# Designing a model for the cost-optimal decommissioning and refurbishment investment decision of gas networks

## Application on a real test-bed in Austria until 2050

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# Todays' agenda

- Background / Motivation
- Core objective
- Materials and methods
- Results of a real test-bed (federal state Vorarlberg, Austria, until 2050)
- Conclusions and outlook

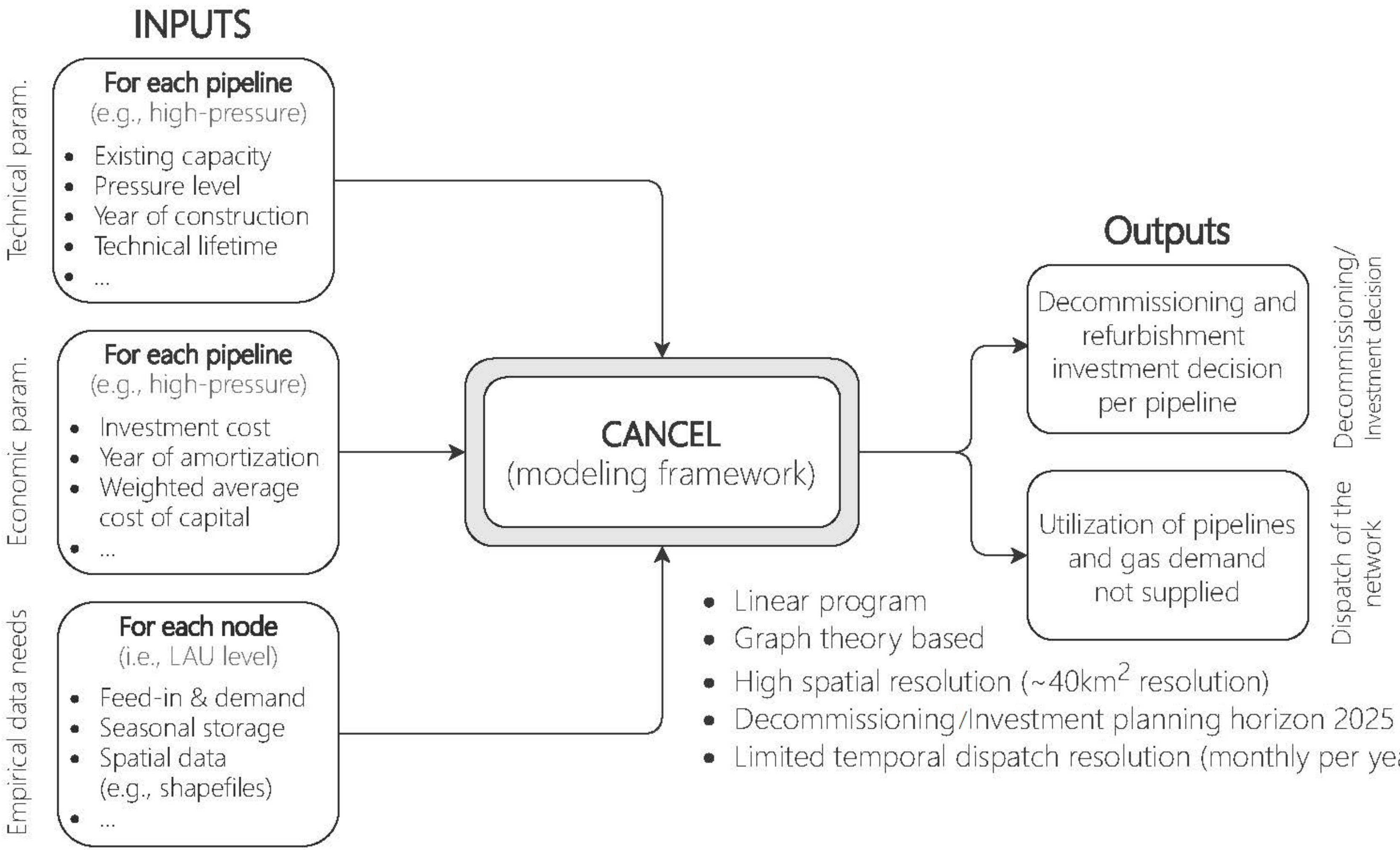
# Background and motivation

- Adherence to the remaining $CO_2$ budget of the 1.5°C / 2.0°C climate target requires rapid **defossilization** of the energy system
- Concrete measures include, among others, the **substitution** of **natural gas** in the provision of energy services by sustainable alternatives
- Substantial **challenge** since natural gas is currently **used** for energy supply of a **wide range** of energy service needs
- Uncertain role of **green gases** (e.g., synthetic gas, hydrogen) related to their economic viable quantities / potentials and penetration time
- …but there are far-reaching gas transmission / distribution networks

# Core objective / main research questions

- The core objective of this work is to investigate the **cost-effective trajectory** of **gas networks** from a systemic point of view under a long-term planning horizon
- In view of necessary refurbishment investments in existing gas network infrastructure and pipelines due to their technical lifetimes, the main research question is of **which decommissioning and refurbishment investment decision result in cost-effective gas networks by 2050.**
- Equally important in the analysis is the trade-off decision from the network operator's perspective whether available **gas demands** within the network area **are supplied or not** as the decommissioning of existing gas pipelines can be cost-effective, but at the same time results in not supplied gas demands.

# Introduction into the model




- Linear program
- Graph theory based
- High spatial resolution (~40km$^2$ resolution)
- Decommissioning/Investment planning horizon 2025 to 2050
- Limited temporal dispatch resolution (monthly per year)

# Mathematical formulation (selection) 1 / 2

| Equation | Type | Short description |
|---|---|---|
| $\min_{x} Capex + Opex - Rev + Purch$ | Objective function | Minimize gas network operator's net present value |
| $Capex = \sum_{y} \alpha_y * w * \Pi_y$ $\quad Opex = \sum_{y} \alpha_y * \mathrm{K}$ | Constraint | Calculation of capital and operational expenditures |
| $\mathrm{K} = \sum_{l} c_l^{fix} * \Upsilon_{l,y}$ | Constraint | Total fixed (operating) costs per pressure / network level $\boldsymbol{l}$ |
| $\Pi_{p,l,y} = \Pi_{p,l,y}^{pre} + f_{p,l}^{ref} * \Pi_{p,l,y_{p,l}^{inv}}^{ref}$ | Constraint | Book value of a pipeline $\boldsymbol{p}$ at $\boldsymbol{l}$ in $\boldsymbol{y}$, where $\boldsymbol{\Pi_{p,l,y}^{pre}}$ is the book value of the pre-existing pipeline (capacity) |
| $\Pi_{p,l,y_{p,l}^{inv}}^{ref} = c_l^{inv} * \Upsilon_{p,l,y_{p,l}^{inv}}^{ref}$ | Constraint | Book value of the refurbishment investment for $\boldsymbol{p}$ and $\boldsymbol{l}$ in $\boldsymbol{y_{p,l}^{inv}}$ |

# Mathematical formulation (selection) 2 / 2

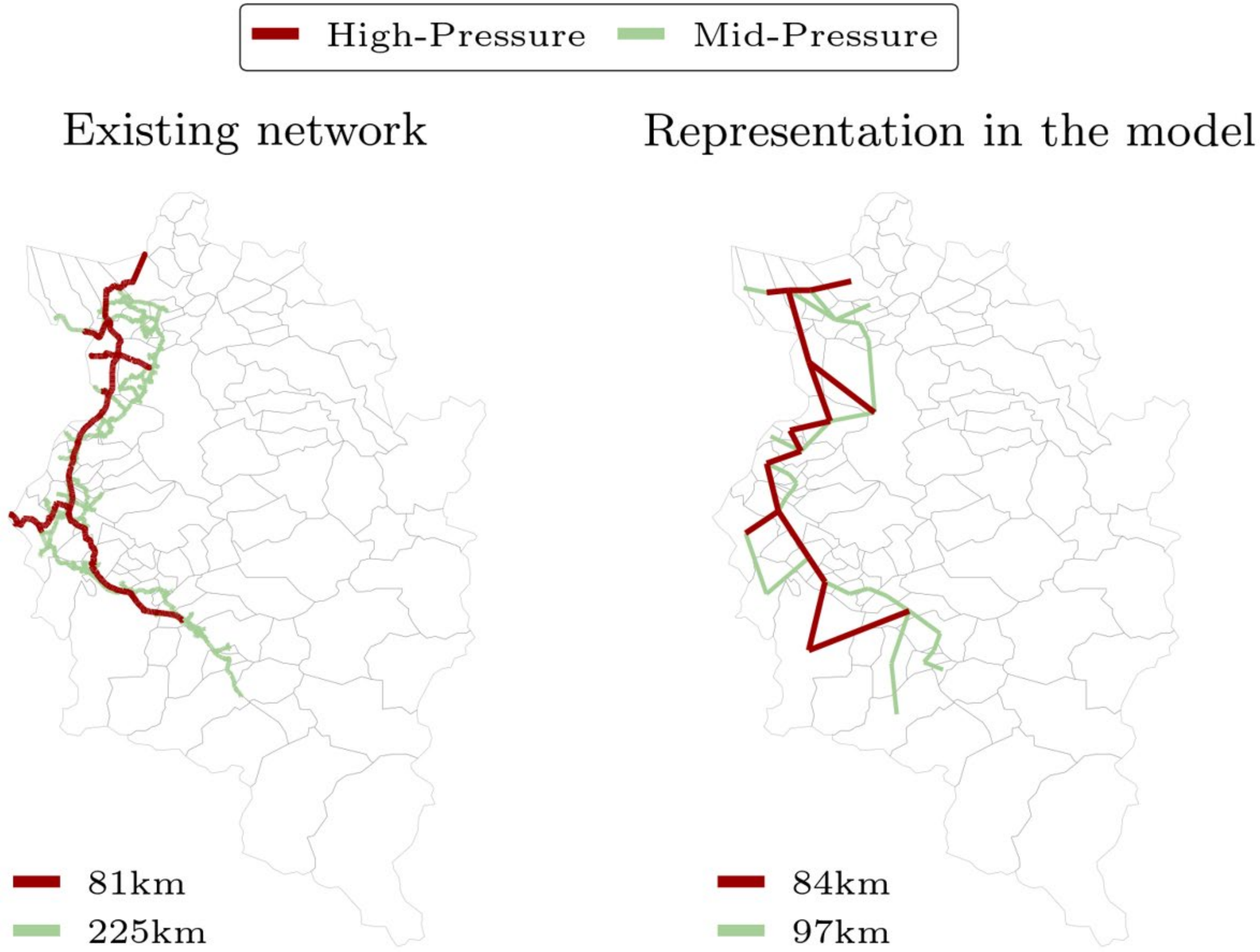
| Equation | Type | Short description |
|---|---|---|
| $q^{fed}_{n,l,y,m} - q^{dem}_{n,ly,m} - \zeta_m * \left(q^{exp}_{n,l,y,m} - q^{imp}_{n,l,y,m}\right) + q^{sto}_{n,l,y,m} = 0$ | Constraint | Nodal gas balance equation at pressure / network level |
| $q^{dem}_{n,l,y,m} = q^{dem,loc}_{n,l,y,m} + q^{del}_{n,l',y,m}$ | Constraint | Gas demand at network level $\boldsymbol{l}$, where $\boldsymbol{q^{del}_{n,l',y,m}}$ is the amount of gas delivered to subordinate pressure level |
| Equation $\boxed{18}$ $\begin{cases} q^{dem,loc}_{n,l,y,m} \leq d^{max}_{n,l,y,m} & : \lambda^{co}_{n,l,y,m} \\ q^{dem,loc}_{n,l,y,m} = d^{max}_{n,l,y,m} & : \lambda^{ES}_{n,l,y,m} \end{cases}$ | Constraint | Essential demand constraint and sets the upper bound of the decision variable $\boldsymbol{q^{dem,loc}_{n,l,y,m}}$ |
| $rev = p^{loc}_{l,y} * q^{dem,loc}_{n,l,y,m}$ | Constraint | Revenues created by the local gas demands covered, where $\boldsymbol{p^{loc}_{l,y}}$ is the grid usage charge at network level $\boldsymbol{l}$ |

# Implication of demand constraint dual variables

| Input | | | Output |
|---|---|---|---|
| Model run | Formulation of Equation $\boxed{18}$ | Scenario description/gas network design (abbreviation) | Results or further used variable |
| 1 | $q^{dem}_{n,l,y,m} \leq d^{max}_{n,l,ym}$ | Cost-optimal without ensured supply (CO) | Demand supplied ($\overset{*}{\mathbf{q}}{}^{dem}_{n,l,y,m}$) |
| 2 | $q^{dem}_{n,l,y,m} = \overset{*}{\mathbf{q}}{}^{dem}_{n,l,y,m}$ | | Shadow price ($\lambda^{CO}_{n,l,y,m}$) |
| 3 | $q^{dem}_{n,l,y,m} = d^{max}_{n,l,ym}$ | Cost-optimal with ensured supply (ES) | Shadow price ($\lambda^{ES}_{n,l,y,m}$) |

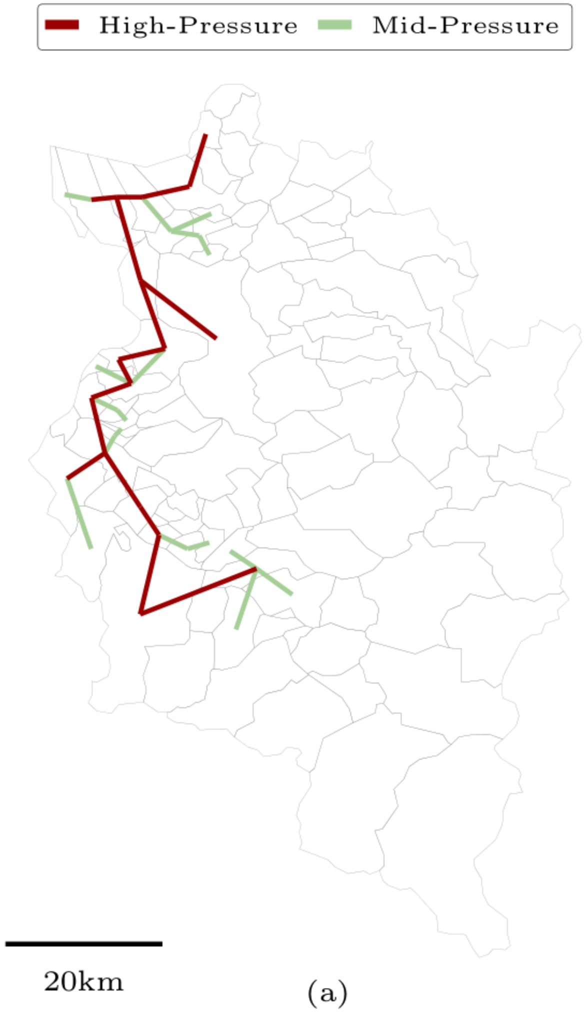
Table 1: Model runs and associated formulation of the gas demand constraint (Equation $\boxed{18}$), scenarios, and results or further used variables.

# Test-bed in Vorarlberg, Austria



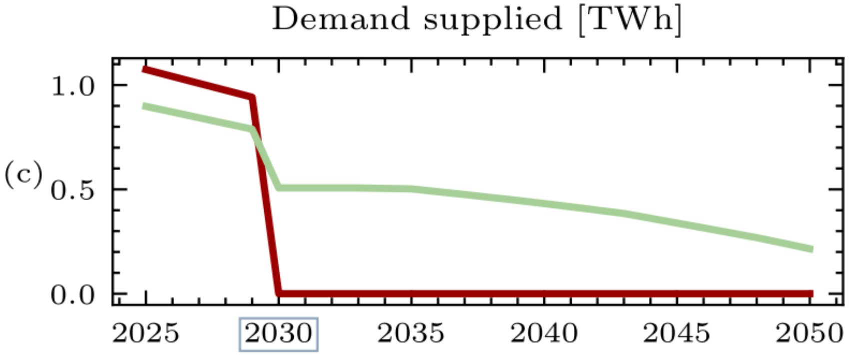

Source [57]: Vorarlberg Netz, Das Erdgasnetz: Allgemeines zum Erdgas-Verteilnetz, https://www.vorarlbergnetz.at/erdgasnetz.htm

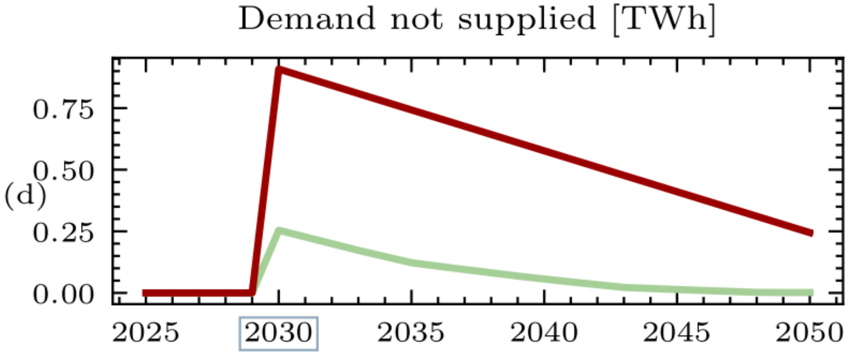
# Cost-optimal network without ensured supply (CO)



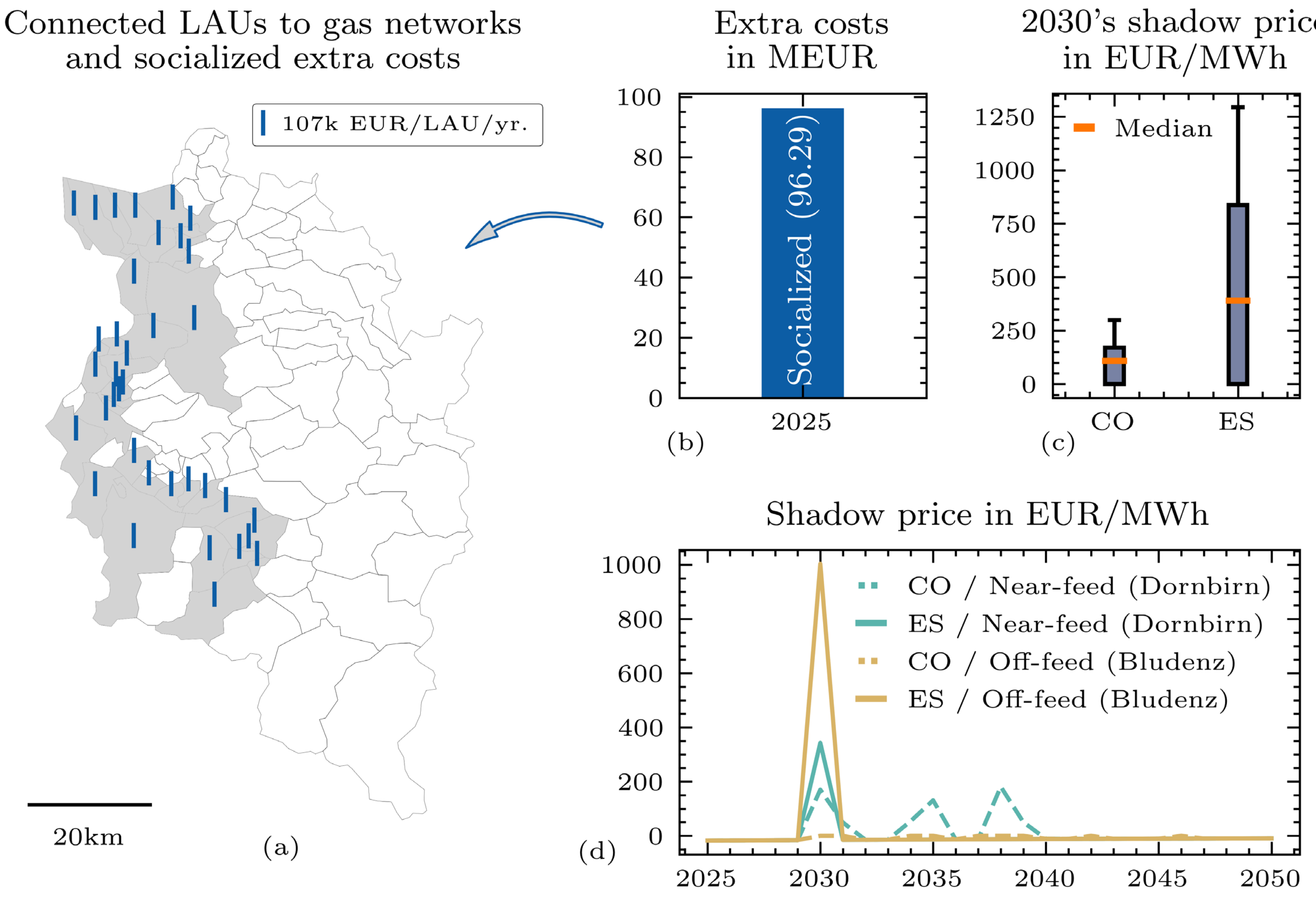

(b)

| | High-Pres. | Mid-Pres. |
|---|---|---|
| Max. [MW] | 161.92 | 40.58 |
| Length [km] | 84.5 | 57.2 |
| Decom. [%] | 0 | 41 |
| Refurb. [%] | 100 | 59 |

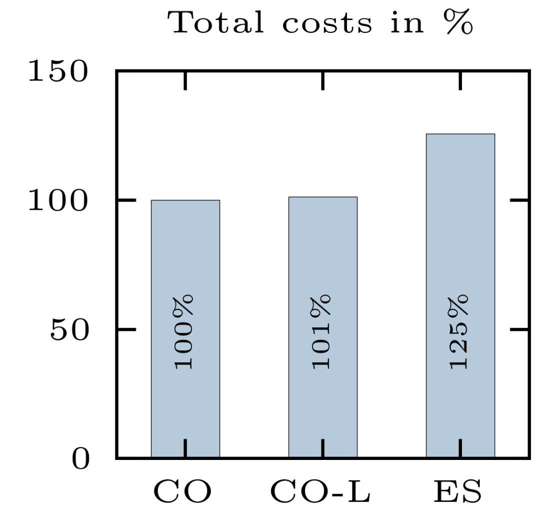


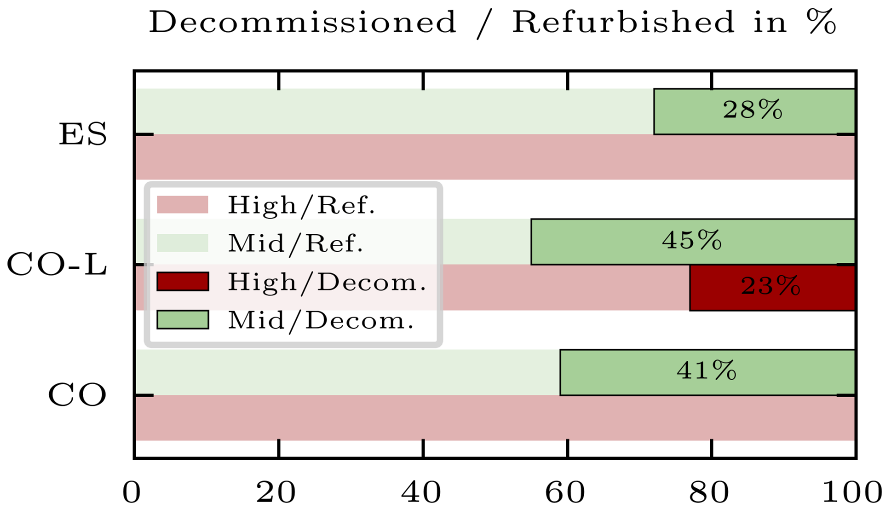



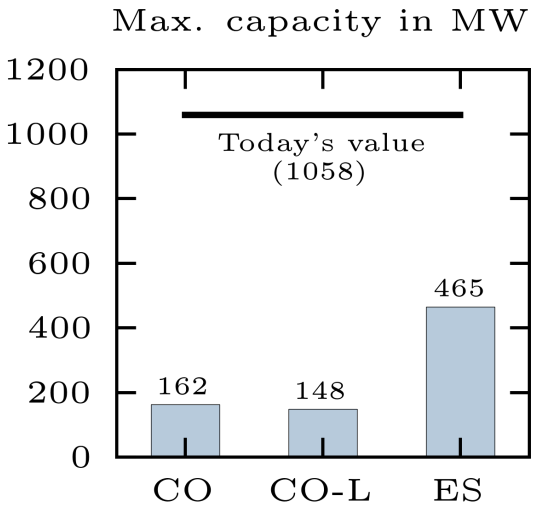
# Comparison of network w/ ensured supply (CO & ES)

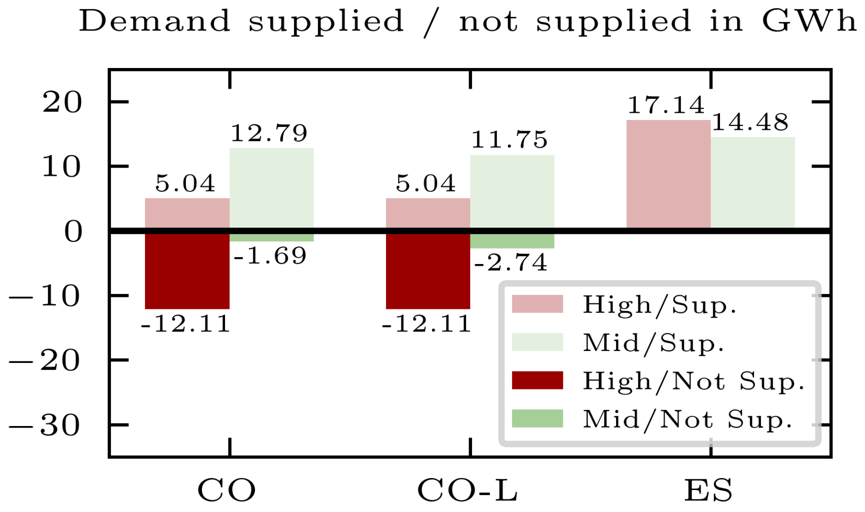


# Overview: CO, ES and cost-optimal with lumpiness (CO-L)



# Conclusions and recommendations

- In the future, **smaller gas networks** in both capacity and length will be necessary (regardless of secured supply) resulting from irreversible defossilization of energy services
- **Wide range of network design** between cost-optimal gas networks **w/ ensured supply** reveal crucial **trade-off** decisions for network operators in the future on how to deal with existing / available demands (i.e., decommissioning despite possible demands)
- **Shadow prices** of local gas balance constraints **indicate** that network operator should **strike a balance between cost-optimal gas network design w/ ensured supply** (e.g., flexibility and management of unexpected changes in (peak) gas demands)
- **Increased** network operator's **total costs** in case of ensured supply need to be **socialized** to a **few consumers** in the future (primarily at subordinate network / pressure levels)
- Influence of **socialized grid / network costs** on economic viability and **profitability** of **sustainable alternatives** substituting natural gas-based energy service needs and related trade-off decisions

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