An interdisciplinary approach to improve heat decarbonization assessments at the urban scale

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E4SMA s.r.l
The framework

COMPANIES

ENERGY CENTRE - EC

PUBLIC ADMINISTRATION

Multi-disciplinarity

Cross-fertilization

UNIVERSITY
The framework

DECISION SUPPORT SYSTEM for PUBLIC ADMINISTRATION
Current research activity – Bando «Metti in Rete la tua idea di ricerca»:

Heat in The Pipe

(2017-2019)

Research Question:
“how different energy carriers such as electricity, hydrogen, biological and synthetic fuels can be combined together for a more prosperous, inclusive society, aware of resources and environment?”

Different scenarios will be considered in the study that will focus in particular on the evolution and role of the gas network in the energy transition.

Partners:

Collaboration:

Financial support:
The framework

- **ENERGY PLANNING Optimization models**
- **DM**
- **UTILITY**

**LONG-TERM CAPACITY PLANNING:**
urban TIMES model

**DATA COLLECTION AND DATA PROTOCOL:**
meeting with stakeholder

**URBAN GIS DATABASE**

**BUILDINGS**

**ENERGY**

**STATISTICS**

**TECHNOLOGY**

**MANAGEMENT AND VISUALIZATION PLATFORM:**
Decision theatre, soft-link with other models

**INFRASTRUCTURE CO-SIMULATION:**
Electricity, gas, DH
Data collection

TORINO, ITALY
i. ≈ 900 kpeople, 2617 HDD
ii. 62% residential, 38% non-residential buildings
iii. 57 Mm³ (35%V) connected volume
iv. 100% natural gas
v. ≈ 740 MW CHP

ENERGY BALANCE 2005

ENERGY CONSUMPTION DATA
Energy map

DISTRICT HEATING,
ENERGY MIX, SOLAR MAP
Generation mix, technical data, connected buildings

BUILDING LAYER
Heated volume, building types

STATISTICAL LAYER
Socio-economic data: population
Model structure

- Building sector
- Space heating, water heating, space cooling, lighting, other electric
- High detail level on retrofit building types
- Retrofit options
- End-use technologies
- DH technologies
- Latest version: P2G and bio-methane

- 2015-2050
- 40 timeslices

- Evolution of building demand together with building evolution
- Potential role of bio-methane and P2G options
## Variables and scenarios

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>DR</th>
<th>FP</th>
<th>DL</th>
<th>CT</th>
<th>ET</th>
<th>DH_E</th>
<th>RES_P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5%</td>
<td>High</td>
<td>Low</td>
<td>No</td>
<td>40% (2030)</td>
<td>No</td>
<td>60% solar WH for New buildings</td>
</tr>
<tr>
<td>S1</td>
<td>5%</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
<td>60% (2050)</td>
<td>No</td>
<td>60% solar WH for New buildings</td>
</tr>
<tr>
<td>S2</td>
<td>5%</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
<td>80% (2050)</td>
<td>No</td>
<td>60% solar WH for New buildings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount rate - DR</td>
<td>3.5%/5%/10%</td>
</tr>
<tr>
<td>Fuel and electricity prices - FP</td>
<td>High/Low</td>
</tr>
<tr>
<td>Decarbonization level of the power sector - DL</td>
<td>Low/Low carbon/High (Figure 6-11)</td>
</tr>
<tr>
<td>Carbon tax- CT</td>
<td>Yes/No (Figure 6-11)</td>
</tr>
<tr>
<td>Environmental target - ET</td>
<td>40%/60%/80%</td>
</tr>
<tr>
<td>DH minimum expansion –DH_E</td>
<td>40-60% of space heating share/ &gt;60% of space heating share/ No</td>
</tr>
<tr>
<td>RES minimum penetration –RES_P</td>
<td>10% of solar/ 60% water heating from solar/No</td>
</tr>
</tbody>
</table>
Reaching targets without renewable gas and P2G

<table>
<thead>
<tr>
<th>Year</th>
<th>Fossil (direct)</th>
<th>Non-fossil</th>
<th>Baseline 40% decarbonization</th>
<th>Low carbon 60% decarbonization</th>
<th>Decarbon 80% decarbonization</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td>-17.4%</td>
<td>-36.4%</td>
<td>-46.7%</td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-17.4% Urban Consumption Mix (TWh)  
-36.4% CO₂ emission reduction (%)
-46.7% Residential final consumption

Baseline 40% decarbonization
Low carbon 60% decarbonization
Decarbon 80% decarbonization

49.6% Total consumption
52.6% Residential final consumption
60% Reduction of space heating demand
16.6% Residential consumption
12.5% Electricity supplied by solar energy
< 130 g/kWh CO₂ emissions of the electricity mix (-64% compared to 2015)
Decarbon 80% decarbonization

Reaching targets without renewable gas and P2G

- Equipment efficiency improvement and fuel switching
- Stock replacement
- Building Retrofit
- Thermal consumption
- Heat intensity

- 49.6% Total consumption
- 52.6% Residential final consumption
- 60% Reduction of space heating demand
- 16.6% Residential consumption
- 12.5% Electricity supplied by solar energy
- <130 g/kWh CO₂ emissions of the electricity mix (-64% compared to 2015)
Reaching targets without renewable gas and P2G

- Baseline: 40% decarbonization
- Low carbon: 60% decarbonization
- Decarbon: 80% decarbonization

- Residential final energy consumption (TWh)
- Renewable share (%)

- Oil derivates
- Natural gas
- Biomass
- Heat
- Electricity
- Solar
- Renewable share

- Fossil (direct)
- Non-fossil

- Baseline
- S1
- S2

- 2015
- 2050

- Total consumption: 49.6%
- Residential final consumption: 52.6%
- Reduction of space heating demand: 60%
- Residential consumption: 16.6%
- Electricity supplied by solar energy: 12.5%
- CO₂ emissions of the electricity mix: < 130 g/kWh (-64% compared to 2015)
Reaching targets without renewable gas and P2G

Baseline
40% decarbonization

49.6%
Total consumption
52.6%
Residential final consumption

60%
Reduction of space heating demand

16.6%
Residential consumption

12.5%
Electricity supplied by solar energy

< 130 g/kWh
CO₂ emissions of the electricity mix (-64% compared to 2015)
Reaching targets without renewable gas and P2G

- Total consumption: 49.6%
- Residential final consumption: 52.6%
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- Electricity supplied by solar energy: < 130 g/kWh

CO₂ emissions of the electricity mix (-64% compared to 2015)
Introducing renewable gas

Important role of biogas for decarbonizing future energy systems at competitive costs, even when the power sector is 37% decarbonized compared to 2015. P2G not selected in these conditions.

52.7 %
Gas has a dominant role
Biogas penetrate in the grid for 37%

< 227 g/kWh
CO₂ emissions of the electricity mix (-36.23% compared to 2015)
P2G option without methanation: delivering H2 from renewable

80% 2050 Decarbonization, limits of the grid: 17% in terms of volume (6.3% in terms of energy)

Variable RES penetration (%)

Yearly hydrogen penetration (%)*

0.0% 0.2% 0.4% 0.6% 0.8% 1.0% 1.2%

0% 10% 20% 30% 40% 50% 60%

Considering technical limits of the gas grid, P2G option without methanation is attractive when it is needed to avoid curtailment and to improve the flexibility of the electricity grid when high decarbonization targets should be met.

To reach the decarbonization goal (investments postponed), at roughly 20% electricity produced by solar RES, P2G starts to penetrate in the energy mix. It contributes for roughly the 1% of the total yearly energy produced by gas.

If methanation is allowed, it is easier to exploit the whole electricity excess, gas maintain the higher share of total consumption.
Co-simulation of electricity and gas networks

Electric Network Model
- Backward-Forward Sweep method
- Steady state
- AC Power Flow

Gas Network Model
1D analytical method –
Steady state –
Non-isothermal –
Multi-component –

Outputs
- Current for each branch
- Voltage at each node

Physical Model

Parameters
- Network Topology –
- Cables Features –
- Power Demand Profiles
- Reference Y, V at slack node

Inputs
- Network Topology –
- Pipelines Features
- Gas Demand Profiles
- P, T, Composition at injection node

Outputs
- Gas Flow for each branch
- P, T, Composition at each node
Case Study 1: Penetration of PV

**Electricity Network Simulation:** rationale of the case study

- **Demand Profiles**
- **PV Progressive Penetration**
- **PV daily generation profile each month**
- **PV + 1kWp each user**

- **Electrical Network Simulation**
- **Abnormal Electrical Network operations ?**
  - Yes → **P2G** → **H₂ Injection**
  - No → **Gas Network Simulation**
Case Study: Electrical Network Simulation

Results:
July case focus: “Duck Curve” formation and generation of Hydrogen production pattern
Case Study: from Electrical to Gas Network

July case, $P_{PV}$ installed = 4 kWp: rationale of the case study

Gas Network in summer operation

- Gas Consumption is 15% wrt Winter Mode
- $H_2$ injection node choice: proximity criteria
  - $H_2$ injection node is the nearest to the HV-MV station

Assumptions

- $H_2$ daily generation profile to avoid reverse flow

$P_{PV}$ Overproduction

$P_{2G}$

$H_2$ Injection in the Gas Network

Abnormal Gas Network operations?
Case Study: Gas Network Simulation

Results: on the H2 presence in the natural gas stream [ % Vol ]

![Graph showing H2 injection at node 30]
Case Study: Gas Network Simulation

Results: from the thermo-fluid-dynamic perspective
Gas distribution network can provide only limited flexibility to an over-producing electricity distribution grid because of a negative overlapping between the seasonal fluctuation of the respective operational mode and limited penetration of hydrogen conversion technologies (e.g. heating, transport) in the short term.
Conclusions

Occupant behaviour
Willingness to invest in new technologies
Multi-criteria methods

Adding sectors (transport, industry)
Enlarging the study at the regional level
Adding models

High level of expertise
Time consuming
Low understanding for decision makers

Low data availability
New DB requires new instruments and resources

Adding models
PLATFORM CREATION
INTEROPERABILITY

DATA
NEW DATA PROTOCOL

HUMAN BEHAVIOUR
STOCASTIC INPUTS & SOCIO-ECONOMIC ANALYSES

TRADITIONAL THINKING
HIGHER TRANSPARENCY
Thanks

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