16th Conference on Sustainable Development of Energy, Water and Environment Systems

Flexibility and resilience from multi-energy systems

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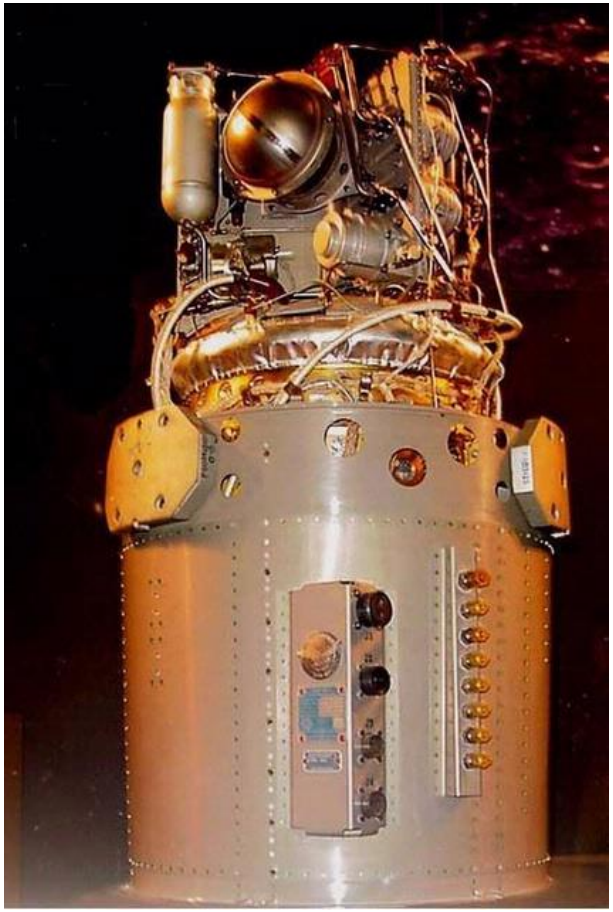
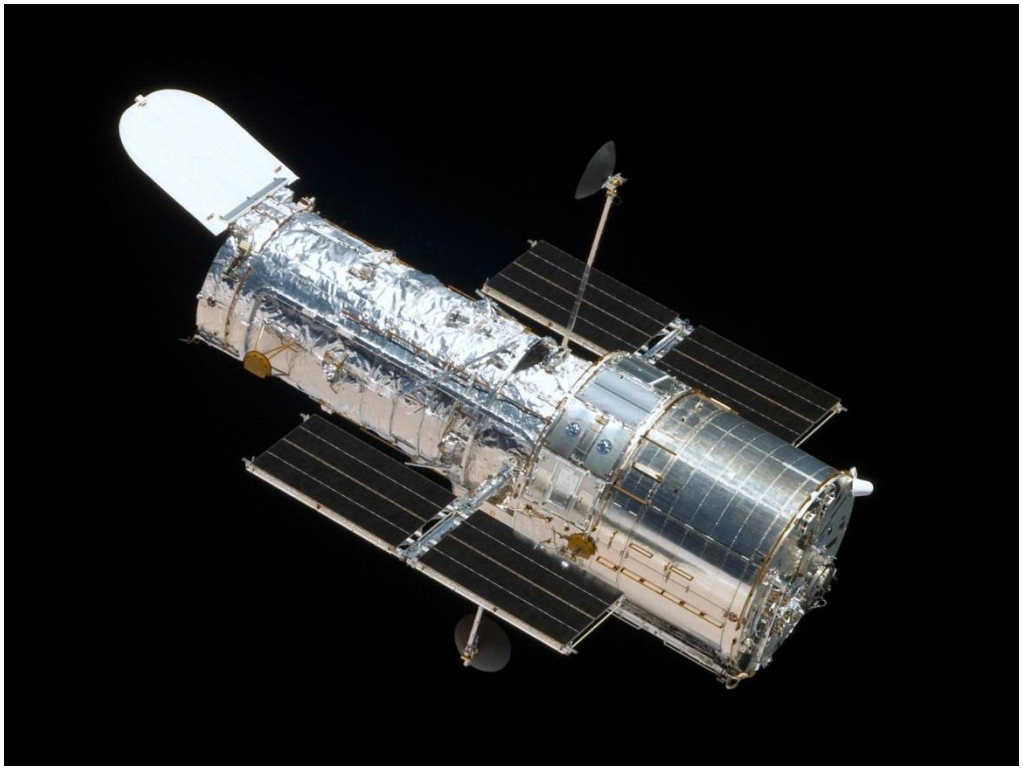
SDEWES '21

Dubrovnik, 14th October 2021

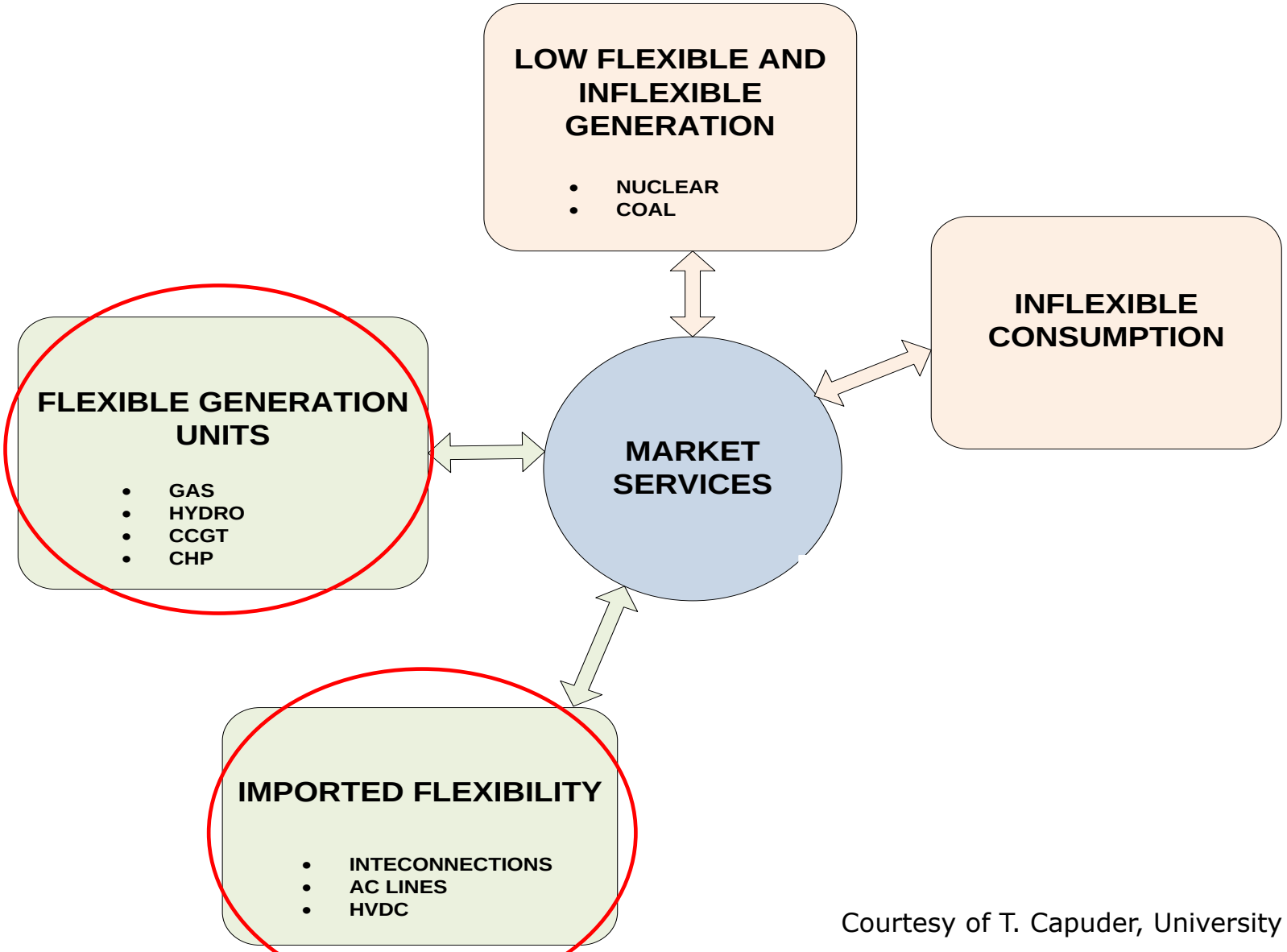
(delivered online)

Back to the future!



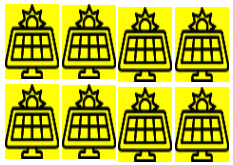


Who provides flexibility, security and reliability today?



Courtesy of T. Capuder, University of Zagreb

Who provides flexibility, security and reliability today?



LOW FLEXIBLE AND INFLEXIBLE GENERATION

- NUCLEAR

[redacted]

INFLEXIBLE CONSUMPTION

[redacted]

MARKET SERVICES

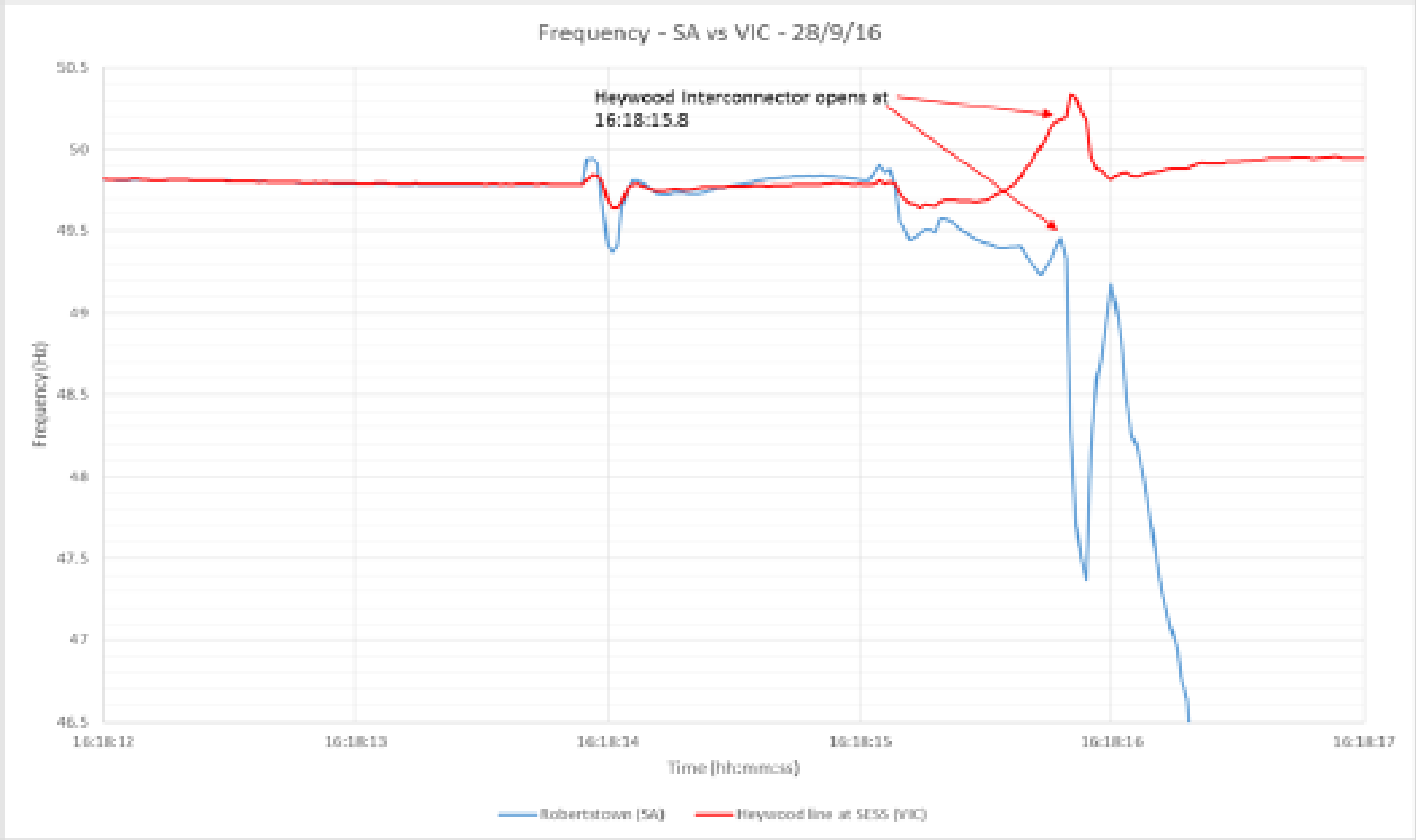
IMPORTED FLEXIBILITY

- INTECONNECTIONS
- AC LINES
- HVDC

Courtesy of T. Capuder, University of Zagreb

Is it a far future?

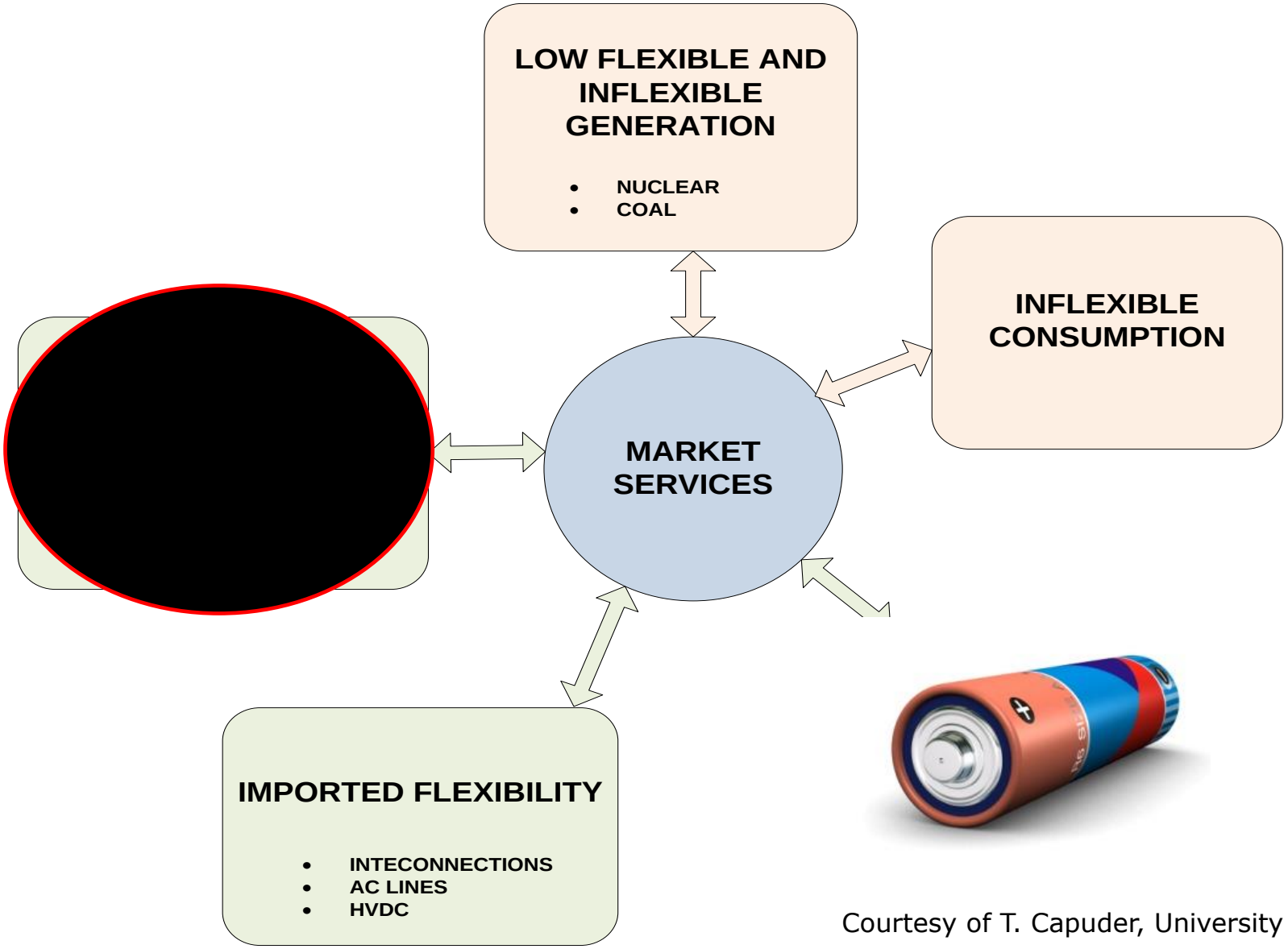
Figure 5 SA frequency compared to Victoria during event



Source: AEMO

Who can help to solve flexibility and security problems?

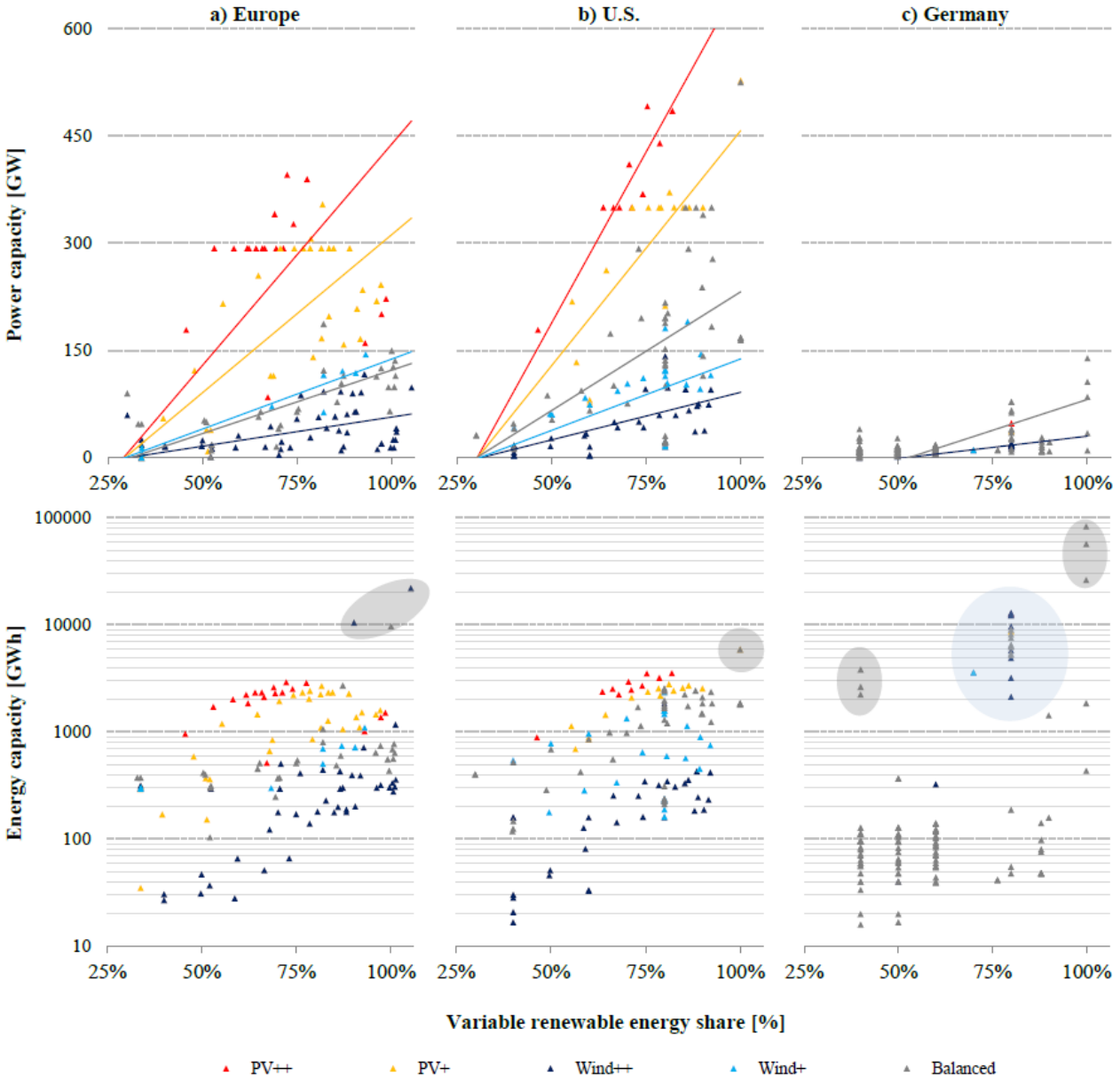
Flexibility in low-carbon power systems



Courtesy of T. Capuder, University of Zagreb

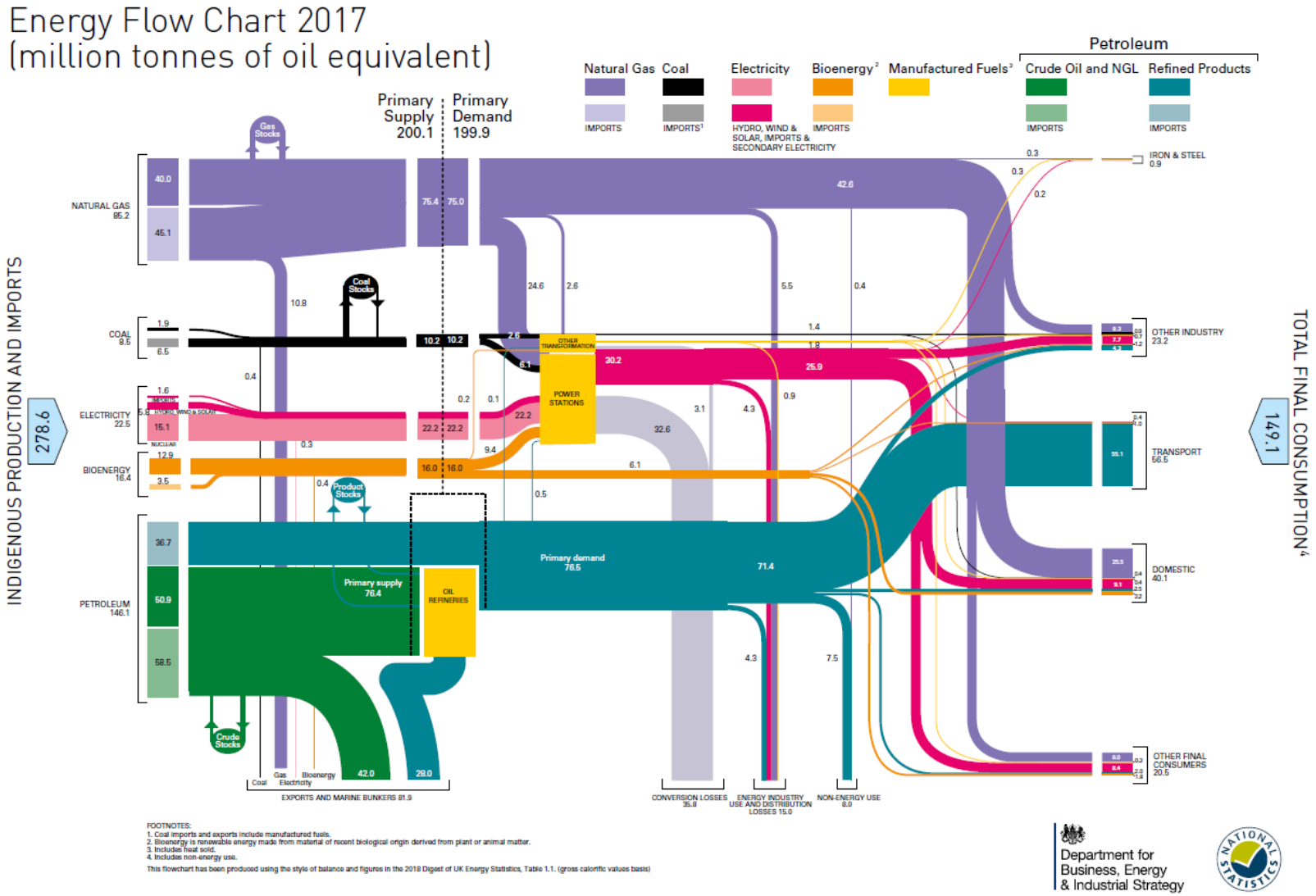
Still worried about delivering a low-carbon energy system?

How much and what storage do we need?

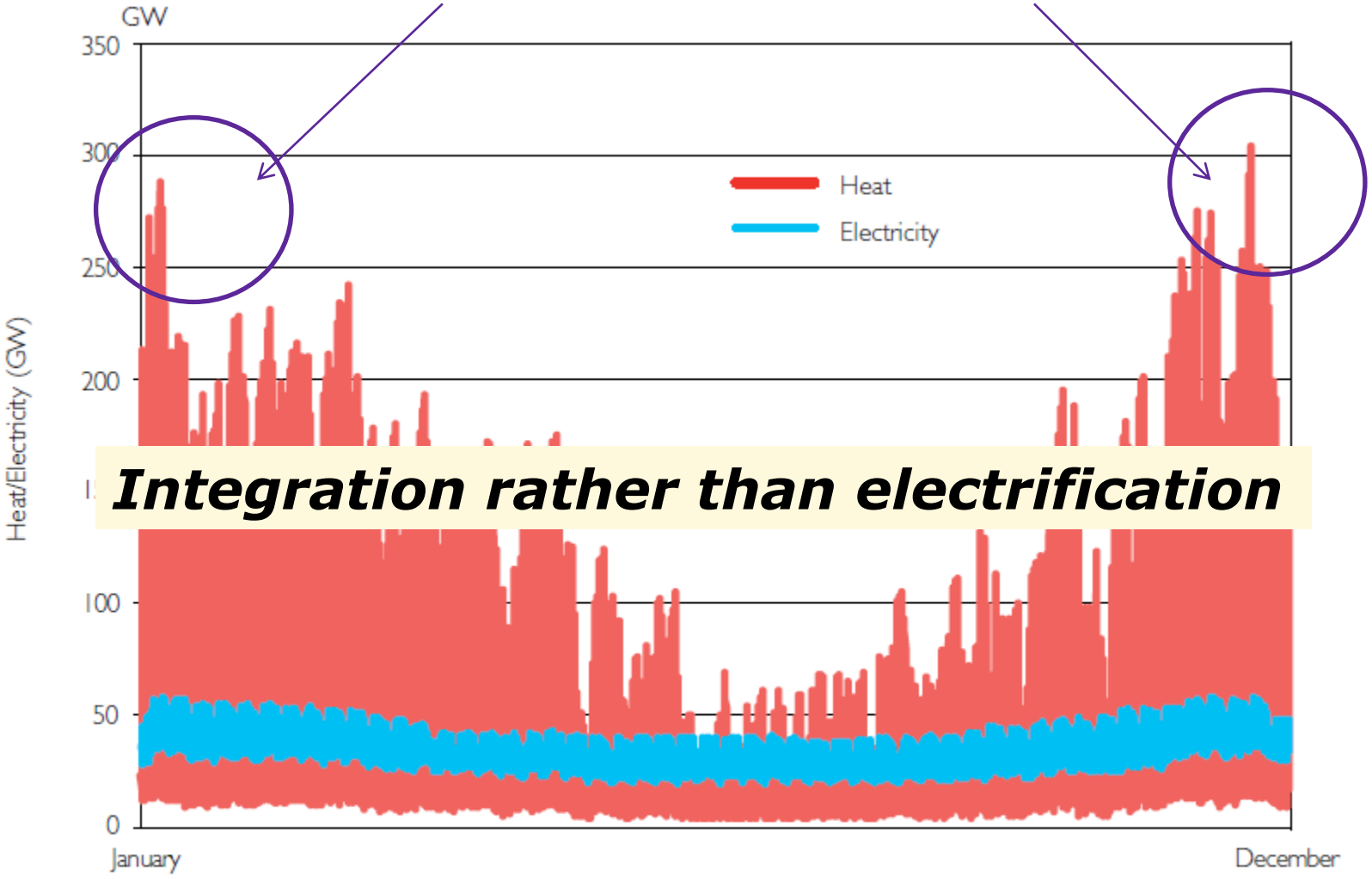


F. Cebulla, *et al.*, "How much electrical energy storage do we need?", *Journal of Cleaner Production*, Volume 181, 20 April 2018, 449-459

The bigger picture: Sector coupling and multi-energy systems



Electrification: the magnitude of the problem…

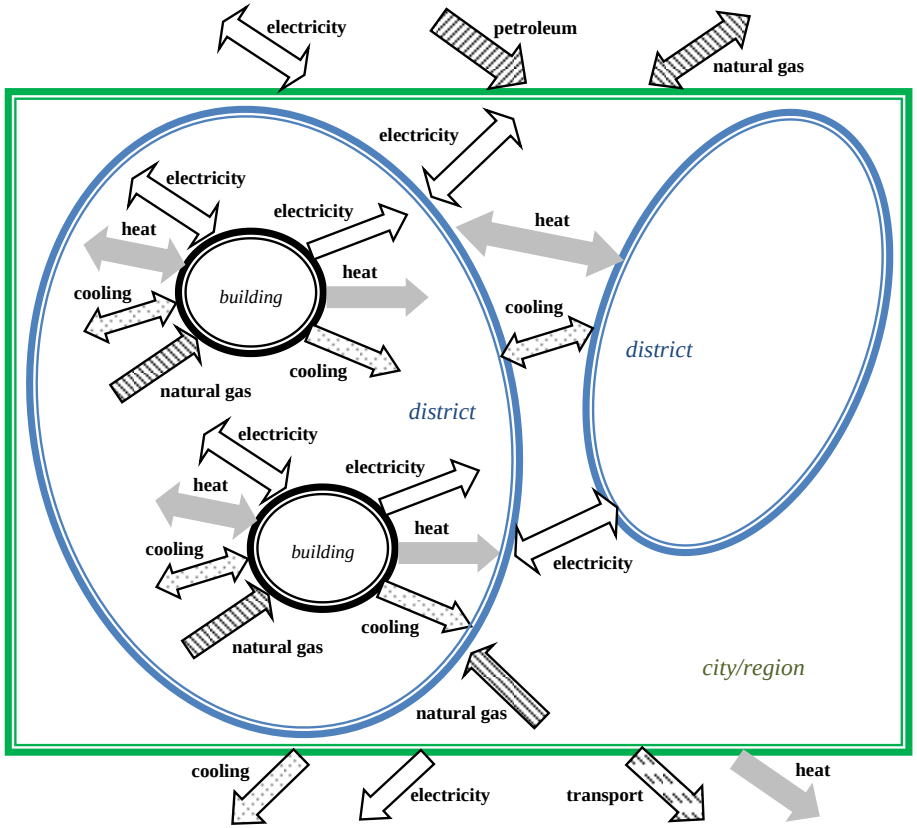


Integration rather than electrification

Source: Courtesy of Imperial College. For illustrative purposes only and based on actual half-hourly electricity demand from National Grid and an estimate of half hourly heat demand.

What are Multi-Energy Systems?

"Systems in which electricity, heat, cooling, fuels, transport, and so on optimally interact with each other at various levels - for instance, within a district, city or region"



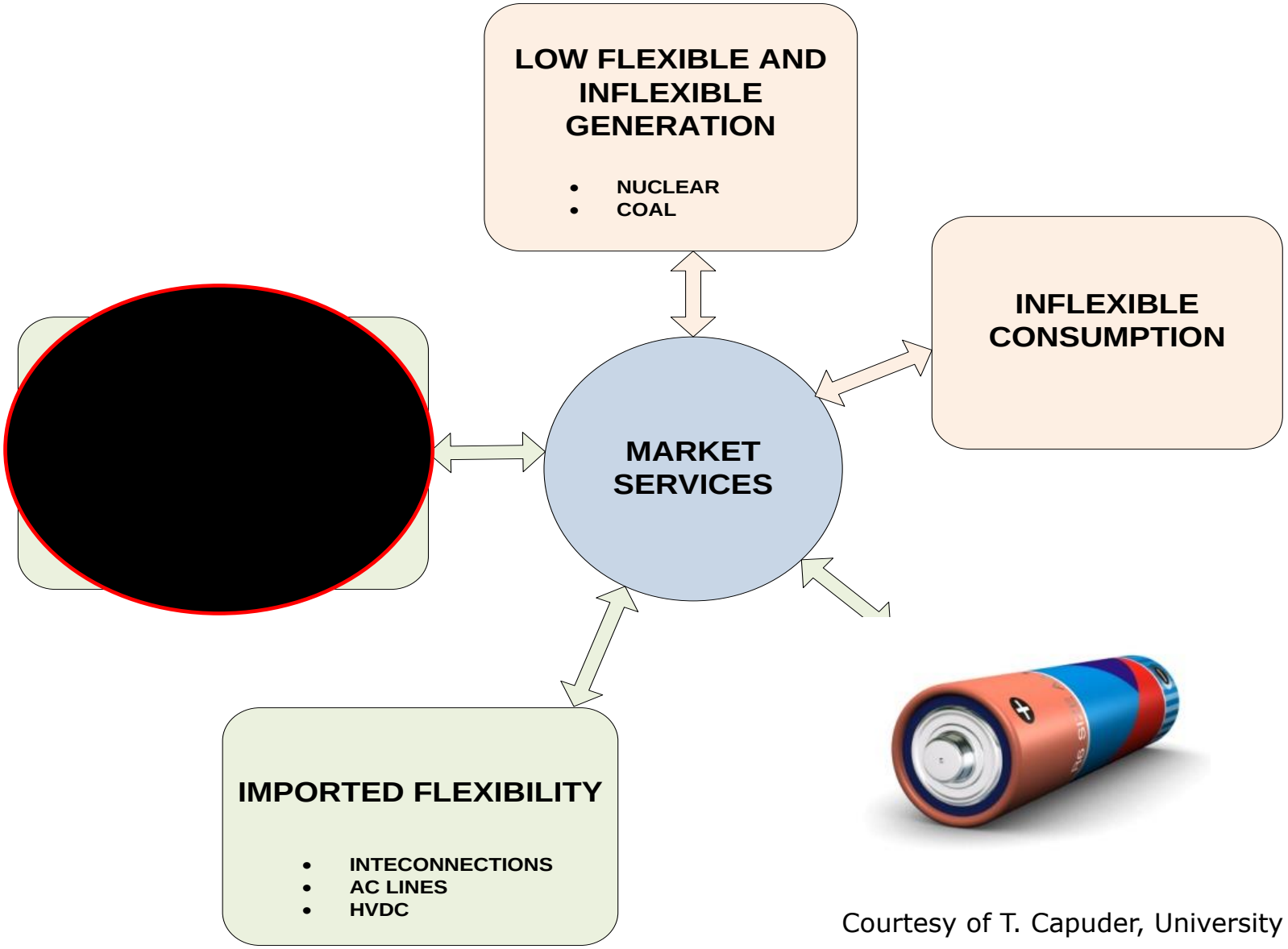
P.Mancarella, "*Multi-energy systems: an overview of models and evaluation concepts*", Energy, Vol. 65, 2014, 1-17, *Invited paper*

What is flexibility in MES terms?

- Can other energy systems/vectors provide flexibility to the electrical power system (= ability to provide supply and demand balance "quickly")?
- Can (lack of) flexibility in other energy systems constrain the electrical power system?

G. Chicco *et al.*, "Flexibility from distributed multienergy systems", *Proceedings of the IEEE*, 2020

So, instead of this…



Courtesy of T. Capuder, University of Zagreb

… could we do this?

LOW FLEXIBLE AND INFLEXIBLE GENERATION

- NUCLEAR
- COAL

INFLEXIBLE CONSUMPTION

[redacted]

MARKET SERVICES

IMPORTED FLEXIBILITY

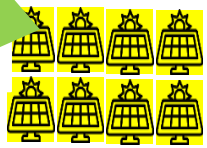
- INTECONNECTIONS
- AC LINES
- HVDC

Heating

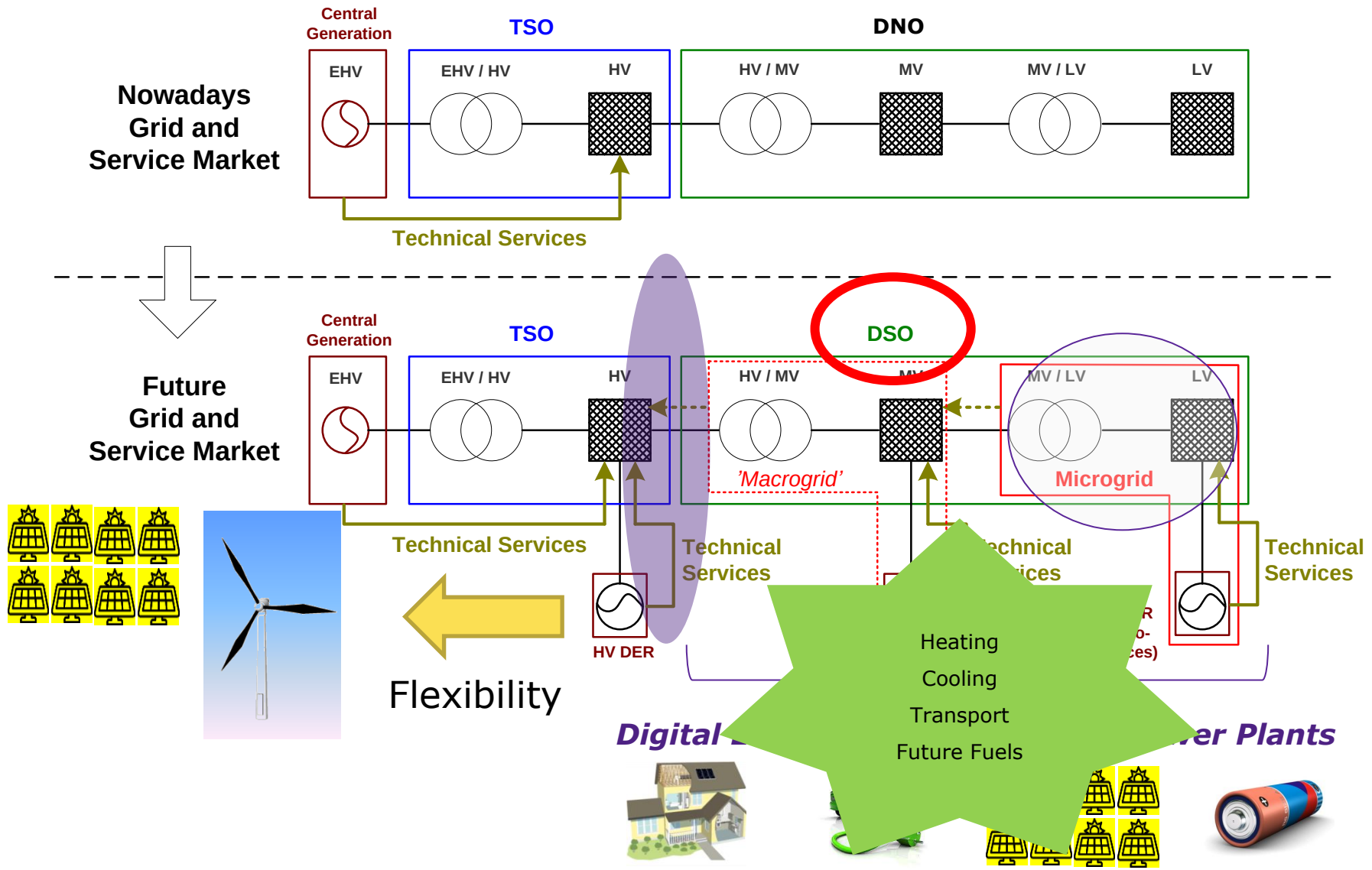
Cooling

Transport

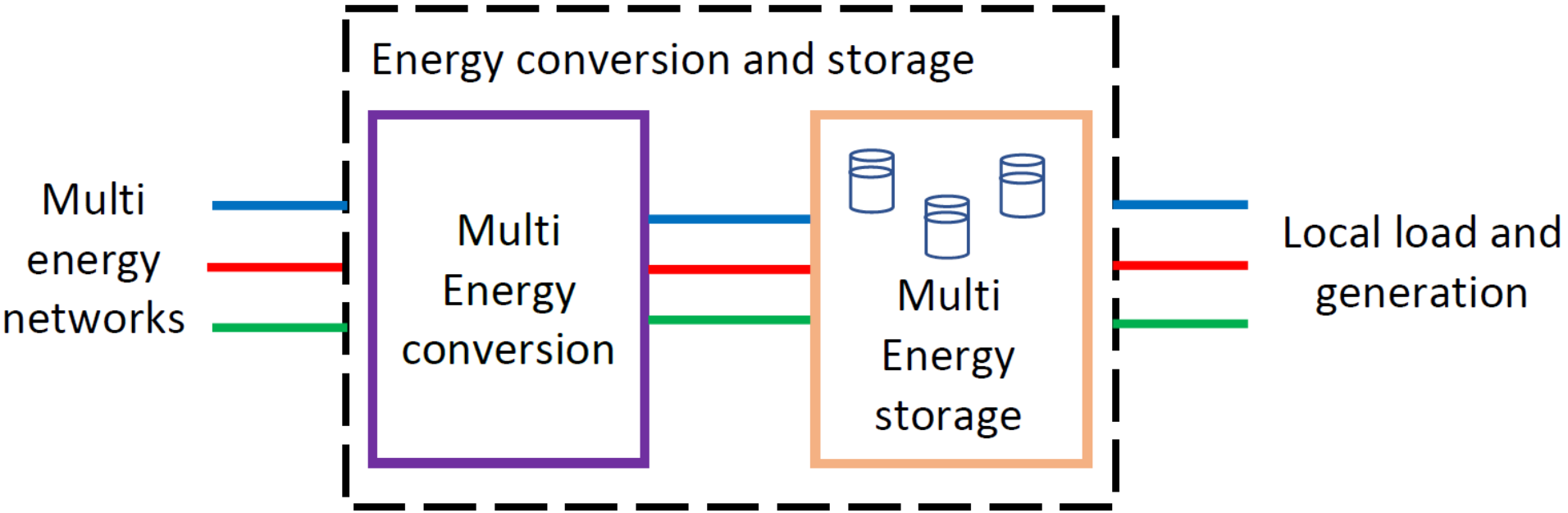
Future Fuels



Who will provide flexibility tomorrow?



Flexibility from DMES: "multi-energy node" model



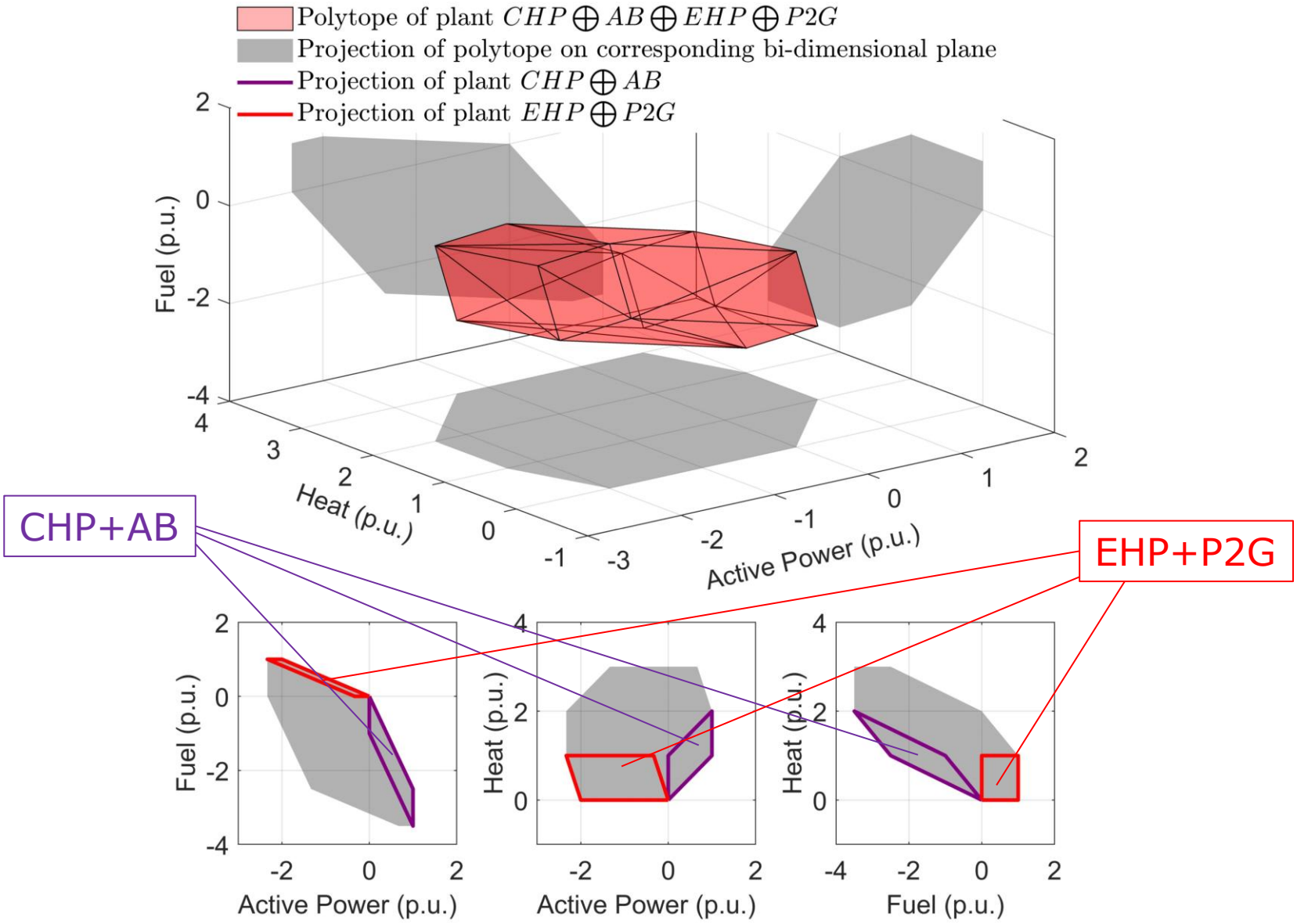
$$\mathbf{S}\,\dot{\mathbf{e}} = \mathbf{H}\,\mathbf{v}_\mathrm{i} - \mathbf{v}_\mathrm{o}$$
$$= \mathbf{H}\,\mathbf{v}_\mathrm{i} - \boldsymbol{\xi} - \mathbf{w}$$

$$\boldsymbol{\xi} = \mathbf{v}_\mathrm{d} - \mathbf{v}_\mathrm{RES}$$
$$\mathbf{w} = \mathbf{v}_\mathrm{d}^{(c)} - \mathbf{v}_\mathrm{RES}^{(c)} - \mathbf{v}_\mathrm{o}^{(c)}$$

"The set of all feasible deviations in the flows of an energy vector from a given operating point, subject to multi-energy node constraints"

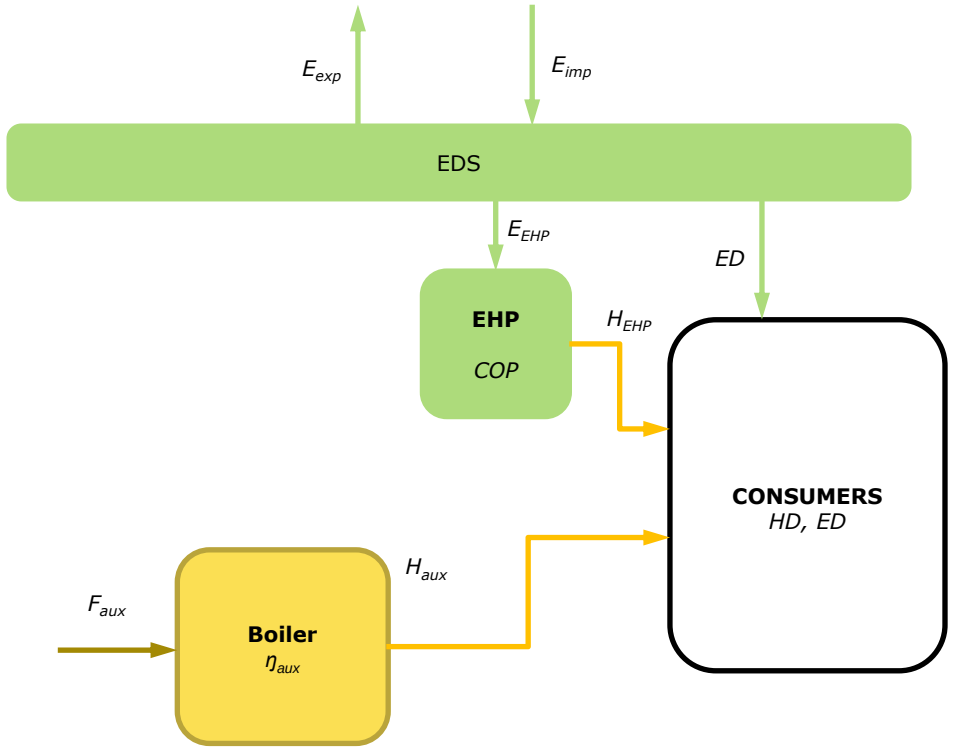
G. Chicco *et al.*, "Flexibility from distributed multienergy systems", *Proceedings of the IEEE*, 2020

Aggregation of multi-energy device in MES



G. Chicco *et al.*, "Flexibility from distributed multienergy systems", *Proceedings of the IEEE*, 2020

Multi-energy flexibility from input energy vector arbitrage



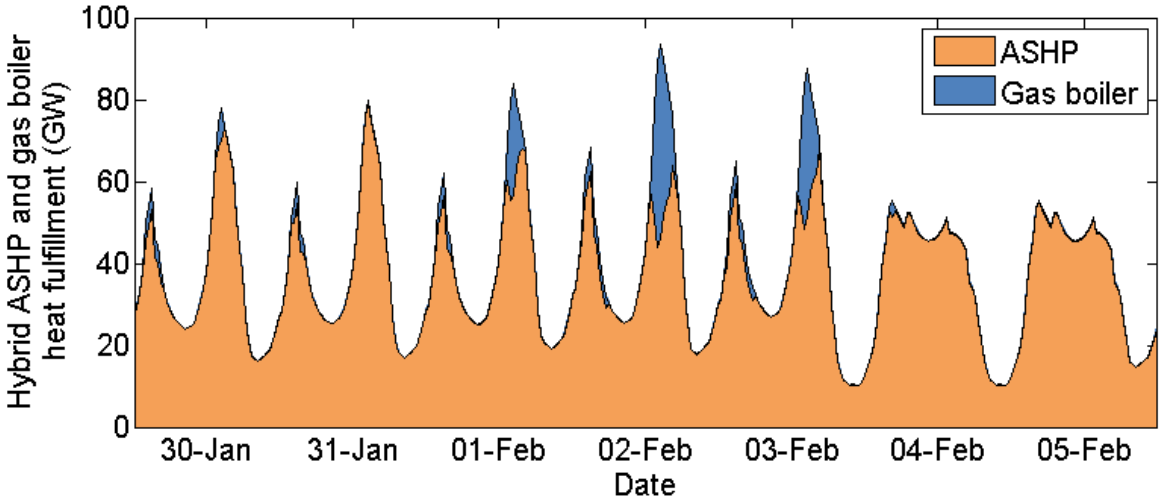
External energy vector arbitrage

T. Capuder and P. Mancarella, "Techno-economic and environmental modelling and optimization of flexible distributed multi-generation options," *Energy*, vol. 71, pp. 516–533, 2014

Example operation of hybrid heating technologies: Integrated air-source heat pump and gas boiler

- Integrated air-source heat pump (ASHP) and gas boiler responds to power system needs – using gas boiler higher electricity price times

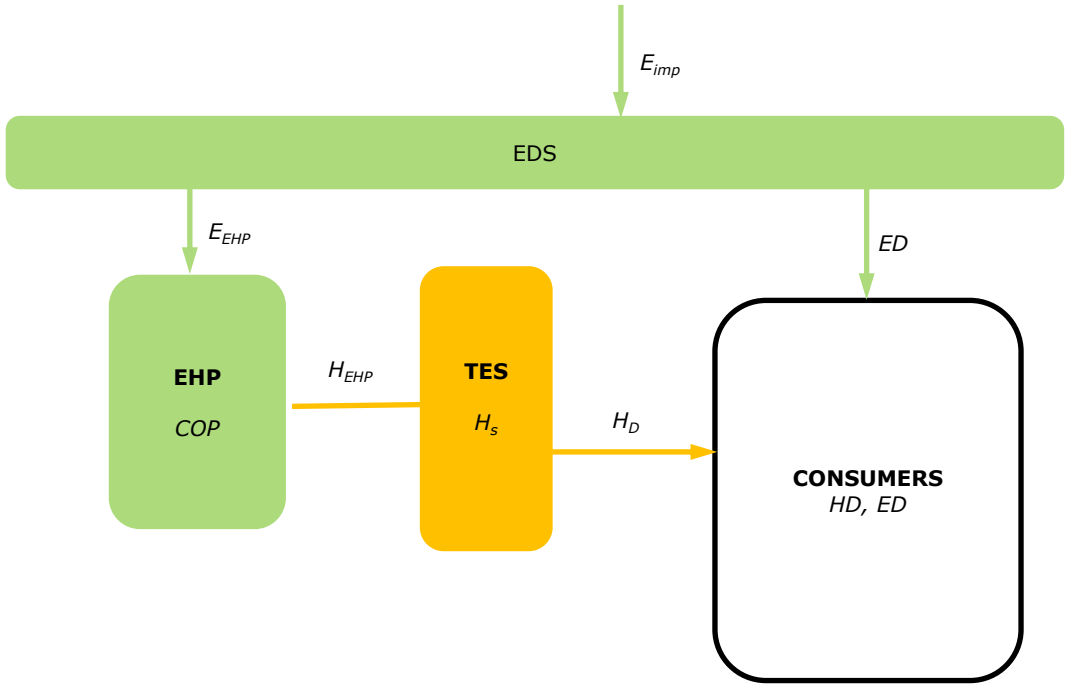
Scenario	Peak conventional generation	Minimum conventional generation
'ASHP'	88GW	29GW
'ASHP and boiler'	67GW	29GW



S. Clegg and P. Mancarella, "Integrated Electricity-Heat-Gas Modelling and Assessment, with Applications to the Great Britain System. Part II: Transmission Network Analysis and Low Carbon Technology and Resilience Case Studies", *Energy*, 2019

S. Clegg and P. Mancarella, "Integrated Electricity-Heat-Gas Modelling and Assessment, with Applications to the Great Britain System. Part I: High-Resolution Spatial and Temporal Heat Demand Modelling", *Energy*, 2019

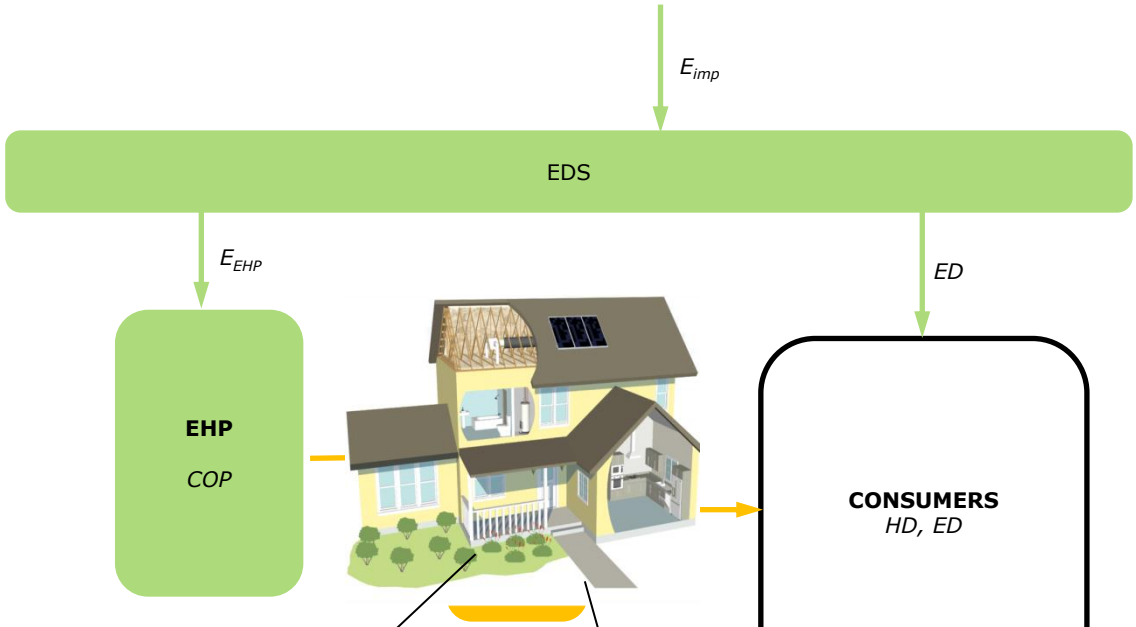
Output energy vector arbitrage: Power-to-heat



Heat load and thermal storage can be seen as an electricity sink and source of flexibility, e.g., for excess renewable electricity

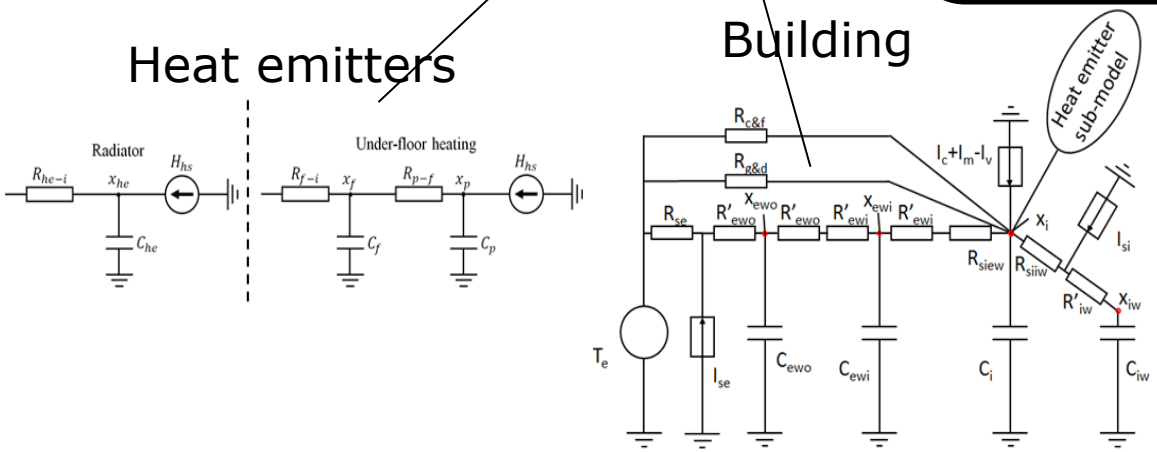
T. Capuder and P. Mancarella, "Techno-economic and environmental modelling and optimization of flexible distributed multi-generation options," *Energy*, vol. 71, pp. 516–533, 2014

Virtual storage in buildings



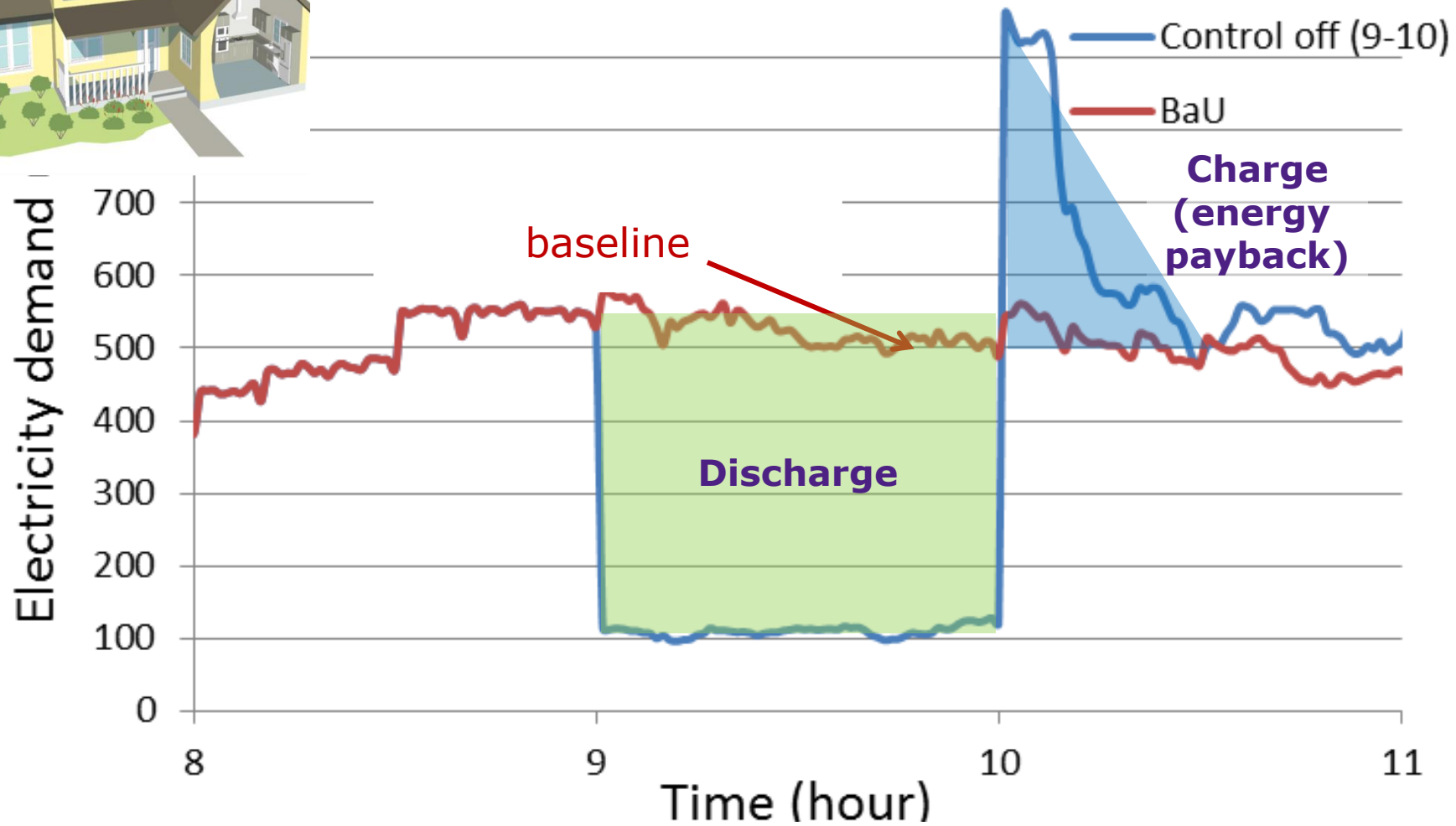
Heat emitters

Building



N. Good, *et al.*, "High resolution modelling of multi-energy domestic demand profiles", *Applied Energy*, vol. 137, pp. 193–210, 1 January 2015

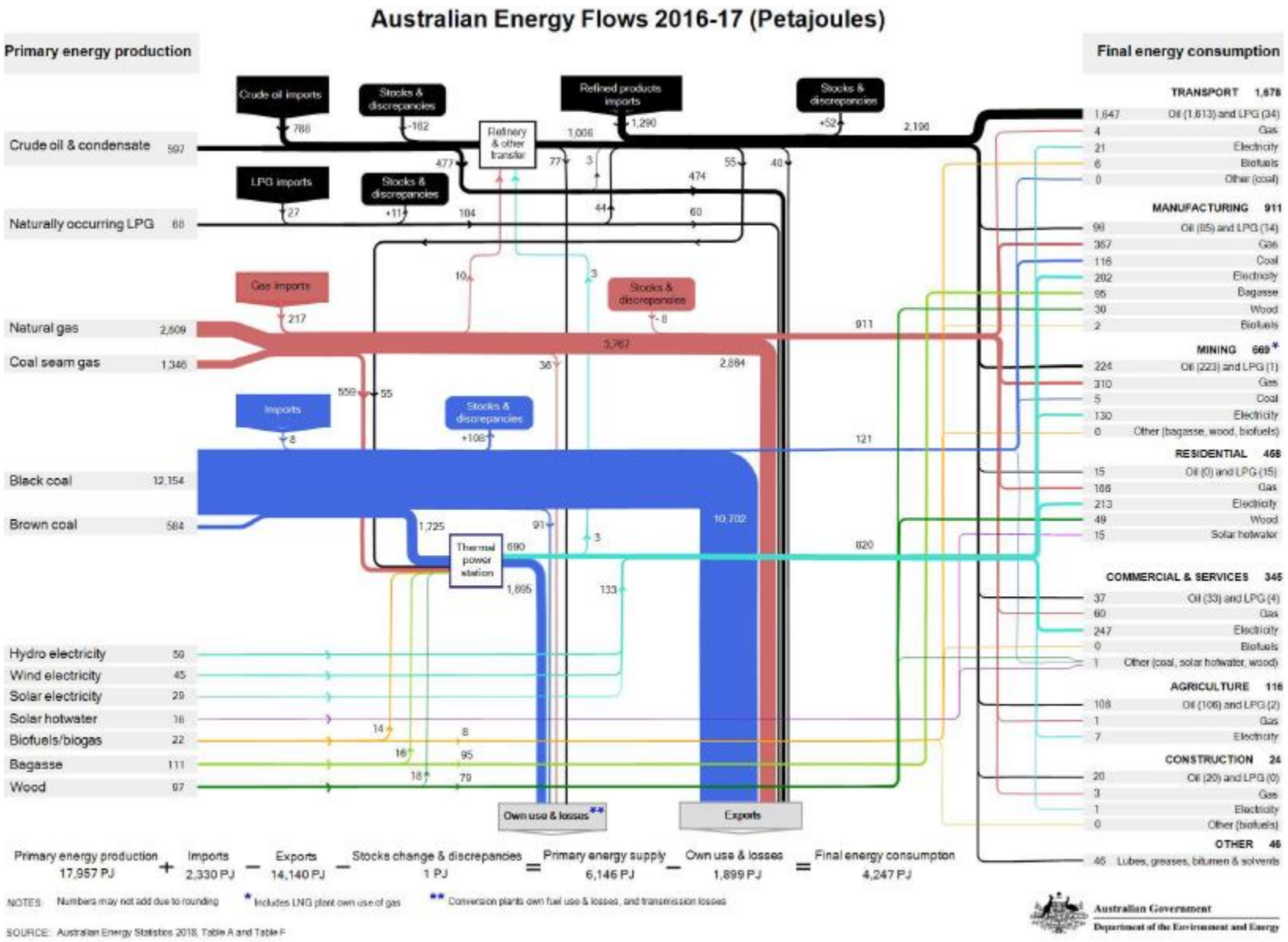
Comfort-to-power arbitrage via "virtual battery" flexibility



N. Good, *et al.*, "Optimization under uncertainty of thermal storage based flexible demand response with quantification of residential users' discomfort," *IEEE Trans. on Smart Grid*, vol. 6, no. 5, pp. 2333–2342, 2015

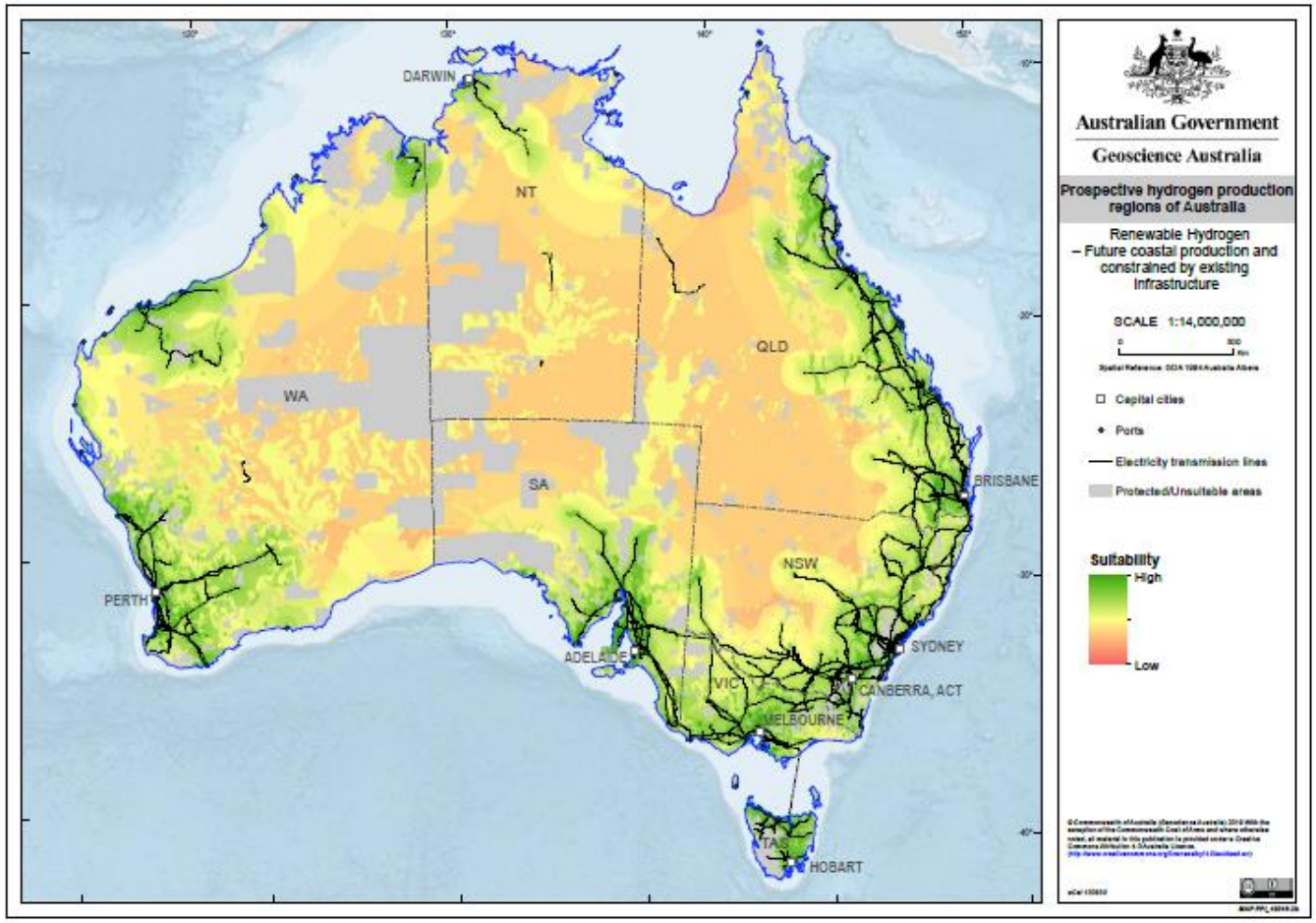
L. Zhang, *et al.*, "Building-to-grid flexibility: Modelling and assessment metrics for residential demand response from heat pump aggregations," *Applied Energy*, vol. 233–234, pp. 709–723, 2019

The big picture down under



Planning BIG:
The Australia's National Hydrogen Strategy and green hydrogen potential

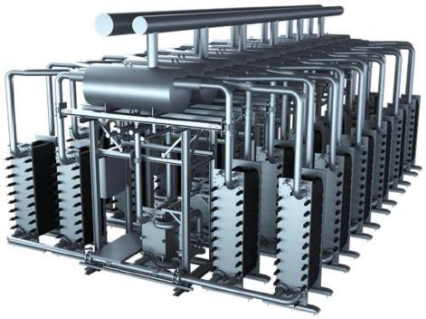
Potential for green hydrogen production with consideration for access to water, ports, pipeline easements, and electricity infrastructure

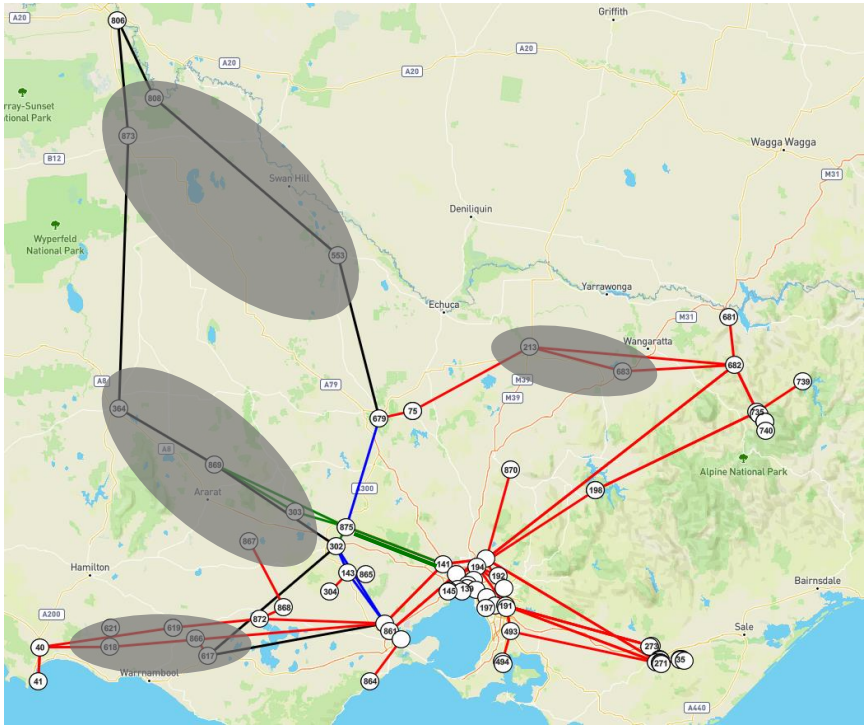


Source: COAG Energy Council, Australia's National Hydrogen Strategy, November 2019

Power-to-gas with Green H_2

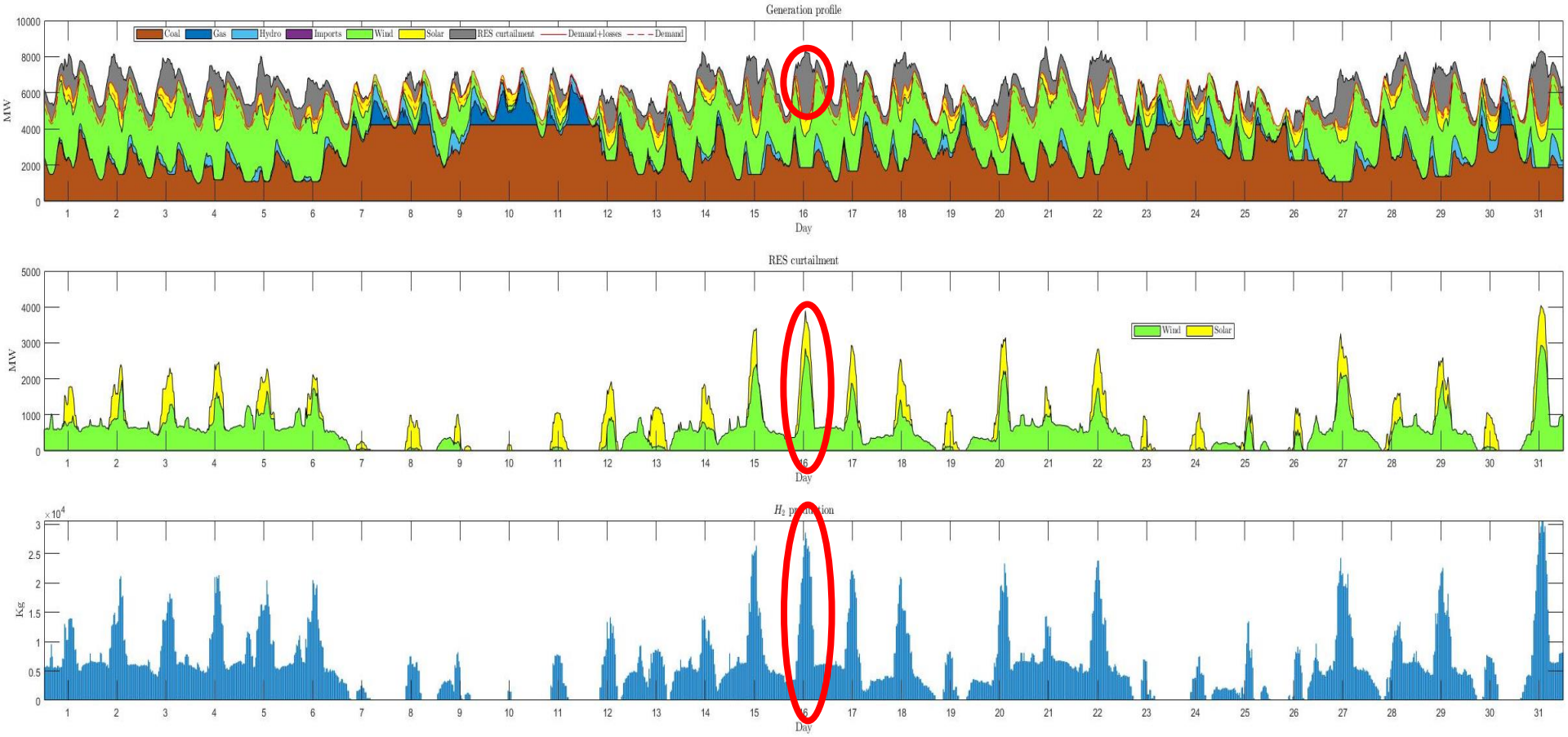
- **Green H_2 production** in RES curtailment areas





S. Clegg, P. Mancarella, "Integrated modelling and assessment of the operational impact of power-to-gas (P2G) on electrical and gas transmission networks", *IEEE Transactions on Sustainable Energy* 6 (4), pp.1234–1244, 2015

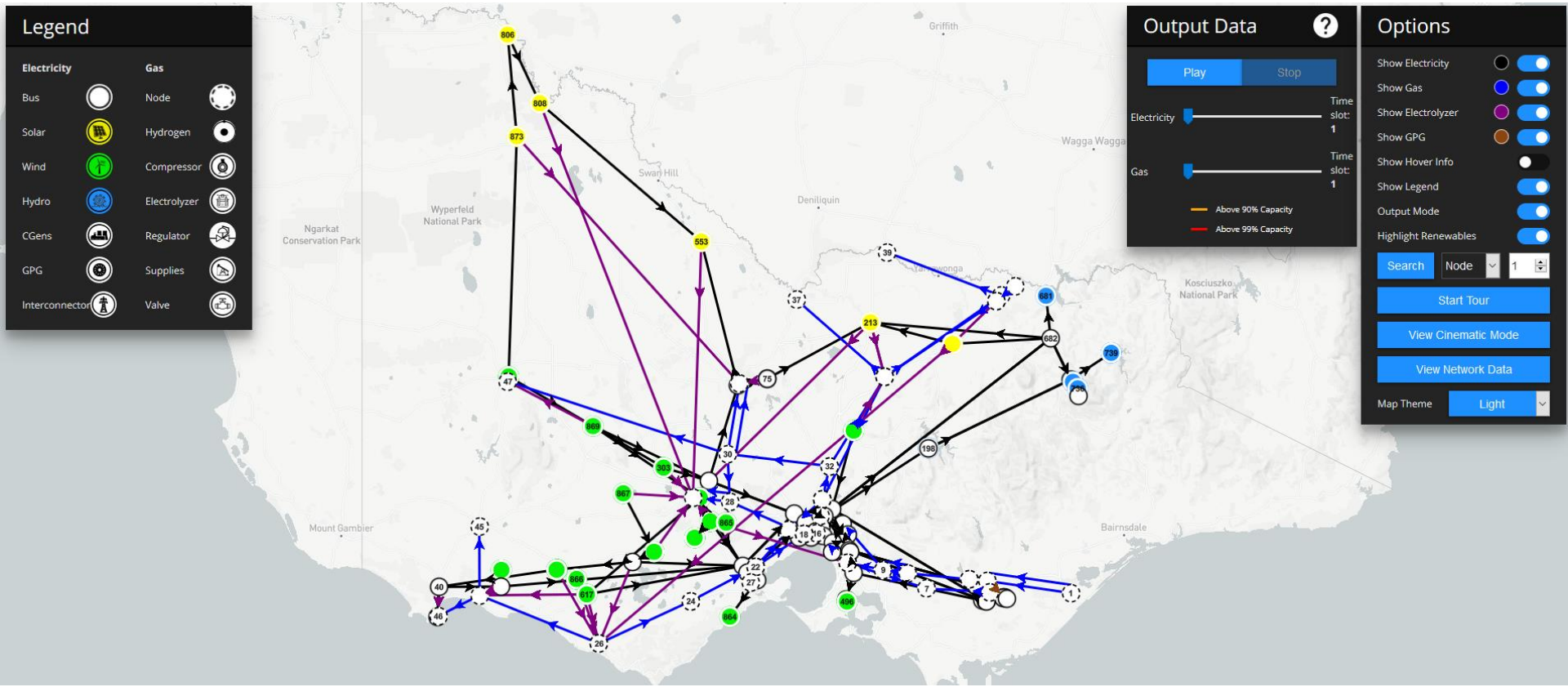
Green H_2 production model



But not all of this hydrogen can be used for network injection!

I. Saedi, S. Mhanna, P. Mancarella, "Integrated Electricity and Gas System Modelling with Hydrogen Injections and Gas Composition Tracking", *Applied Energy*, August 2021

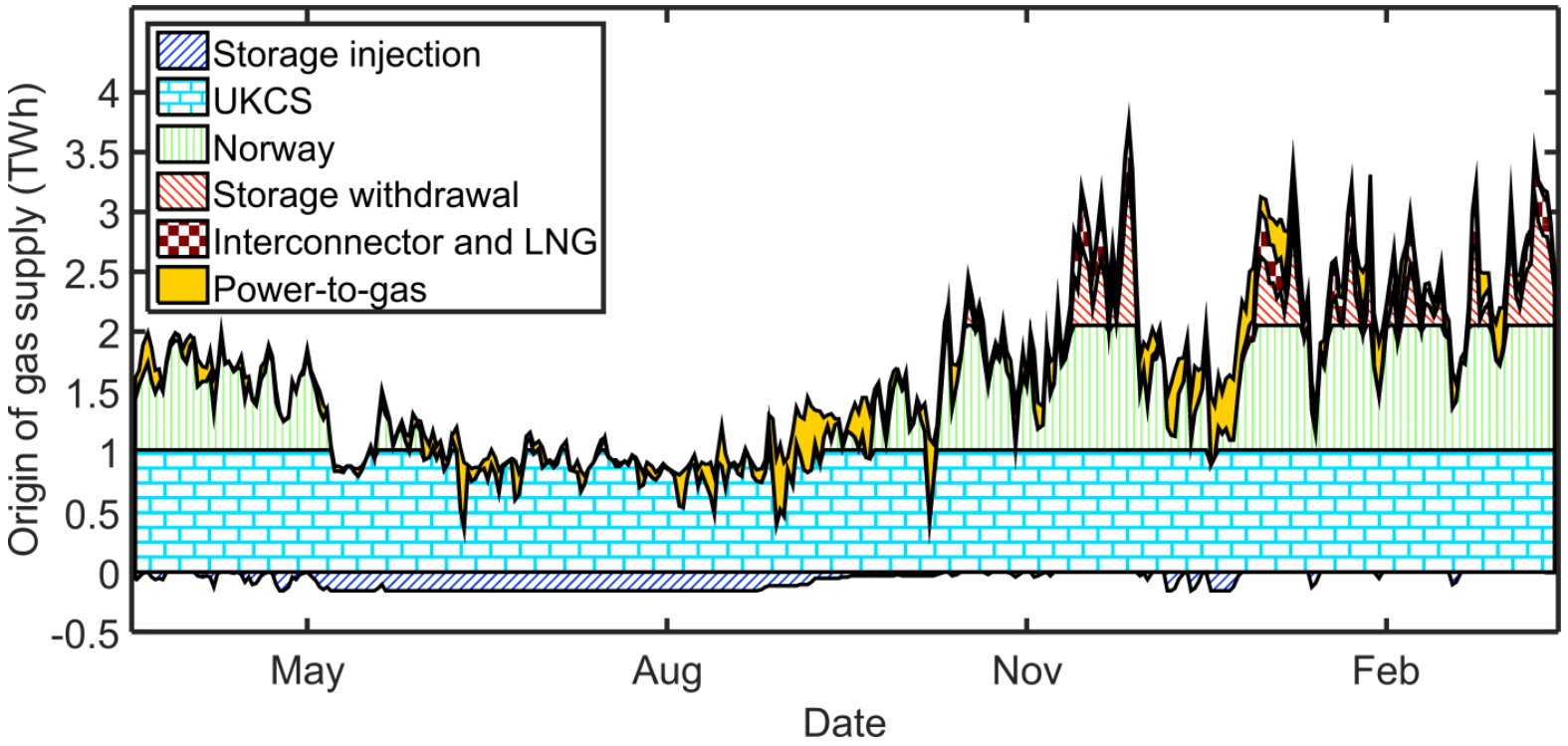
Integrated electricity-gas-hydrogen network model



S. Mhanna, I. Saedi, P. Mancarella, "Iterative LP-based Methods for the Multiperiod Optimal Electricity and Gas Flow Problem", *IEEE Transactions on Power Systems*, June 2021

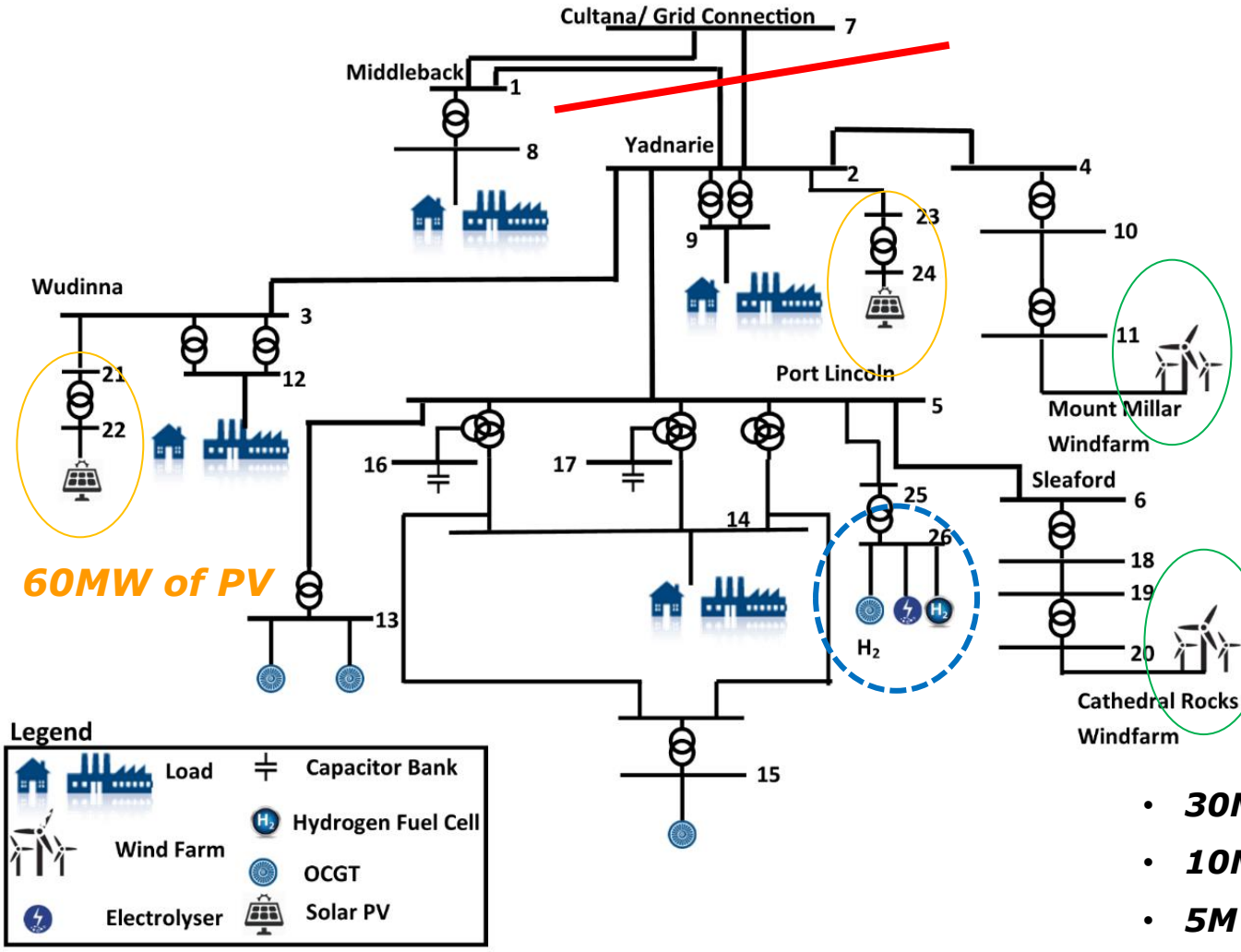
I. Saedi, S. Mhanna, P. Mancarella, "Integrated Electricity and Gas System Modelling with Hydrogen Injections and Gas Composition Tracking", *Applied Energy*, *accepted for publication*, August 2021

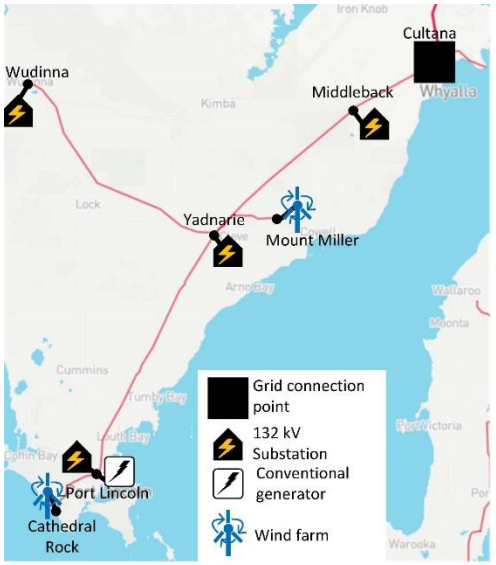
Power-to-gas with seasonal storage in the gas network



S. Clegg, P. Mancarella, "Storing renewables in the gas network: modelling of power-to-gas seasonal storage flexibility in low-carbon power systems", IET Generation, Transmission & Distribution, 10 (3), pp.566–575, 2015

Hydrogen-RES multi-energy VPP





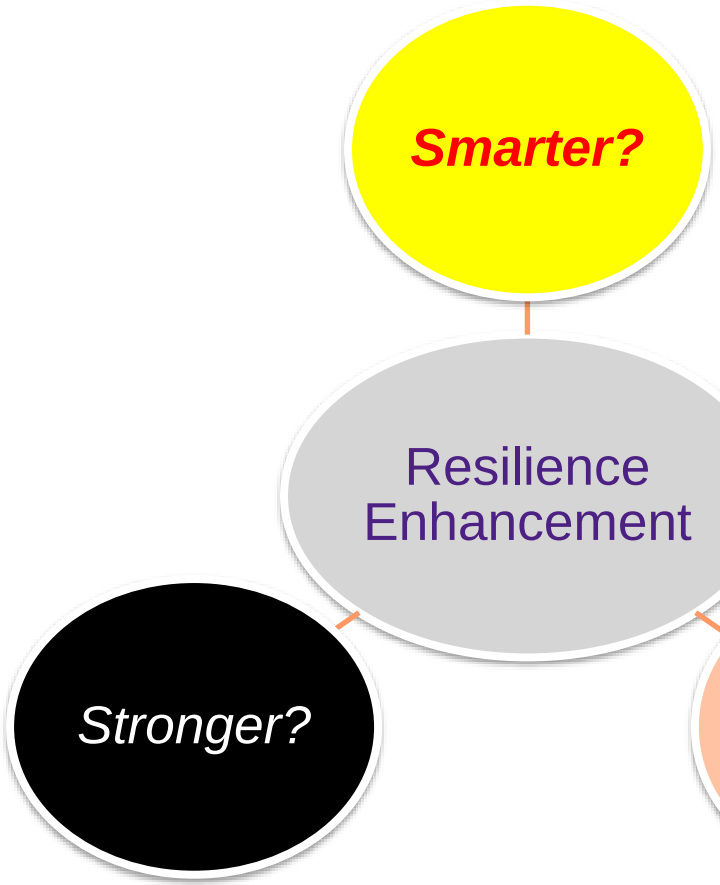
- ***60MW of PV***
- ***136MW of Wind***

- ***30MW Electrolyser***
- ***10MW H2 OCGT***
- ***5MW Fuel Cell***
- ***100MWh of H2 Storage***
- ***73MW OCGT***

J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power Syst. Research*, 2020

How to plan for the black swan?

Planning for Resilience: The Resilience Trilemma



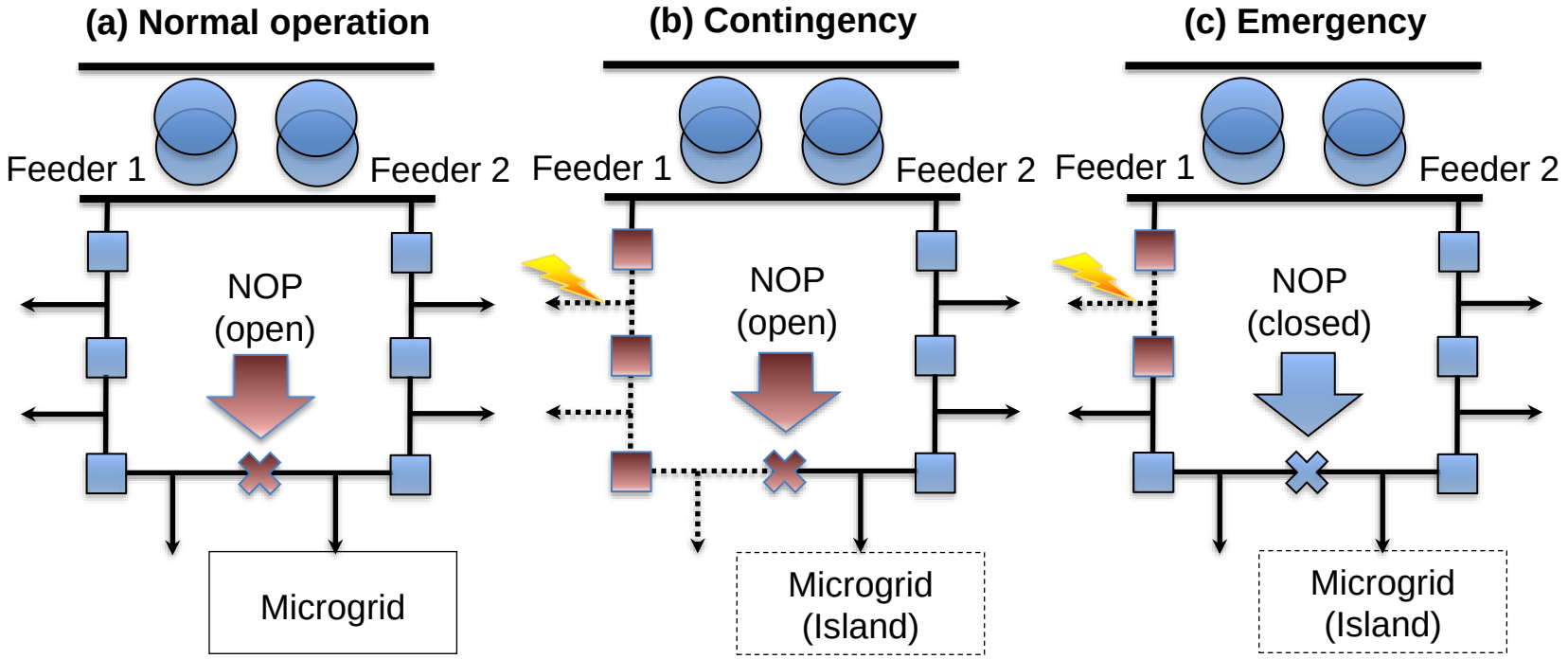
Make the network more responsive (e.g. faster restoration), self-adaptive, resourceful, etc.

Upgrade existing infrastructure, asset life extension, etc.

Build new infrastructure, e.g. transmission lines, substations, etc.

M. Panteli and P. Mancarella, The Grid: Stronger, Bigger, Smarter? Presenting a conceptual framework of power system resilience, *IEEE Power and Energy Magazine,* May/June 2015

Flexibility and resilience from Multi-energy Microgrids

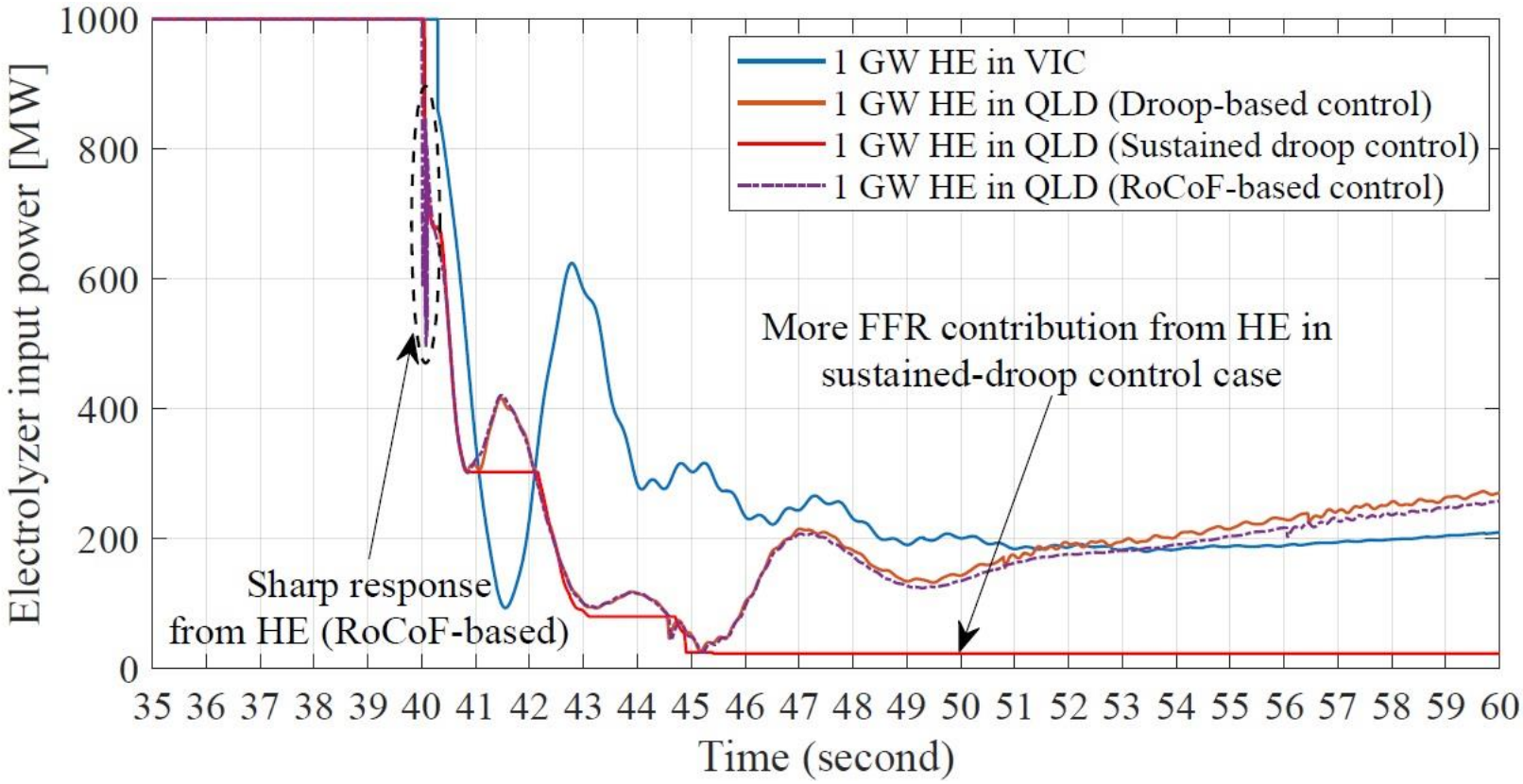


E. A. Martínez Ceseña, N. Good, A. L. A. Syrri, P. Mancarella, "Techno-economic and business case assessment of multi-energy microgrids with co-optimization of energy, reserve and reliability services," Applied Energy, 2017

T. Lagos, *et al.*, "Identifying Optimal Portfolios of Resilient Network Investments Against Natural Hazards, With Applications to Earthquakes", *IEEE Transactions on Power Systems*, *2020*

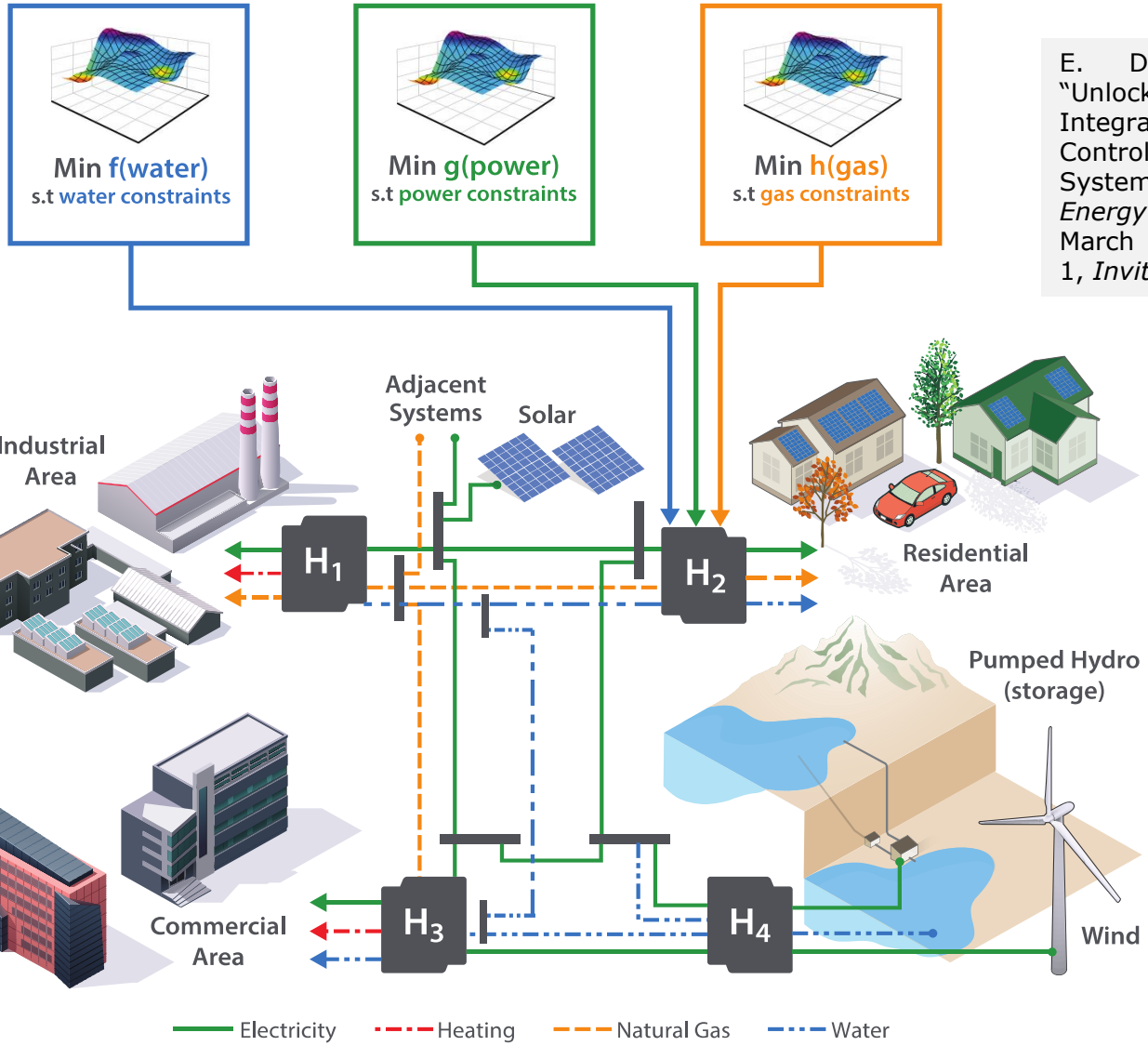
Not only batteries: Fast frequency response from electrolysers

- FFR capabilities of large-scale electrolyzers can support frequency resilience after system split



M. Ghazavi, A. Jalali, and P. Mancarella, "Fast frequency response from utility scale hydrogen electrolysers", *IEEE Transactions on Sustainable Energy*, March 2021

Next: Unlocking multi-energy flexibility via optimization, control, and integrated energy markets



E. Dall'Anese, *et al.*, "Unlocking Flexibility: Integrated Optimization and Control of Multienergy Systems", *IEEE Power and Energy Magazine*, January-March 2017, Vol. 15, Issue 1, *Invited Paper*

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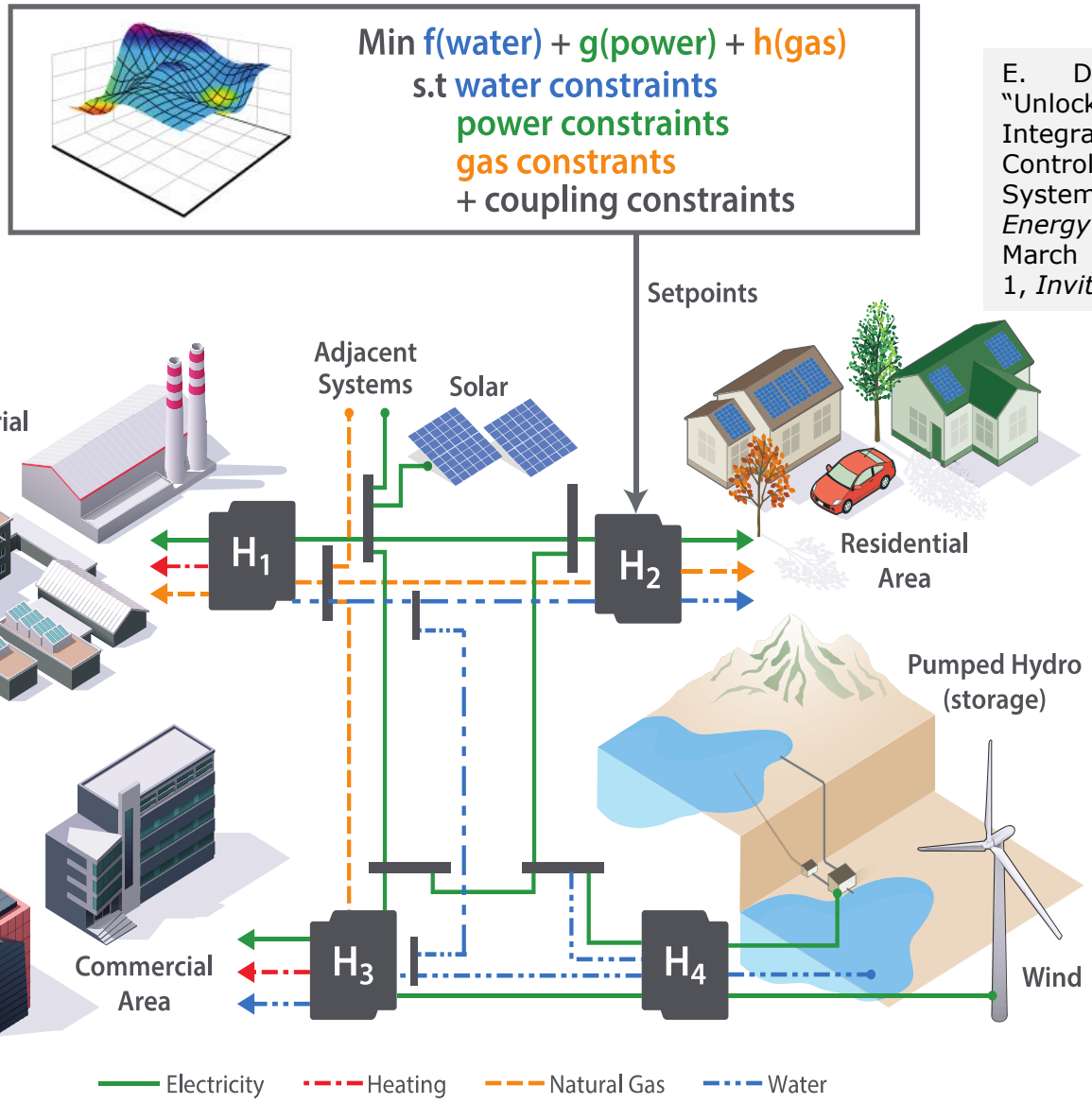

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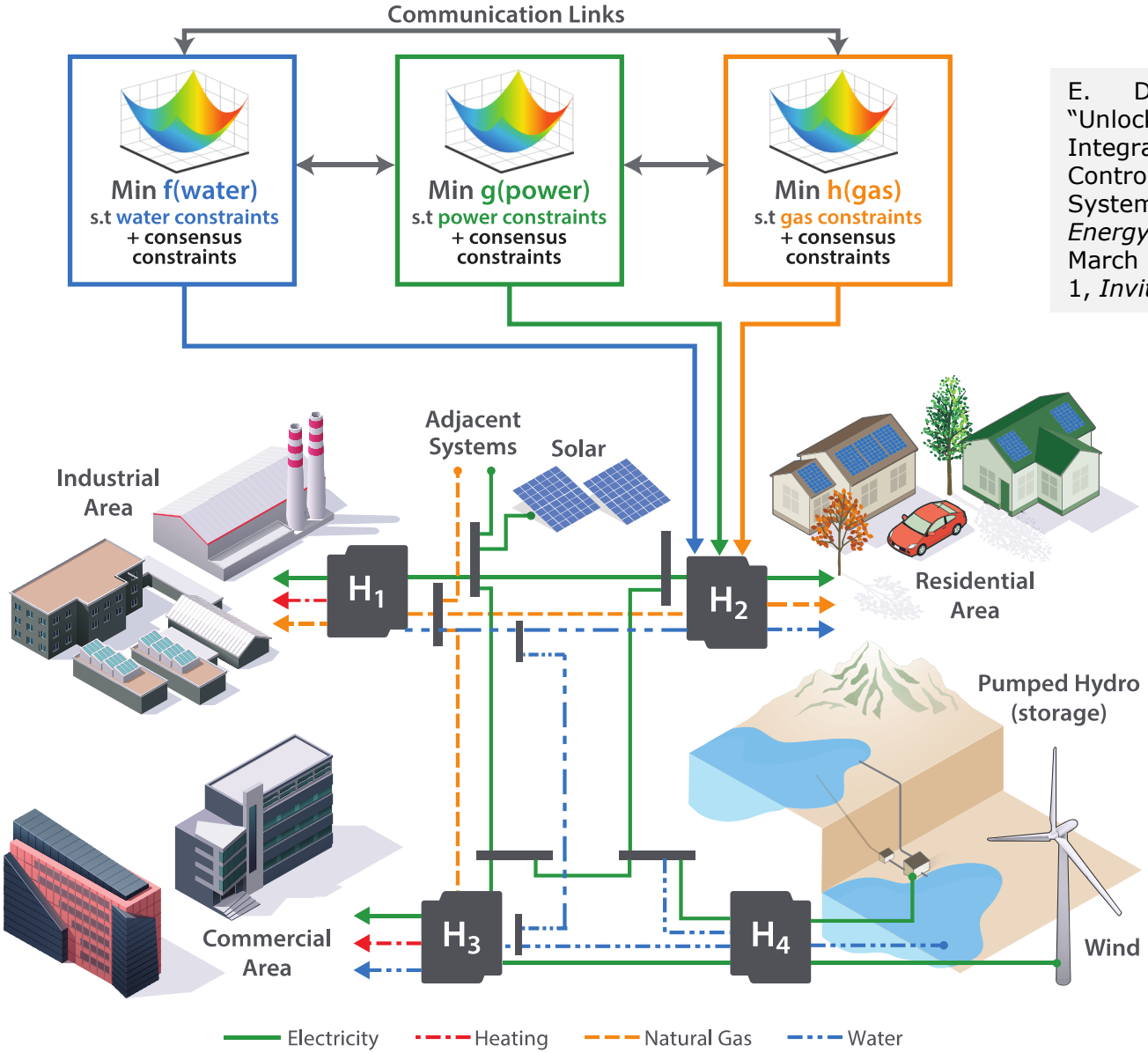
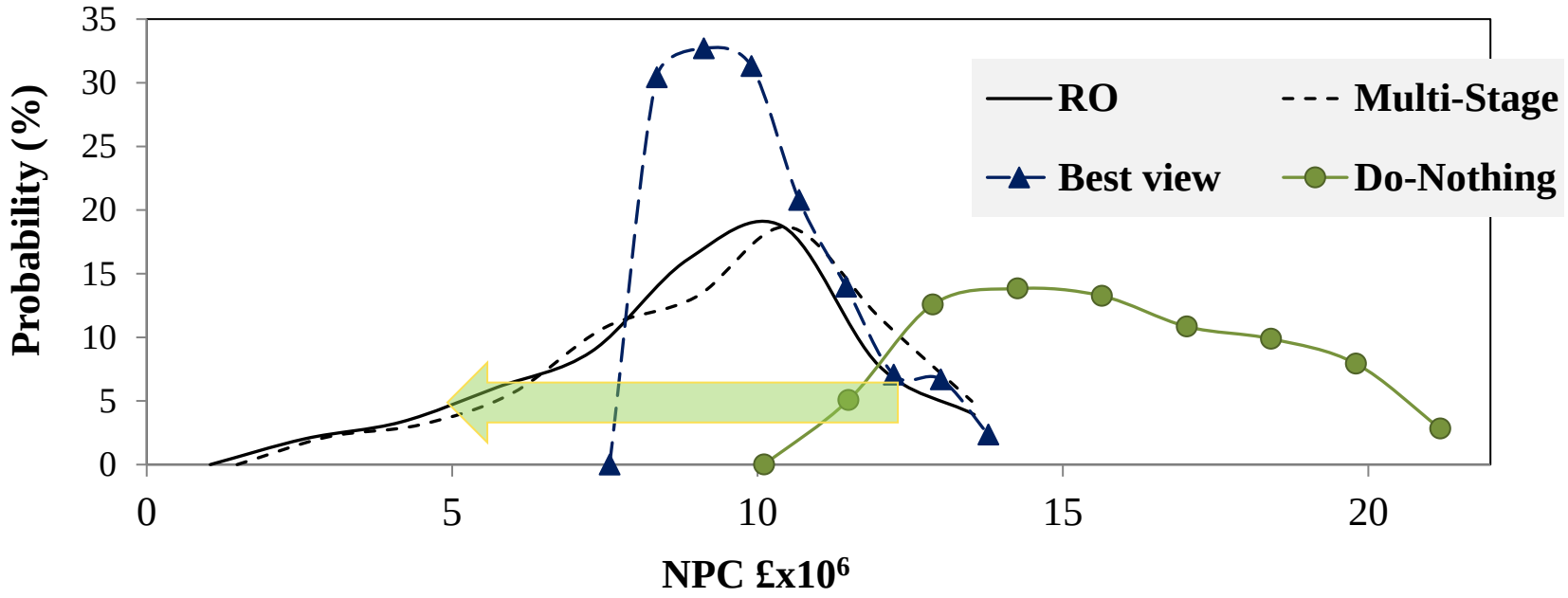


E. Dall'Anese, *et al.*, "Unlocking Flexibility: Integrated Optimization and Control of Multienergy Systems", *IEEE Power and Energy Magazine*, January-March 2017, Vol. 15, Issue 1, *Invited Paper*

Flexibility-in-planning fully exploits MES flexibility-in-operation

- The value of **flexible operation and investment** skews the expected economic performance of the DMES



E. A. Martinez Cesena, T. Capuder and P. Mancarella, "Flexible distributed multienergy generation system expansion planning under uncertainty," IEEE Transactions on Smart Grid, 2016

Key remarks

- **Superior flexibility** can be harnessed from *multi-energy systems*
- Substantial grid flexibility can be unlocked at **relatively low cost** from other energy vectors
- MES have a key role to enable **local** and **system-level** flexibility and market participation in multiple commodities and grid services
  - Electricity and heat, gas, hydrogen
  - Frequency response, reactive support, etc.
  - Resilience services
- **Scalability** of MES flexibility concepts (building, district, city, region, country)
- Synergy between **flexibility-in-operation** and **flexibility-in-planning** to hedge against investment uncertainty and risk
- Regulatory, market, and policy framework to create the right price signals to optimally deploy flexibility across MES

Back to the future

"Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.

Someday the coal-rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power."

Jules Verne, *"The Mysterious Island",1874*

"For the anxious, progress towards a hydrogen future is too slow. But look back a few decades from now and history will record the hydrogen industry as an overnight success"

Dr Alan Finkel, Chief Scientist of Australia, November 2019

Source: COAG Energy Council, Australia's National Hydrogen Strategy, November 2019

Acknowledgments

- My research teams in Melbourne and Manchester
- The Victorian Government and *veski* for my *veski* Innovation Fellowship
- The Future Fuels Cooperative Research Centre, Australia
- The UK EPSRC (MY-STORE and TERSE projects)
- The UK-Chile Newton-Picarte "*Disaster management and resilience in electric power systems*" project
    - Project awarded a 2018 international Newton Prize
- The European Commission for the support provided throughout the years via ADDRESS, COOPERATE, DIMMER, ATTEST, EUniversal projects

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(delivered online)