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XXXIII Cycle

Graph-based Modelling and Simulation of Energy Networks

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Research context and motivation

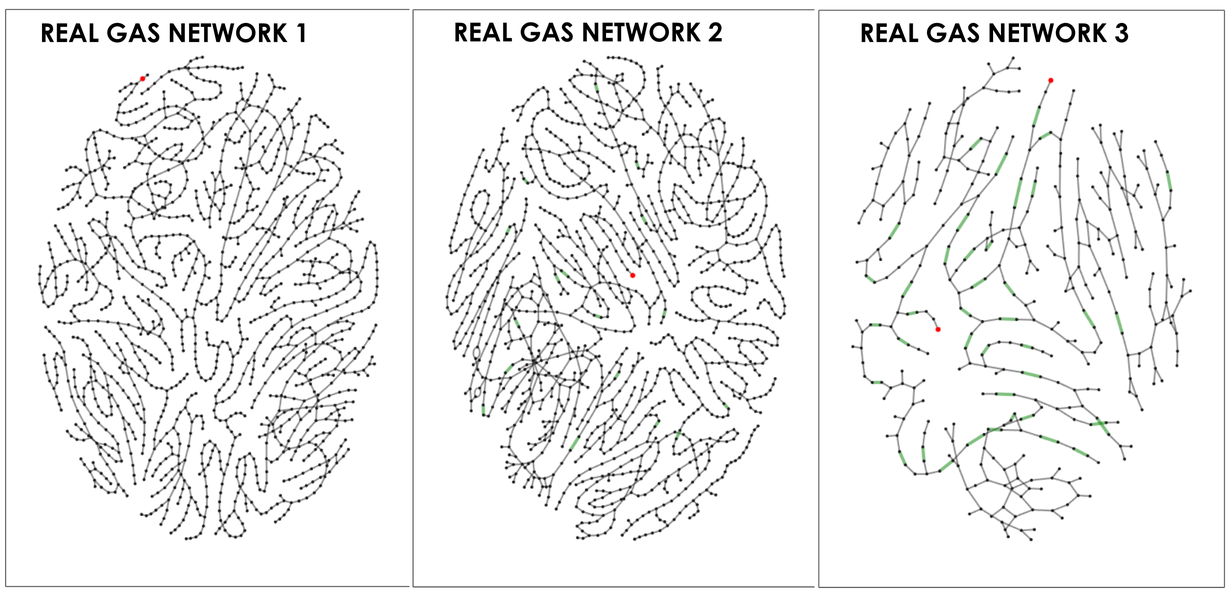
- Nowadays, **energy infrastructures** face several technical challenges to maintain certain levels of reliability.
- Specific technologies, such as **power-to-gas (and heat pumps)**, could provide a **strategic link between the power grid and the gas**, allowing for less frequent curtailments of renewables and decarbonizing other sectors, like heating.
- Investigations on both the **mutual impact of energy networks** and the opportunities deriving from an **enhancement of their integration** are of topical interest.
- The study of coupled energy network infrastructures, however, **lacks of available information due to privacy, security and industrial secrecy reasons**.
- Tools for the generation of **synthetic models of fictitious energy networks with realistic topological and technical properties** will be extremely beneficial.

Workplan and novel contributions

- YEAR #1. Development of a **steady-state, isothermal and single-gas-quality model** for transmission and distribution **gas networks** (done); model validation (done);
- YEAR #2. Extrapolation of **topological characteristics of real gas networks** (done); development of a gas network model generator **mimicking and anonymizing real network infrastructures** (done); development of a tool able to build greenfield models of gas network for whatever distribution case study where the information about the real infrastructure is completely lacking (in progress)
- Augmentation of the fluid-dynamic model (see year #1) for handling **multiple gas qualities** (distributed injection of renewable gases) and **dynamic** simulations;
- Development and/or implementation of graph-based models for the simulation of **electricity systems**;
- **Co-simulation of the gas and electricity network**;

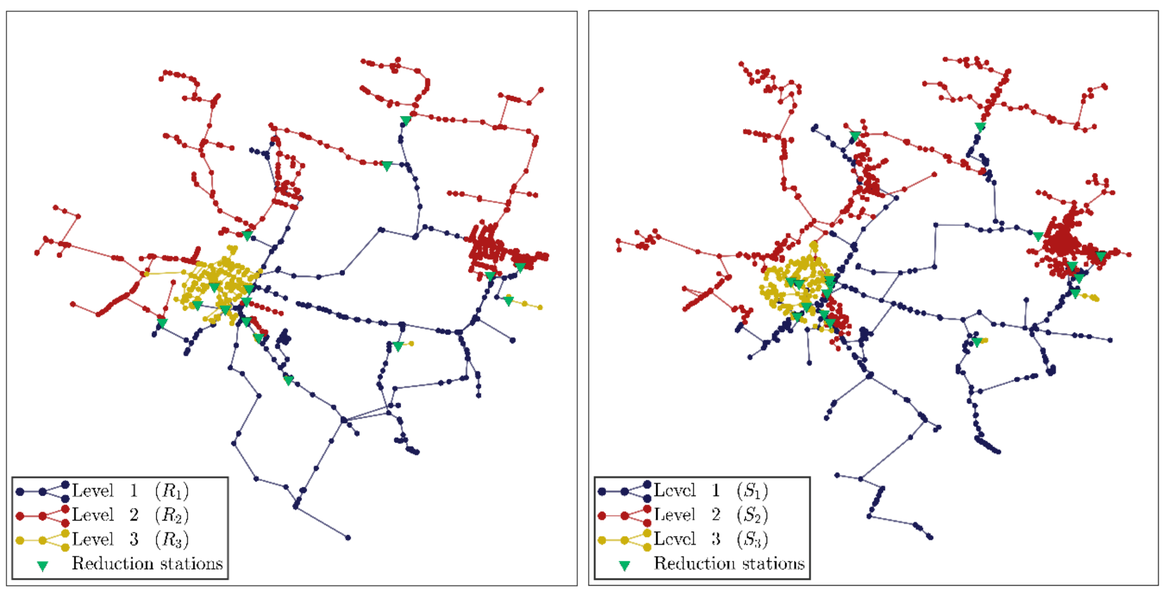
Addressed research questions/problems

- **Random generation of synthetic gas networks** to overcome the public unavailability of real case studies.
- **Graph-based approach with spatial embedding**, to simulate the spatial development of the networks over time.
- **Mimicking of real network infrastructures**: generation of random, "anonymized" models of real distribution grids with similar spatial and structural properties.
- Based on observations of real case studies: individuation of **properties of real gas networks** on a topological and spatial level (e.g. number of nodal connections, length of the pipelines, …)

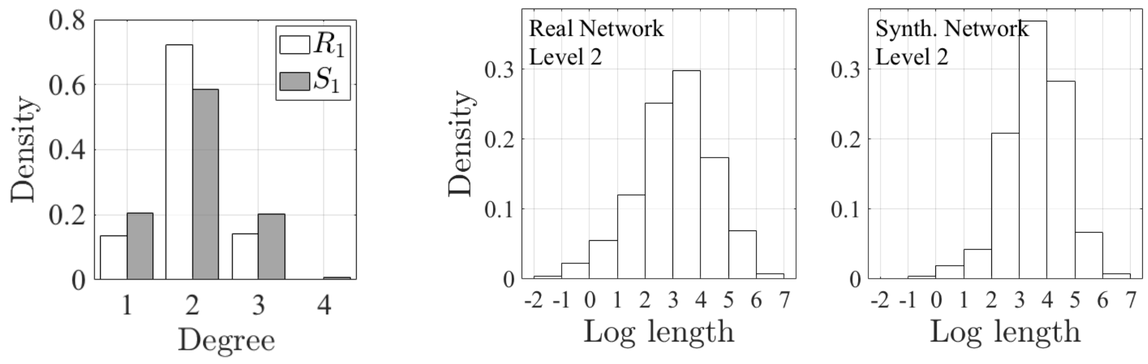


Adopted methodologies and results

- **Graph-based representation of a gas network**
- **Separate analysis by network (pressure) levels**
- **Gaussian Mixture Models (GMM)** to describe the geographical position of real network nodes and generate synthetic nodes with similar spatial distribution
- **Parameter-based probabilistic methods** to determine whether connecting or not couples of synthetic nodes
- **Result: synthetic gas network** with similar spatial distribution as the real network and realistic topological properties
- **Validation of the synthetic network** via comparison of degree distribution, length distribution of pipelines, global clustering coefficient and average path length.



REAL GAS NETWORK — SYNTHETIC GAS NETWORK



Degree distributions - Real vs Synth. — Pipeline length distributions - Real vs Synth.

Future work (short/medium term)

- Augmentation of the tools for the generation of synthetic network models with additional spatial constraints (e.g. buildings, roads, …) (SHORT TERM)
- Make the model independent from the information about the real network infrastructure (SHORT-MEDIUM TERM)
- Add technical specifics to the generated networks, such as nominal flow rates of components, diameters of pipelines, … (MEDIUM TERM)

Submitted and published works

- E. Vaccariello P. Leone, F. G. Canavero, I. S. Stievano, "Topological modelling and simulation of gas networks for multi-energy applications", *ELECTRIMACS 2019*, Salerno, Italy, May 21-23, 2019.
- E. Vaccariello, P. Leone, I. S. Stievano, "Generation of synthetic models of gas distribution networks with spatial and multi-level features", *International Journal of Electrical Power and Energy Systems* (*Elsevier*). **Submitted, under review**.

List of attended classes

01SWSRV – Design and Optimization of Integated Energy Systems (Jun '18, 15 hours), 01QTLIV – Computational Models for Thermo-fluid Networks (Mar '18, 20 hours), 02ITTRV – Photovoltaic Generators and Systems (Apr '18, 25 hours), 01QSFIV – Global Energy Trends and Outlook (Sep '18, 10 hours), 01SHCRV – Unsupervised Neural Networks (Apr '18, 30 hours), Data mining concepts and algorithms (Dec '18, 20 hours), Machine Learning for Pattern Recocnition (Jun '19, 20 hours), 01RISRV Public Speaking, 01SWPRV Time Management, 01TGRRV Uso degli strumenti e delle strategie per un efficace uso del tempo, 01QORRV Writing Scientific Papers in English. Total Soft Skills : 26 hours

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