ESMAP
Energy Sector Management Assistance Program

MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA

WORLD BANK GROUP

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RSE Ricerca Sistema Energetico — we move research

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Advantages of adopting a holistic view in the planning of the future energy systems

Gianluigi Migliavacca, Project Manager

Milan, Italy

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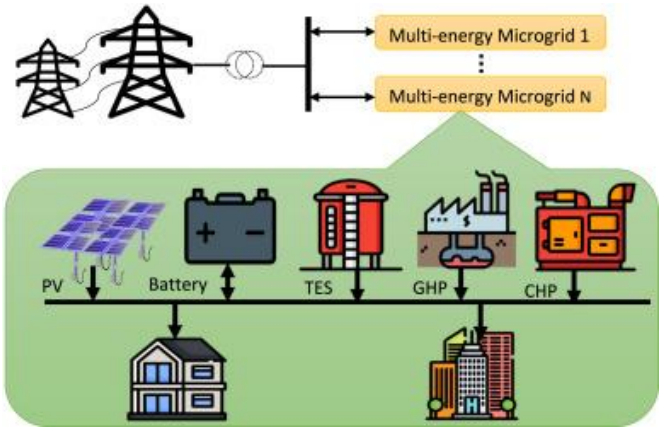
Agenda

- What is the multi-energy approach
- First study case: hydrogen and grid planning
- Second study case: Direct Reduction steel production (hard-to-abate sector)
- Characteristics of the new MEPS simulator of RSE

What is the multi-energy approach



- The future energy landscape will possibly see a **strong prevalence of the electric vector over gas**. However, decarbonization needs will force **more and more the deployment of RES** and decommissioning of dispatchable generation based on fossil fuels. This will entail an **increased necessity of ancillary services** to cope with RES variability. As the electric system has but a limited capability of storage, **other vectors will become indispensable** to provide flexibility to the electric system (gas linepack, hydrogen daily and seasonal storage, thermal inertia of district heating, swimming pools and other, …).

- These **carriers will become more and more interdependent**, mutually and with the electric energy vector (e.g. hydrogen storage could be an interesting option, but electrolysers consume a significant amount of electricity making it necessary to refurbish the nearby electric system; better to make hydrogen close to RES generation and transport it with a dedicated network or to make it where it is needed and expand locally the electrical grid?).

- In an optic of overall TOTEX minimization, it becomes key to **clarify what is the overall system minimum cost trajectory** by considering at the same time the development of all carriers in a holistic prospect.

What is the multi-energy approach

The multi-energy approach is an extension of the traditional scenario simulations and planning studies for the electric system by including other carriers (natural gas, hydrogen, district-heating) with which the electricity system is (and will be more and more in the future) interconnected.

This approach allows to put the development of the different carriers in competition in a global approach of total cost optimization for the system.

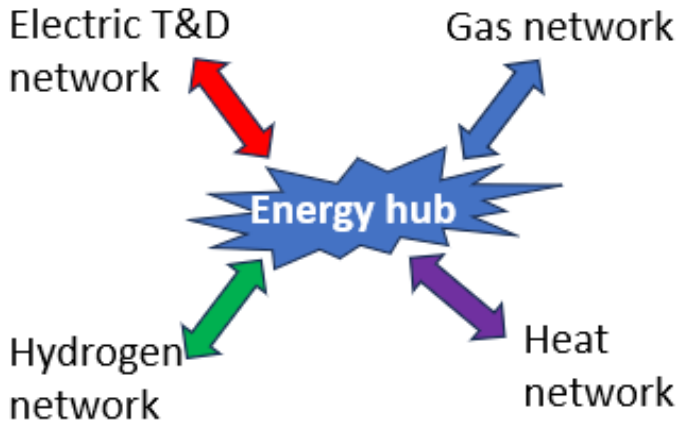
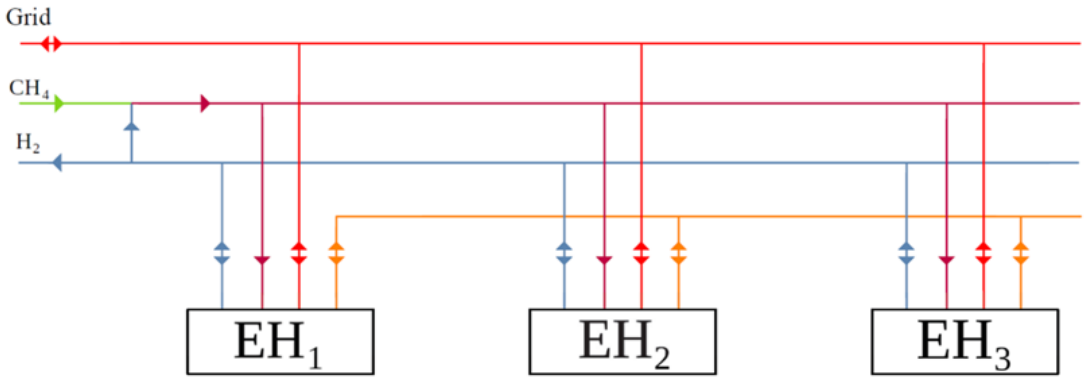


Table 1. Typical interactions between energy carriers

Unit	Gas	Electricity	Heat
Turbo compressor	control	consumed	
Heat pump		consumed	produced
Gas boiler	consumed		produced
Electric boiler		consumed	produced
Circulation pump		consumed	control
Gas turbine	consumed	produced	produced
Gas-fired generator	consumed	produced	
Power-to-gas	produced	consumed	



Markensteijn, A.S. Mathematical Models for Simulation and Optimization of Multi-Carrier Energy Systems. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2021. Available online: https://research.tudelft.nl/en/publications/mathematical-models-for-simulation-and-optimization-of-multi-carr (accessed on 6 February 2025).

The multi energy approach in the official documents

European Commission communication "*Powering a climate neutral economy: an EU Strategy for energy system integration*" (2020):
"Energy system integration – the coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors – is the pathway towards an effective, affordable and deep decarbonisation of the European economy".

ACER document "*Electricity infrastructure development to support a competitive and sustainable energy system - 2024 Monitoring Report*" - 1.3 - Recommendations to grid developers, regulators and governments on focused and timely grid development:
"Grid developers to extend the use of multi-vector scenarios to grid development planning at the national level and ensure consistency between EU TYNDP and national scenarios"

ENTSO-E ENTSOG joint scenarios released for TYNDP 2024 (https://www.entsoe.eu/news/2024/05/22/entso-e-and-entsog-release-their-joint-scenarios-for-tyndp-2024/):
"The scenarios evaluate the interactions between the gas, hydrogen and electricity systems, vital to delivering the best assessment of the infrastructure from an integrated system perspective."
(ENTSOG General Director)

ARERA: "orientamenti per l'aggiornamento delle disposizioni in materia di piano decennale di sviluppo della rete di trasporto del gas naturale» (DCO 522/2024/R/GAS):
"L'Autorità è orientata a valutare l'adozione di un approccio maggiormente strutturato e integrato all'identificazione dei system needs per il settore gas … Sarà da valutare il trade-off dei costi tra sviluppi della rete gas con nuove soluzioni di sviluppo nel settore elettrico. Specularmente, laddove vi fosse capacità inutilizzata nel sistema del gas naturale, occorre comprendere se, e in che misura, tale capacità possa essere utilizzata in ottica cross-settoriale per risolvere limitazioni nelle capacità di trasmissione di energia elettrica."

Scenari congiunti TERNA-SNAM: documento di descrizione degli scenari 2024:
"L'obiettivo dell'attività di Snam e Terna è quello di giungere a una visione coerente delle possibili evoluzioni future del sistema energetico italiano, mettendo a fattor comune le competenze specifiche dei due operatori – nella consapevolezza che l'interazione tra i due settori sia al contempo complessa e fondamentale nel processo della transizione energetica. "

First study case: hydrogen and grid planning

- Increasing renewable energy penetration calls for effective storage solutions: batteries, pumped hydro, hydrogen storage. A flexible management of the electrolysers can help smoothing peak demand and absorb RES generation surplus.
- The time required for grid upgrades - especially for transmission networks - is long and often the deployment of new grid infrastructure is delayed by public opposition.
- Deploying new electrolyzers is much faster and does not require detailed communication with the grid operators. This can cause delays in planners' ability to keep up with investments, resulting in temporary congestion in certain areas of the grid.
- As hydrogen demand grows, transport will shift from truck-based delivery to dedicated hydrogen networks, making coordinated planning of electricity and hydrogen infrastructure essential to minimize overall system costs
- Grid-connected electrolysers will pose challenges related to:
  - necessity for grid reinforcements depending on their location and capacity,
  - need for coordinated planning between electric and hydrogen grids,
  - need to analyze dynamic behaviors and the interactions with the wider electric system by means of stability simulations.

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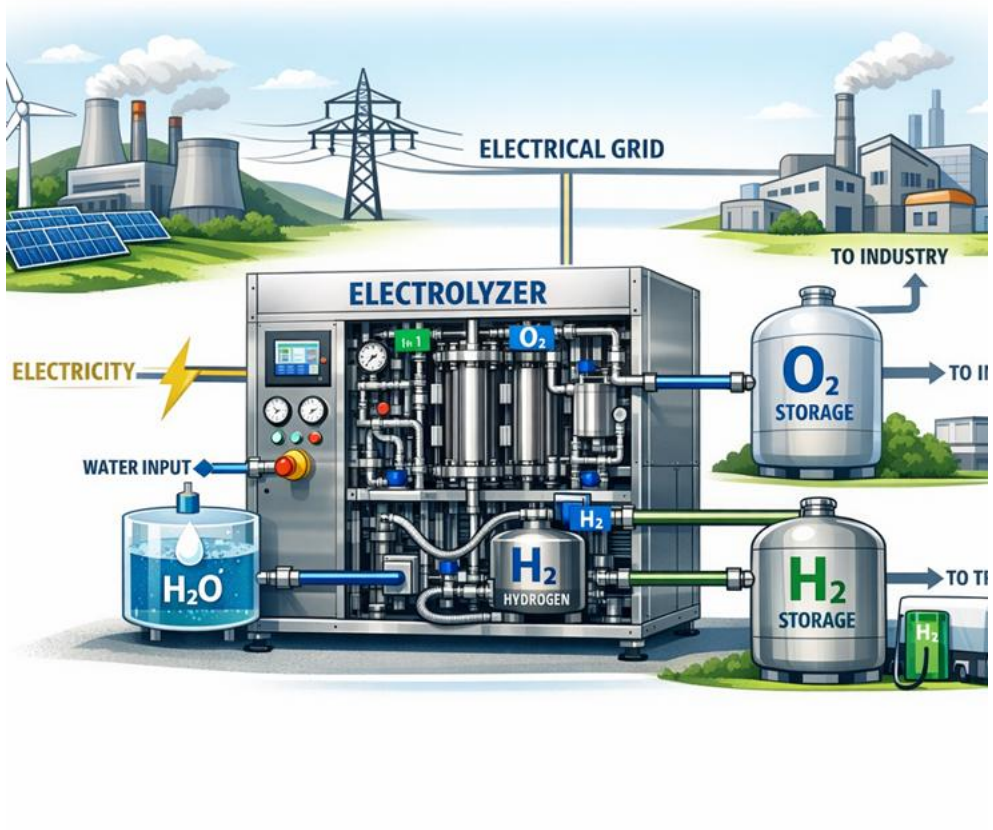
Electrolysers localization



- Proximity to existing industrial infrastructure allows for shared resources and easier integration of hydrogen into processes, ensuring stable demand and greater operational efficiency.
- Locating electrolysers near renewable sources allows direct use of electricity during peak production, reducing the need for storage and emissions from energy transport.
- From a grid planning perspective, locating electrolysers near industrial plants requires upgrading the local electric network, while producing hydrogen near renewables requires building a hydrogen transport network.

An integrated approach to investments in electricity, gas, and future hydrogen networks is needed, with cooperation between grid operators (TSOs).

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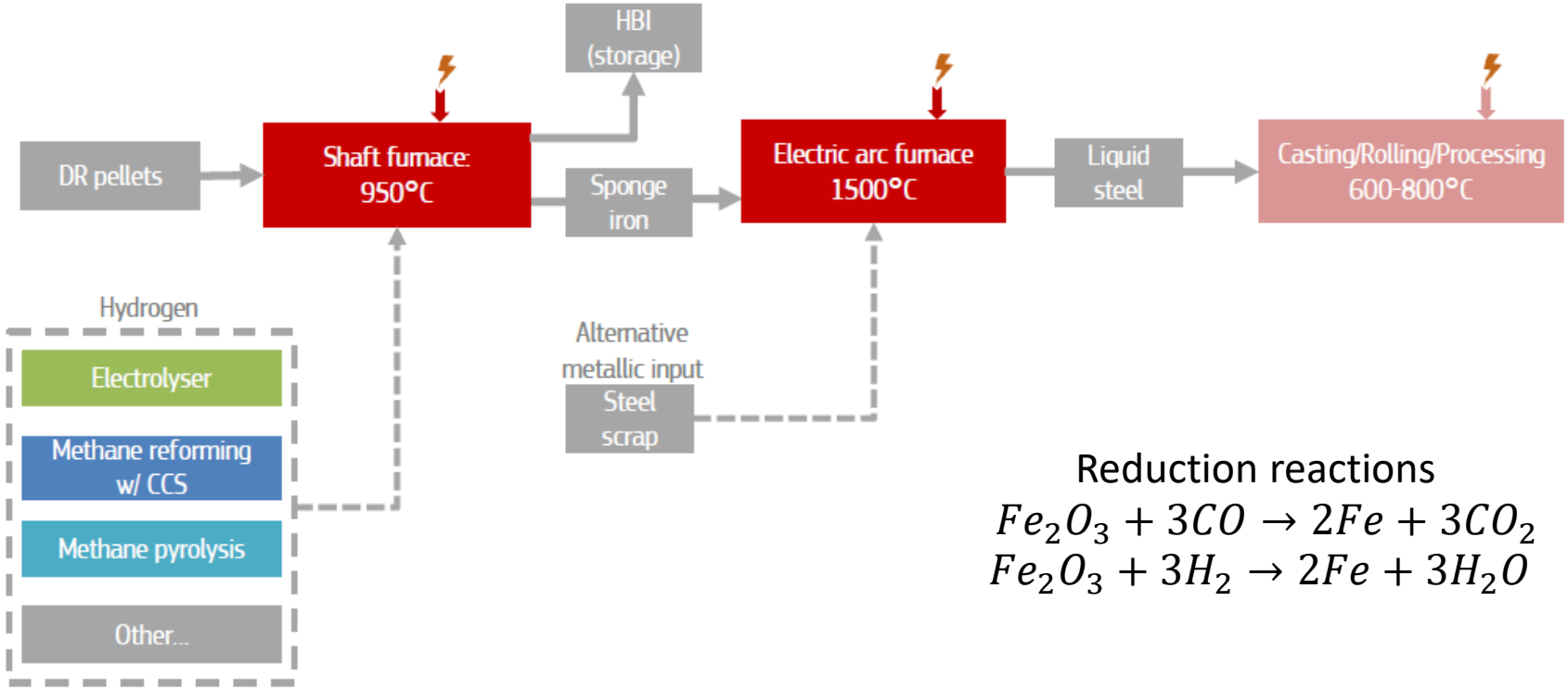
Second study case: Direct Reduction steel production

(hard-to-abate sector)

Figure 15 Simplified flow diagram of the hydrogen DRI process

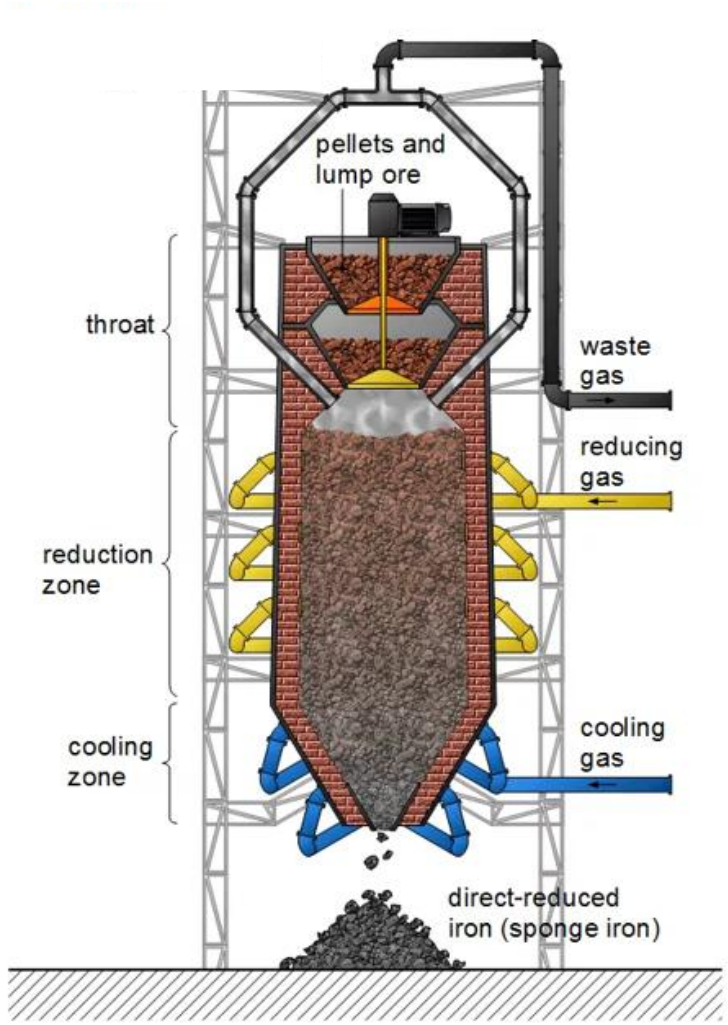


Source: JRC

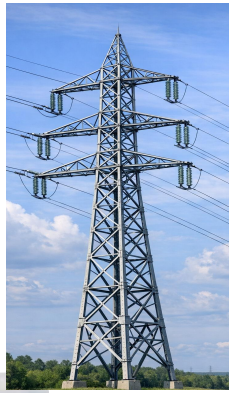
Reduction reactions

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$



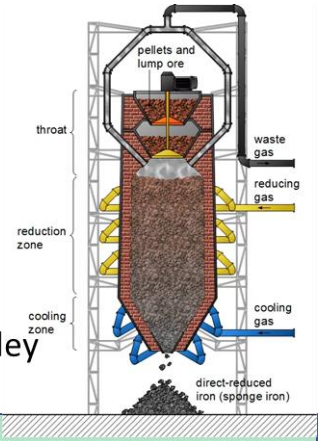
A flexible configuration exploiting multi-energy



Electric grid +
Local RES generation

Electrolizer

Hydrogen from a local hydrogen valley



Hydrogen

- Direct feeding of reduction process
- Direct feeding of "downstream" heating processes

Storage of excess production

Fuel cell

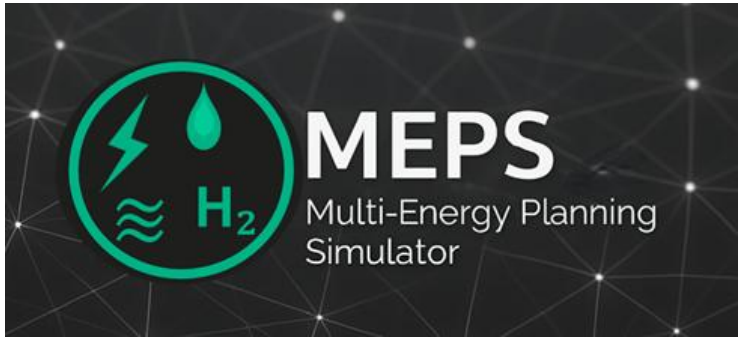
Green electricity

Feeding local auxiliaries

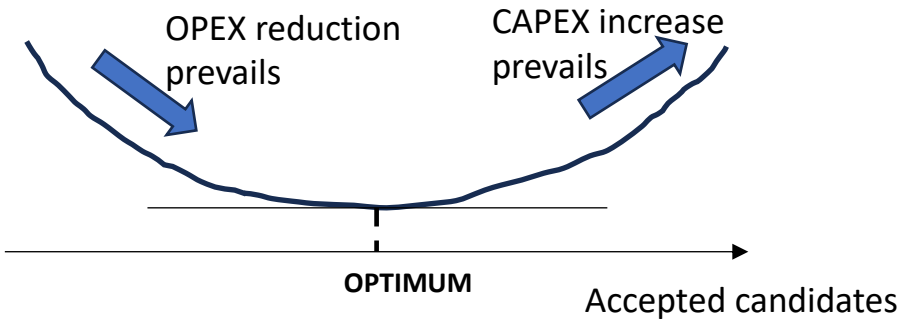
Services towards the surrounding grid

Electrochemical batteries

- Extra burden on the electric grid (reinforcement needs)
- Possible services based on:
  - hydrogen storage surplus
  - process flexibility
- Possible competition between electricity grid and hydrogen grid refurbishment needs



Characteristics of the new MEPS simulator of RSE



⚠️ Modeling assumptions

- Quasi-static, **linear steady-state** models
- **Temporal** dynamics only for **storage** systems

🔍 Important design aspects

- Separation between **solver** and **library**
- Fit for the creation of very **wide models**
- Allows **heritage** between components

- Optimal development of electricity T&D networks in **synergy with all the other carriers** (gas, district heating and, in the future, hydrogen).
- All energy vectors can have planning candidates (grid elements, flexibility, flexible loads…), and the **overall minimum cost solution** is sought for with a holistic multi-energy/multi-carrier approach by minimizing the overall system development cost (TOTEX: sum of investment costs + dispatch cost).
- Flexibility of **one carrier can provide services to others** (e.g.: storage of RES peak capacities, smoothing of winter-summer RES generation differences, etc). **Different networks can be put in competition** (e.g.: development of electric grid vs hydrogen network).
- The tool will be able to run in "**planning mode**" by providing a list of candidates on the different networks or in pure "**operational mode**" (without candidates) to forecast optimal dispatching costs at several time horizon (e.g. 2030-2040-2050 solved together).

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MEPS – Modeled Energy Networks and Components

Electricity transmission network

- Nodes and lines
- Generators, loads, and renewable sources
- Flexible loads and storage systems

Electricity distribution network

- Nodes, lines, and transformers
- Distributed generation and renewable sources
- Flexible loads and storage systems

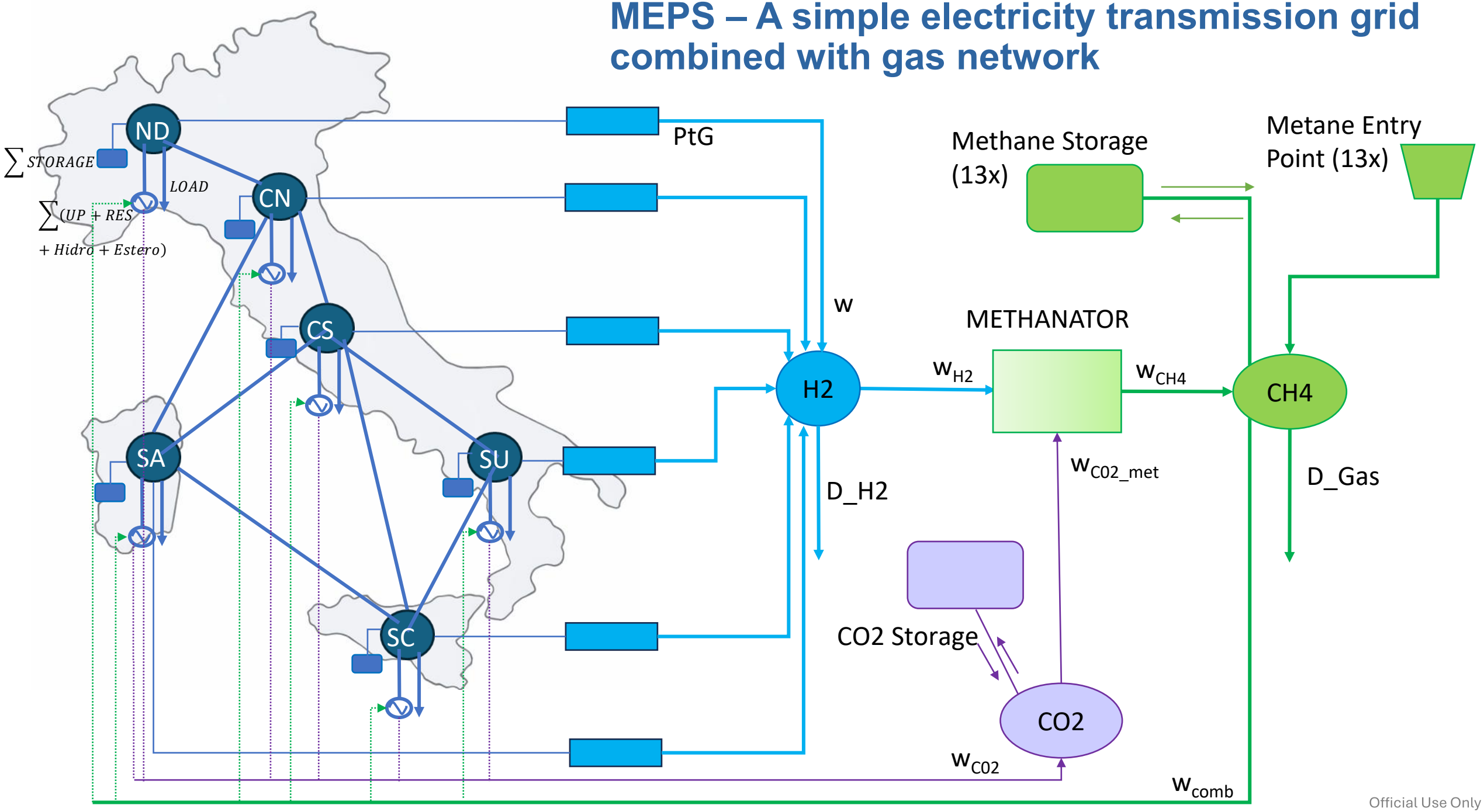
Gas network

- Nodes and pipelines
- Entry points and loads
- Gas storage and conversion units (Power-to-Gas, Methanator, Compressor)

District heating network

- Nodes and loads
- Combined Heat and Power (CHP)

MEPS – A simple electricity transmission grid combined with gas network



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Conclusions

- Planning future energy systems requires an integrated multi-energy approach to properly capture the strong interdependencies between electricity, gas, hydrogen, and heat.
- Minimizing total system costs (TOTEX) cannot be achieved through siloed, sector-specific planning, but only through a holistic and coordinated view of all energy carriers.
- Hydrogen and other non-electric vectors are key providers of flexibility, essential to support power systems with high shares of renewable energy.
- The case studies show that infrastructure and location choices (electrolysers, electricity and hydrogen networks, hard-to-abate industries) have significant system-wide impacts and therefore require coordinated planning.
- RSE's MEPS simulator enables this paradigm shift, allowing integrated assessments, competition among networks, and consistent analyses across multiple time horizons.
- Coordination among system operators and institutions is a key enabler of an effective, cost-efficient, and resilient long-term energy transition.

Thank you…

Gianluigi Migliavacca

Contact Information

Affiliation:	RSE S.p.A.
Phone:	+39 320 8395654
Email:	gianluigi.migliavacca@rse-web.it