IEEE Power and Energy Society

Distinguished Lecture

Operational and planning flexibility in low-carbon multi-energy systems

Prof Pierluigi Mancarella

Chair of Electrical Power Systems, The University of Melbourne

Professor of Smart Energy Systems, The University of Manchester

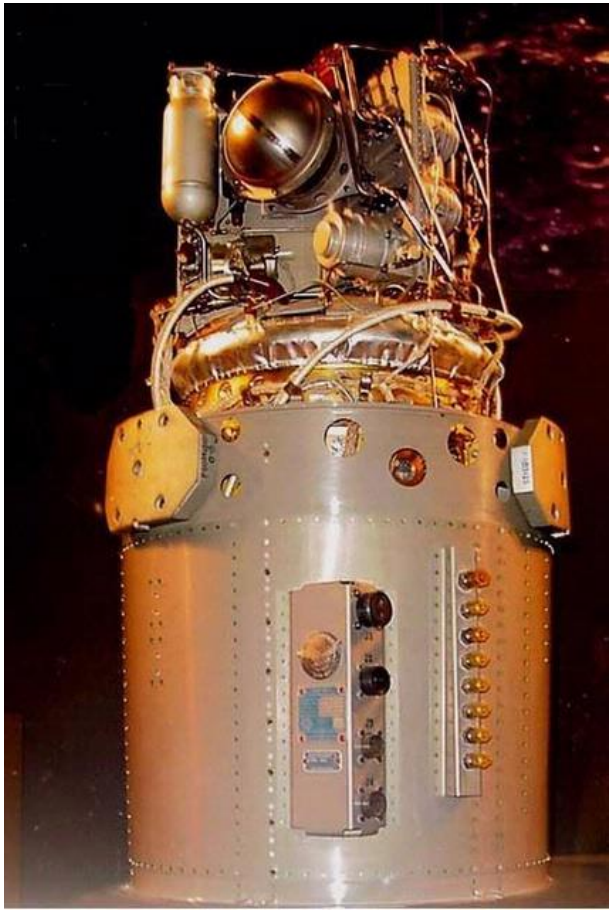
veski Innovation Fellow

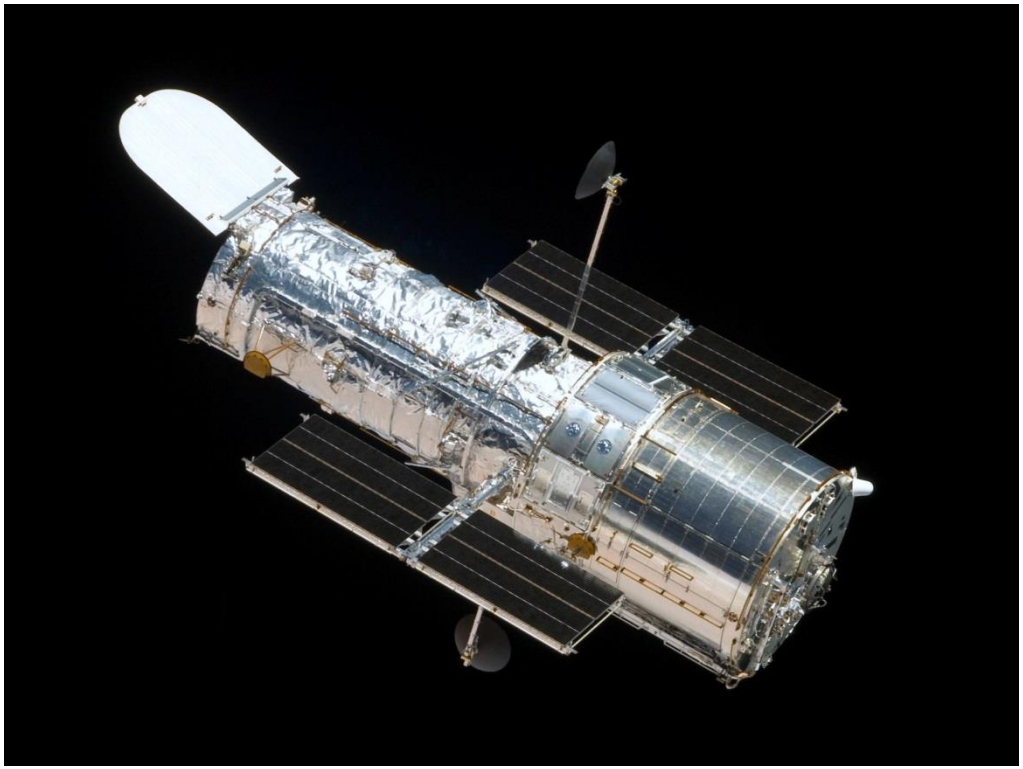
pierluigi.mancarella@unimelb.edu.au

Delft, The Netherlands

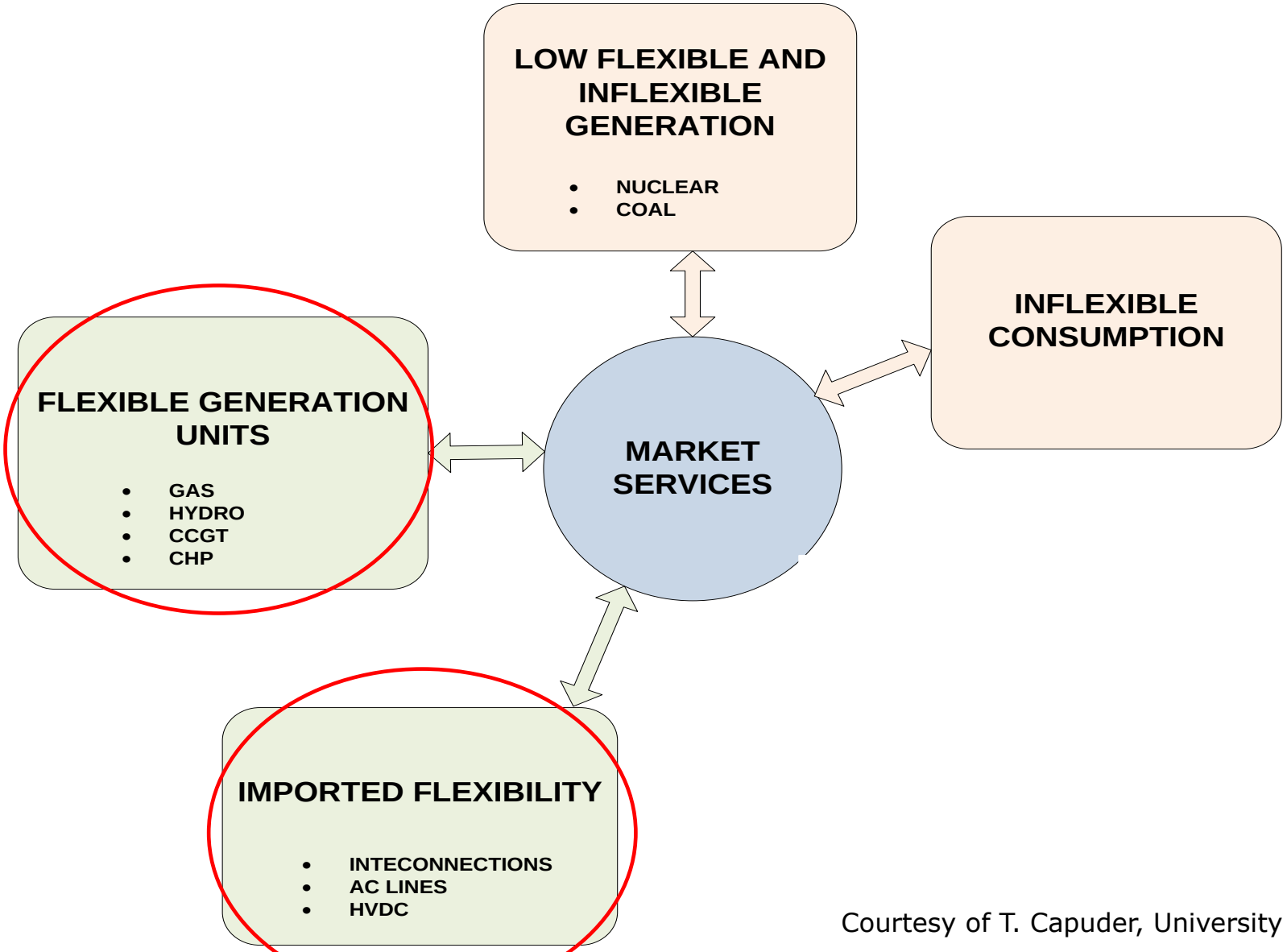
16/12/2019

Science fiction?



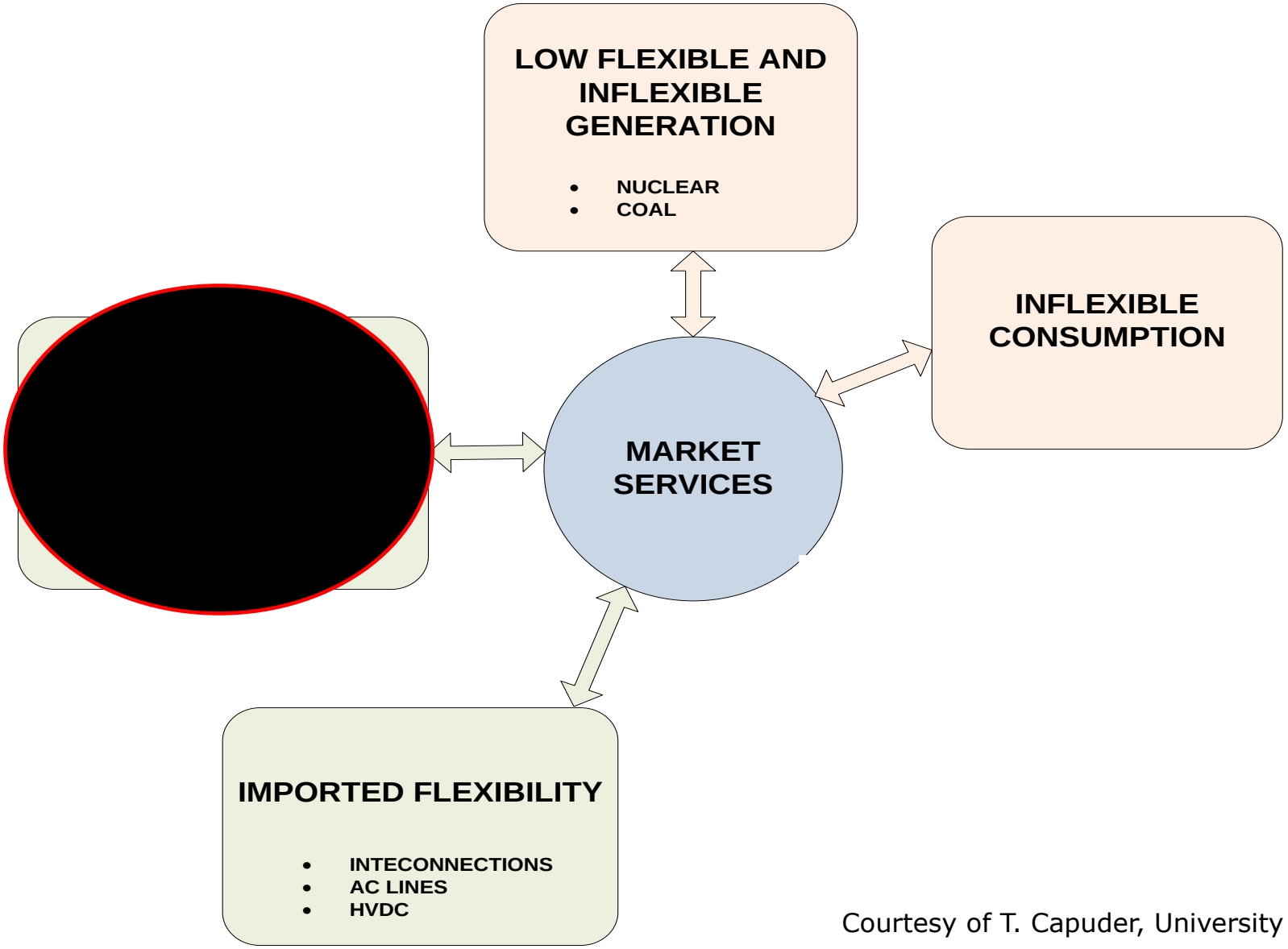


Who provides flexibility, security and reliability today?



Courtesy of T. Capuder, University of Zagreb

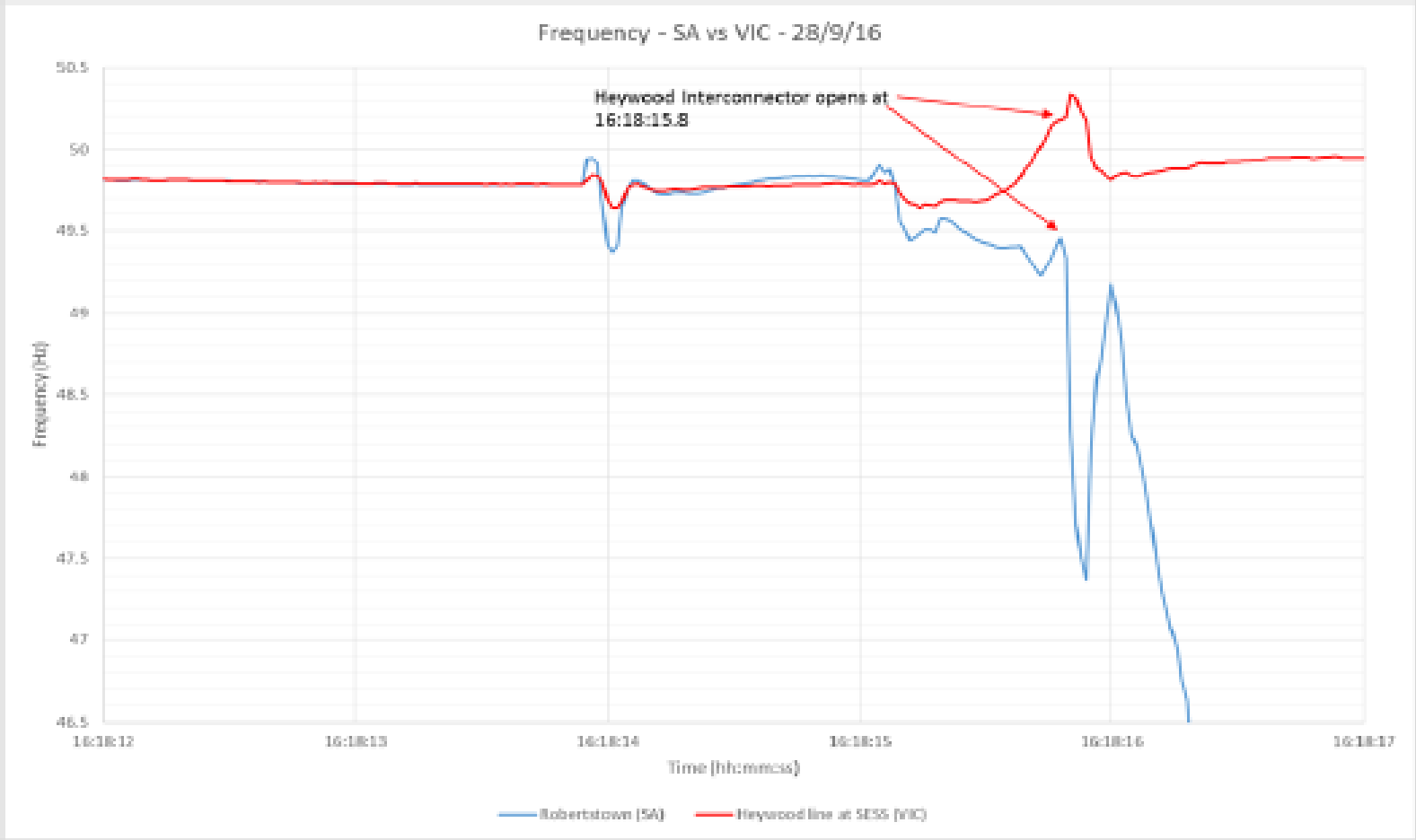
Who provides flexibility, security and reliability today?



Courtesy of T. Capuder, University of Zagreb

Is it a far future?

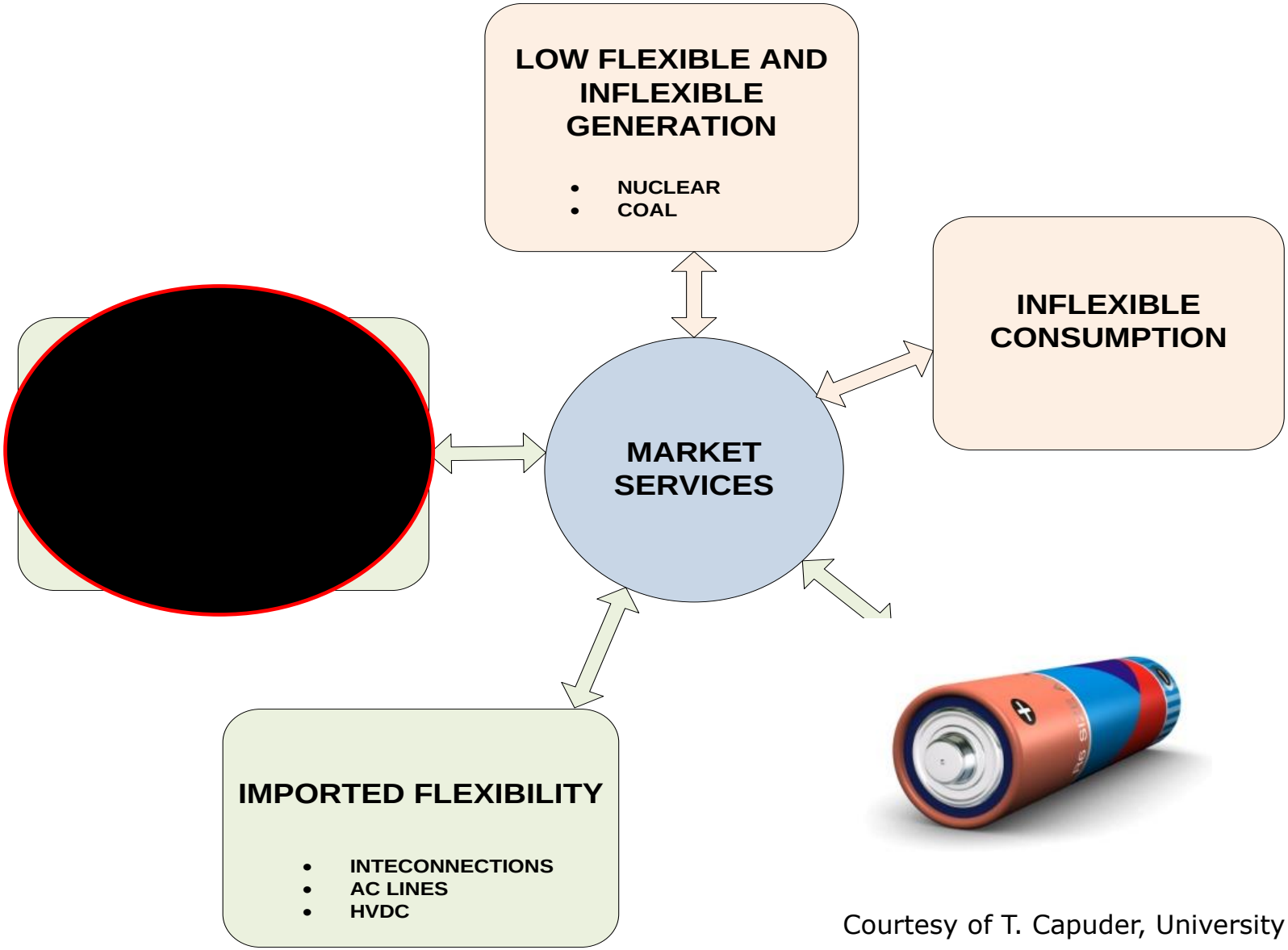
Figure 5 SA frequency compared to Victoria during event



Source: AEMO

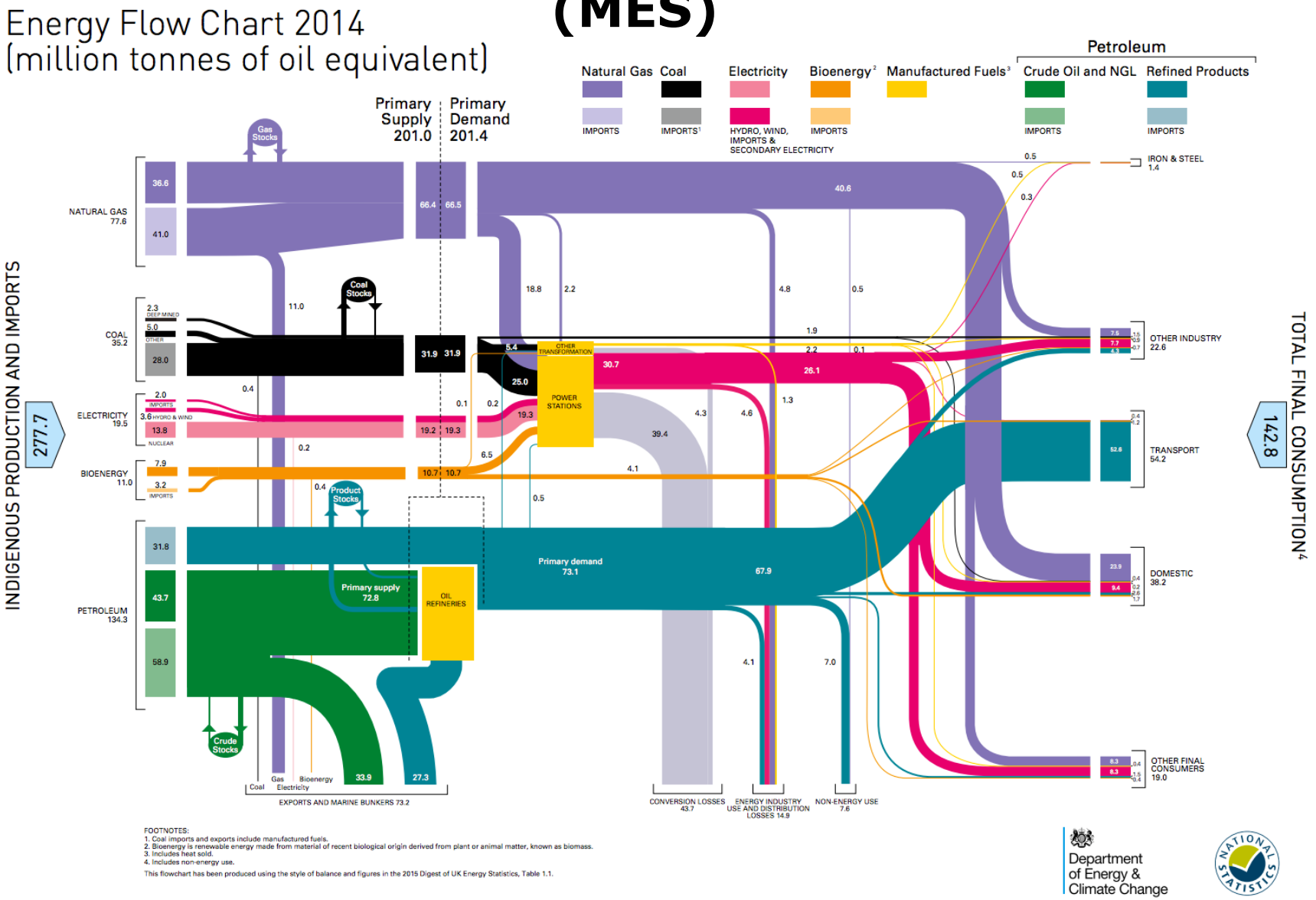
Who can help solving the problem?

Flexibility in low-carbon power systems

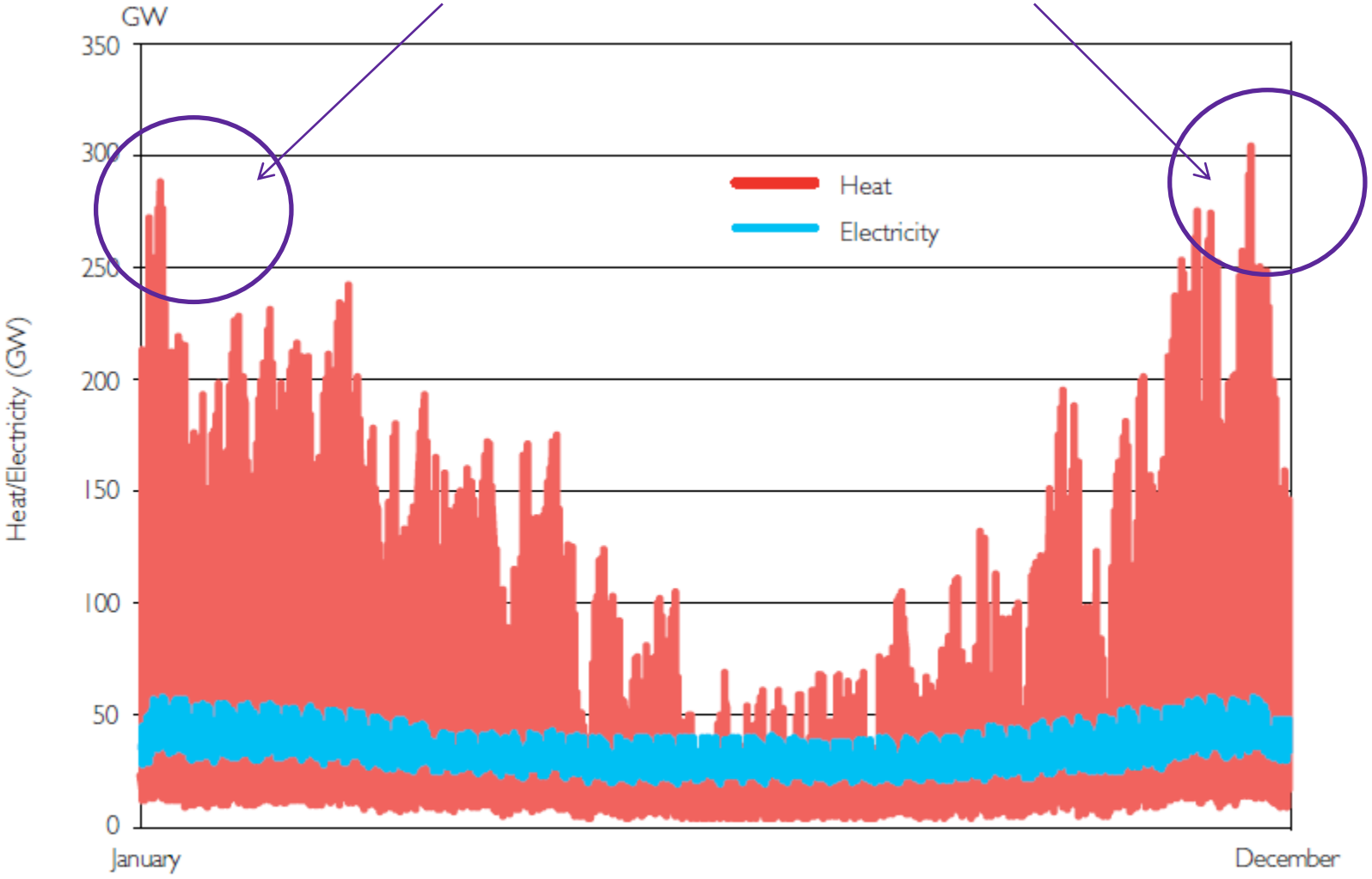


Courtesy of T. Capuder, University of Zagreb

The big picture: Sector coupling and multi-energy systems (MES)

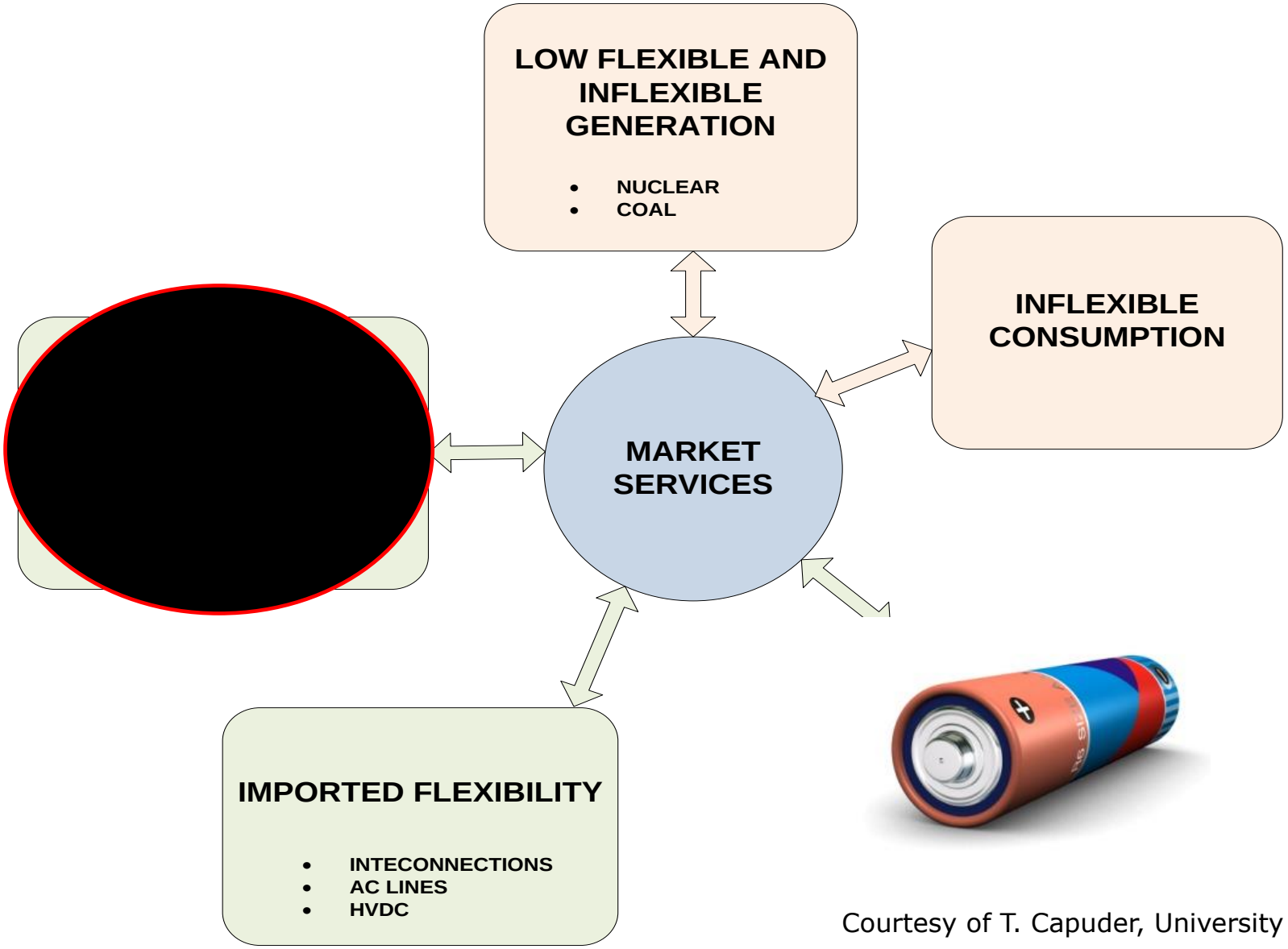


Electrification: the magnitude of the problem…



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.

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

Heating

Cooling

Transport

Future Fuels

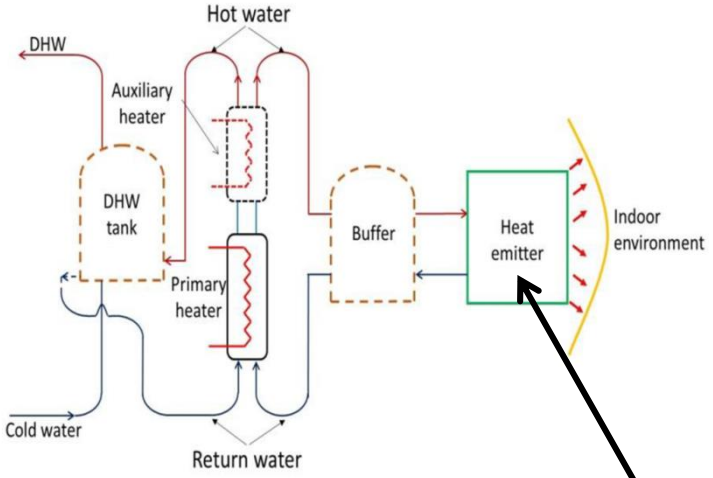
Industry

IMPORTED FLEXIBILITY

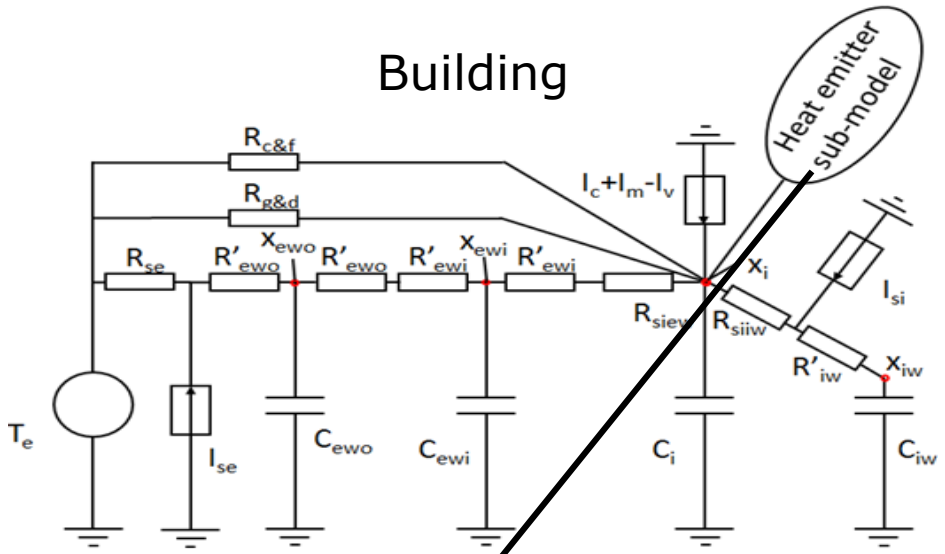
- INTECONNECTIONS
- AC LINES
- HVDC

Modelling storage from buildings

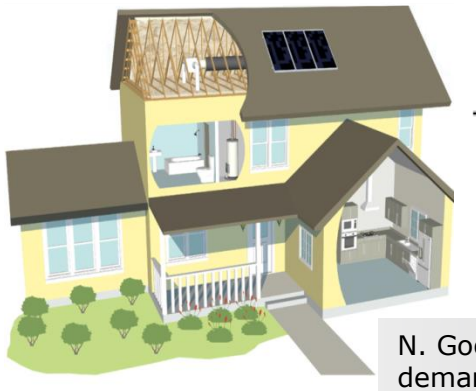
Supply

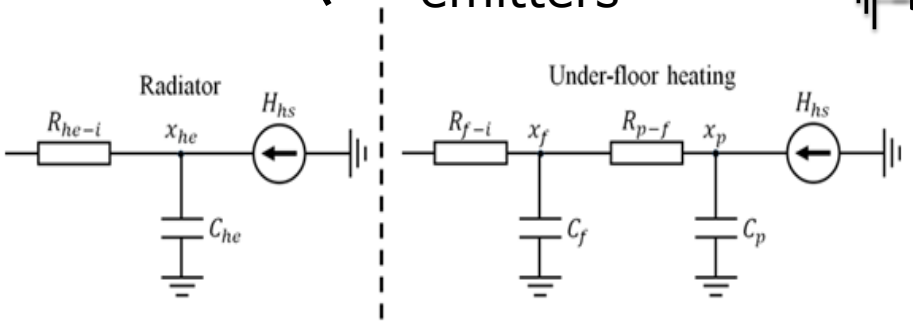


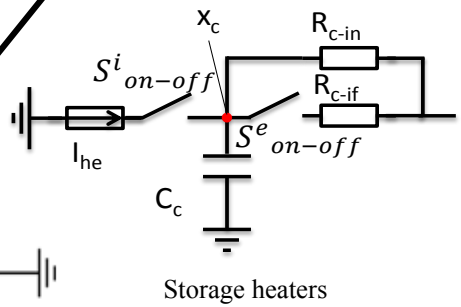
Building



Heat emitters

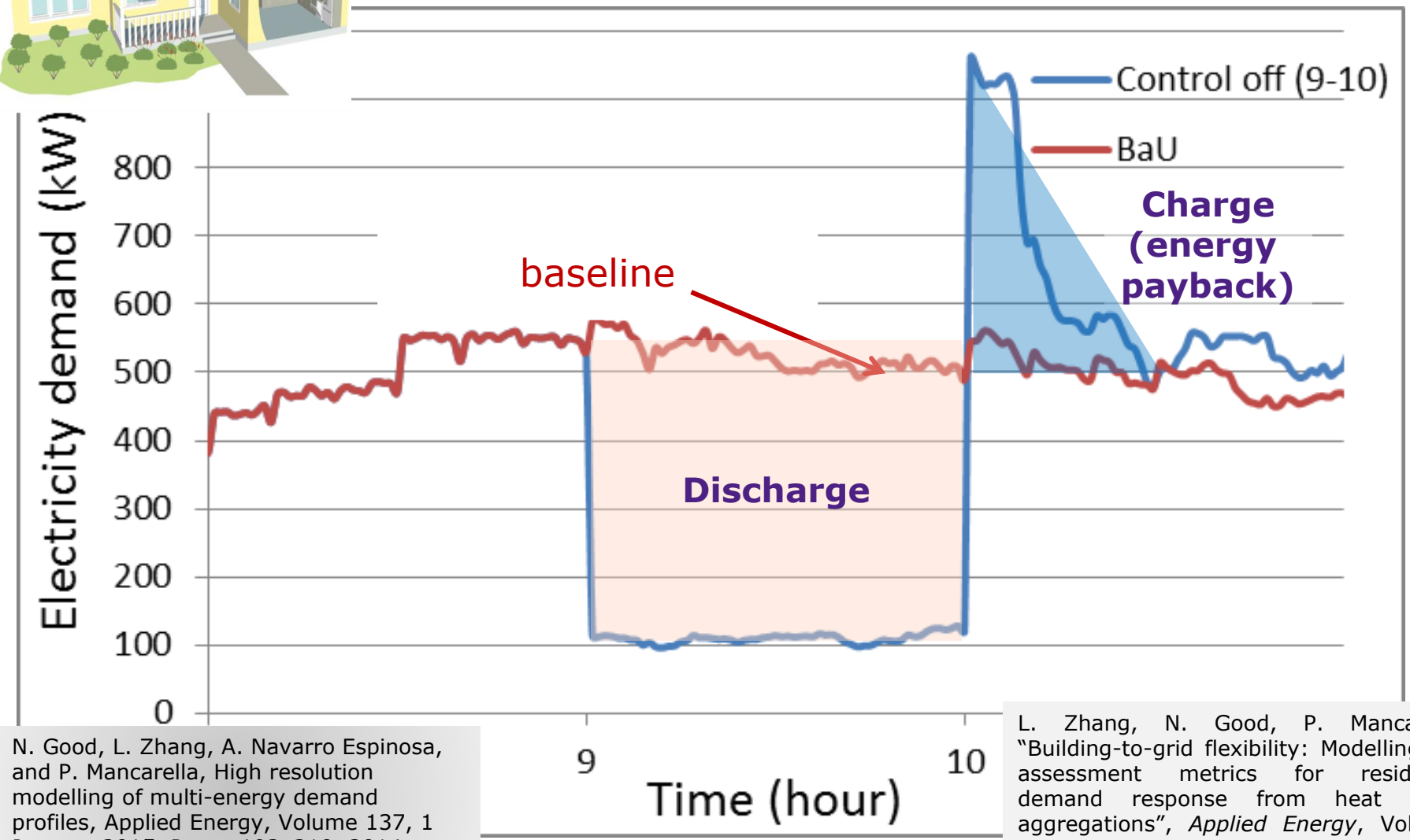






N. Good, L. Zhang, A. Navarro Espinosa, and P. Mancarella, High resolution modelling of multi-energy demand profiles, Applied Energy, Volume 137, 1 January 2015, Pages 193–210, 2014

Virtual storage and building-to-grid flexibility

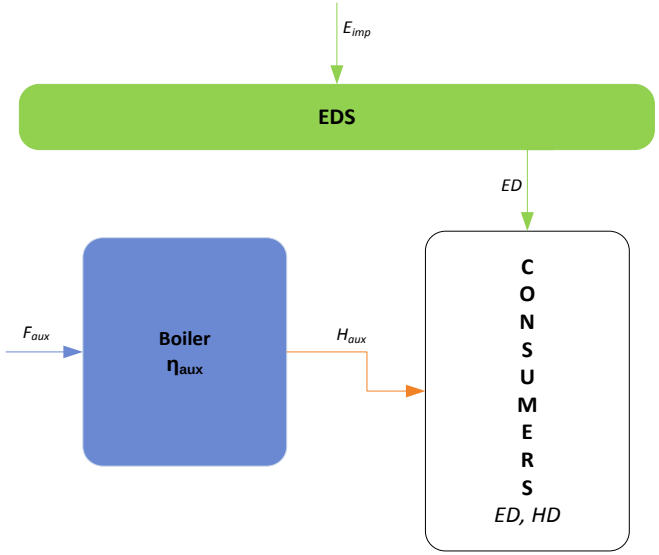


N. Good, L. Zhang, A. Navarro Espinosa, and P. Mancarella, High resolution modelling of multi-energy demand profiles, Applied Energy, Volume 137, 1 January 2015, Pages 193–210, 2014

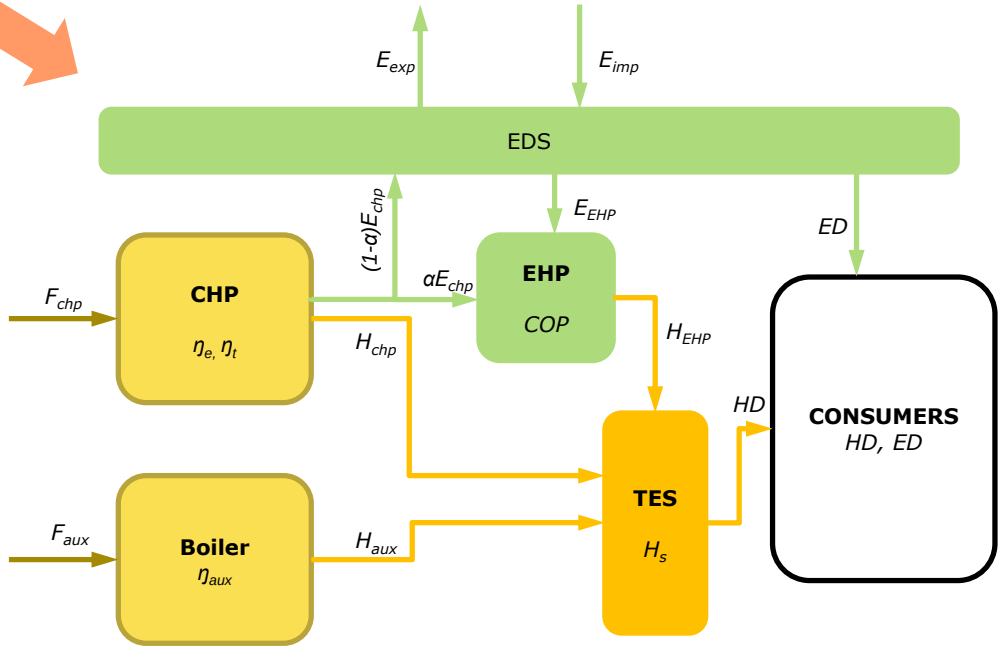
L. Zhang, N. Good, P. Mancarella, "Building-to-grid flexibility: Modelling and assessment metrics for residential demand response from heat pump aggregations", *Applied Energy*, Volumes 233–234, 1 January 2019, Pages 709-723

Flexibility from community and districts energy systems

From today's inflexible energy system...

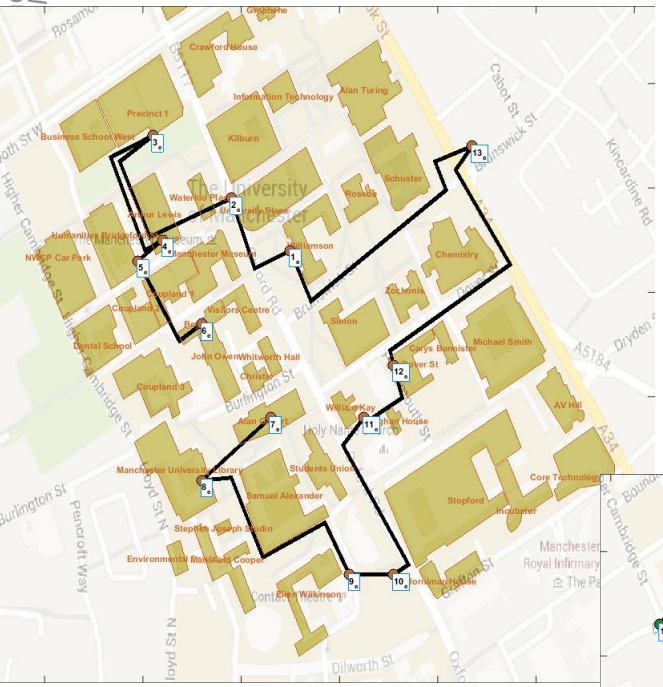


... to tomorrow's highly flexible distributed Multi-Energy System (MES)



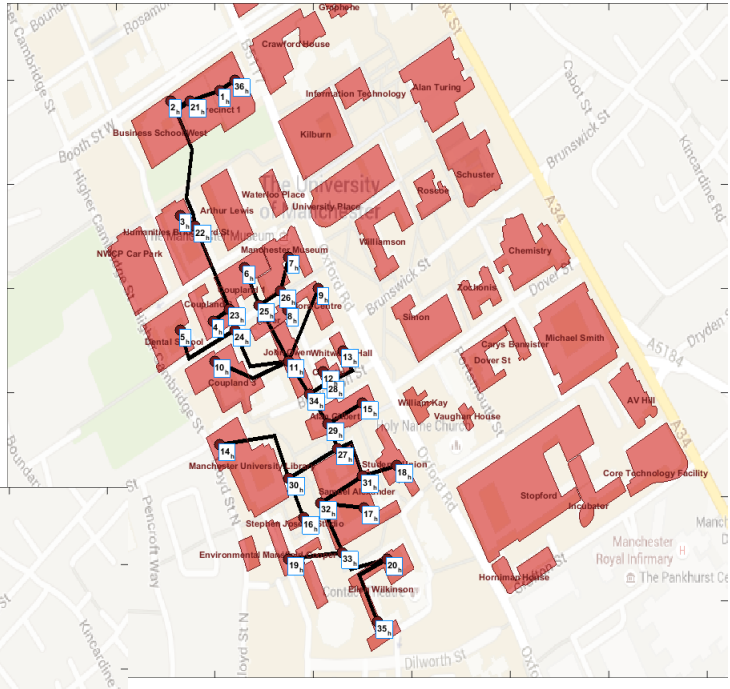
T. Capuder and P. Mancarella, Techno-economic and environmental modelling and optimization of flexible distributed multi-generation options, Energy, 2014

Integration of energy vectors in multi-energy communities and campuses



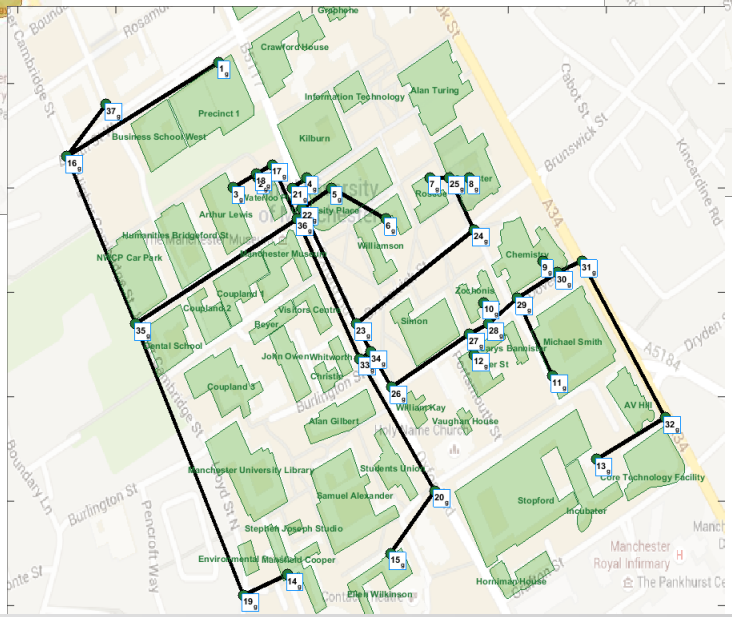
Gas:

- 27 buildings
- 37 nodes



Electricity:

- 17 buildings
- 13 nodes

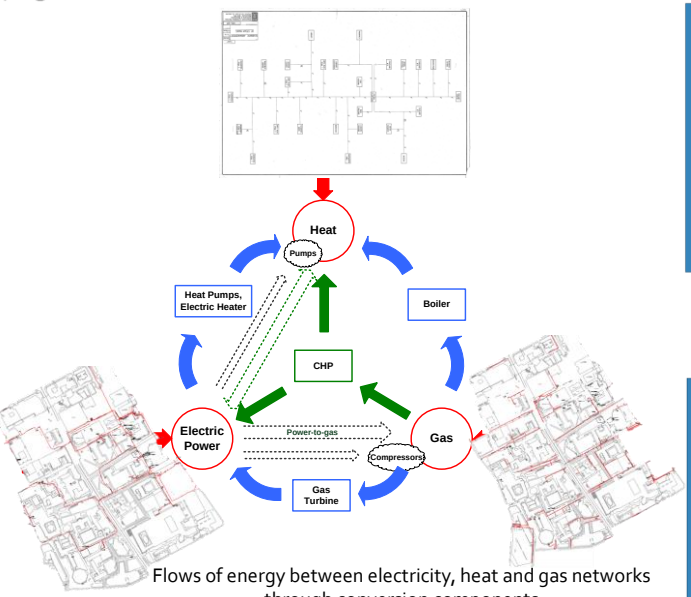


Heat:

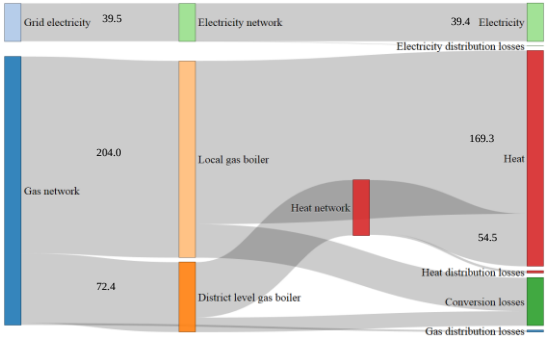
- 30 buildings
- 36 nodes

E.A Martinez Cesena and P. Mancarella, "Energy systems integration in smart districts: robust optimization of multi-energy flows in integrated electricity, heat and gas networks", IEEE Transactions on Smart Grid, 2018

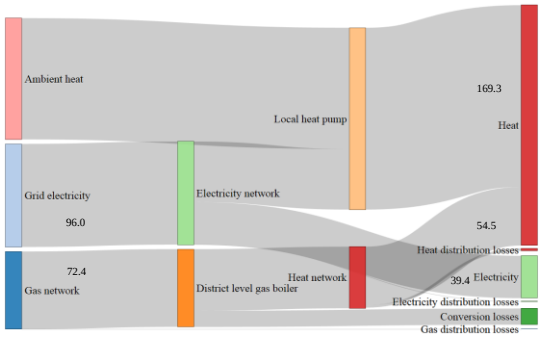
Transformative changes in multi-energy systems



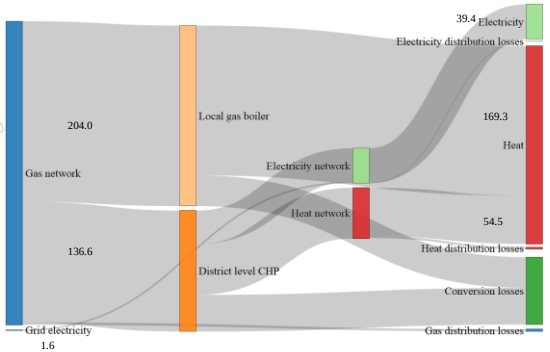
Flows of energy between electricity, heat and gas networks through conversion components



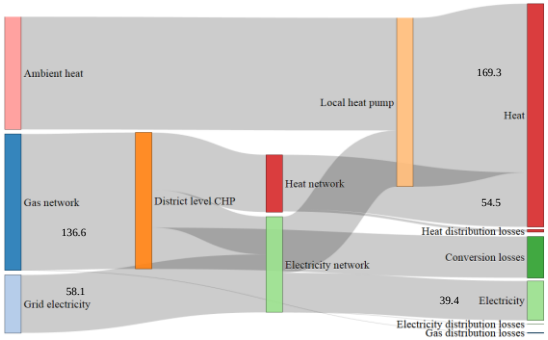
(a) Scenario 1: District level gas boilers + local gas boilers



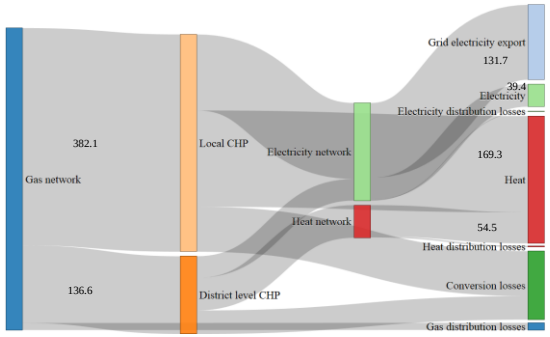
(b) Scenario 2: District level gas boilers + local heat pumps



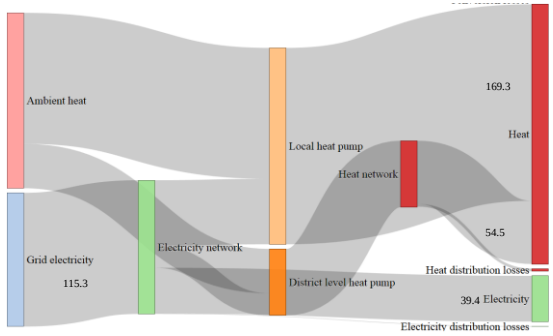
(c) Scenario 3: District level CHP + local gas boilers



(d) Scenario 4: District level CHP + local heat pumps



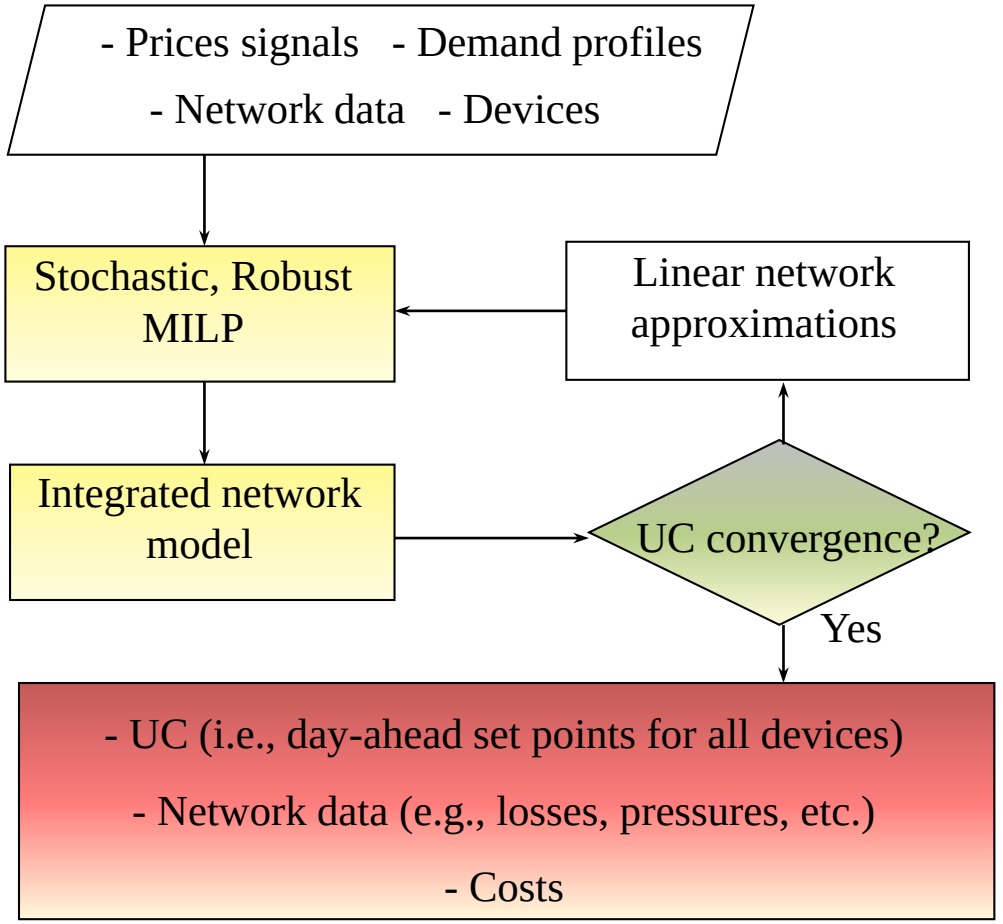
(e) Scenario 5: District level CHP + local CHP



(f) Scenario 6: District level heat pumps + local heat pumps

X. Liu and P. Mancarella, Modelling, assessment and Sankey diagrams of integrated electricity-heat-gas networks in multi-vector district energy systems, Applied Energy, 2016

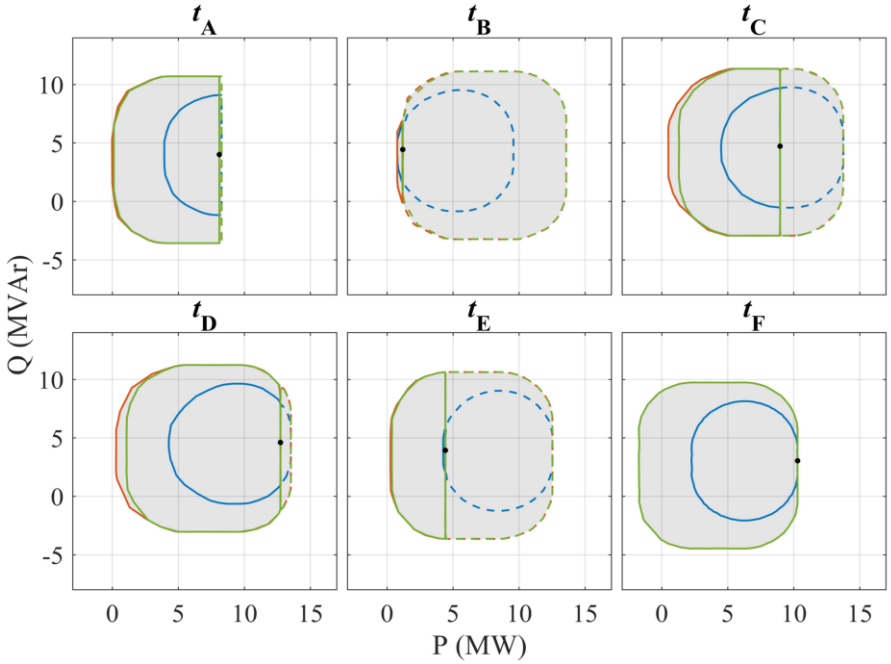
Multi-vector multi-service network constrained system optimization tool

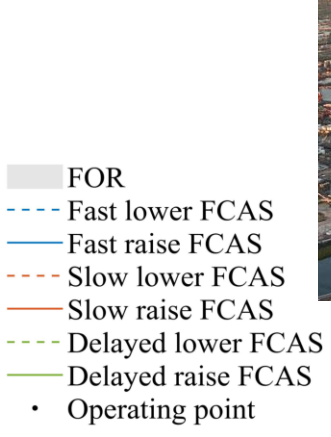


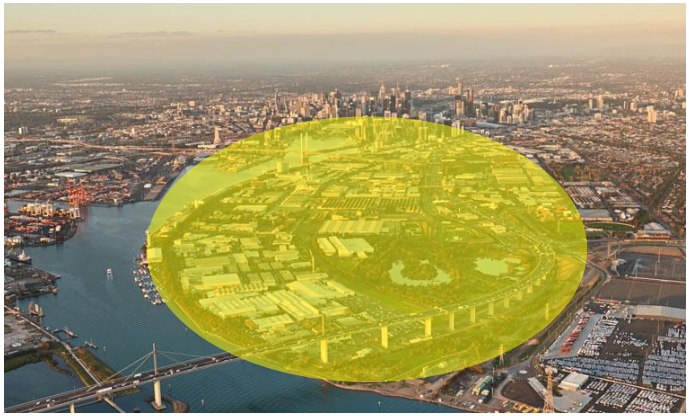
Source: X. Liu and P. Mancarella. Modelling, assessment and Sankey diagrams of integrated electricity-heat-gas networks in multi-vector district energy systems. Applied Energy, 2016

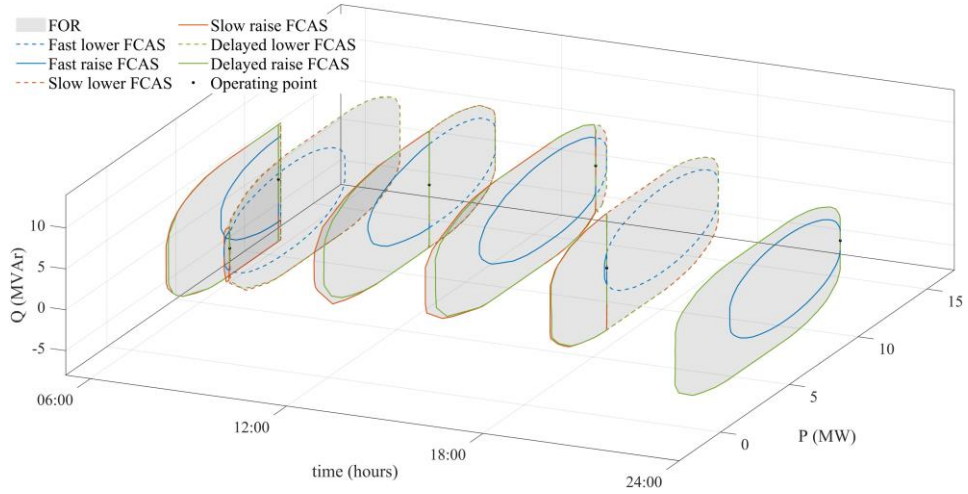
E.A Martinez Cesena and P. Mancarella, "Energy systems integration in smart districts: robust optimization of multi-energy flows in integrated electricity, heat and gas networks", IEEE Transactions on Smart Grid, 2018

Urban-scale Virtual Power Plants



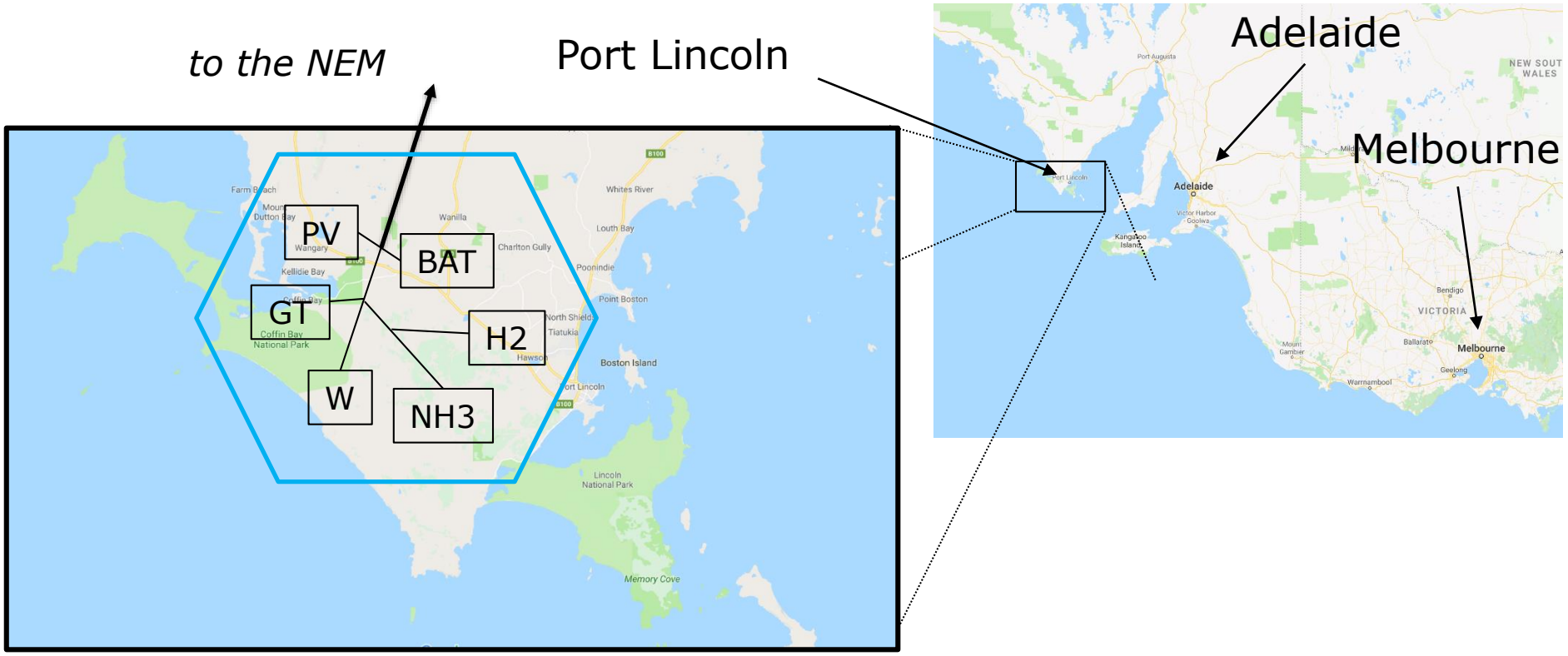




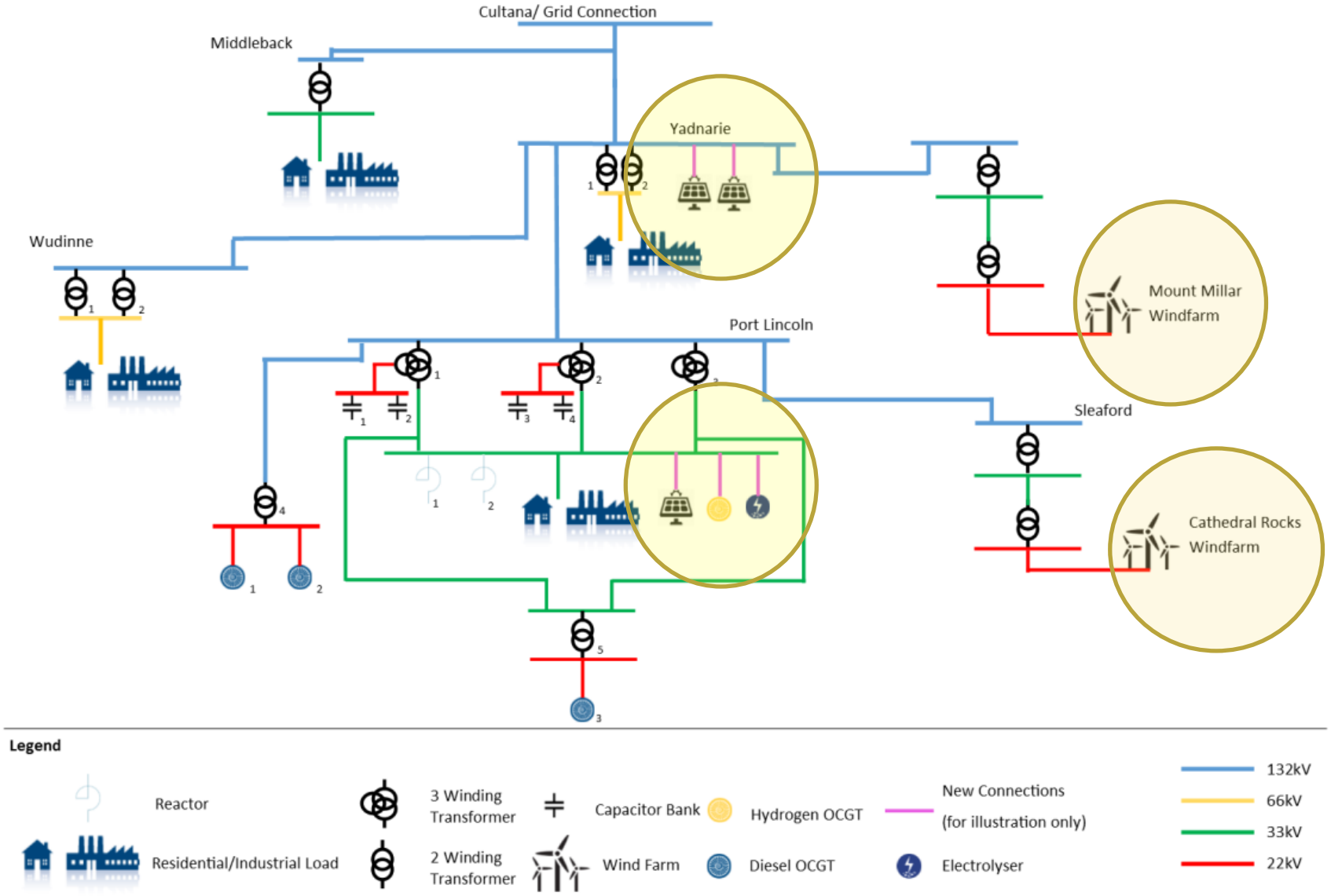


H. Wang, S. Riaz, P. Mancarella, "Integrated Techno-economic Modeling, Flexibility Analysis, and Business Case Assessment of an Urban Virtual Power Plant with Multi-market Co-optimization", *Applied Energy, in press, November 2019*

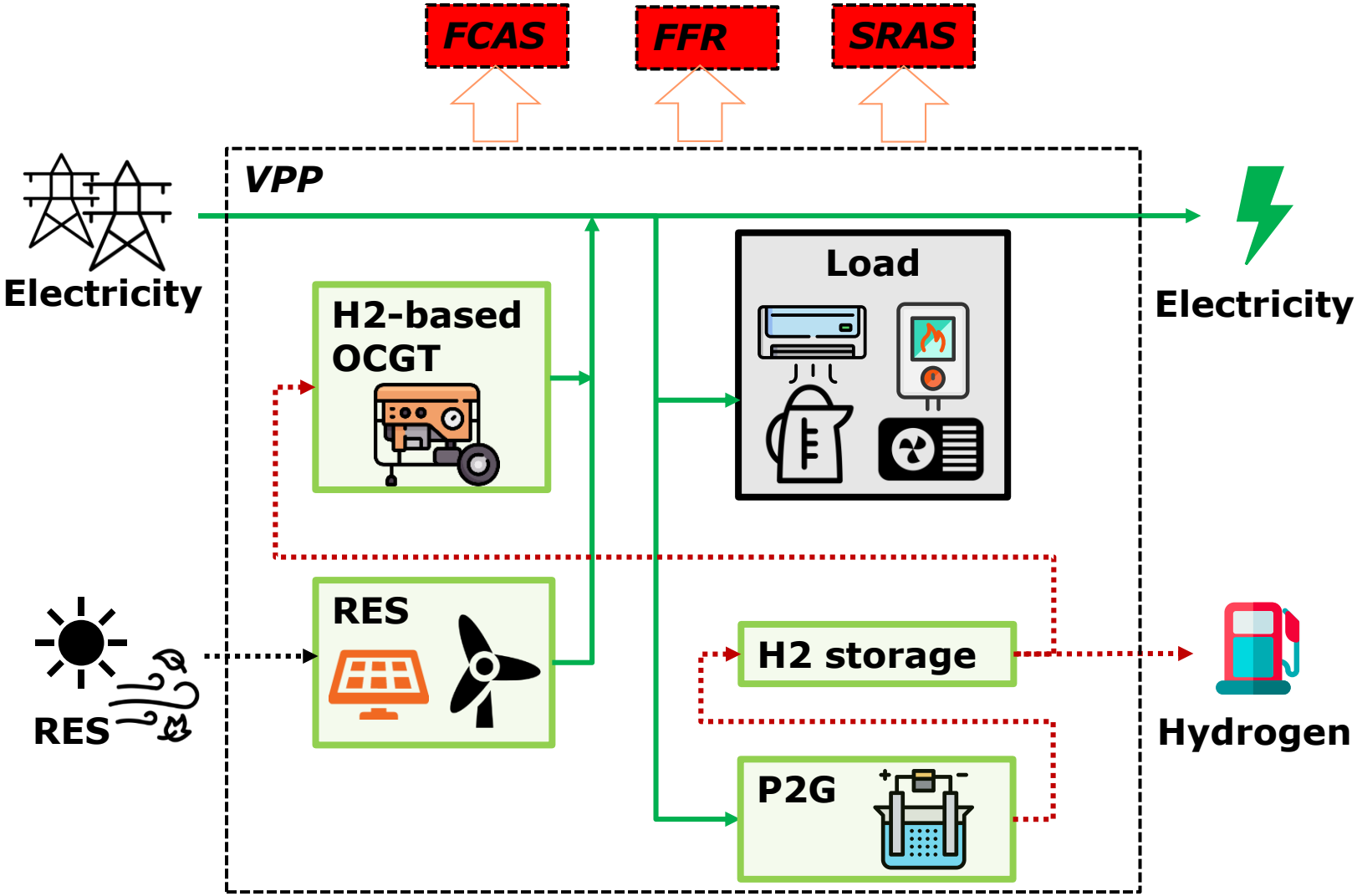
Large-scale sector coupling: Port Lincoln multi-commodity hub



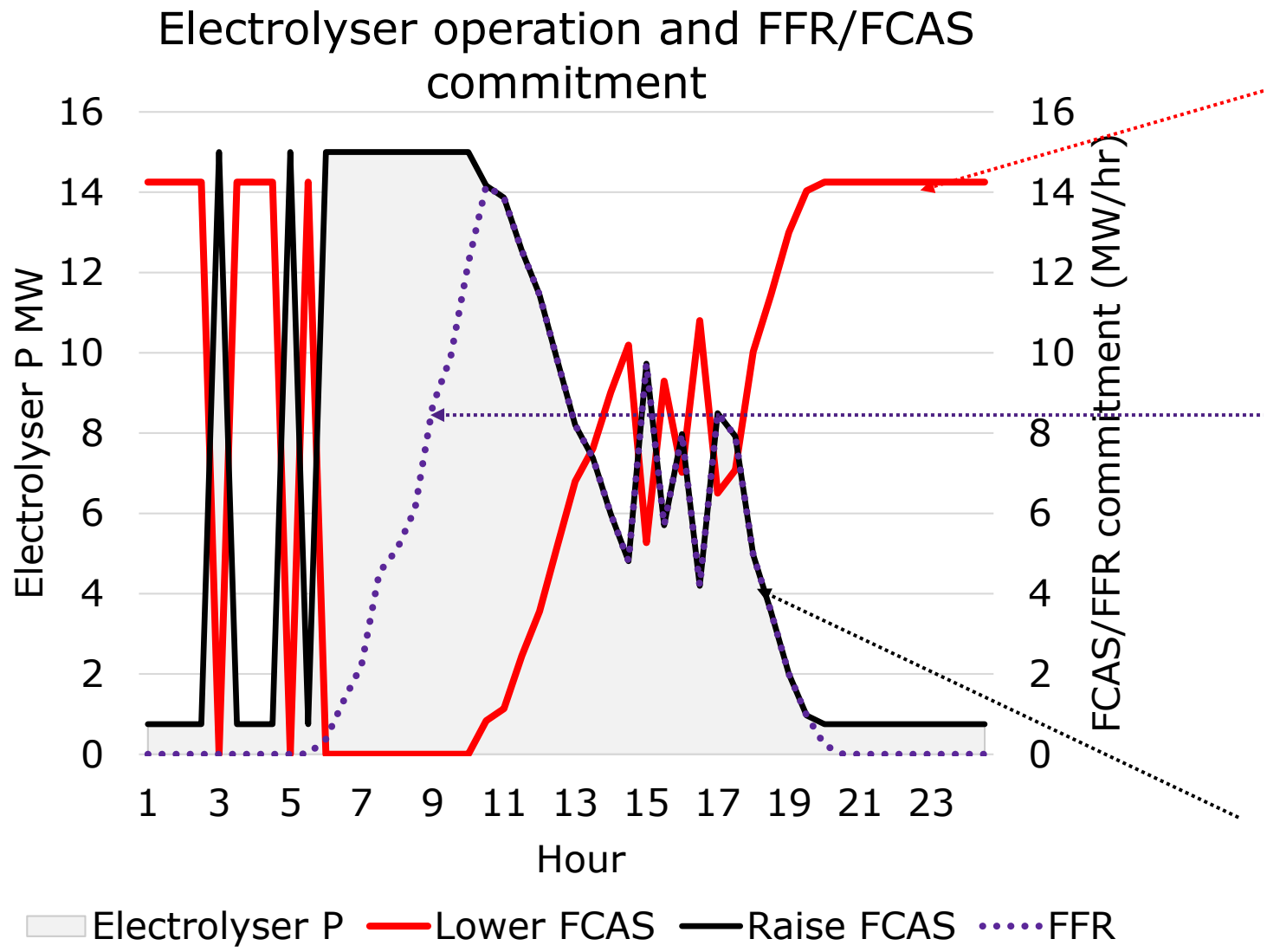
Big challenges, innovative solutions



Integrated electricity, hydrogen and RES VPP



New business case opportunities from integrated services

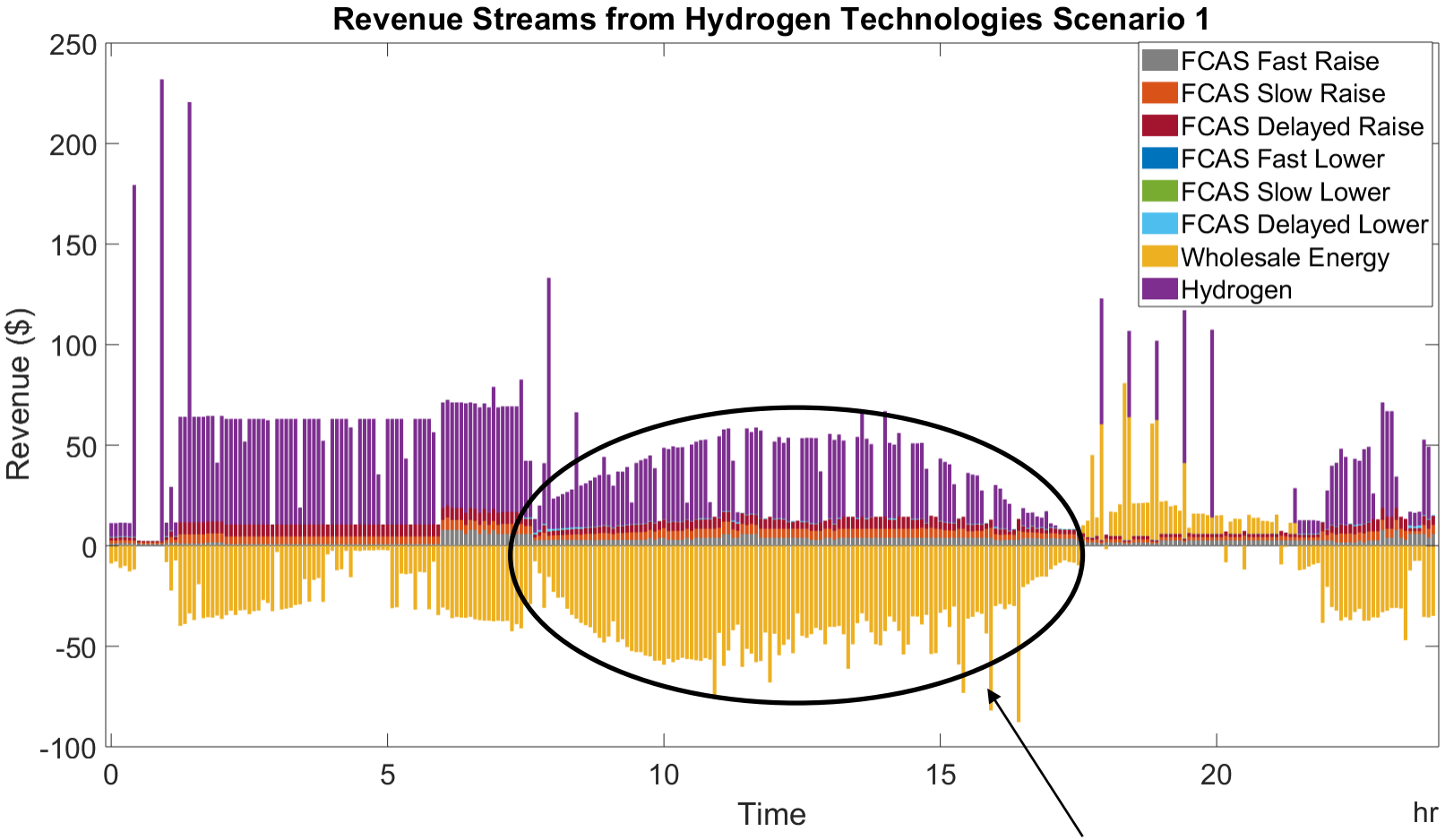


The **headroom** of the electrolyser can participate in **lower FCAS** markets

FFR equal to 49% of the PV output is provided by the electrolyser using its **footroom**

The **footroom** of the electrolyser can participate in **raise FCAS** markets

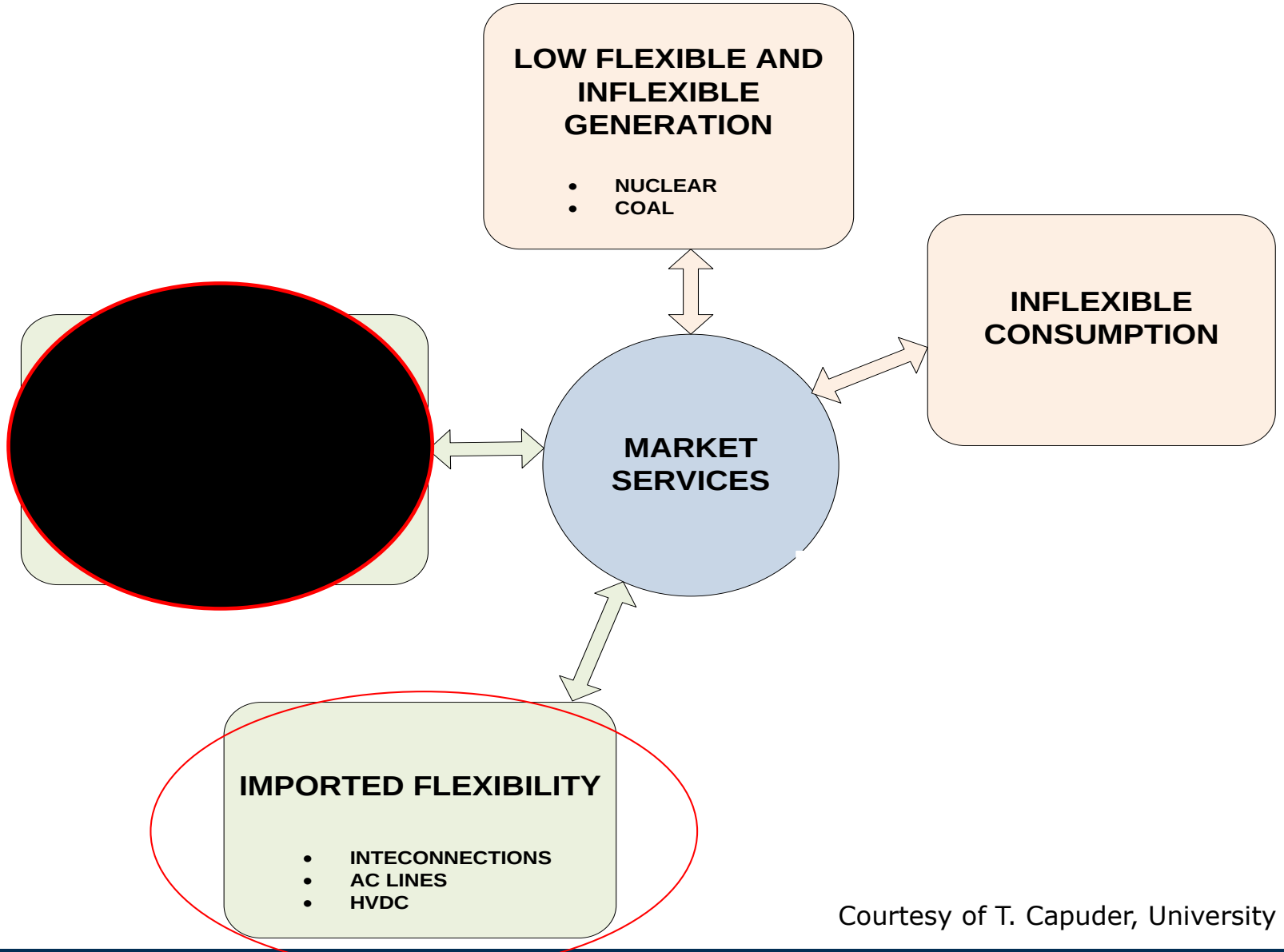
Integrated multi-commodity markets



Note: Potential revenue from the FFR agreement *not* included

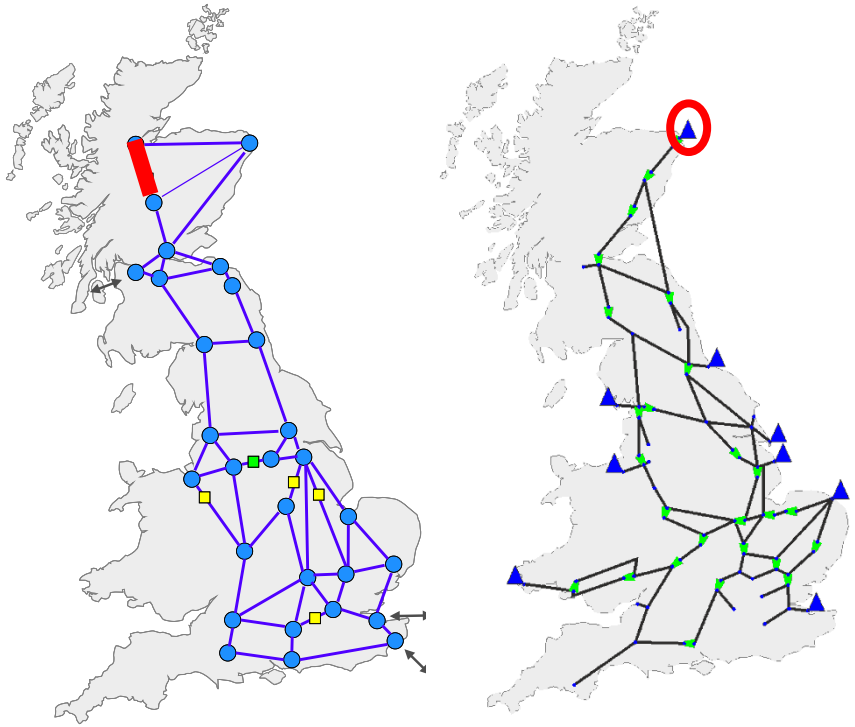
Hydrogen-based devices providing FFR for PV

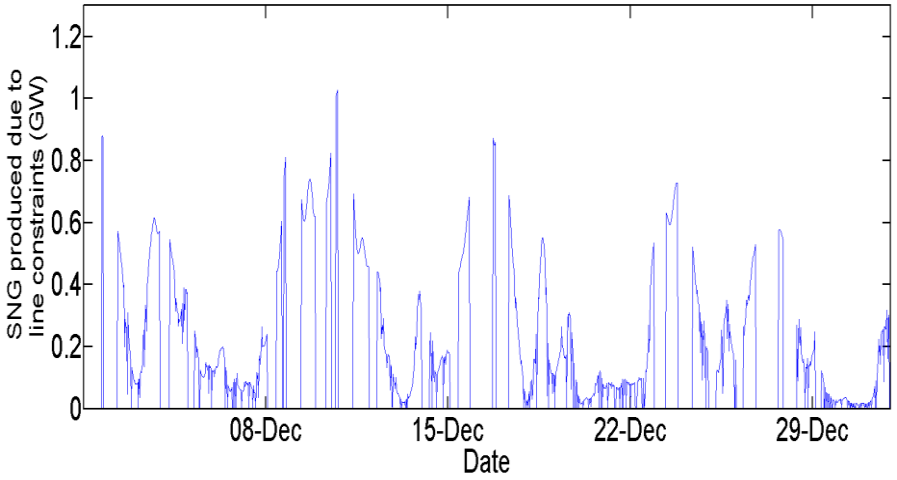
Flexibility from networks

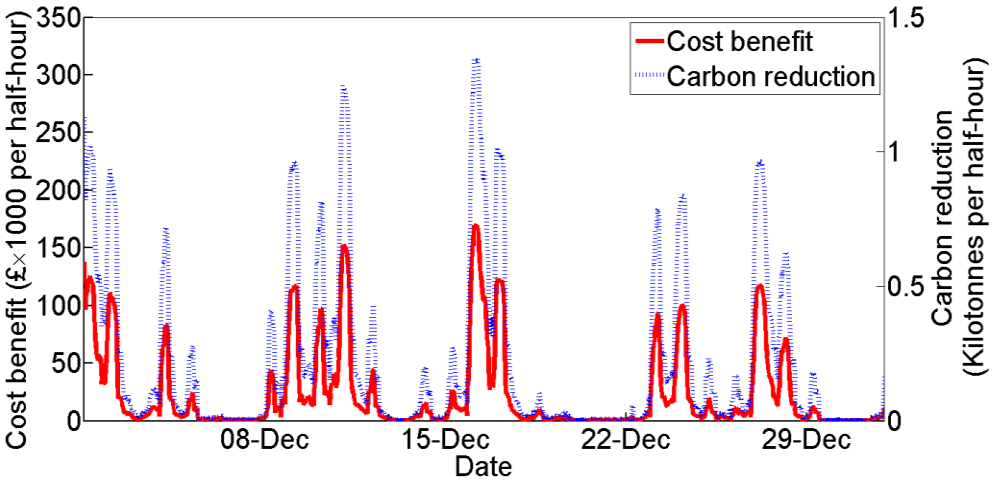


Courtesy of T. Capuder, University of Zagreb

Flexibility across infrastructure: Power-to-gas (P2G) for network arbitrage





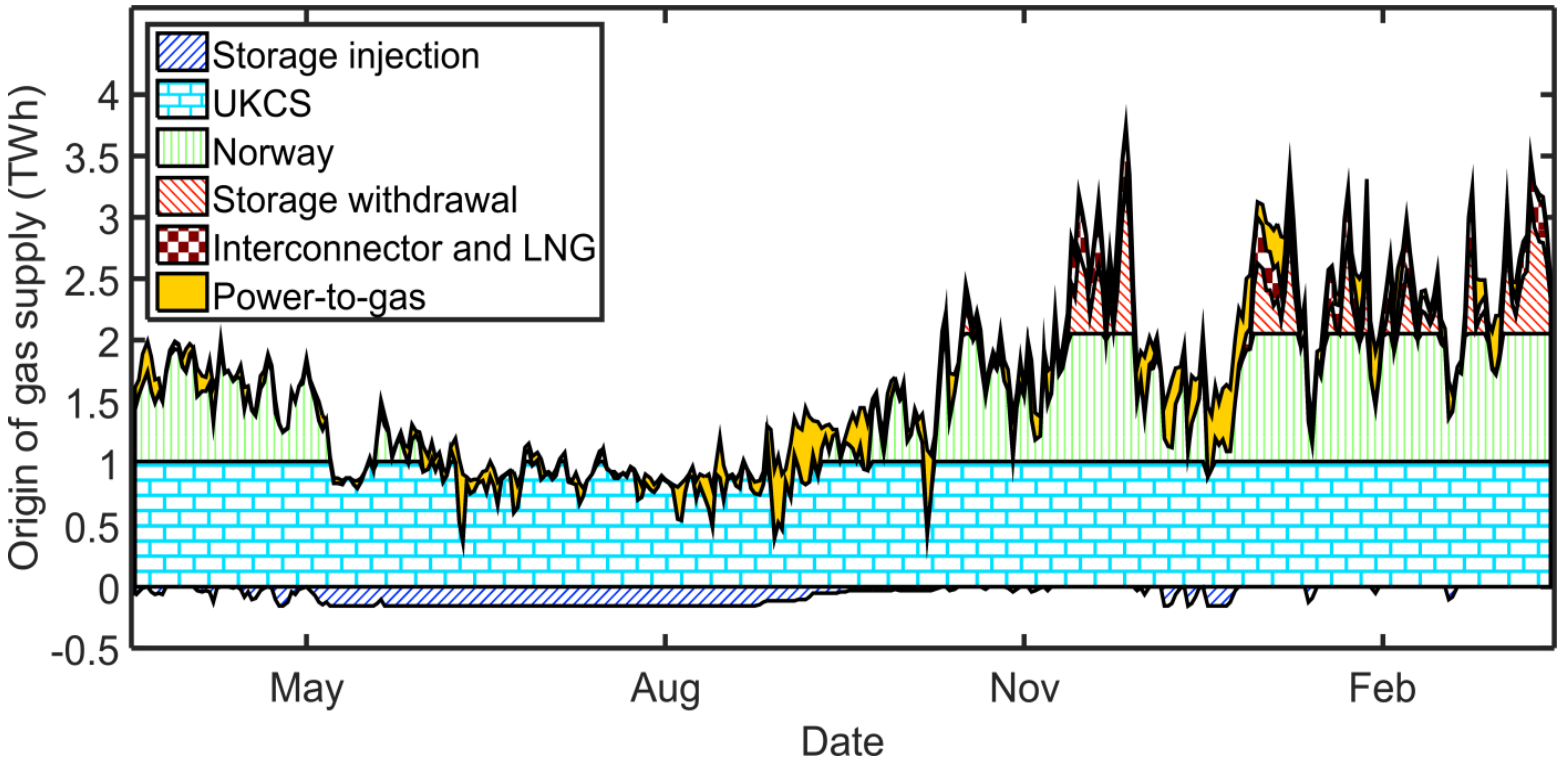


Modelling the impact of H2 injection on gas flows

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

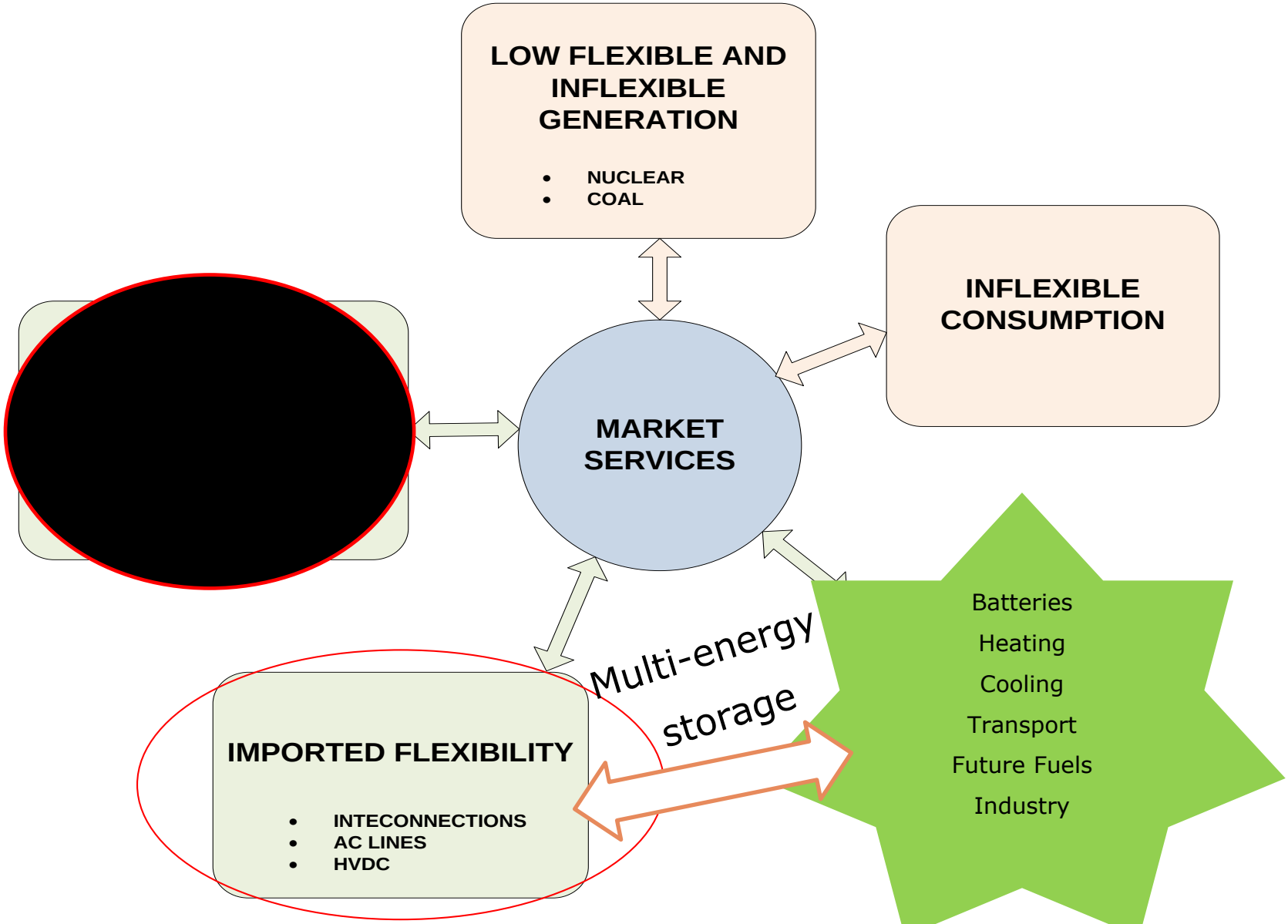
More and new forms of flexibility: Power-to-gas (P2G) for seasonal storage

Installed generation capacities		Peak demand [GW]
Wind [GW]	Solar [GW]	
92	40	87

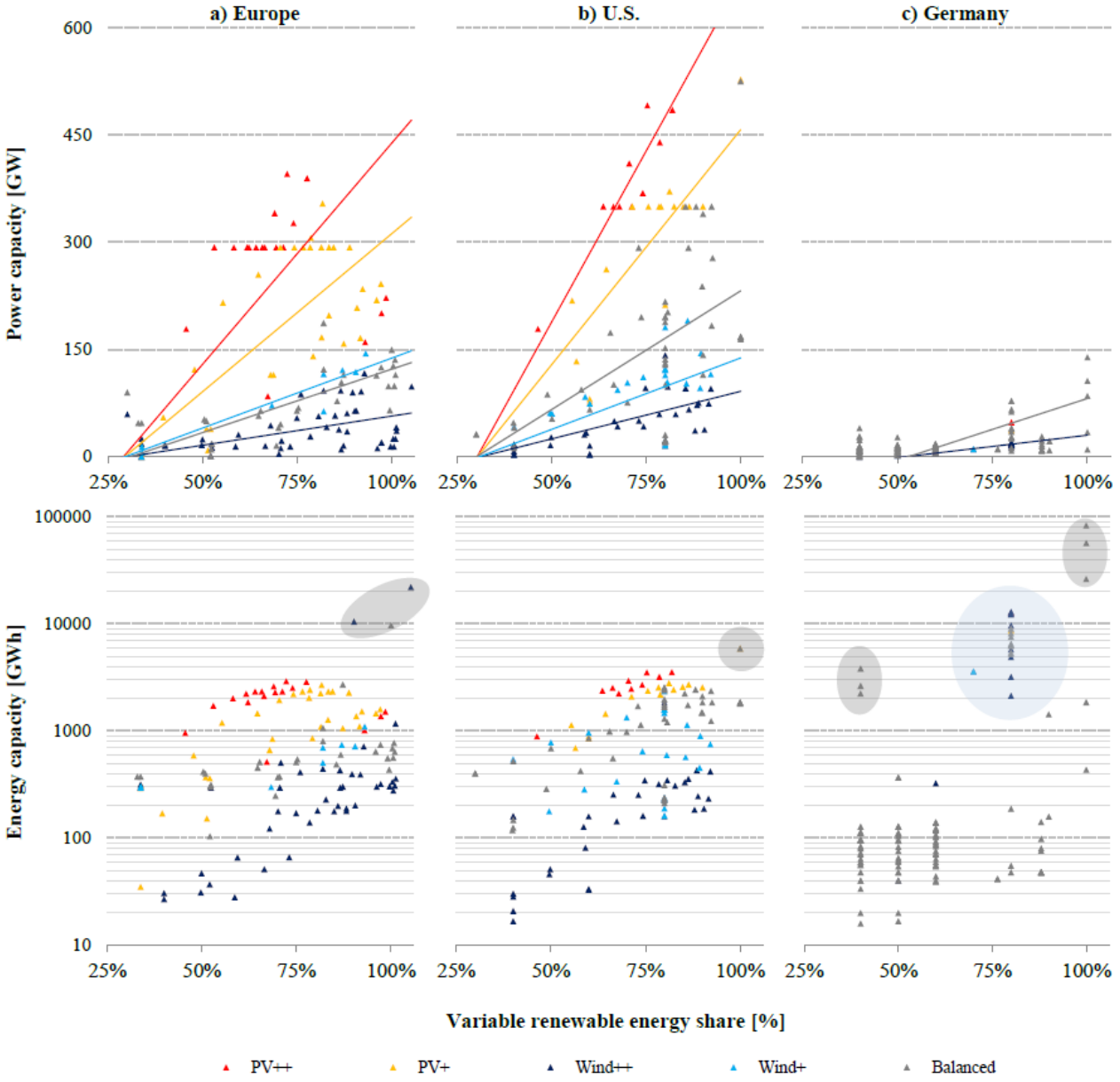


S. Clegg, P. Mancarella, "Storing renewables in the gas network: modelling of power-to-gas seasonal storage flexibility in low-carbon power systems", IET Generation, Transmission & Distribution, 10 (3), pp.566–575, 2015

Integrated flexibility

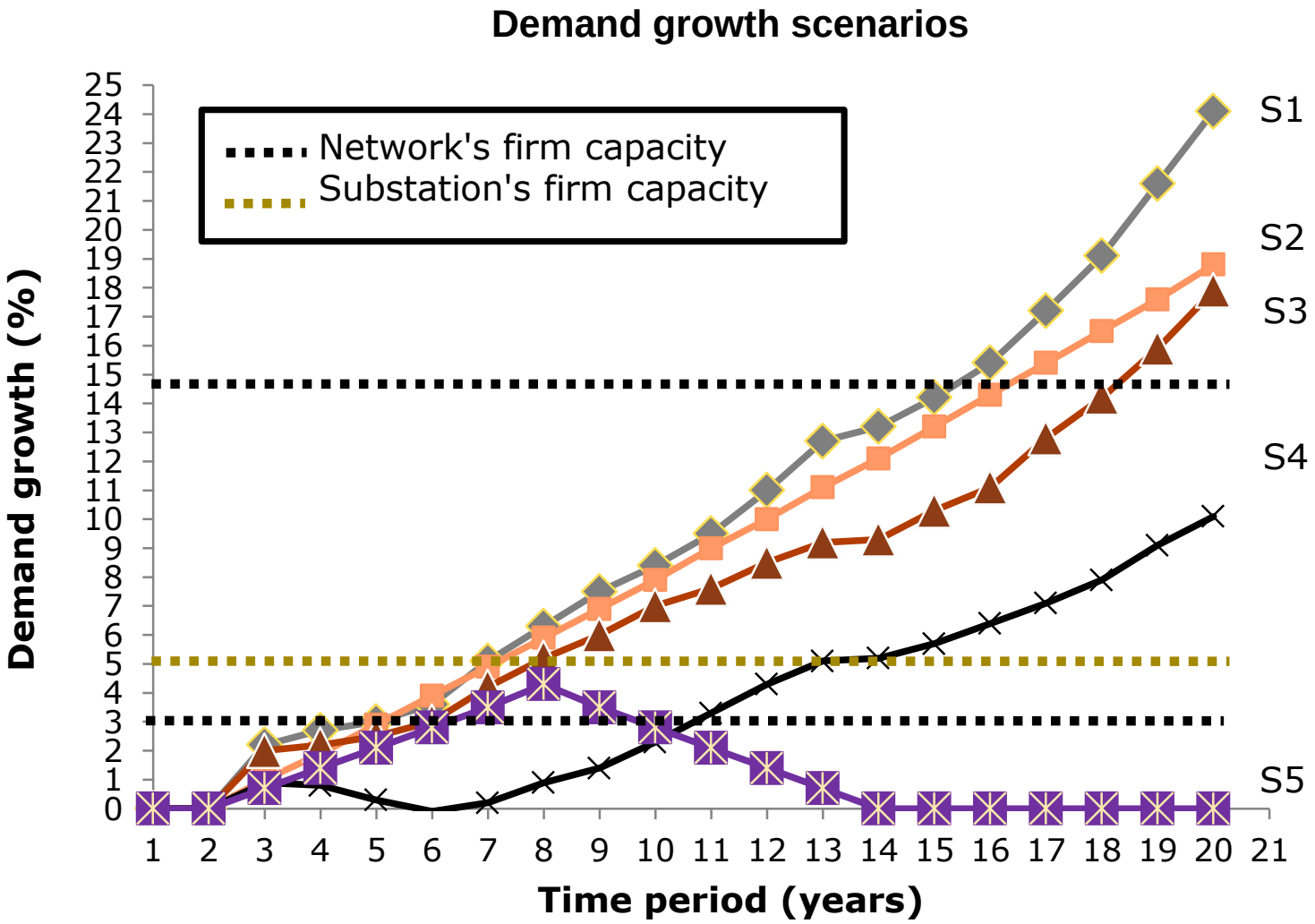


How much storage?



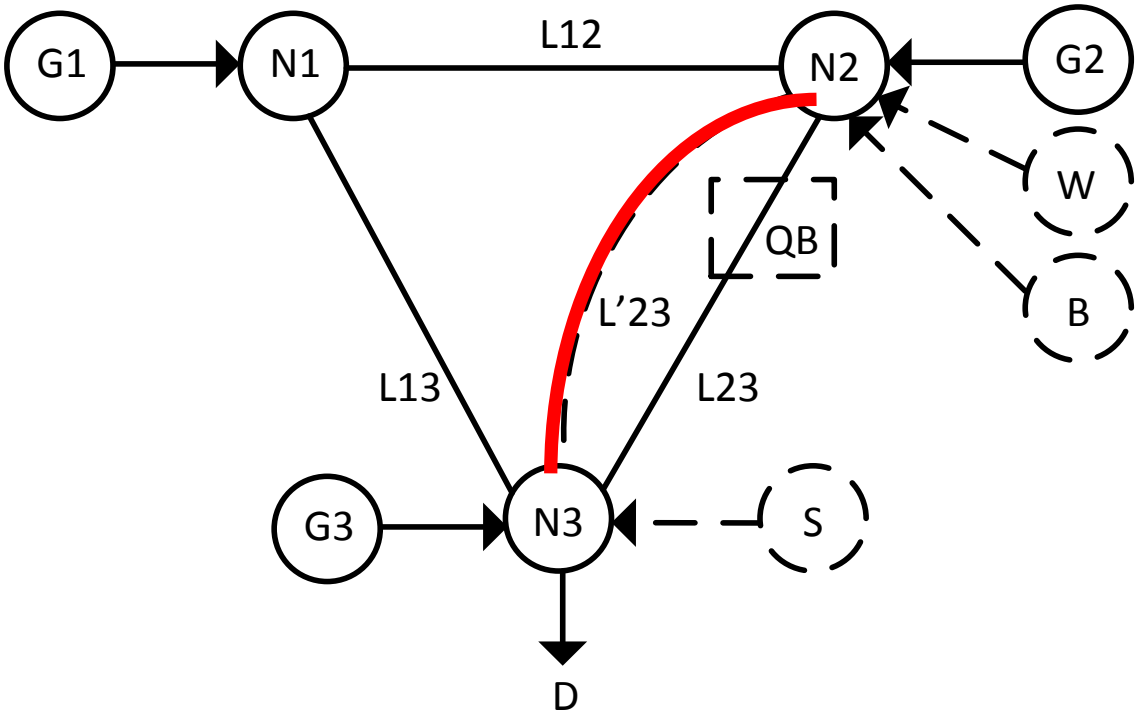
F. Cebulla, *et al.*, "How much electrical energy storage do we need?", *Journal of Cleaner Production*, Volume 181, 20 April 2018, 449-459

Planning for an integrated system: Do we really know the future?



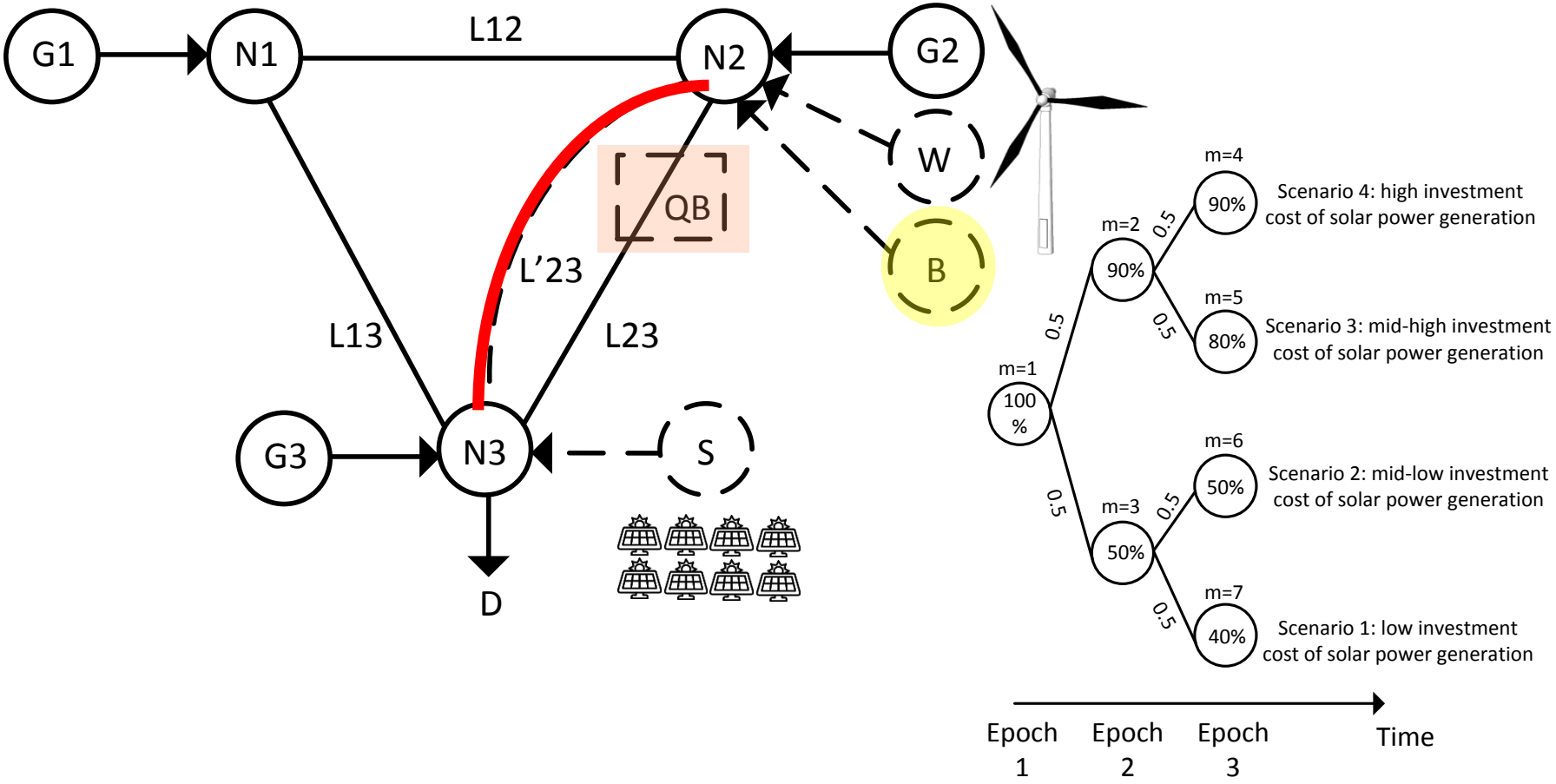
Courtesy of Electricity North West, UK

Planning for the Smart Grid



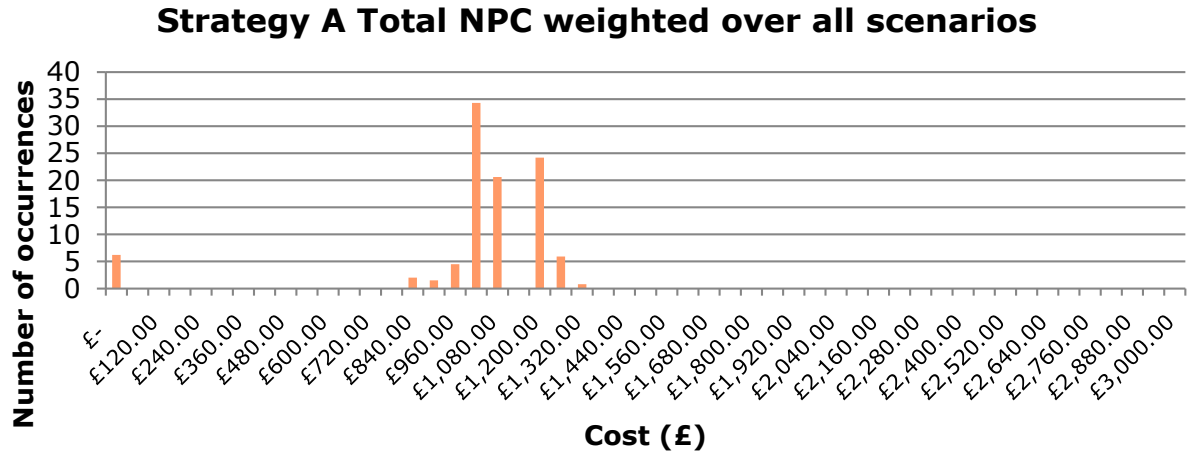
R. Moreno, A. Street, J.M. Arroyo, and P. Mancarella, "Planning Low-Carbon Electricity Systems under Uncertainty Considering Operational Flexibility and Smart Grid Technologies", *Philosophical Trans. Royal Society A*, June 2017

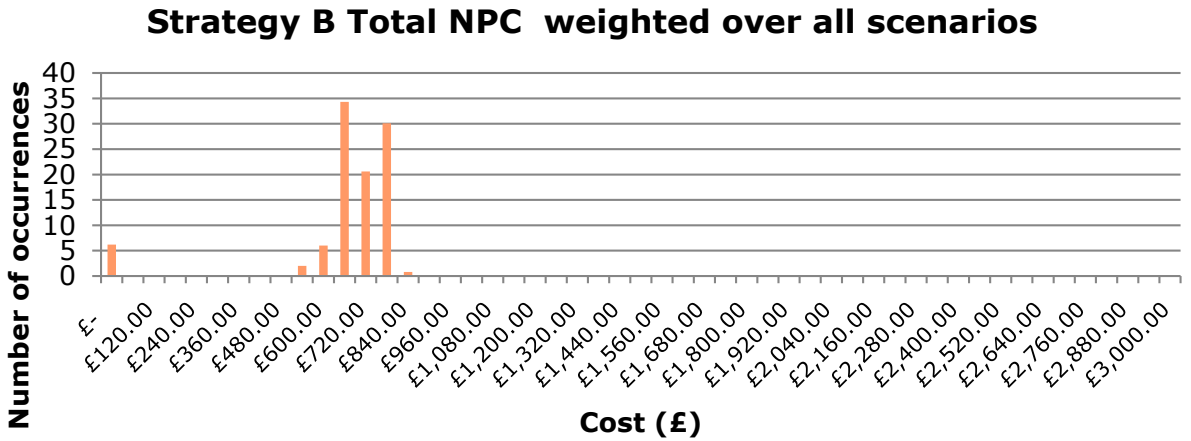
Planning for the Smart Grid

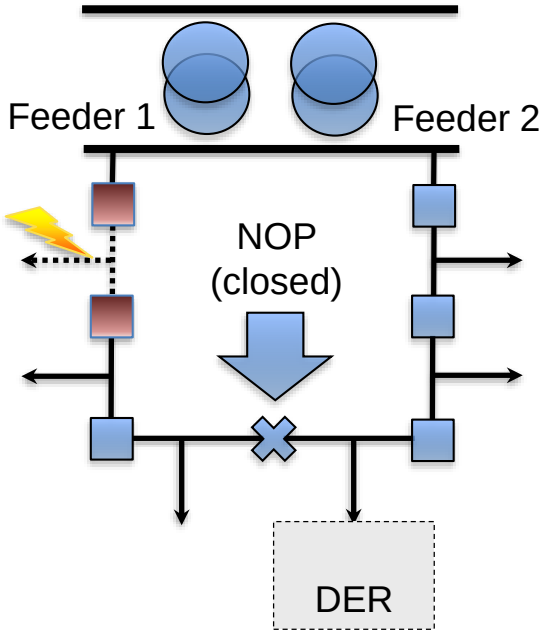


R. Moreno, A. Street, J.M. Arroyo, and P. Mancarella, "Planning Low-Carbon Electricity Systems under Uncertainty Considering Operational Flexibility and Smart Grid Technologies", *Philosophical Trans. Royal Society A*, June 2017

Network vs non-network solutions: need for updated regulation



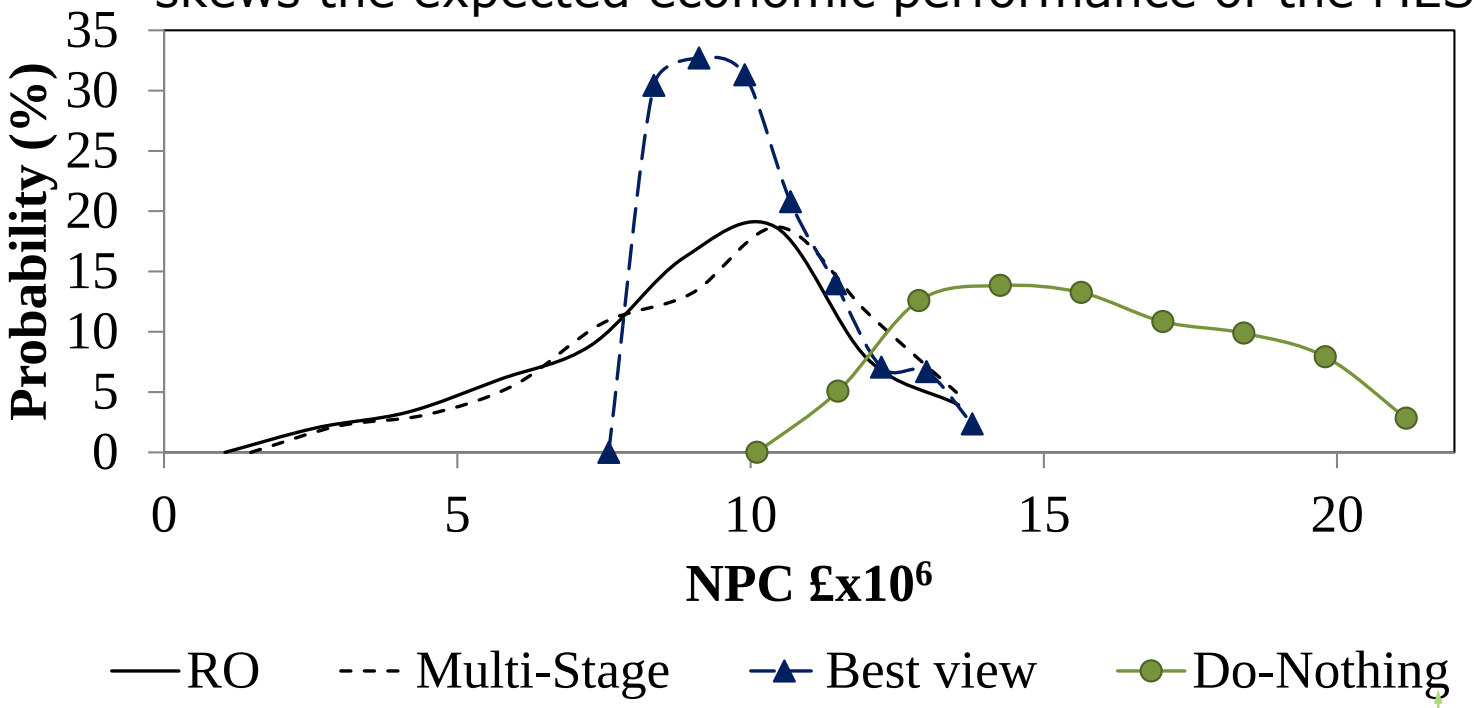


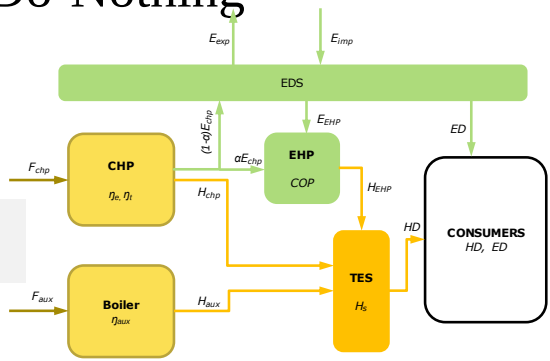


J. Schachter, P. Mancarella, J. Moriarty, and R. Shaw, Flexible investment under uncertainty in smart distribution networks with demand side response*:* Assessment framework and practical implementation, *Energy Policy*, Volume 97, October 2016, Pages 439–449.

Flexible planning and risk: Application to MES

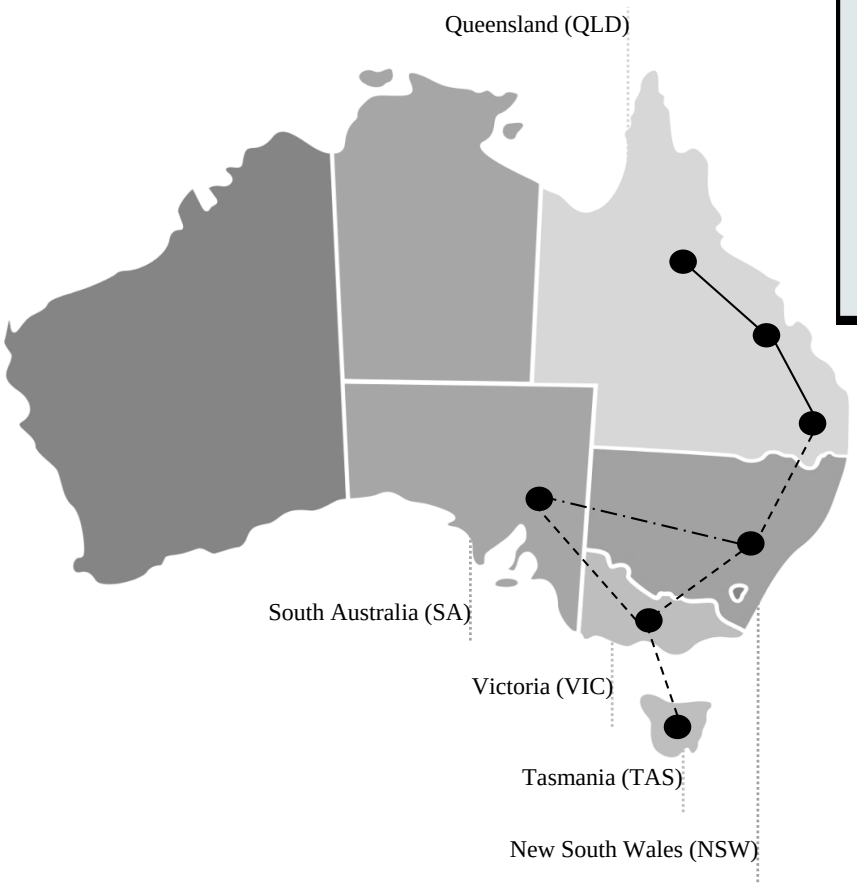
Flexible operation and investment
skews the expected economic performance of the MES

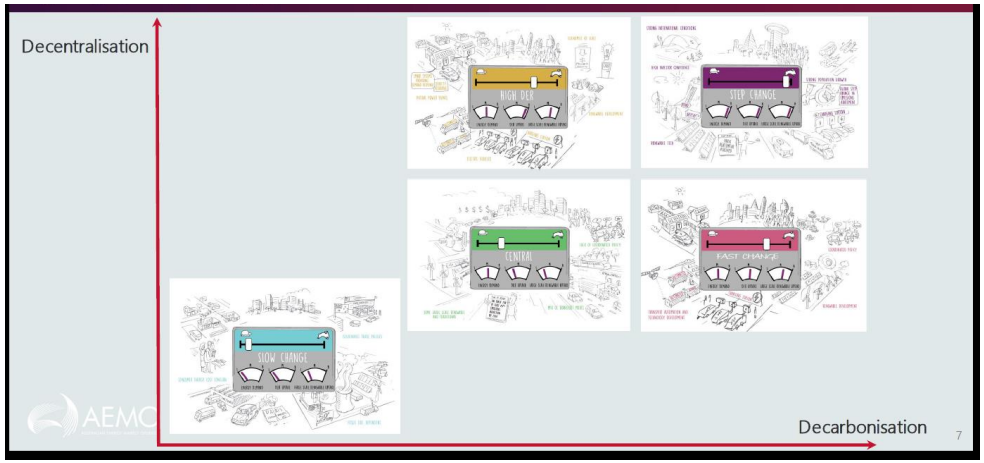




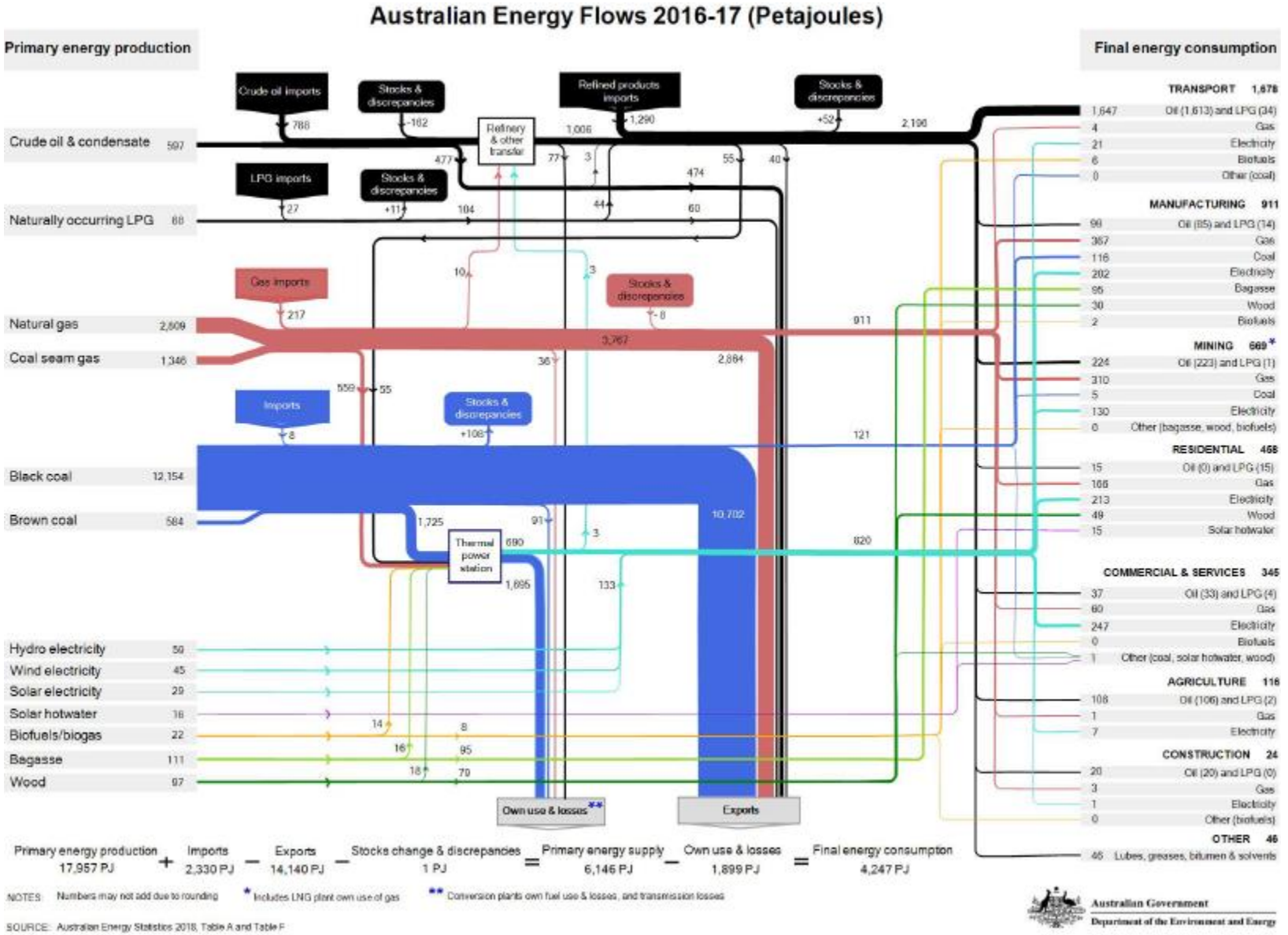
E. A. Martinez Cesena, T. Capuder and P. Mancarella, "Flexible distributed multi-energy generation system expansion planning under uncertainty," IEEE Transactions on Smart Grid, 2016

In progress: Stochastic Integrated System Plan





The bigger picture (down under): It's not (at all) only about electricity...

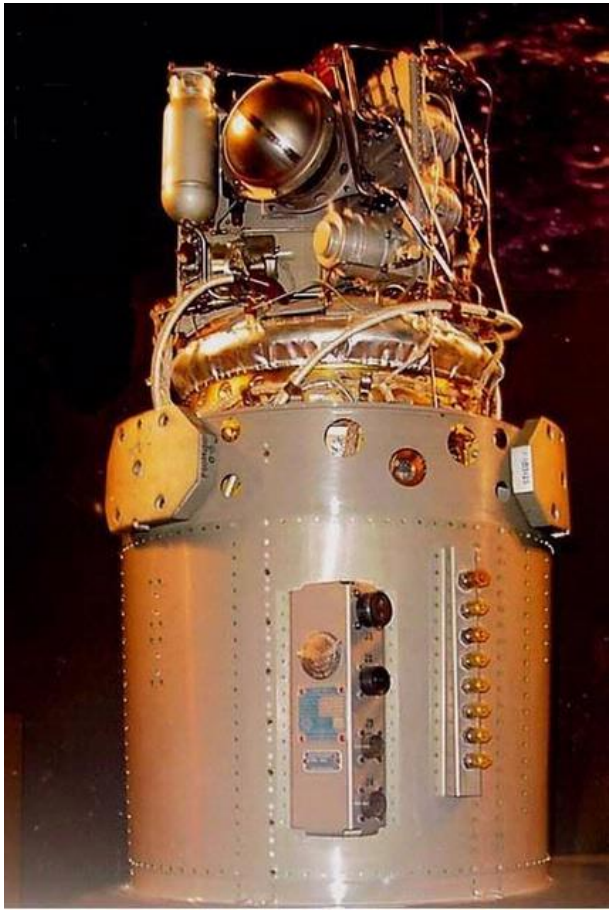


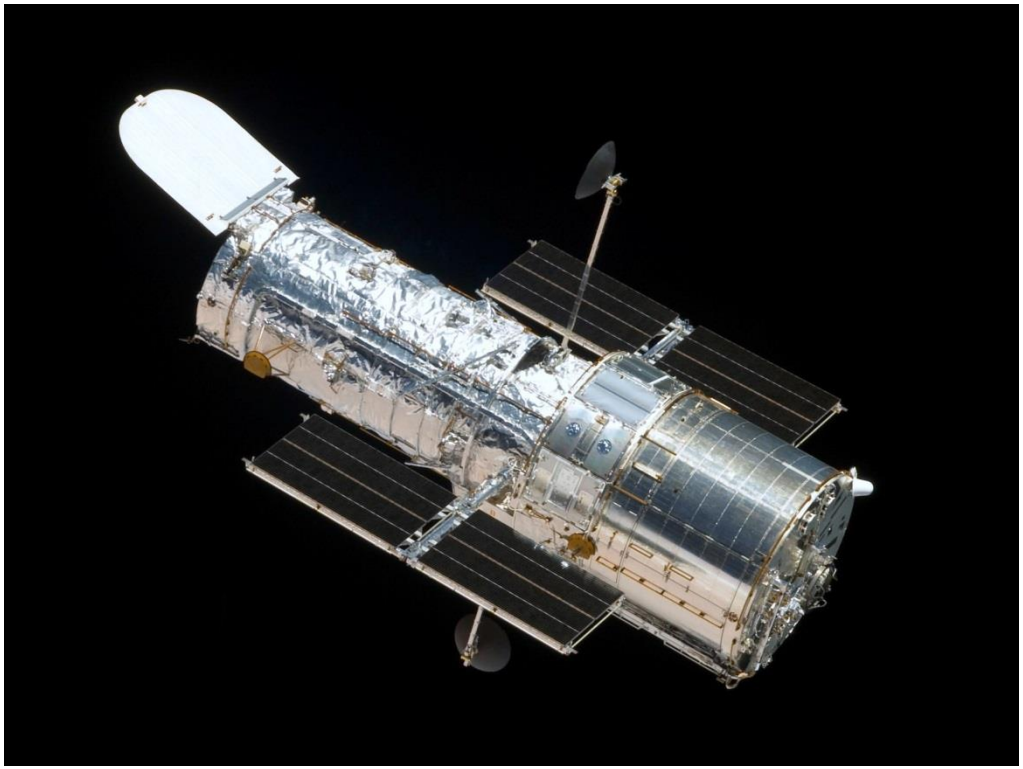
Australia Potential Exports of Hydrogen In the Next 20 Years

Scenario	Country	2025		2030		2040	
		PJ	'000 tonnes	PJ	000 tonnes	PJ	000 tonnes
Low hydrogen scenario	Japan	2.1	17.3	21.9	182.2	47.1	392.1
	Korea	1.0	8.0	4.8	40.1	12.9	107.4
	Singapore	0.04	0.3	0.5	3.9	1.5	12.5
	China	0.1	0.5	1.4	11.6	10.7	88.9
	Rest of the World	0.05	0.4	0.5	4.3	2.4	20.3
	Total	**3.2**	**26.5**	**29.1**	**242.1**	**74.6**	**621.3**
Medium hydrogen scenario	Japan	12.7	106.1	44.2	368.1	102.3	852.2
	Korea	2.9	23.9	9.4	78.1	28.1	233.6
	Singapore	0.2	2.1	0.9	7.4	2.7	22.6
	China	0.3	2.6	4.5	37.6	23.7	197.3
	Rest of the World	0.2	1.8	1.3	11.0	5.4	44.8
	Total	**16.4**	**136.5**	**60.3**	**502.1**	**162.2**	**1,350.4**
High hydrogen scenario	Japan	33.0	275.0	96.4	803.0	237.7	1,978.8
	Korea	6.4	53.0	20.1	167.4	68.4	569.5
	Singapore	0.5	4.2	1.8	15.1	7.5	62.5
	China	0.9	7.9	9.5	79.3	55.7	463.9
	Rest of the World	0.6	4.8	2.8	23.5	12.7	105.6
	Total	**41.4**	**344.8**	**130.7**	**1,088.4**	**382.0**	**3,180.4**

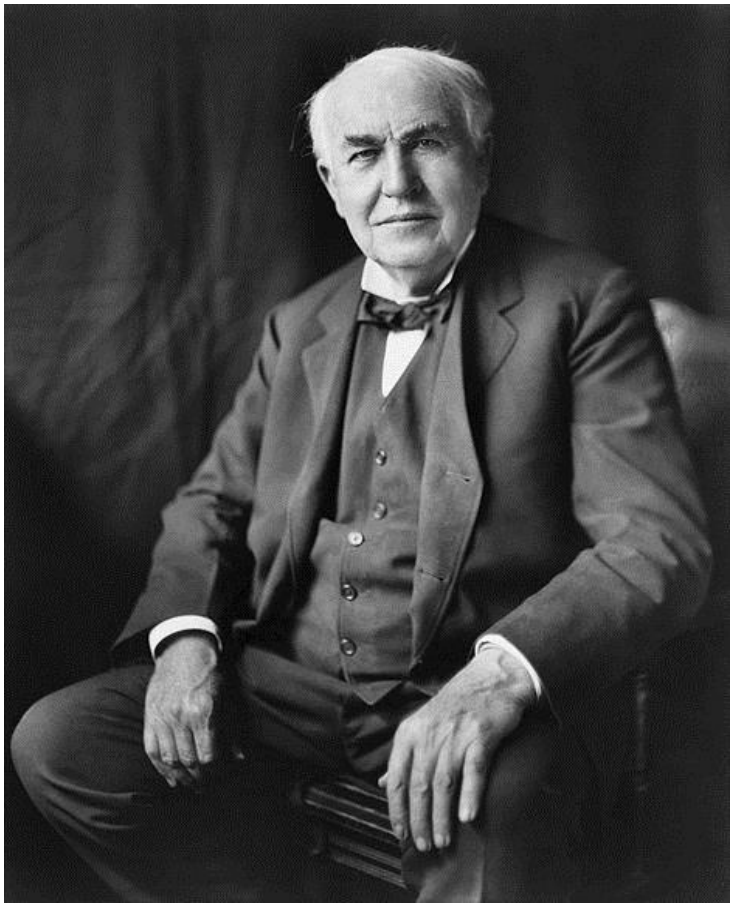
SOURCE: ACIL ALLEN ESTIMATES

Science fiction?





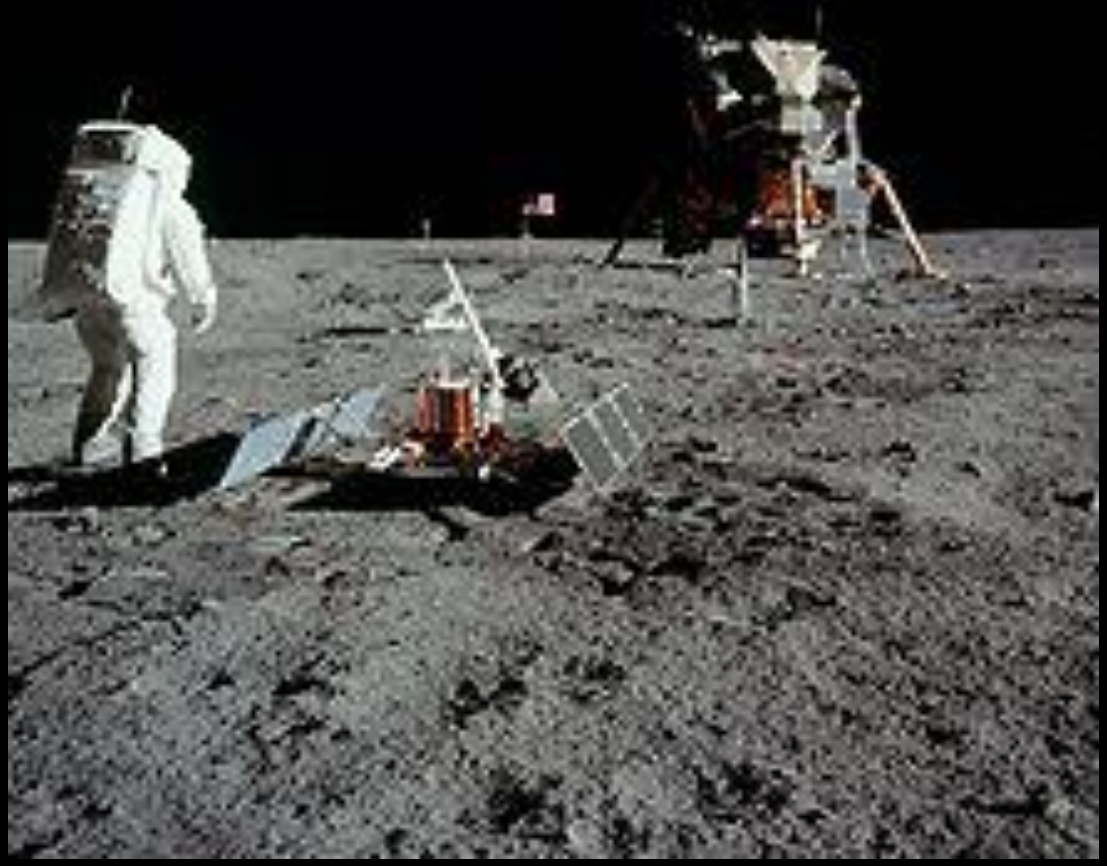
Back to the future



1878: “We will make electricity so cheap that only the rich will burn candles”

1882: Edison switched on his Pearl Street electrical power distribution system, which provided 110 volts DC to 59 customers in lower Manhattan

We'll get there



Acknowledgements

- The UK EPSRC for the:
  - *"MY-STORE"* project
  - *"TERSE"* project
- The Victorian Government for the *veski* Innovation Fellowship
- The "*Future Fuels*" Cooperative Research Centre, Australia
- Ausnet Services, Australia
- My research team(s) in Melbourne and Manchester

Selected references: MES operational flexibility

- E.A Martinez Cesena and P. Mancarella, "*Energy systems integration in smart districts: robust optimization of multi-energy flows in integrated electricity, heat and gas networks*", IEEE Transactions on Smart Grid, 2018
- N. Good and P. Mancarella, "*Flexibility in multi-energy communities with electrical and thermal storage: A stochastic, robust optimization model for multi-service demand response"*, IEEE Transactions on Smart Grid, 2018
- E. A. Martínez Ceseña, N. Good, A. L. A. Syrri, and P. Mancarella, "*Techno-economic and business case assessment of multi-energy microgrids with co-optimization of energy, reserve and reliability services*," Appl. Energy, vol. 210, pp. 896–913, 2018
- P. Mancarella, G.Chicco, T. Capuder, "*Arbitrage opportunities for distributed multi-energy systems in providing power system ancillary services*", Energy, Aug 2018
- N. Good, E.A. Martinez-Cesena, and P. Mancarella, "*Techno-economic assessment and business case modelling of low carbon technologies in distributed multi-energy systems"*, Applied Energy, 2016
- T. Capuder and P. Mancarella, "*Techno-economic and environmental modelling and optimization of flexible distributed multi-generation options*", Energy, 2014
- P. Mancarella and G. Chicco, "*Real-time demand response from energy shifting in Distributed Multi-Generation"*, IEEE Transactions on Smart Grid, vol. 4, 2013
- P. Mancarella, "*Multi-energy systems: an overview of models and evaluation concepts"*, Energy, Vol. 65, 2014, 1-17, *Invited paper*
- A. Monti, D. Persch, K. Ellis, K. Kouramas, and P. Mancarella (eds.), "*Energy positive neighborhoods and smart energy districts: methods, tools and experiences from the field*" , Elsevier, Sept 2016

Selected references: MES planning flexibiltiy

- R. Moreno, A. Street, J. M. Arroyo, P. Mancarella, "Planning low-carbon electricity systems under uncertainty considering operational flexibility and smart grid technologies", *Philosophical Transactions of the Royal Society A*, Vol. 375, Issue 2100, Aug 2017, pp. 1-29
- F. Cebulla, *et al.*, "How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany", *Journal of Cleaner Production*, Volume 181, 20 April 2018, Pages 449-459
- J. Haas, *et al.*, "Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review", *Renewable and Sust. Energy Reviews* 80 (December 2017) 603–619
- J. Schachter, P. Mancarella, J. Moriarty, and R. Shaw, "Flexible investment under uncertainty in smart distribution networks with demand side response*:* Assessment framework and practical implementation", *Energy Policy*, Volume 97, October 2016, Pages 439–449
- E. A. Martinez Cesena, T. Capuder and P. Mancarella, "Flexible distributed multi-energy generation system expansion planning under uncertainty," IEEE Transactions on Smart Grid, 2016
- M. Panteli and P. Mancarella, "The Grid: Stronger, Bigger, Smarter? Presenting a Conceptual Framework of Power System Resilience", *IEEE Power and Energy Magazine*, vol. 13, no. 3, pp. 58-66, 2015

MANCHESTER 1824

The University of Manchester

THE UNIVERSITY OF MELBOURNE

IEEE Power and Energy Society

Distinguished Lecture

Operational and planning flexibility in low-carbon multi-energy systems

Prof Pierluigi Mancarella

Chair of Electrical Power Systems, The University of Melbourne

Professor of Smart Energy Systems, The University of Manchester

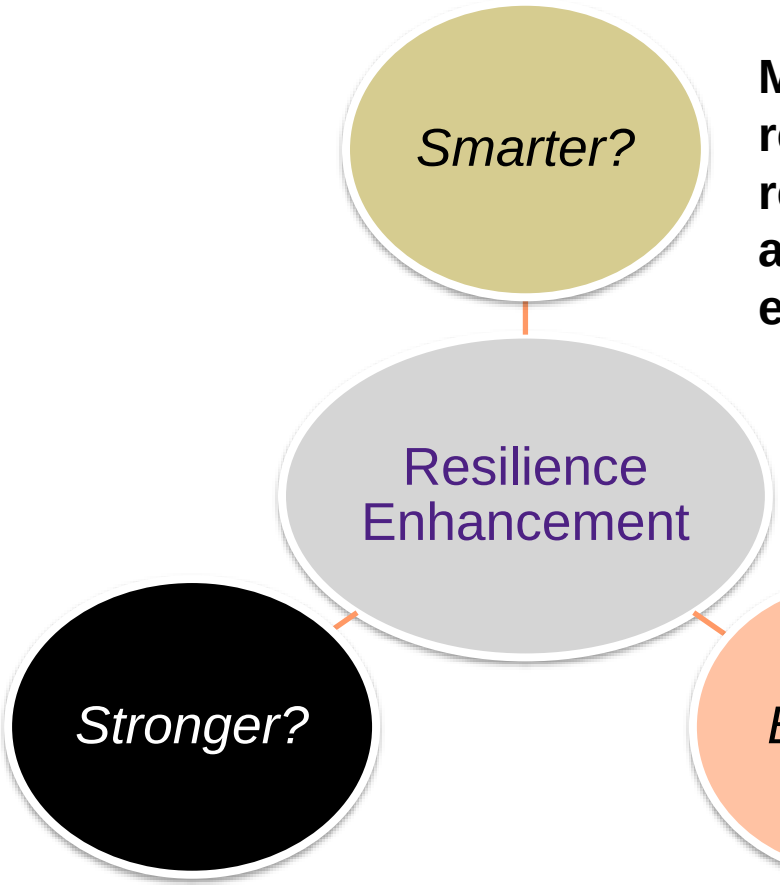
veski Innovation Fellow

pierluigi.mancarella@unimelb.edu.au

Delft, The Netherlands

16/12/2019

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*, Invited Paper*.