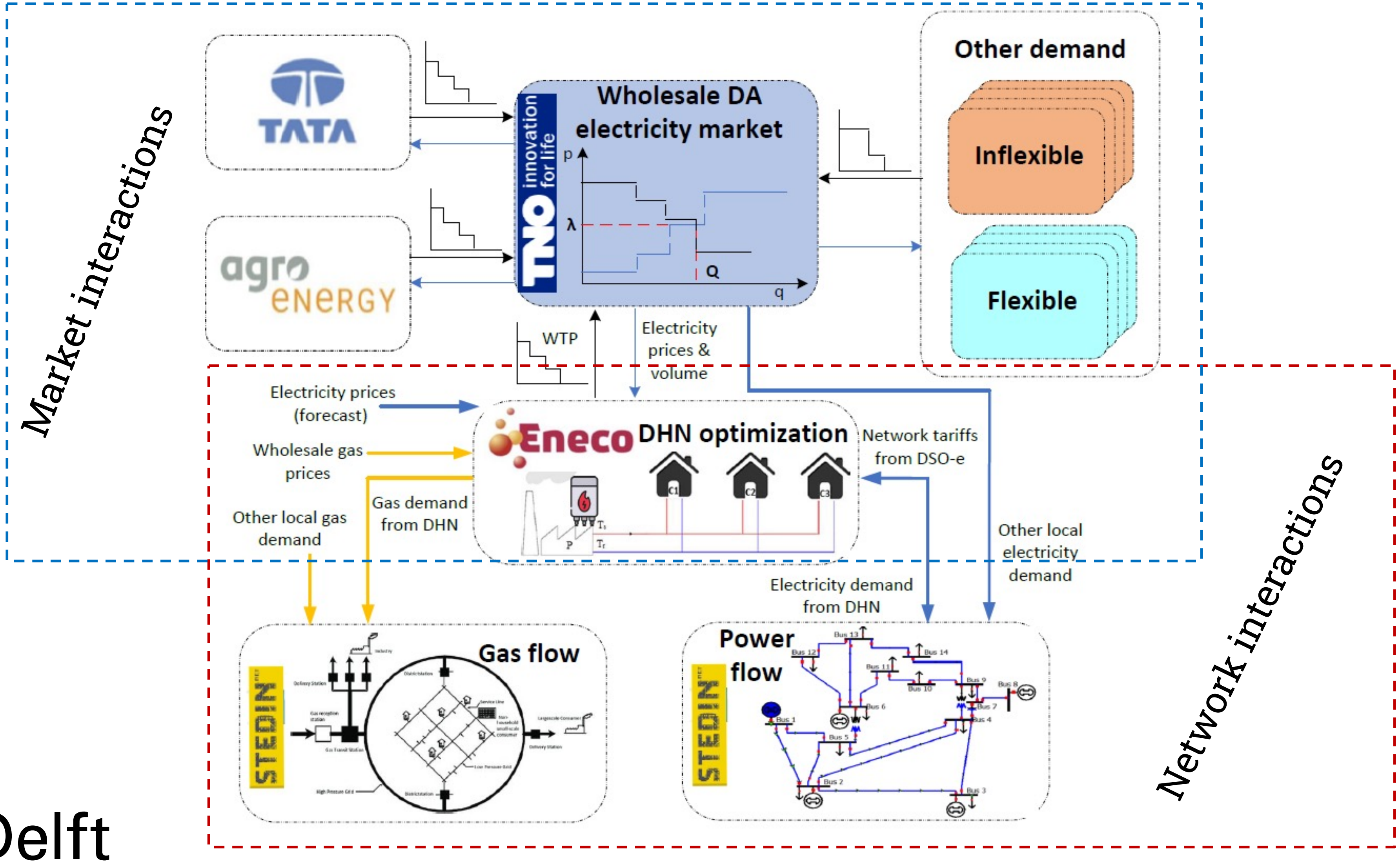
Qualitative comparison of modeling approaches

Coordination models for flexibility scheduling			
	Co-optimization	Model coupling based on price response algorithm	Model coupling based on market auction algorithm
Coordination architecture	Centralized	Distributed	Decentralized
Coordination mechanism	Centrally optimize a global utility through a one-shot optimization	Cooperatively optimize a global utility through iterations	Match agents' bids through rolling horizon-based market clearing
Required information exchange	Complete information of agents including internal states	Only interface variables: demand and supply timeseries	Only interface variables: demand and supply bid functions
Autonomy in agent's local decision making	No autonomy: based on top-down control signals from a central entity	Partial autonomy: based on consensus price and global constraints	Full autonomy: solely based on expected market price signals

TU Delft

Source: Christian Doh Dinga, TU Delft

How to model interactions between market players, markets and networks?



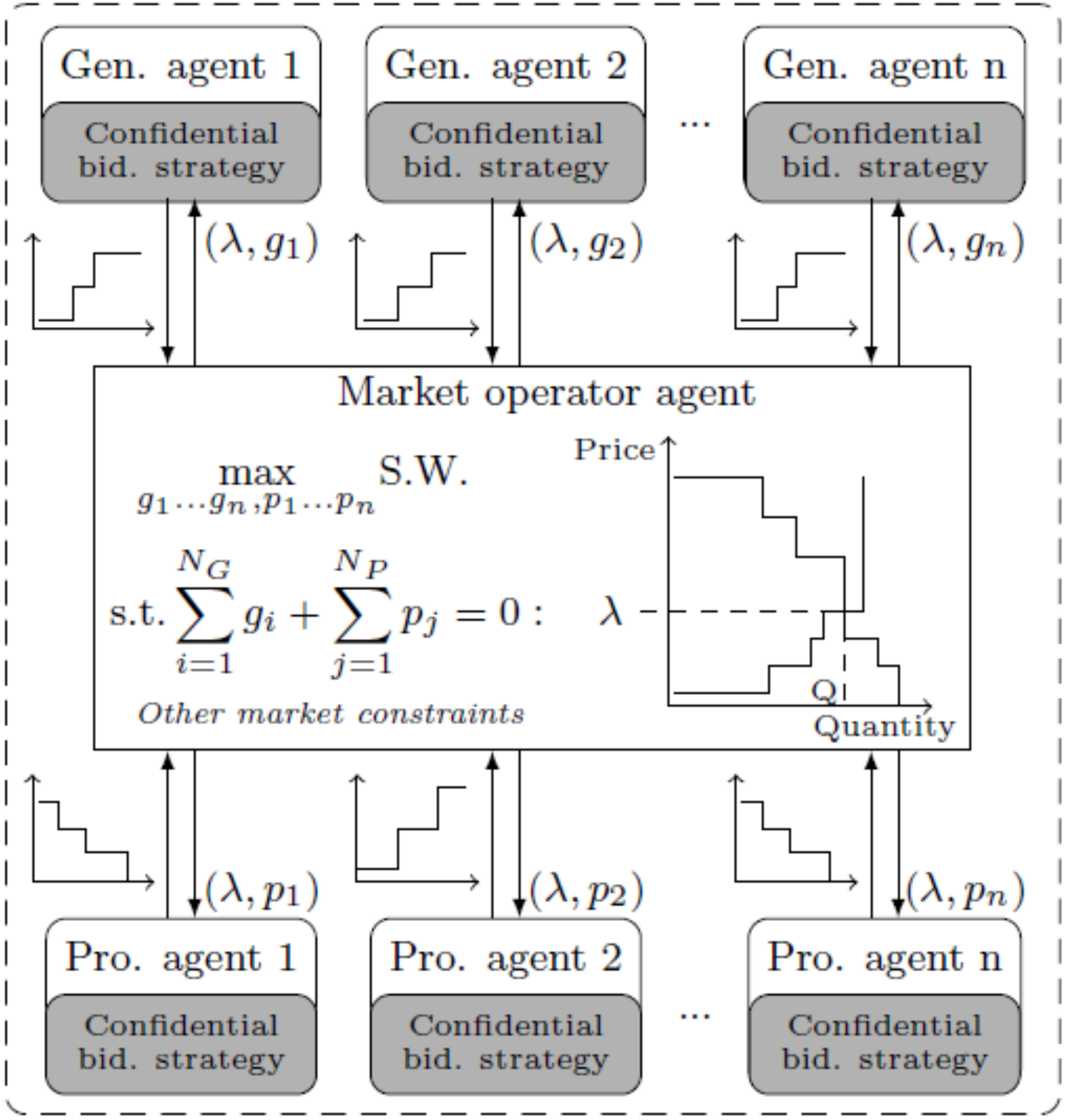
Source: Christian Doh Dinga, TU Delft

Market simulation + optimization

Taxes, grid tariffs etc. are signaled to the satellite models

Agents (‘satellite’) models submit bids.

Central model simulates supply, imports and exports and clears the market.

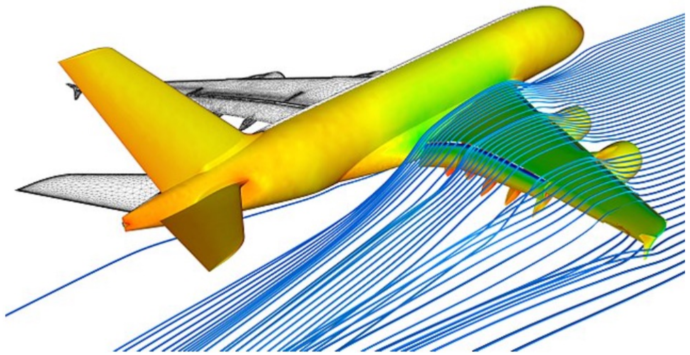


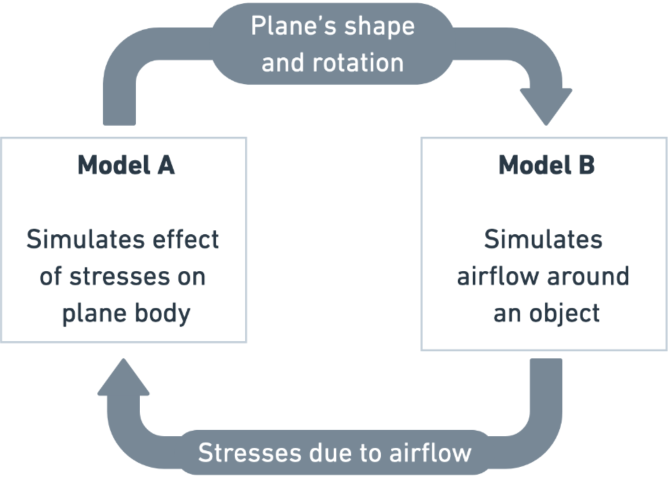
Source: Christian Doh Dinga, TU Delft

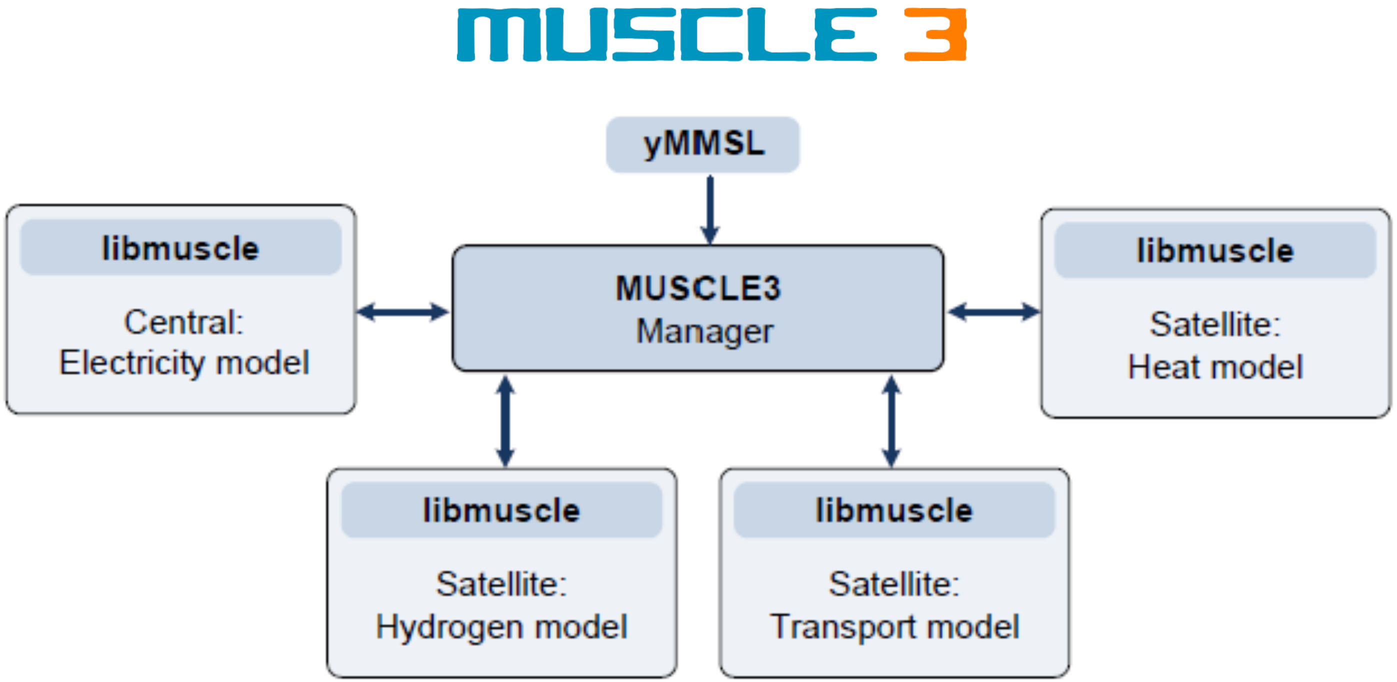
TU Delft

The model coupling software

MUltiScale Coupling Library and Environment developed by the Netherlands eScience Center





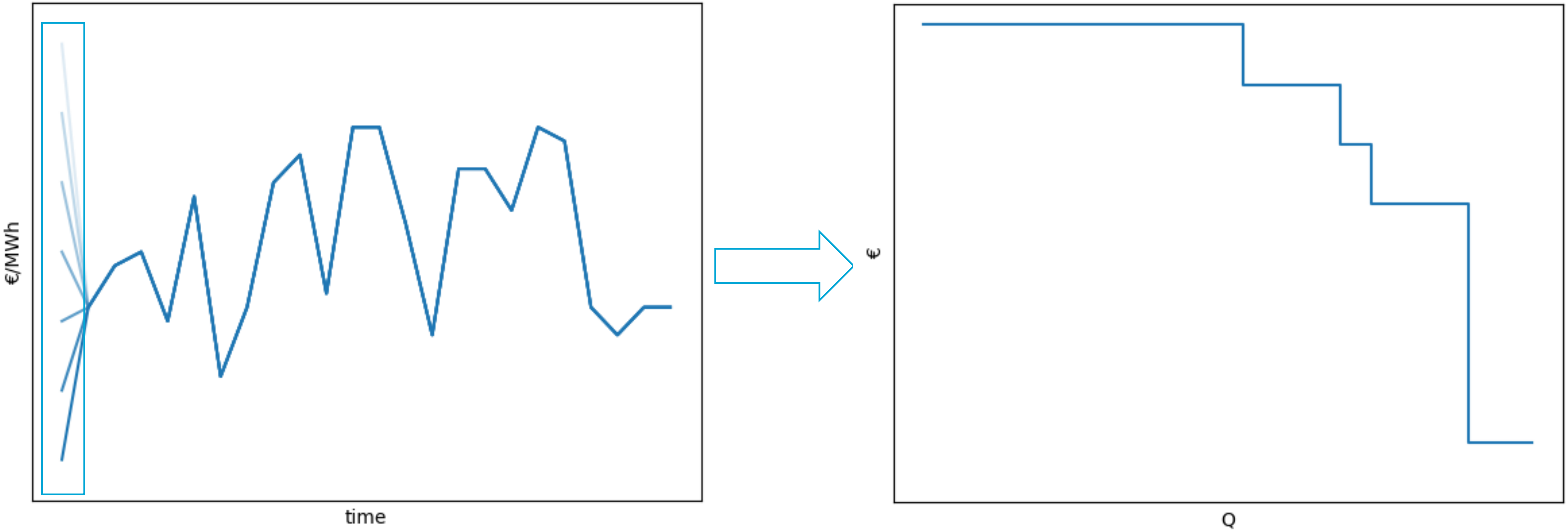


Model coupling software architecture with high-level components

Challenge: how satellite models (agents) generate bids

Agents with flexible resources have rolling time horizon stochastic optimization problem.

Their solutions depends on what the other agents do, but the market doesn't provide enough coordination!



DEMOSES - assessment

Reduction in scope compared to TradeRES: focus on barriers to flexibility. Underlying notion: these barriers will affect short-term operational efficiency as well as long-term investment efficiency.

Model coupling again.

- Why?To unlock private information
- Operational, so less complicated than an investment model.
  - But: still the problem of scheduling flexibility
  - Market design problem, too! – out of scope for this project.

Benefits:

- Computational behavior: not too slow, scaleable.
- Possibility of including any kind of financial incentive/distortion: grid fees, taxes, subsidies.

Challenge:

- How to simulate intelligent scheduling of flexibility over a multi-day time horizon.

TU Delft

Next step: MODES
Market Organization of the Dutch Energy System
2025-2029

Funded by the Dutch Research Council

PI: Laurens de Vries

TU Delft

From fixing current problems to a future market vision

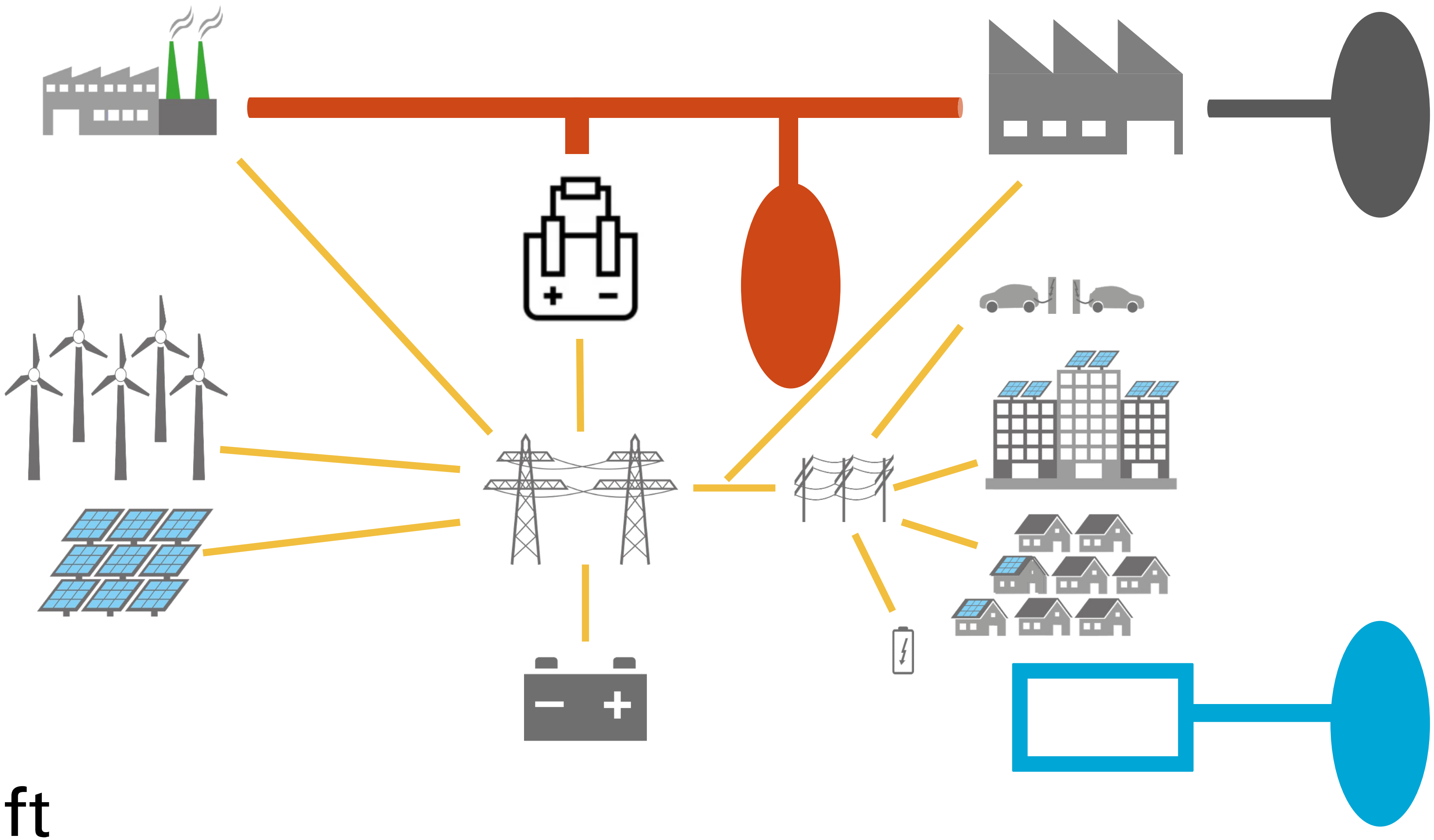
Market design, network regulation and flanking policies for:

- A long-term, carbon-free market design
- The transition path

One of the topics: efficient markets for an integrated electricity – hydrogen system

- Rolling time horizon market clearing?
- Mini-forward markets for short time steps over a 5-10 day period?

Research challenges addressed in MODES

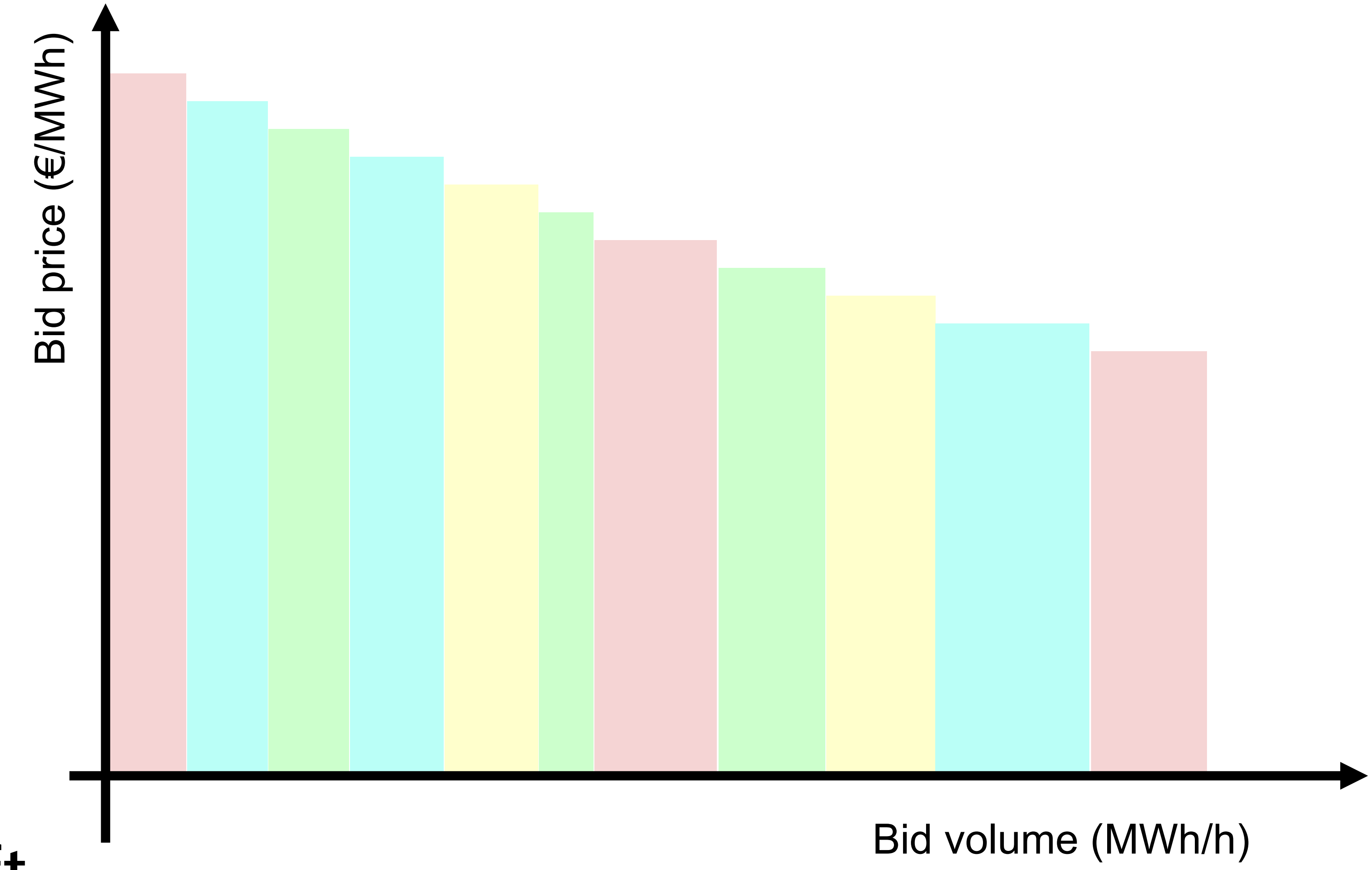


TU Delft

Questions?


Plug-in and
speak out!
Uitgezonderd
lijnbussen
en trams
LET OP
Busbaan

Scaleability



TU Delft