National Centre for Energy Systems Integration

CESI

EPSRC
Engineering and Physical Sciences Research Council

Newcastle University

Durham University

Heriot Watt University

University of Sussex

The University of Edinburgh

National Centre for Energy Systems Integration

Operation and Design of Energy Systems Infrastructure

Gas and Electricity Infrastructure Interaction

Professor Phil Taylor

Director of the National Centre for Energy Systems Integration

Siemens Professor of Energy Systems

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Overview

- CESI
- Coupled Gas and Electricity Modelling and Simulation
- Full Scale Demonstrators
- Supergen Energy Networks

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- Spatial and Temporal Detail, Full scale multi vector Demonstrators

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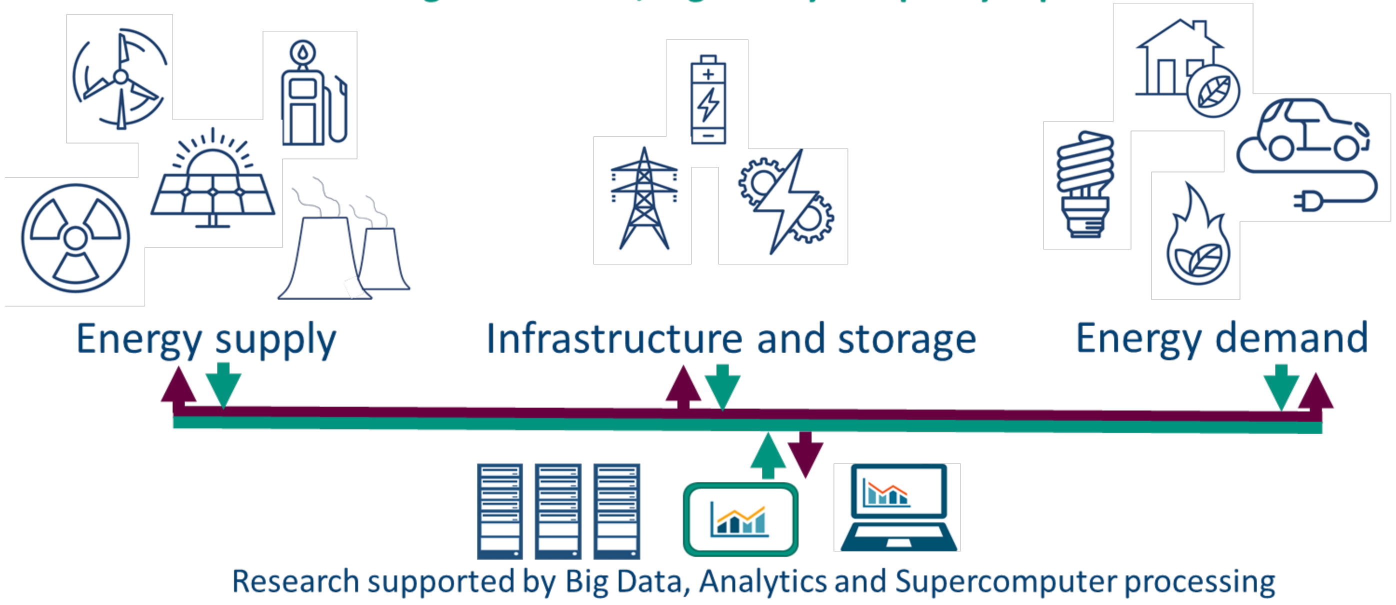
Whole Energy Systems Approach

including commercial, regulatory and policy aspects



- **International Scientific Advisory Board**

Nanyang Technological University | NREL National Renewable Energy Laboratory | CenSES Centre for Sustainable Energy Studies | Skoltech Skolkovo Institute of Science and Technology | iiESI International Institute for Energy Systems Integration | DTU | enzen | EPRI Electric Power Research Institute | UKERC UK Energy Research Centre | i-STUTE | The Alan Turing Institute | Centre on Innovation and Energy Demand | ITRC mistral | CIE-MAP Centre for Industrial Energy, Materials and Products

CESI Work Package Streams

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Commercial, regulatory and policy aspects

- Energy Policy
- Sector Regulation
- Social interaction
- Commercial
- Behaviour

Energy supply

- Multi –Vector Generation
- Interconnection
- Spatio-temporal

Infrastructure and storage

- Systems modelling
- Storage
- Networks and Infrastructure

Energy Demand

- Multi-vector Consumer Demand
- Buildings
- Transport
- Highly temporal

Demonstration and Validations

- Cross-vector demonstration
- Validation within living labs
- Real-time data

Multi-Scale Architectures

- Whole systems planning tool
- Co-evolution cycles
- Integration of models
- Stochastic optimisation

Co-Evolution Methodology (Process not a model)

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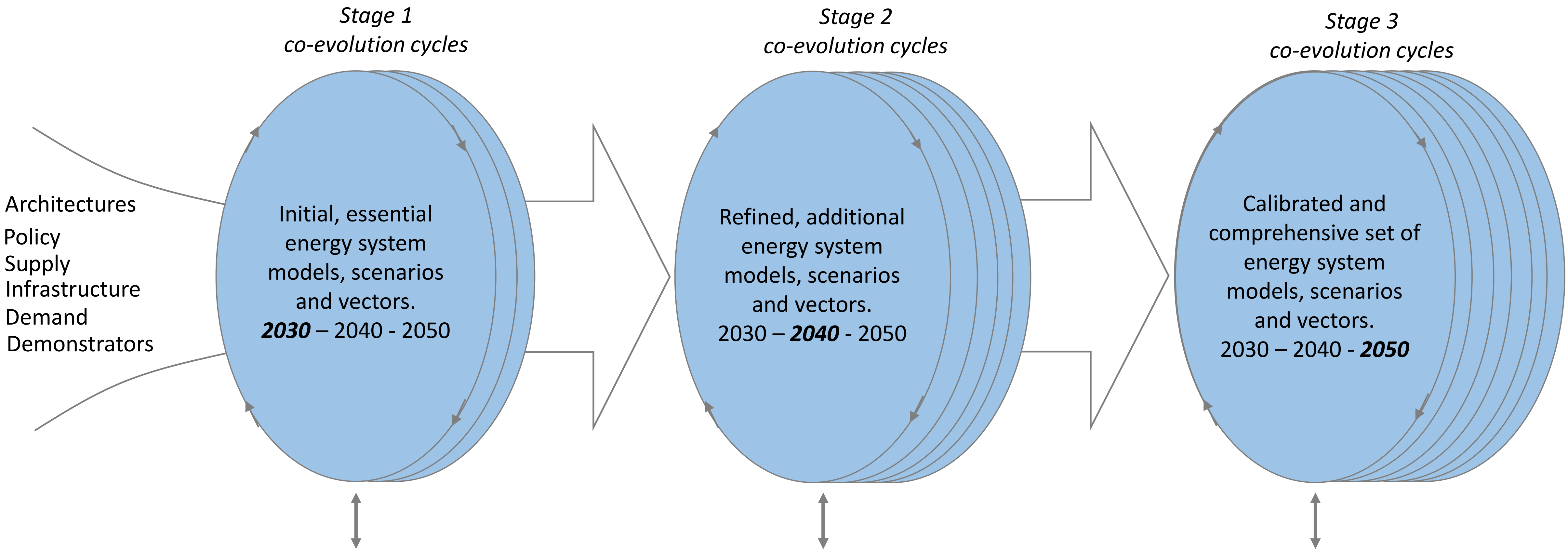


Trilemma Evaluation - Energy Systems Community and UKERC
(Assessment of planning and operation models and development of scenarios)

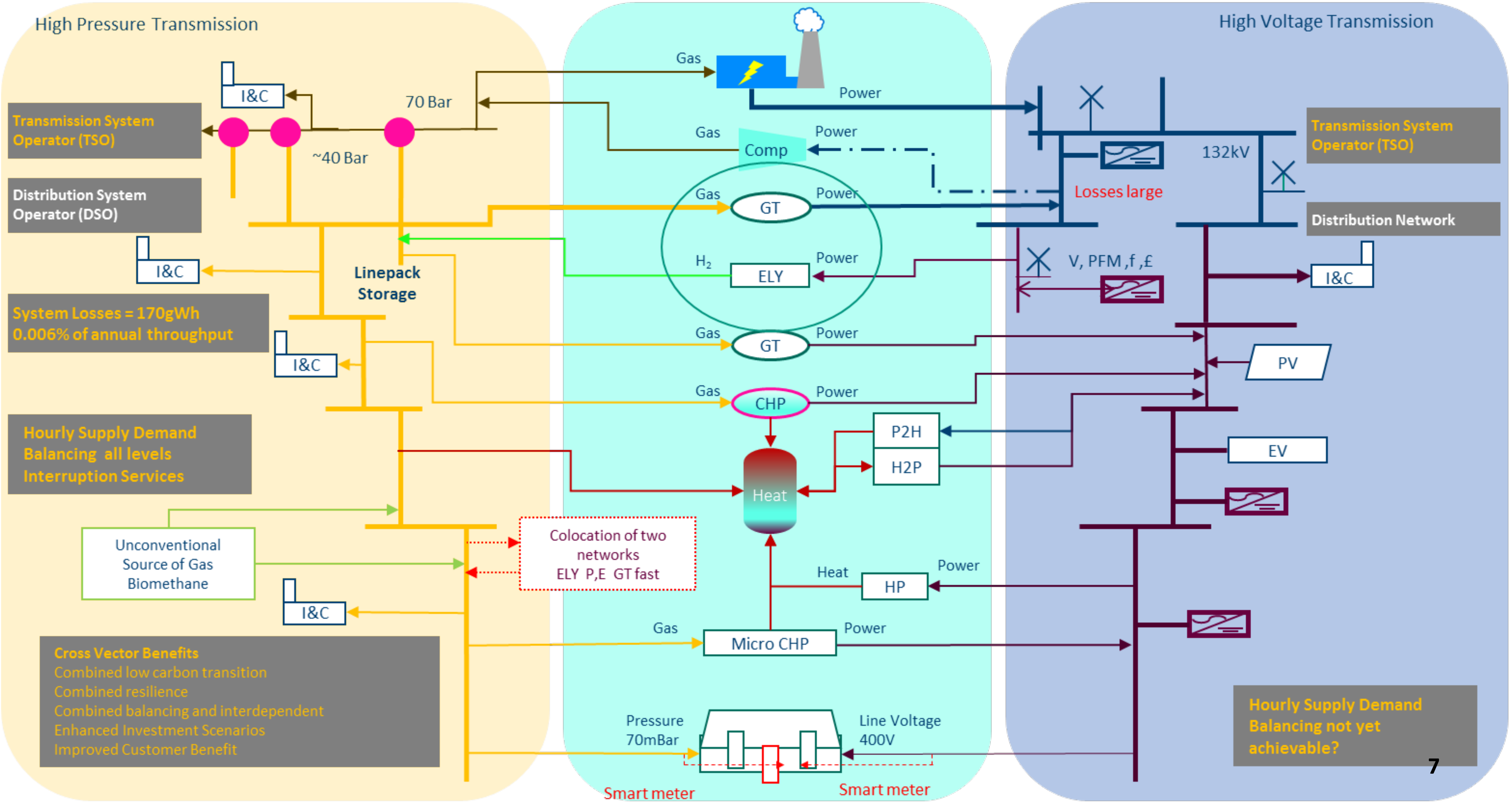
Industrial Innovation Board - **System Architect** - International Advisory Committee

Deliverables

- Robust transition pathways
- Common Framework
- Detailed models
- Advance test and demo facilities
- Workshops, engagement

Value of a whole systems approach ?

Whole Systems Cross-Vector Infrastructure



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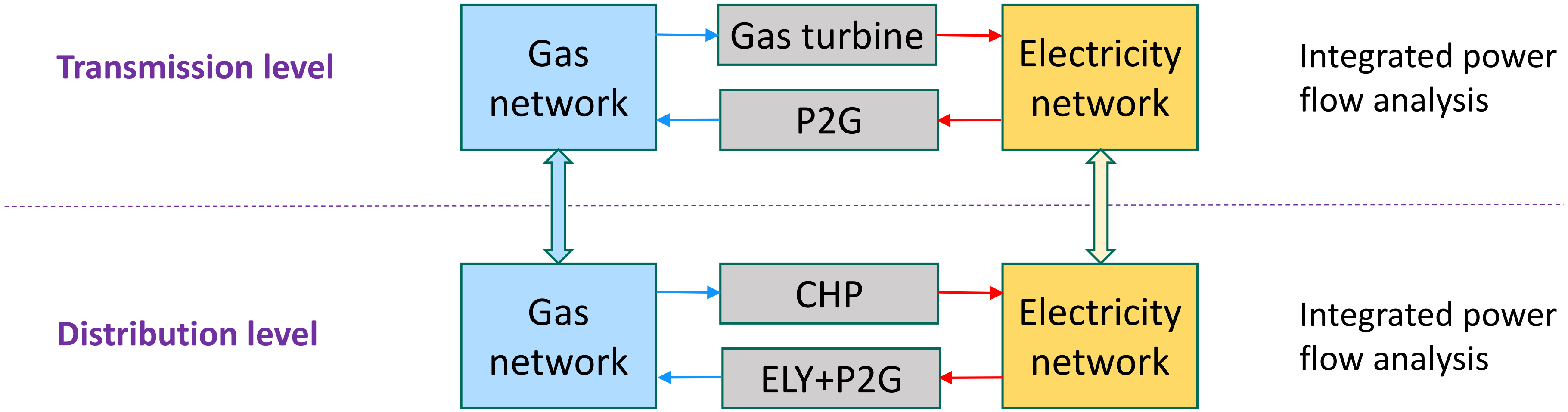
Framework developed for power flow analysis of integrated electricity and gas networks



Steady state modelling and simulation

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Unified Gas and Power Flow Solution

$$\Delta M_k = \sum_{m\in k} M_p^{km} + \sum_{m\in k} \mathrm{sgn}_c(k,m) M_C^{km} + \sum_{m\in k} \tau_C^{km} - M_{gs}^k + M_{gl}^k + M_{gl}^{k,i} = 0 \quad \forall k = 1,\cdots,(N_{ng}-1)$$

$$\Delta HP_C^{km} = BHP^{km} - 0.0854 Z_a \left[\frac{M_C^{km} T_k}{E_C \eta_C}\right]\left[\frac{c_k}{c_k - 1}\right]\left[\left(\frac{\Pi_m}{\Pi_k}\right)^{\frac{c_k - 1}{c_k}} - 1\right] \quad \forall C \in N_C, \quad k \in N_{ng}, \quad m \in N_{ng}, \quad k \neq m$$

$$\Delta R_C^{km} = \frac{\Pi_m}{\Pi_k} - R^{km} = 0 \quad \forall C \in N_C, \quad k \in N_{ng}, \; m \in N_{ng}, \quad k \neq m.$$

$$\Delta P_k = P_{Gk} - P_{Lk} - \sum_{i=1}^{n} P_k^{i\,\mathrm{cal}} = 0,$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - \sum_{i=1}^{n} Q_k^{i\,\mathrm{cal}} = 0.$$

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Steady state modelling and simulation

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The proposed unified solution approach consists of applying Newton's method to provide an approximate solution to the total set of equality constraints:

$$F(X) = [\Delta M, \Delta HP, \Delta R, \Delta P, \Delta Q,]^t = 0$$

by solving for:

$$\Delta X = [\Delta x_{ng}, \Delta x_e]^t$$

$$J^\ell \Delta X^\ell = -F(X^\ell)$$

$$X^\ell = [x_{ng}^\ell, x_e^\ell]^t$$

$$J = \left[\begin{array}{ccc|ccc} \frac{\partial \Delta M}{\partial \Pi} & \frac{\partial \Delta M}{\partial BHP} & \frac{\partial \Delta M}{\partial M_C} & 0 & 0 & \frac{\partial \Delta M}{\partial \Delta P_{\text{gen}}} \\ \frac{\partial \Delta T_g}{\partial \Pi} & 0 & \frac{\partial \Delta T_g}{\partial M_C} & 0 & 0 & 0 \\ \frac{\partial \Delta HP}{\partial \Pi} & \frac{\partial \Delta HP}{\partial BHP} & \frac{\partial \Delta HP}{\partial M_C} & 0 & 0 & 0 \\ \frac{\partial \Delta R}{\partial \Pi} & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & \frac{\partial \Delta P}{\partial BHP} & 0 & \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial V} & \frac{\partial \Delta P}{\partial \Delta P_{\text{gen}}} \\ 0 & 0 & 0 & \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial V} & 0 \end{array}\right]$$

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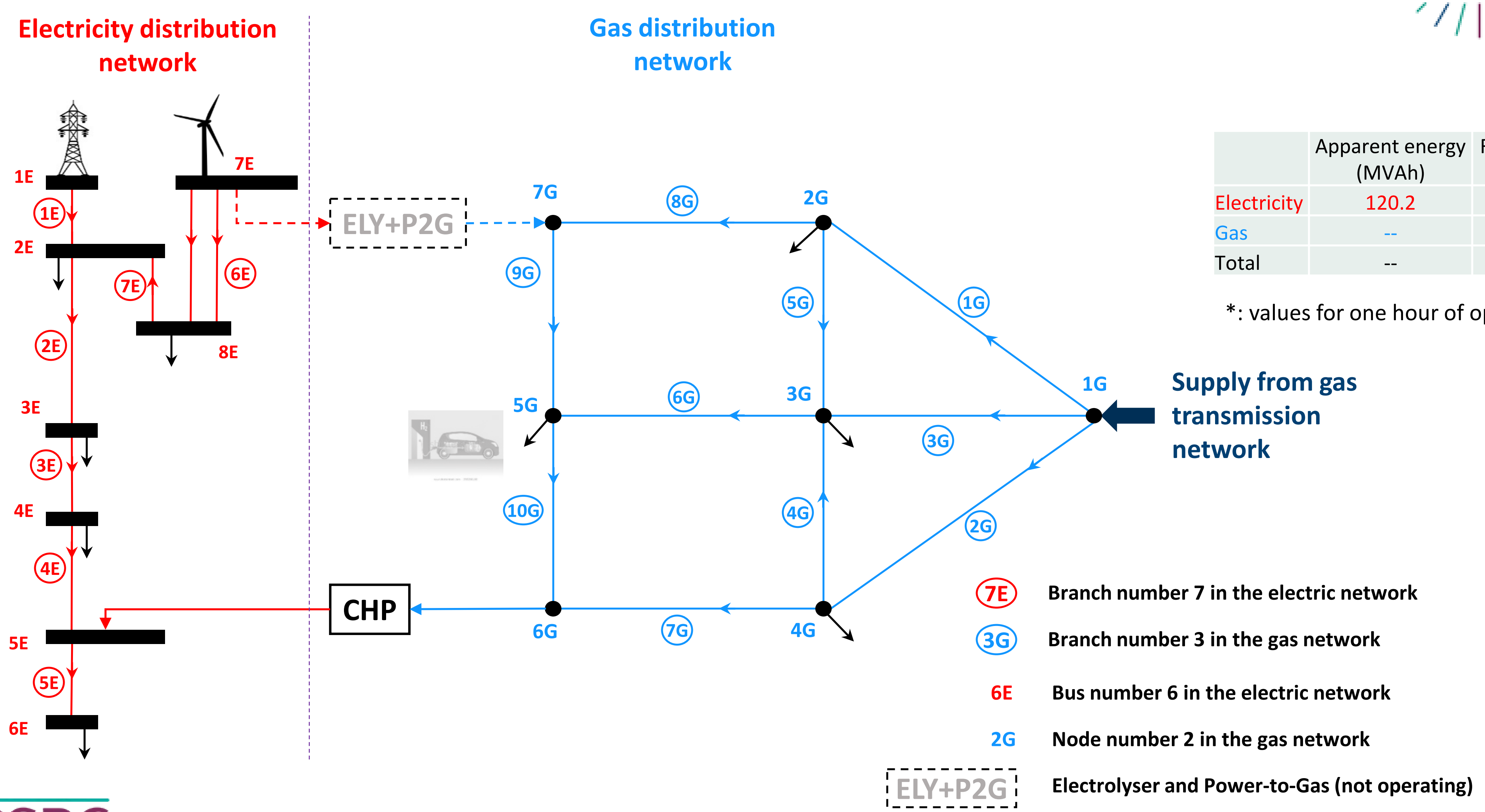
Distribution networks: Base case



	Apparent energy (MVAh)	Real energy (MWh)	tonCO2*
Electricity	120.2	86.2	46.7
Gas	--	191	17.2
Total	--	277.2	63.9

*: values for one hour of operation of the network

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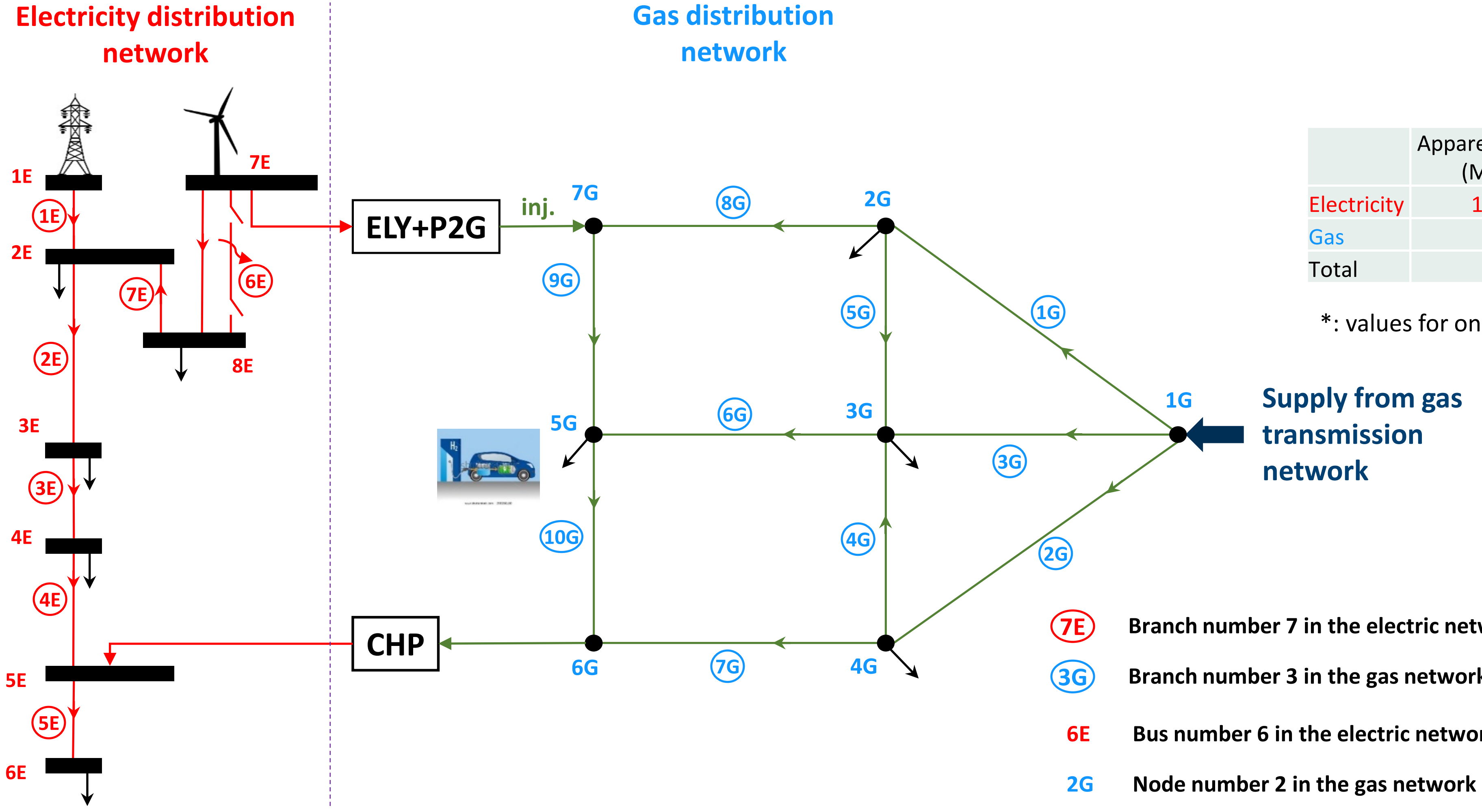
Distribution networks:
Scenario1: Fault in the electricity network



	Apparent energy (MVAh)	Real energy (MWh)	tonCO2*
Electricity	129.2	97.8	52.4
Gas	--	182.3	16.4
Total	--	280.1	68.8

*: values for one hour of operation of the network

7E	Branch number 7 in the electric network
3G	Branch number 3 in the gas network
6E	Bus number 6 in the electric network
2G	Node number 2 in the gas network
ELY+P2G	Electrolyser and Power-to-Gas (operating)
inj.	Molar fraction: 70% natural gas + 30% Hydrogen

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Distribution networks: Scenario2: 10% reduction in supply from gas transmission

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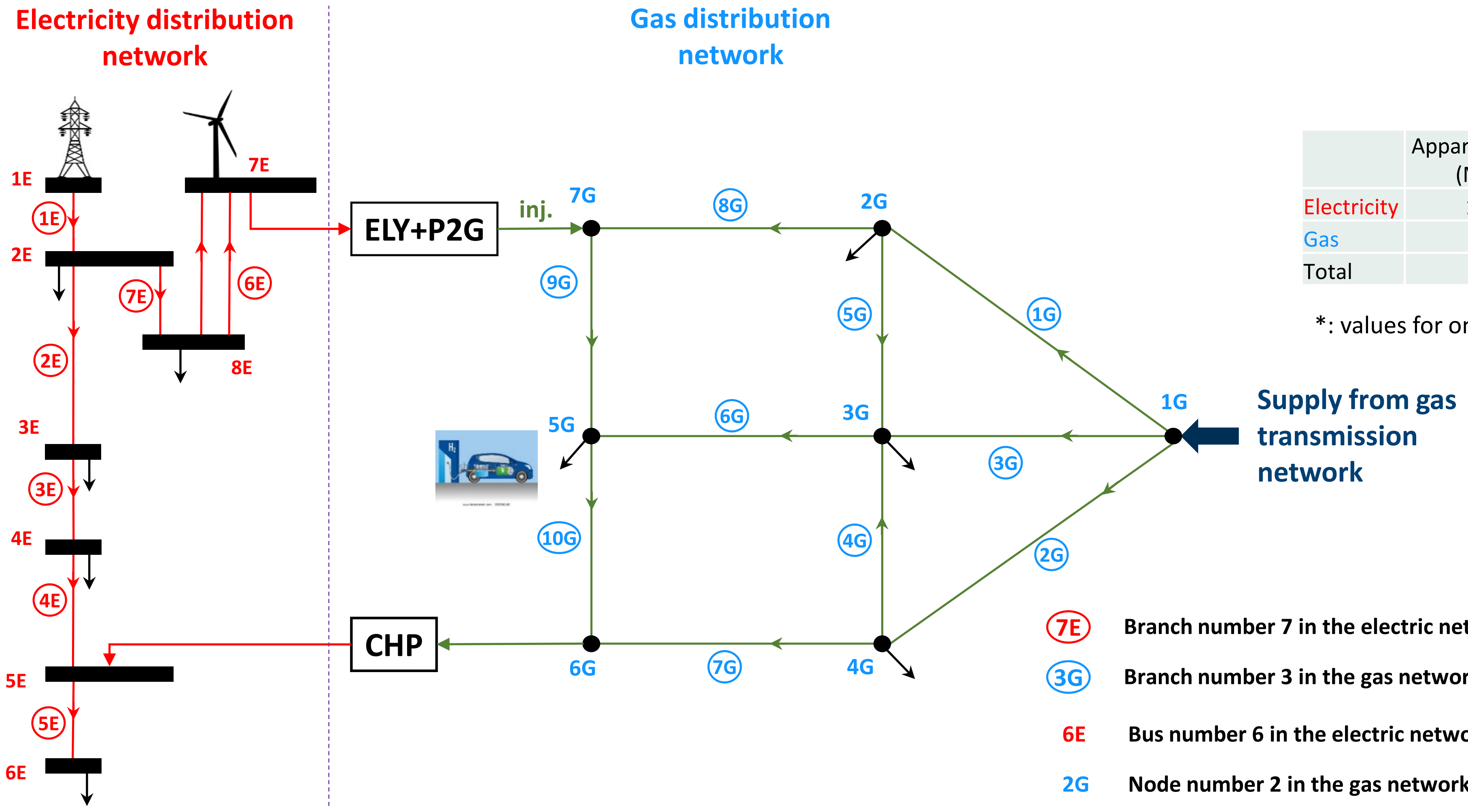

	Apparent energy (MVAh)	Real energy (MWh)	tonCO2*
Electricity	140.5	111.6	59.2
Gas	--	172	15.4
Total	--	283.6	74.6

*: values for one hour of operation of the network

- 7E — Branch number 7 in the electric network
- 3G — Branch number 3 in the gas network
- 6E — Bus number 6 in the electric network
- 2G — Node number 2 in the gas network
- ELY+P2G — Electrolyser and Power-to-Gas (operating)
- inj. — Molar fraction: 70% natural gas + 30% Hydrogen

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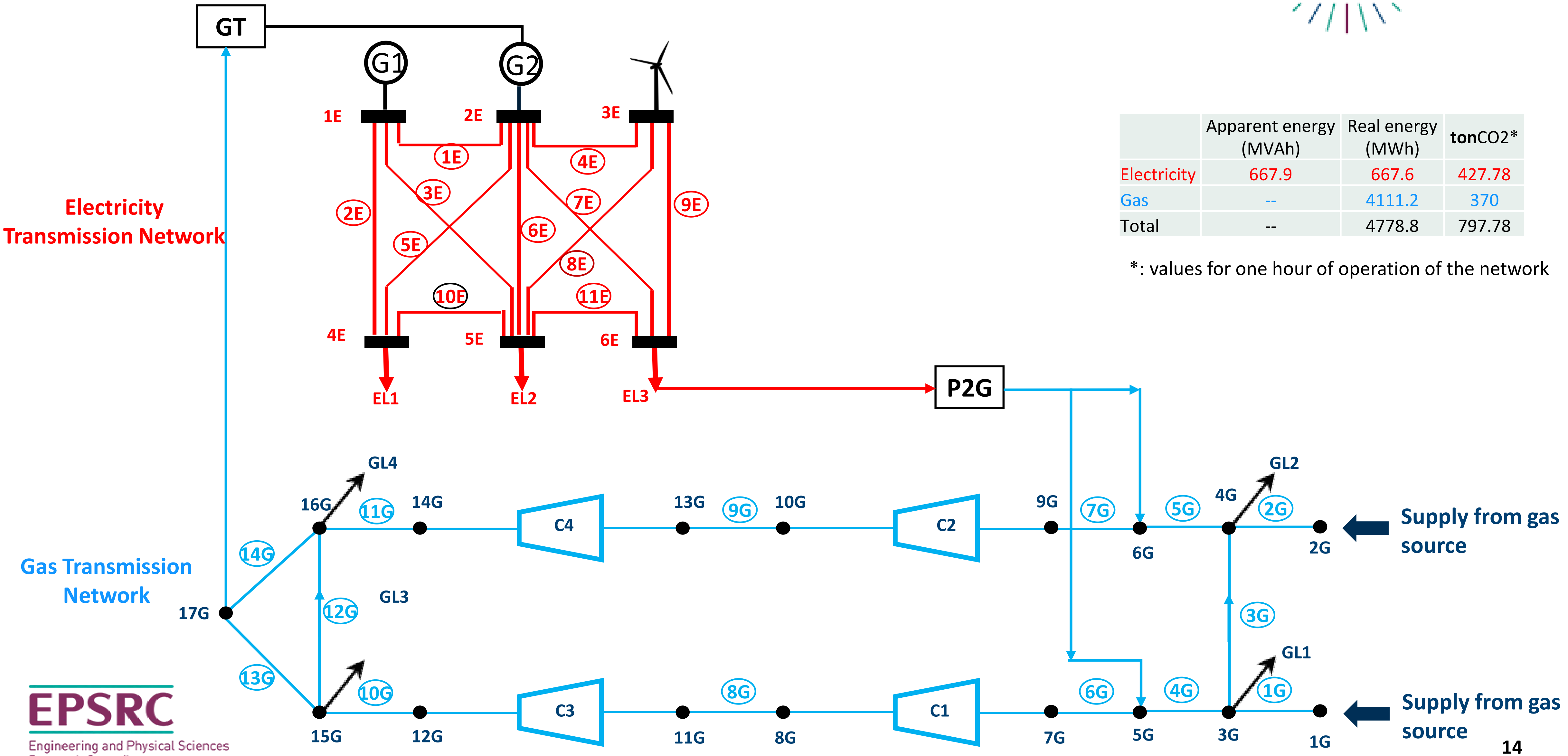
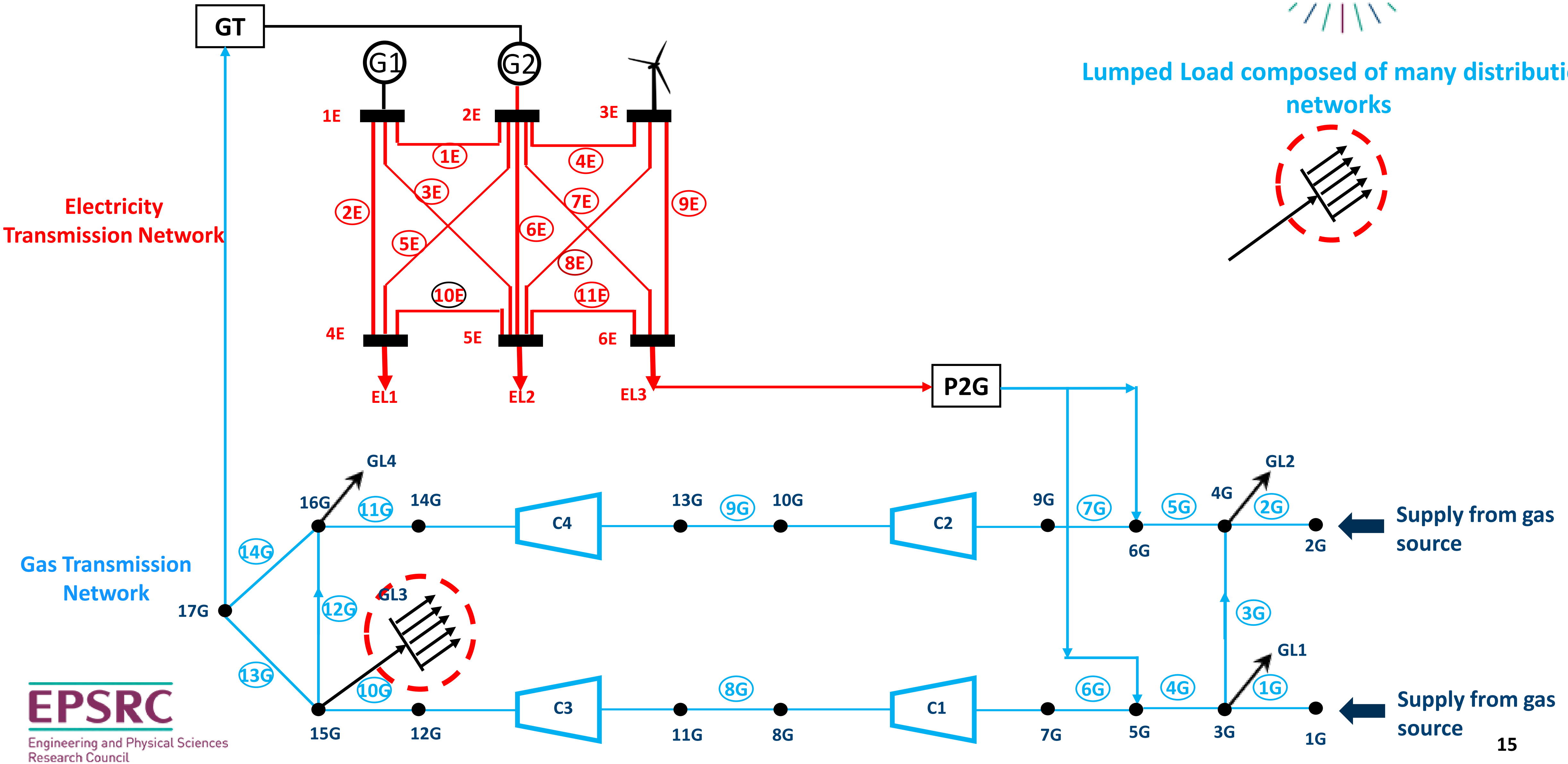
Transmission networks – Base Case



	Apparent energy (MVAh)	Real energy (MWh)	**ton**CO2*
Electricity	667.9	667.6	427.78
Gas	--	4111.2	370
Total	--	4778.8	797.78

*: values for one hour of operation of the network

Scenario1: Impact of 13% increase of distribution networks loads at Transmission level



Scenario1: Impact of 13% increase of distribution networks loads at Transmission level

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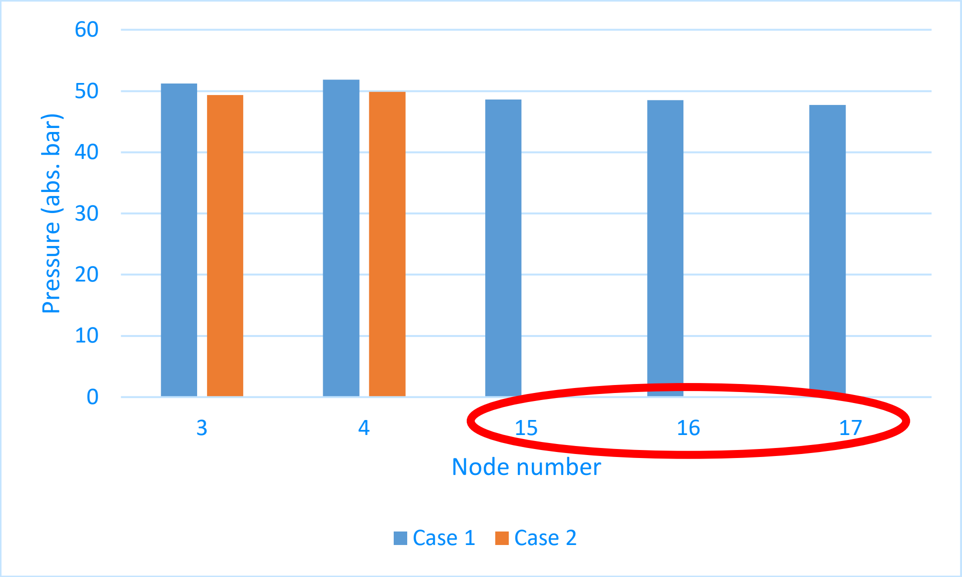

	Apparent energy (MVAh)	Real energy (MWh)	**ton**CO2*
Electricity	667.9	667.6	427.78
Gas	--	4344	391
Total	--	5011.6	818.78

*: values for one hour of operation of the network

Case1: Base case,
Case2: Increase the gas demand by 13%

The pressures at the farthest nodes from the sources are nearly zero (estimated in mbar).

Can the electricity transmission network help to solve this problem?

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Scenario 2: Mitigating the effect of gas load increase using P2G in the integrated system

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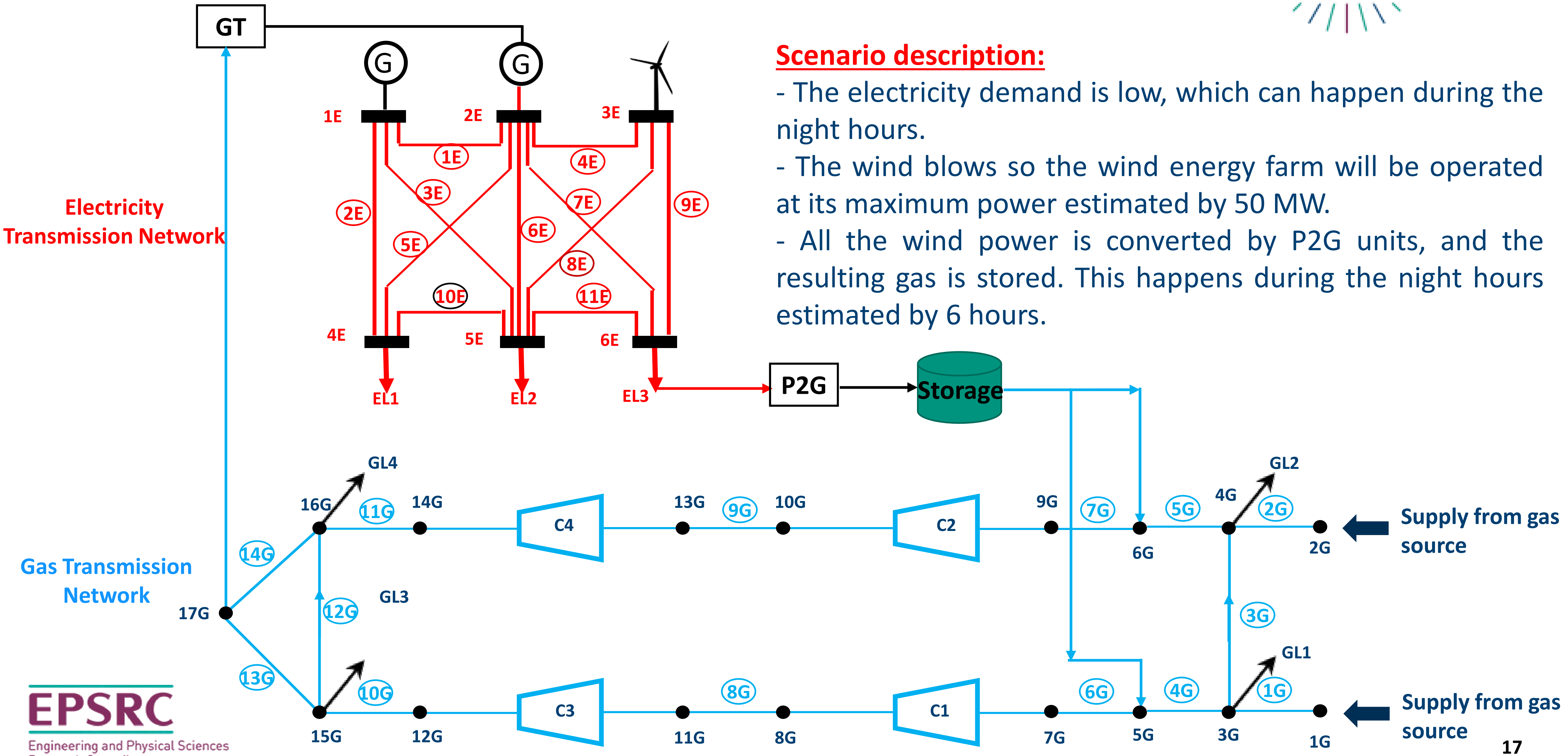

Scenario description:

- The electricity demand is low, which can happen during the night hours.
- The wind blows so the wind energy farm will be operated at its maximum power estimated by 50 MW.
- All the wind power is converted by P2G units, and the resulting gas is stored. This happens during the night hours estimated by 6 hours.

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Scenario 2: Mitigating the effect of gas load increase using P2G in the integrated system

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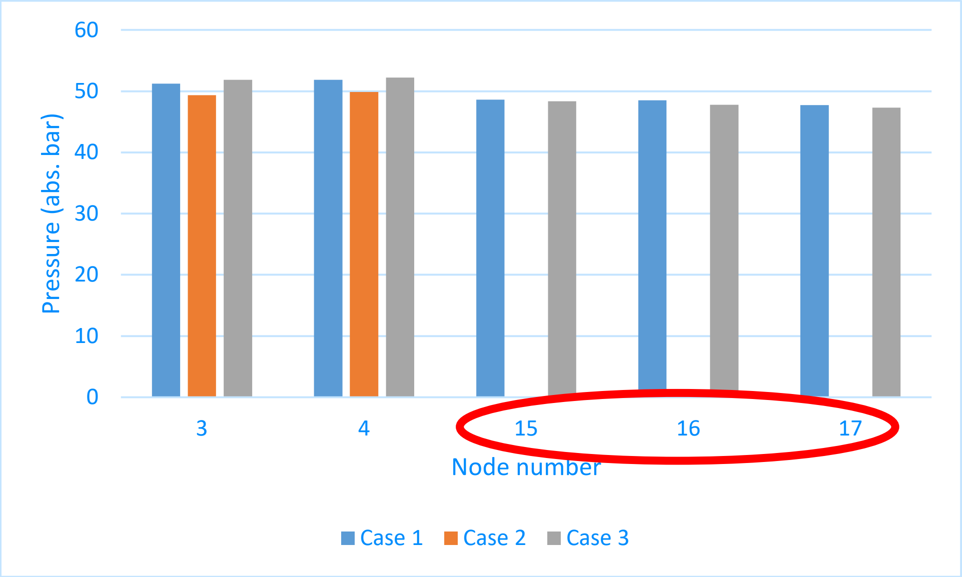
Scenario description (con.):

- The stored gas will be used to overcome the problem of pressure decrease which happened when the gas demand increased by 13%.

Stored gas = 23502 m3 = 243.2457 MW



Case1: Base case,
Case2: Increase the gas demand by 13%,
Case 3: Using the stored gas during 1 hour.

Results of Case 2

	Apparent energy (MVAh)	Real energy (MWh)	tonCO2*
Electricity	667.9	667.6	427.78
Gas	--	4344	391
Total	--	5011.6	818.78

Results of Case 3

	Apparent energy (MVAh)	Real energy (MWh)	tonCO2*
Electricity	667.9	667.6	427.78
Gas	--	4102	369.18
Total	--	4769.6	796.96

*: values for one hour of operation of the network

Industrial Partners

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- Lead Industrial Partner
  - SIEMENS — Ingenuity for life
- Government Support
  - Department for Business, Energy & Industrial Strategy
  - The Scottish Government
  - Catapult Energy Systems
  - Department for Transport
  - ofgem
  - Innovate UK
- Leading Energy Industry Partners

Supply	Infrastructure and Storage		Demand
DONG energy	nationalgrid	Scottish & Southern Electricity Networks	gentoo — It's how you live
centrica	Northern Powergrid	triphase	Research Councils UK Energy — For a Low Carbon Future
ScottishPower	Northern Gas Networks	redT energy storage	Newcastle City Council
			Durham County Council

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Unique collection of Whole Systems Demonstrators:

Demonstrator	Key Features
Science Central	Urban, Mixed Use, New Build, Multi Vector, Data Rich
ETI/ESCat Smart Systems and Heat	Urban, Domestic, Retrofit, Heat and Power
Findhorn	Eco Village, Socio Technical
Haringey	Socio Technical Urban Living Laboratory
Thames Valley Vision	Industrial and Commercial Demand Response
Cockle Park Farm	Rural, Farming, Anaerobic Digester, Heat and Power
Customer Led Network Revolution	Storage, Smart Grids, Suburban, Rural, Medium and Low Voltage

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InTEGReL – Integrated Transport Electricity and Gas Research Laboratory

A Unique Collaboration between:

- EPSRC National Centre for Energy Systems Integration (CESI)
- Northern Gas Networks
- Northern Powergrid

A UK research and demonstration facility to:

- Explore how energy systems can be integrated in real physical environment
- Develop cross-vector and multi-vector approaches
- Develop and deploy SMART energy system technologies
- Cross pollination of ideas between utilities

Benefits

- Help minimise costs in the Energy System
- Provide an open facility for 3rd parties, particularly SMEs
- Contribute to UK innovation and growth
- Develop solutions and tools we need to address the energy trilemma
- Support the development of ideas and their commercialisation in the UK

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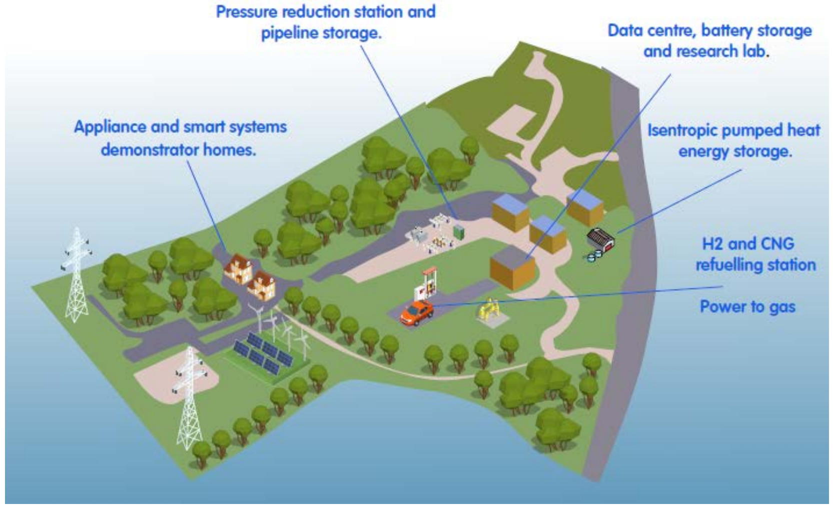
InTEGReL

Integrated | Transport | Electricity | Gas | Research | Laboratory



InTEGReL – Integrated Transport Electricity and Gas Research Laboratory

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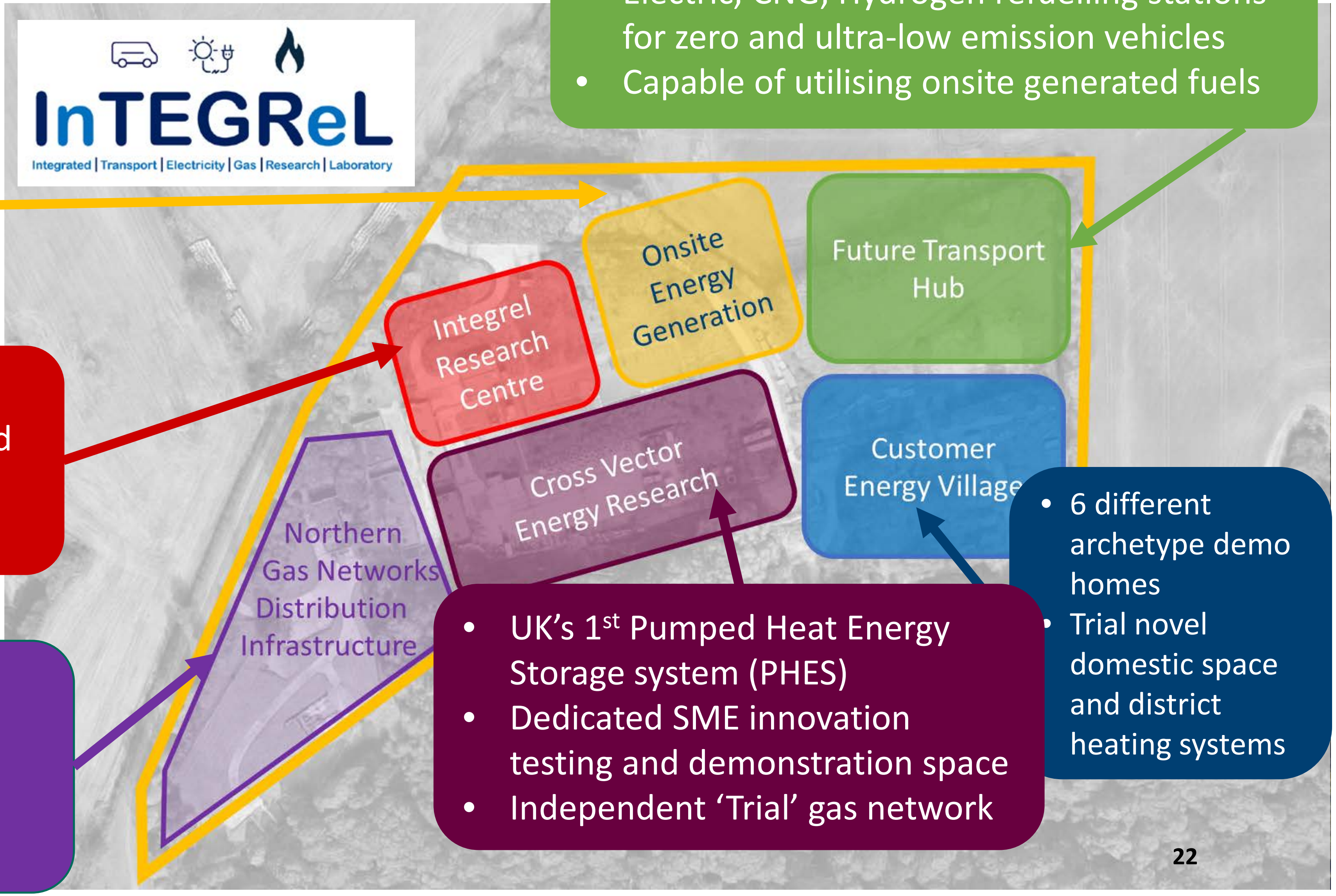
- Gas Fired CHP
- 4MW Wind Turbine
- PV Array
- PEM Electrolyser
- AD with Bio methane Injection
- Hydrogen Storage and Grid Injection

- Electric, CNG, Hydrogen refuelling stations for zero and ultra-low emission vehicles
- Capable of utilising onsite generated fuels



- Sector Training and Skills Hub
- Stand-by gas distribution control and data centre
- Visitor Centre and Research Office

- 6 different archetype demo homes
- Trial novel domestic space and district heating systems

- Cross Vector Telemetry
- 11kV Transformer and Substation
- Electrical Energy Storage
- Pressure Reduction (38Bar to 19Bar)

- UK's 1st Pumped Heat Energy Storage system (PHES)
- Dedicated SME innovation testing and demonstration space
- Independent 'Trial' gas network

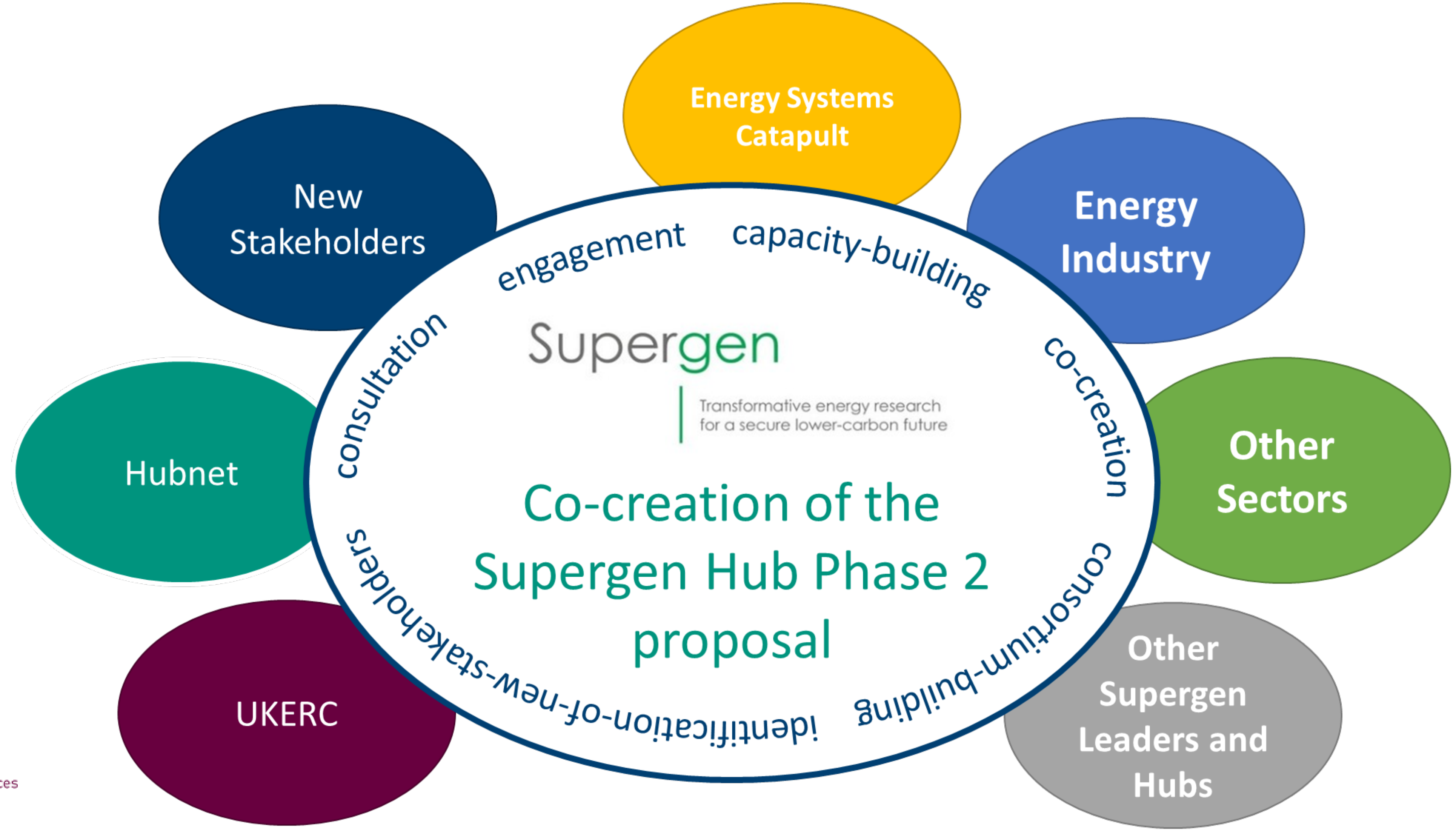
Conclusions

- Developed the modelling and simulation tools to investigate the interactions between Gas and Electricity infrastructure
- Aim is to understand the value of a whole systems approach
  - Cost
  - Carbon
  - Resilience
- Working with Gas and Electricity Network Operators to gather data and create realistic scenarios
- Launched a full scale Gas and Electric Demonstrator to provide data and validate the models/simulations
- Policy
  - Aligned Gas and Electricity Regulation
- Supergen Energy Networks Hub

EPSRC Supergen Energy Networks

Supergen Energy Networks hub

- Addressing Energy Network research challenges with a Whole Systems View



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