MODELLING THE IMPACT OF THE ENERGY TRANSITION ON GAS DISTRIBUTION NETWORKS IN GERMANY

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00 Agenda

01 Motivation

Global Trends

- **Paris Agreement** and **German defossilization plan** to reach the 2°C / 1.5°C goal
- Fundamental **shift to renewable, CO_2[1]-neutral energies** within global energy supply
- **Phase out of gas** is a major challenge over the next decades

Heating structure will change massively

- **Defossilization** results in application of renewable heat sources
  - E.g., heat-pumps, solar-thermal, geo-thermal
  - Future role of green, CO_2 -neutral heating applications uncertain

➡ **Change of energy supply infrastructure** affected by pathway towards green house gas neutrality
  - Importance of the role of gas for decentralized heating affects gas networks
  - Today's investments come with potential for lock-ins or sunk costs

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[1] Carbon Dioxide

UN (2015); Bundesregierung (2019), Brauers et al. (2021)

02 Status Quo – The current research is focused on single sub-sectors

Natural gas is used in a wide range of applications

- **Industrial consumers** use gas for process heat or as feedstock
- **Energy sector** uses gas in power plants (e.g., gas turbines, combined cycle)
- **Private households** and commercial, trade and services (CTS) use gas mainly for space heating and hot water
  - 41.5 % of German gas demand in 2019
  - 48 % of residential heating is based on natural gas
- Niche applications in **mobility** and other sectors

Role of gas infrastructure

- Long distance transportation via gas **transportation grid**
- Decentral supply via **distribution grid**
  - 80.5 % of gas demand is supplied via distribution grids
  - More than 10.5 million existing consumer connections
- **Characteristics** of the distribution networks **vary** from region to region
  - Historically grown infrastructure
  - Former access to domestic gas fields

AGEB (2020), BDEW (2019), BNetzA (2019), Cerbe and Lendt (2016)

02 Research Gaps and linked Questions

How will gas distribution networks change by 2050?

- Effect of energy transition on gas distribution networks uncertain
- Probably reduced relevance of gas distribution network in greenhouse gas neutral system

What is the transition pathway?

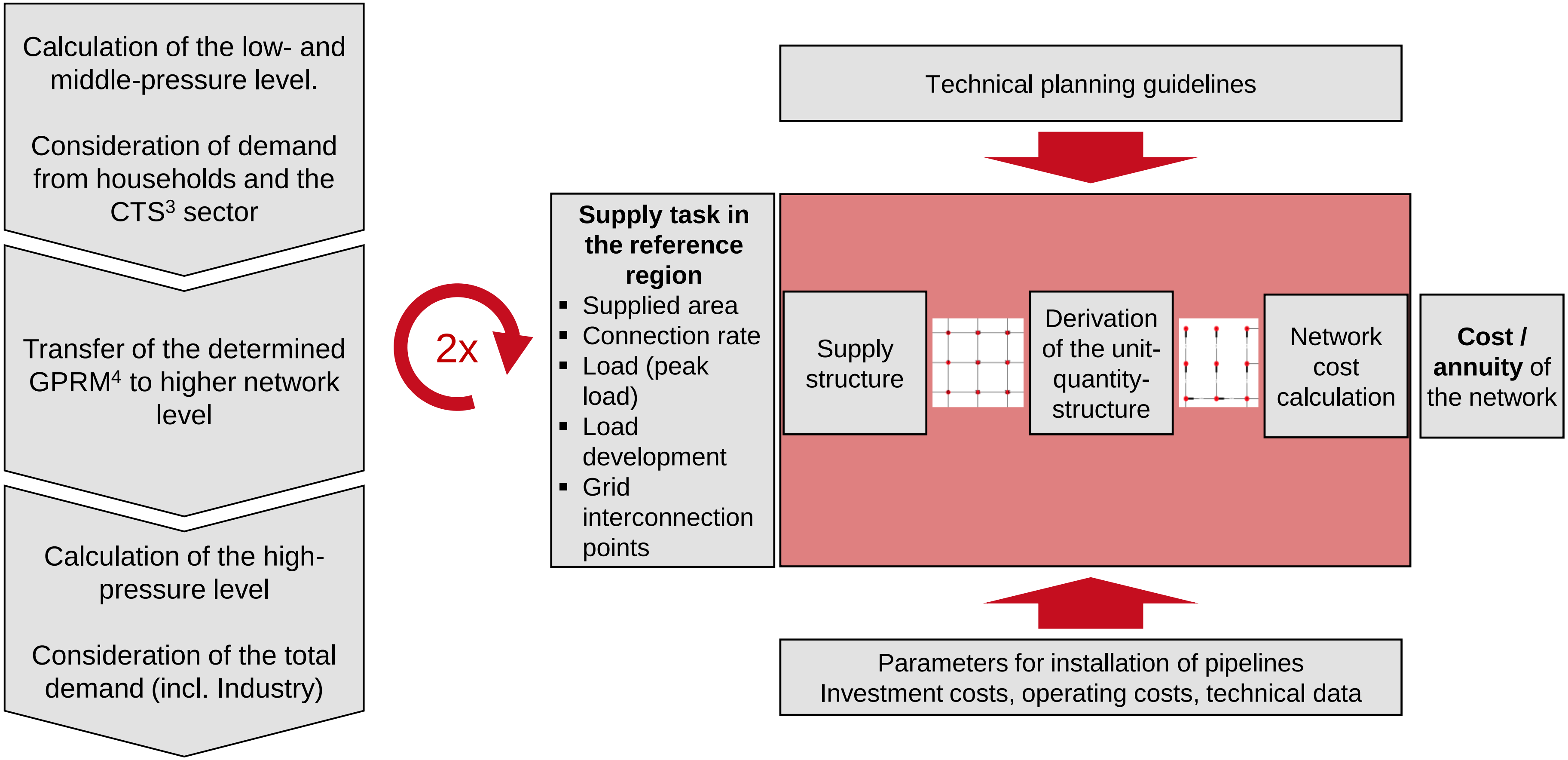
- Required measures unclear
- Scope of infrastructure depends on transition scenario

What are the transition costs in the gas distribution networks?

- Extent of network change drives the costs
- Possible measures are dismantling, conversion or expansion

03 Methodology – Two loops to derive the gas distribution grid infrastructure

The model network analysis as a greenfield approach to derive the infrastructure development and costs



Calculation of the low- and middle-pressure level.

Consideration of demand from households and the CTS[3] sector

Transfer of the determined GPRM[4] to higher network level

Calculation of the high-pressure level

Consideration of the total demand (incl. Industry)

2x

Technical planning guidelines

Supply task in the reference region

- Supplied area
- Connection rate
- Load (peak load)
- Load development
- Grid interconnection points

Supply structure

Derivation of the unit-quantity-structure

Network cost calculation

Cost / annuity of the network

Parameters for installation of pipelines
Investment costs, operating costs, technical data

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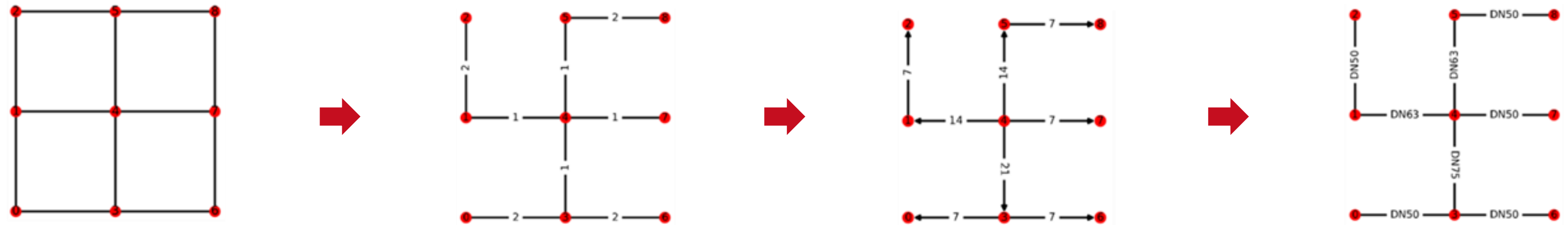
[3] Commercial, trade and services; [4] Gas pressure regulating and measuring unit
Cerbe and Lendt (2016), Consentec GmbH et al. (2006), Fritz (2005), Fritz and Maurer (2006)

03 Methodology – Four steps of the infrastructure determination



1 **Span cubic grid**

2 **Optimize Grid**

3 **Calculate gas flow**

4 **Derive pipeline diameter**

1. Span cubic grid

- Surface corresponds to supplied area per region
- Cubic grid
- Connection points are equally distributed

2. Optimize Grid

- Grid length optimization
- Shortest path from a source node in the centre
- Grid is a ray network (no mashed network)

3. Calculate gas flow

- Gas flow for each edge is calculated backward
- Start at end nodes of the rays
- Flow increases with ray length

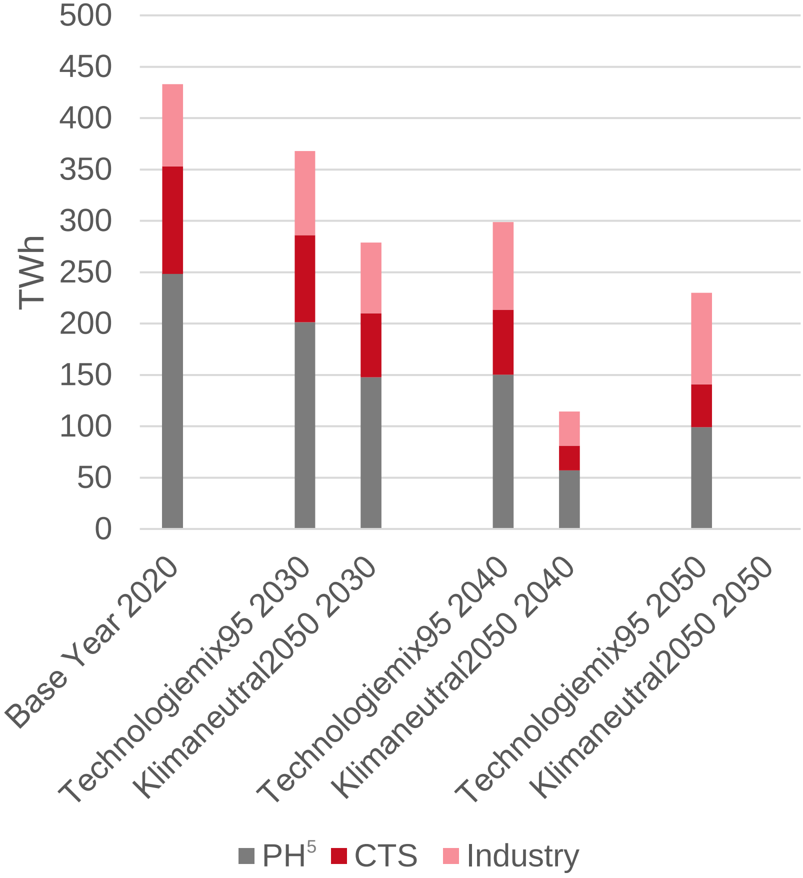
4. Derive pipeline diameter

- Based on calculated gas flows
- Using existing pipe diameter classes

Cerbe and Lendt (2016), Consentec GmbH et al. (2006), Fritz (2005), Fritz and Maurer (2006)

04 Data – Demand Development as key input for the grid development

Demand development in distribution grids



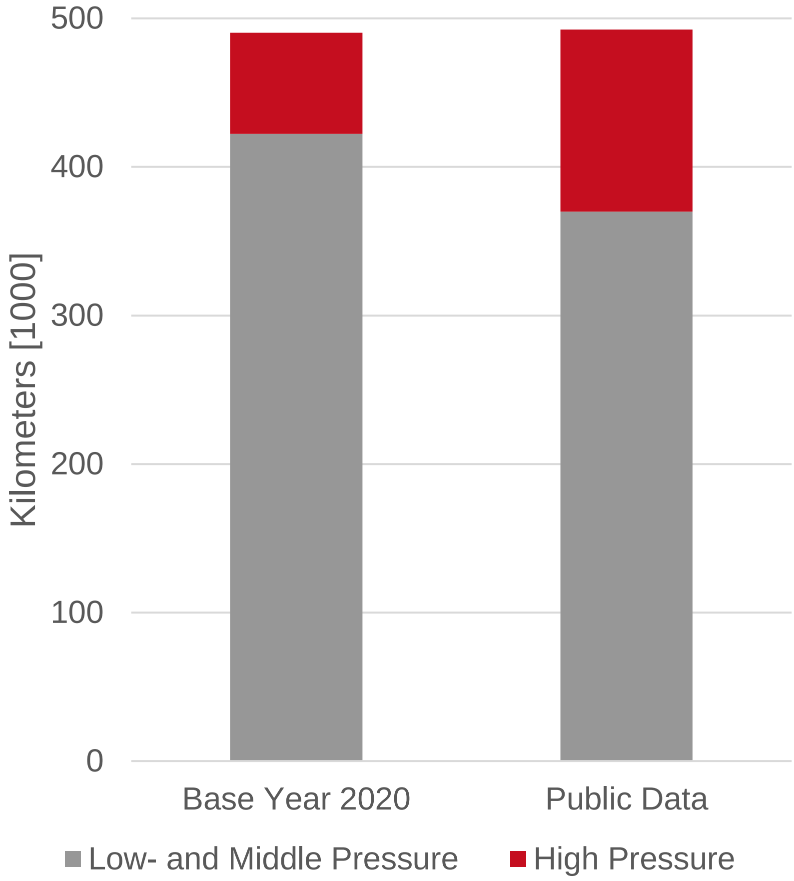
Declining gas demand in the investigated sectors

- **Synthetic gas scenario** (“Technologiemix 95”)
  - Replacement of fossil gas by synthetic methane in the energy system (Dena (2018))
  - Wide use of synthetic gases across all sectors
  - Gas stays dominant energy carrier for space heating
- **All-electric scenario** (“Klimaneutral 2050”)
  - Strong reduction of gas / methane in the energy system (Prognos, Öko-Institut, Wuppertal-Institut (2020))
  - Complete gas phase out for decentral heating applications
  - Accelerated reduction also in industry
- **Two scenarios that represent the range of the possible development**
- No hydrogen considered in distribution grids
  - No recent energy study indicates its use for space heating
  - Rather application in certain industrial processes and long-distance transportation

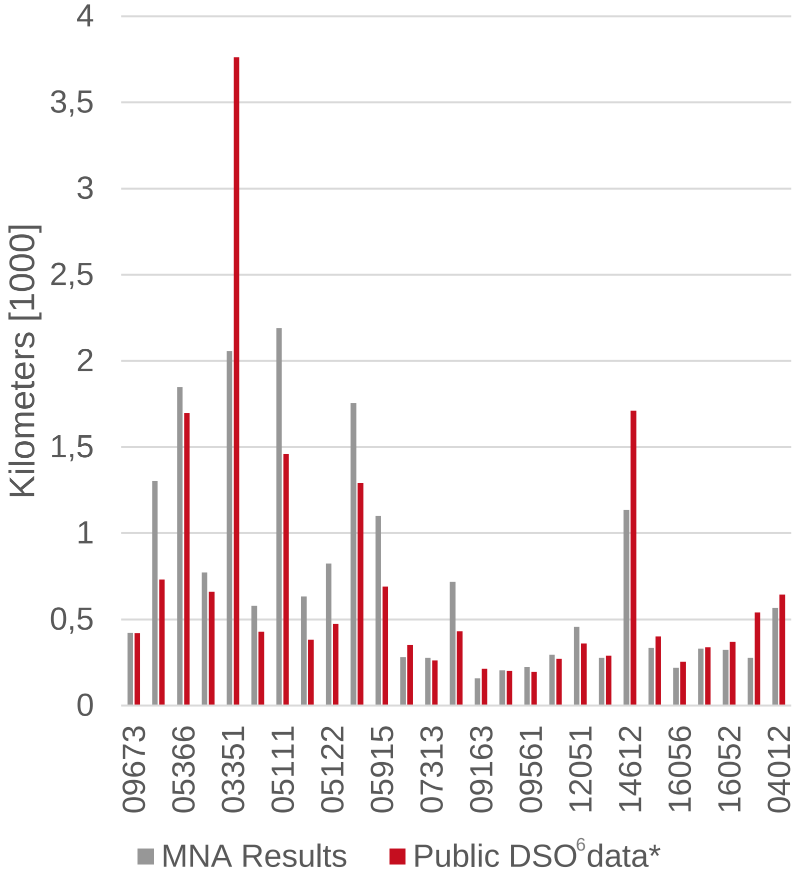
[5] Private Households; Dena (2018); Prognos, Öko-Institut, Wuppertal-Institut (2020), spatial distribution based on Gotzens et al. (2020); Gerhardt et al. (2020)

05 Findings – Results largely represent reality

Grid length comparison for Germany



Grid length comparison for counties



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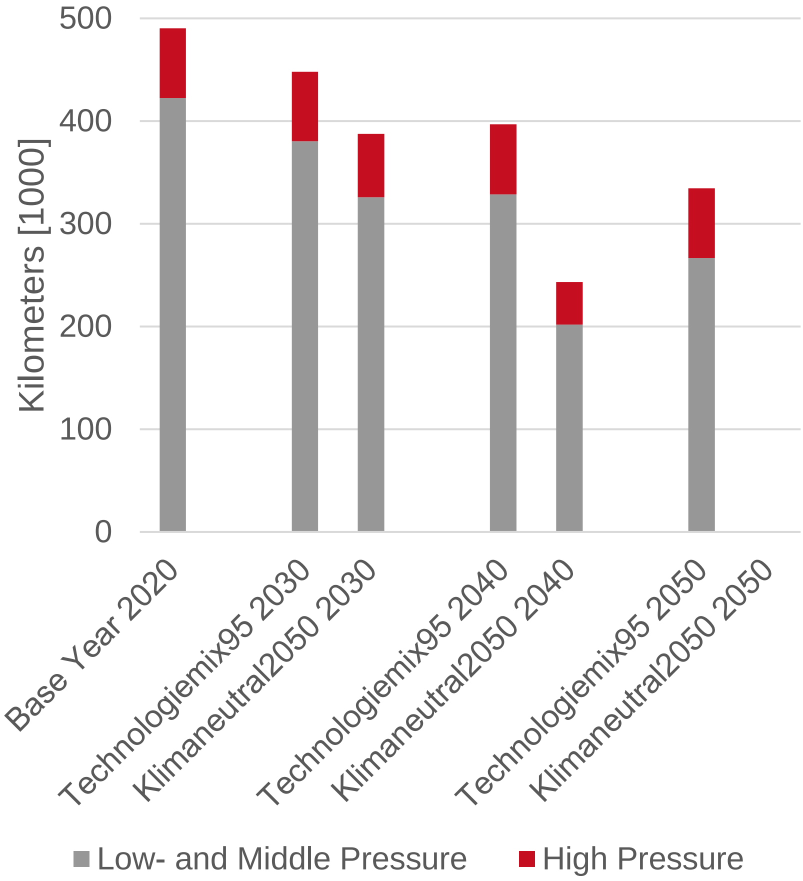
[6] Distribution system operator

*public DSO data is extracted from available information of the German DSO about their grid infrastructure

05 Findings - Declining network infrastructure in all scenarios

Grid development

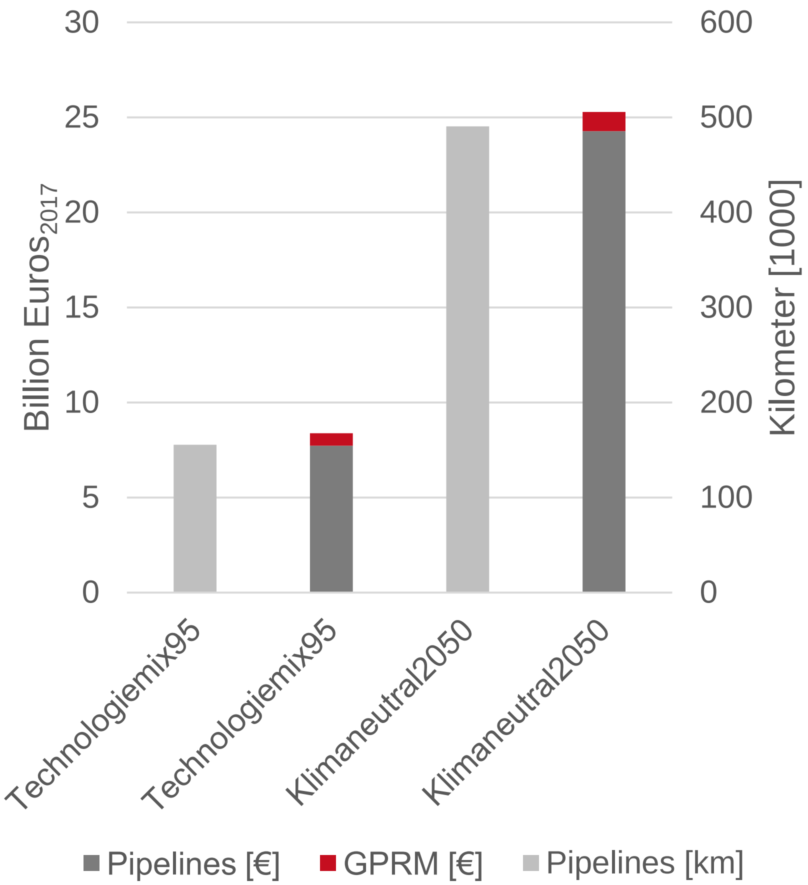


Declining need for gas distribution networks

- Lower network requirements evident from now on
  - Slight difference between the scenarios in 2030
  - All-electric scenario (Klimaneutral 2050) with almost half the infrastructure needs in 2040
  - **One third less** infrastructure in the synthetic gas scenario (Technologiemix 95) in 2050
  - **Decrease of grid length to zero** for all-electric scenario in 2050
- Reduction mainly seen in low and middle pressure level
  - Demand reduction for space heating by households and CTS
  - Demand in the high-pressure level almost constant across all sectors

05 Findings – Cost driver of decommissioning are driven by pipelines

Decommissioning Volume 2020 – 2050

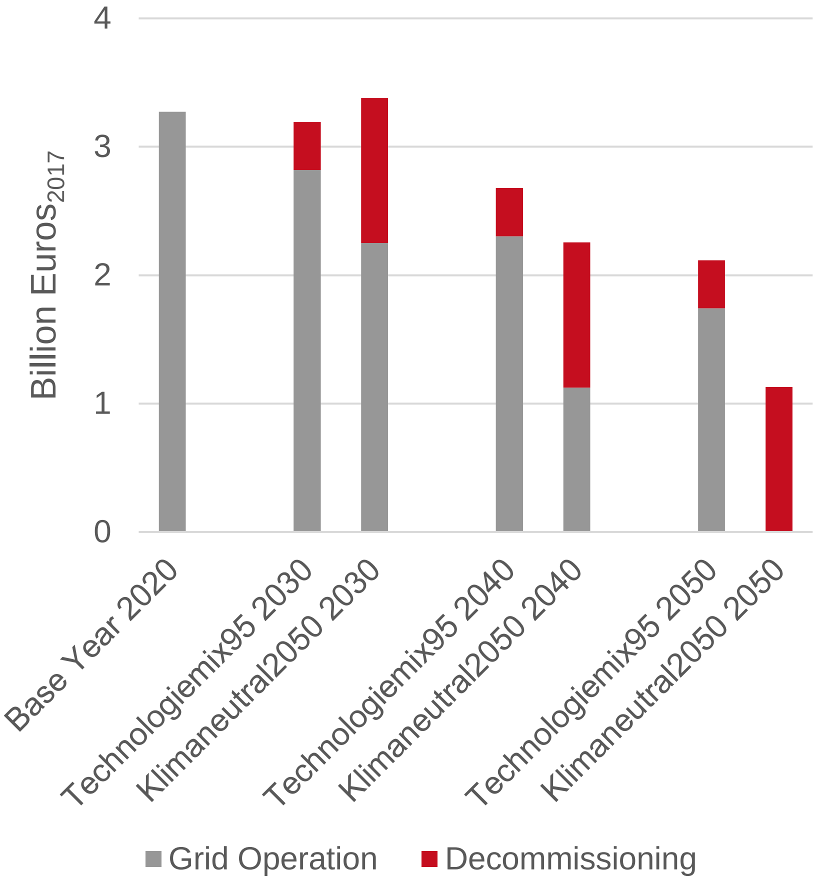


Different paths lead to different costs

- Complete decommissioning of the distribution grids in the all-electric scenario
- Partial decommissioning in the synthetic methane scenario
- Costs can be significantly reduced by choice of measure
  - Assumed ratio of deconstruction (5 %), filling and sealing (30 %) and sealing (65 %) is crucial
- Financing volume for decommissioning (annuity):
  - 1,130 Mio € in the all-electric scenario (Klimaneutral 2050)
  - 374.5 Mio. € in the synthetic methane scenario (Technologiemix 95)

05 Findings - Annuity costs declining in the long term

Annuities



Main cost blocks depend on scenario

- Operating costs are greatest cost block in the synthetic gas scenario
  - Operating costs in 2050 will still be 50 % of today's operating costs
  - 18 % of the annuity in 2050 are decommissioning costs
- Costs in the all-electric scenario dominated by decommissioning costs in the long term
  - From 2040, more than 50 % is spent on infrastructure reduction
  - Decommissioning costs the only cost block in 2050
- Decommissioning and conversions associated with long-term planning and financing issues

06 Conclusions and Further Research

Declining need for gas distribution grids in all greenhouse gas neutral scenarios

- **Path differences from 2030**
  - **Complete dismantling** in all-electric scenarios
  - **Extensive grid reduction** in moderate scenarios
  - Even high shares of synthetic methane in space heating get along with decreased gas distribution infrastructure
- **Main driver is the demand for space heating** by households and CTS
- Current and future grid expansion projects should be questioned
- Requirement for funding and planning standards for decommissioning

Further Research

- **Detailed look by diameter at network measures**
  - Accurate breakdown of costs by diameter
- **Effects of the use of hydrogen** in space heating
  - Comparable development to synthetic methane expected
  - Higher costs due to conversion assumed

Thank you for your attention

Chair of Energy and Resource Management

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A Appendix

03 Methodology

Kirchhoff's nodal rule

- sum of all inflows and outflows ($\dot{V}_k$) in a node is zero

$$\sum_{k=1}^{j} \dot{V}_k = 0$$

Darcy-Weisbach equation for pipeline diameters

- Stationary and turbulent flow within the pipeline
- Calculation of the pressure loss (Δp_{v})
- over the length (l) of a pipe,
- results from friction between the fluid and the pipe wall (described by the pipe roughness λ).
- **Simplification based on given pipeline diameters (d)** in gas distribution networks

$$\Delta p_{\mathrm{v}} = \lambda * \frac{l}{d^5} * \frac{8 * \delta}{\pi^2} * V^2$$

$$Flow_{ij} = \sqrt[2]{\frac{d_{ij}^5 * T_{norm} * \pi^2 * \left(p_i^2 - p_j^2\right) * 3600^2 * \frac{10^5}{16}}{\lambda * l * \delta * K_m * T * p_{norm}}}$$

$$s.t.\ Flow_{ij} \geq Flow_{i,j-1}$$

Derivation of GPRM

- Tow sets of nodes created
- intersection of both sets returns nodes of gas pressure measuring and regulating stations

$$DN_{larger} = \{nodes\ \in DN = DN_{max}\}$$

$$DN_{smaller} = \{nodes\ \in DN < DN_{max}\}$$

$$GPRM_{\mathrm{Total}} = DN_{larger} \cap DN_{smaller}$$

Homann et al. (2016), Rüdiger (2009), Cerbe and Lendt (2016)

03 Methodology

Total cost from three components

- Pipeline cost
- Connection cost
- GPRM cost

$$C_{\mathrm{Total}} = \sum C_{\mathrm{Pipelines}} + C_{\mathrm{Connection}} + C_{\mathrm{GPRM}}$$

Pipeline cost result from installation and material

- Pipeline cost (C_{Pipetype_i} in EUR/meter) per diameter type
- Installation depending (pro rata) on ground conditions:
  topsoil (IC_{T_i}), concrete soil (IC_{C_i}) and asphalt soil (IC_{A_i})
- other construction costs (p_{cs}) on a percentage basis

$$C_{\mathrm{Pipelines}} = \sum_{i=0}^{n} \left(\left(C_{\mathrm{Piptype}_i} + IC_{\mathrm{T}_i} * p_{\mathrm{T}} + IC_{\mathrm{C}_i} * p_{\mathrm{C}} + IC_{\mathrm{A}_i} * p_{\mathrm{A}} \right) * l_i \right) * (1 + p_{\mathrm{CS}})$$

Connection cost per connection

- Depending on number of connections and type

$$C_{\mathrm{Connection}} = C_{\mathrm{Connectiontype}} * A_{\mathrm{PressureLevel}}$$

GPRM cost

- Depending on number GPRM and pressure level

$$C_{\mathrm{GPRM}} = C_{\mathrm{GPRM}} * AGPRM_{\mathrm{PressureLevel}}$$

Annual network cost as annuity

- CAPEX from investments
- OPEX included as an annual percentage of CAPEX

$$Annuity = \sum CAPEX_R + OPEX_R$$

04 Data – Technical parameters for the calculations

	Standard Diameter	Diameter [m]	Cost [€/m]
low and middle pressure	DN32 – DN225	0.026 – 0.184	5.26 – 81.06
High pressure	DN32 – DN630	0.026 – 0.5156	5.26 – 232.51

Parameter	**description**	**Value**	**unit**
Lambda	Pipe roughness	0.026	
K_m	Compressibility Factor	0.91	
Rho_{norm}	Density	0.783	[kg/m3]
P_{norm}	Pressure	1.01325	Bar
T_1	Temperature	285	K
T_{norm}	Temperature	273	K

Symbols used in formulas (Page 8 and 9)

- $\dot{V}_k$ – flow at node k
- d – diameter
- l – length
- DN – standard diameter
- λ – pipe roughness
- K_m – compressibility factor
- δ – density
- Δp_{v} – pressure difference; p_i – pressure
- T – temperature
- IC_{T_i} – topsoil ,
- IC_{C_i} – concrete soil
- IC_{A_i} – asphalt soil
- $p_{\mathrm{T}}, p_{\mathrm{C}}, p_A$ – share of soil type

Cerbe and Lendt (2016), frank GmbH (2020), Kirchner et al. (2020),

04 Data – Technical parameters for the calculations

	Standard Diameter	Diameter [m]	Cost [€/m]
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High pressure	DN32 – DN630	0.026 – 0.5156	5.26 – 232.51

	Cost [€/unit]	Share of CAPEX [%/a]	Lifetime [a]
Pipeline	Depending on diameter	0.8	45
Connection	2,500	0.8	25
GPRM	14,000	5.8	25

Deconstruction and dismantling parameters	Share of grid [%]	Cost [€/km or €/unit]
Deconstruction	5	280.000
Filling and sealing*	30	70.000
Sealing	65	20.000
GPRM high pressure		75.000
GPRM low and middle pressure		10.000

Costs depend on the specific grid element

- Costs differentiated by pipeline diameter, GPRM and connection type
- Interest rate: 2 % p.a.

- $C_{\text{Pipelines}}$ – pipeline cost
- $C_{\text{Connection}}$ – connection cost
- C_{GPRM} – GPRM cost
- p_{CS} – share of other construction cost

- $AGPRM_{\text{PressureLevel}}$ – amount of GPRM at pressure level
- $CAPEX_R$ – capital expenditures in region R
- $OPEX_R$ – operational expenditures in region R

*a lower number than in the pulication is used based on information from the authors
frontier economics et al. (2017), Cerbe and Lendt (2016), frank GmbH (2020), Kirchner et al. (2020)