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Grids for Energy Efficient systems – electricity, district heating and gas grids

Energy Efficiency First Summit
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Brussels, Belgium

KU Leuven, Europa-Universität Flensburg, Halmstad University, Aalborg University

dirk.saelens@kuleuven.be, rui.guo@kuleuven.be, simon.meunier@kuleuven.be, christina.protopapadaki@kuleuven.be, bernd.moeller@uni-flensburg.de, eva.wiechers@uni-flensburg.de, urban.persson@hh.se, luis.sanchez_garcia@hh.se, iva@plan.aau.dk, noemi@plan.aau.dk

Context: Electrical, thermal & gas grids in a smart energy system

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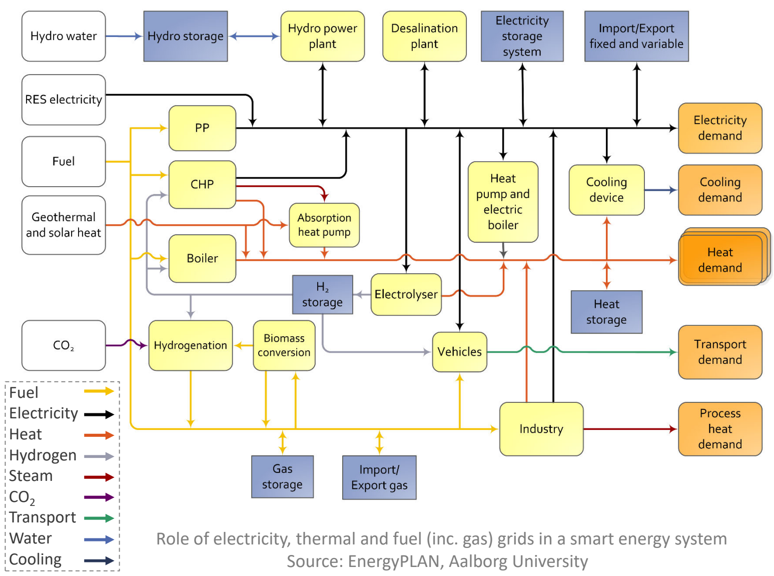
Problems

- **General:** Current energy grids are designed to integrate centralized carbon-intensive generation sources and there is a lack of interaction between the different energy grids.
- **Electrical (T4.1 & 4.2):** High transmission and distribution losses.
- **Thermal (T4.3):** Unexploited potential of heating networks.
- **Gas (T4.4):** Low transmission of biogas, hydrogen, syngas through current gas grids.

Research questions

- **General:** What is the potential of energy grids and how to modify them in order to integrate a higher share of low-carbon technologies at the lowest cost?
- **Electrical (T4.1 & 4.2):** Cost of reinforcing the distribution grids for allowing low-carbon technologies (LCT) integration ?
- **Thermal (T4.3):** Potential for district heating & associated infrastructure cost ?
- **Gas (T4.4):** Potential for power-to-gas and the transmission of new energy vectors (e.g. hydrogen) & associated infrastructure cost ?



Role of electricity, thermal and fuel (inc. gas) grids in a smart energy system
Source: EnergyPLAN, Aalborg University

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Assessment and simulation of EU **electricity** distribution grids

KU Leuven
Rui Guo
Simon Meunier
Christina Protopapadaki
Dirk Saelens

Challenges for the electricity grid

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The integration of the following low-carbon technologies (LCT) into the low-voltage grid can contribute to GHG emissions reduction:

- Photovoltaic (PV) systems
- Heat pumps (HP)
- Electric vehicles (EV)

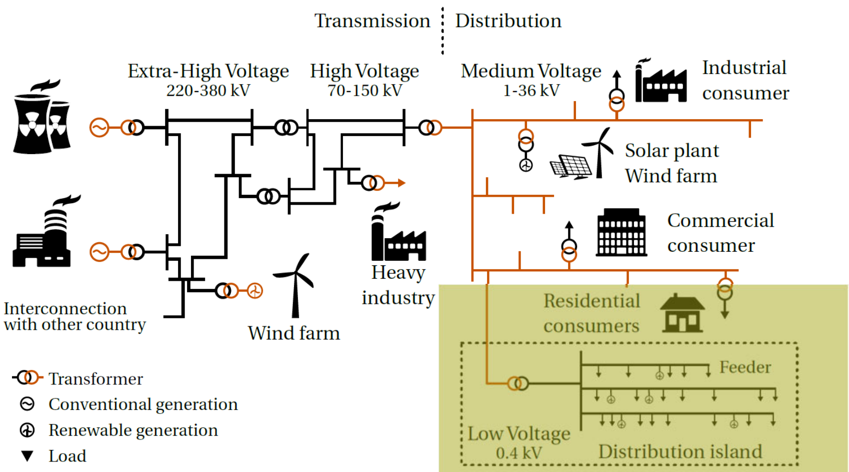
However, it triggers
grid stability problems:

- Voltage deviation and unbalance
- Cable and transformer overloading

Reinforcements are thus required:

- Transformer replacement
- Cables replacement
- Connecting LCTs to 3 phases

This comes at an added cost.



Detailed Analysis

What is the cost of the **cheapest** reinforcements to allow LCT integration?
What is the impact of the insulation level on the reinforcement costs?

The formula

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Life-cycle cost (LCC) of reinforcing the grid for a given low-carbon technology integration and building insulation scenario ($LCT\&U$) in a given *country*

Number of dwellings in rural/urban areas of the country

$$LCC^*(country, LCT\&U) = D_r(country) \cdot LCC^*_{d,r}(country, LCT\&U) + D_u(country) \cdot LCC^*_{d,u}(country, LCT\&U)$$

Grid reinforcement cost per dwelling for representative rural/urban grids for the considered scenario

Dwelling model

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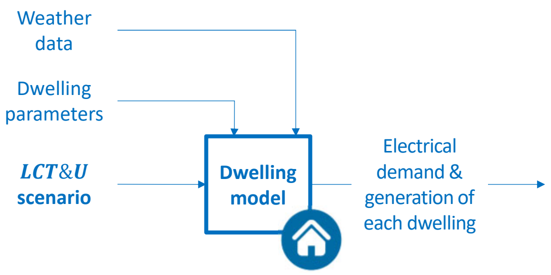

Dwelling model
- Based on occupant behaviour & dwelling parameters
- 10 minutes thermo-electric simulations

MODELICA

- **Weather data** from Meteonorm
- **Dwelling parameters** from WP1

Low-voltage grid model

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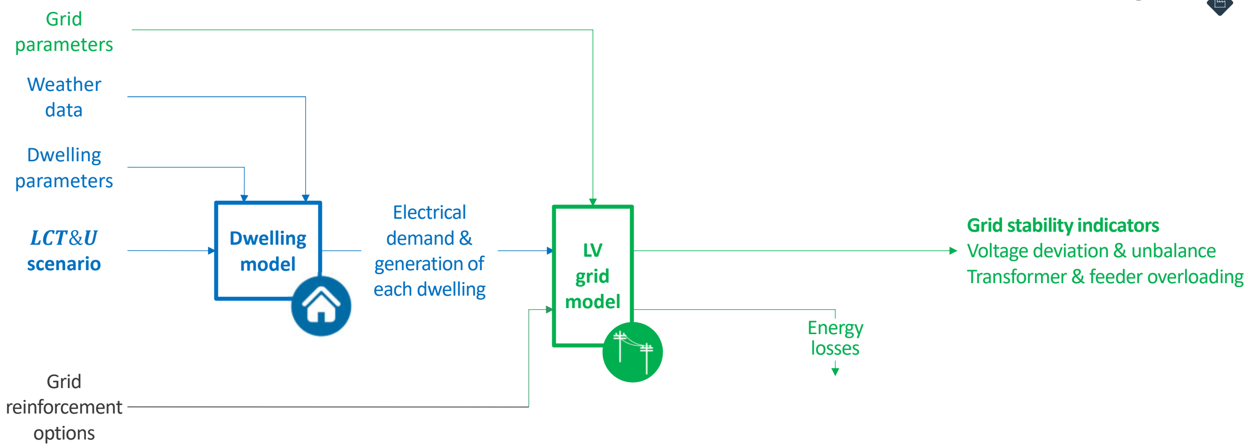

LV grid model
- Unbalanced power flow
- Defined grid stability indicators specific to EU standards

Representative **grid parameters** for EU countries obtained from **24** open access grids & **23** articles

Economic model

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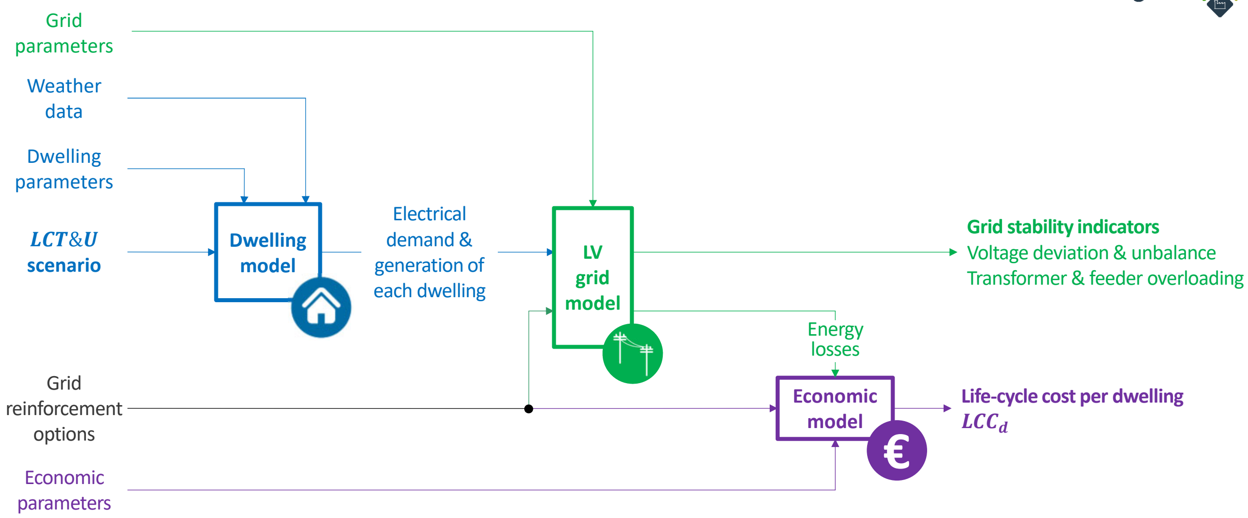

Economic model
- Investments in reinforcements
- Operating costs related to energy losses

Representative **economic parameters** for EU countries obtained from **23** articles

Computing the reinforcement cost per dwelling for representative grids

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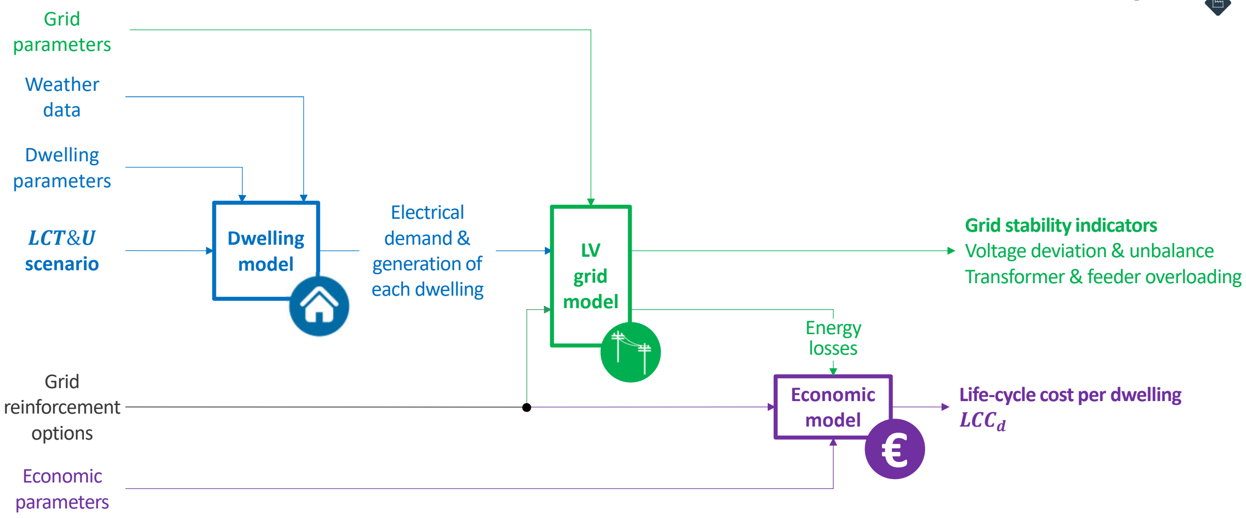

- ➢ For a given LCT integration rate and dwelling insulation level (e.g. 20% HP, 40% PV & U decreased by 50%), the grid stability is evaluated and the cost is computed for all reinforcement options.
- ➢ We select the cheapest technically viable reinforcement option, and deduced the reinforcement cost per dwelling LCC_d^*.

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Application to all EU countries – Country grouping

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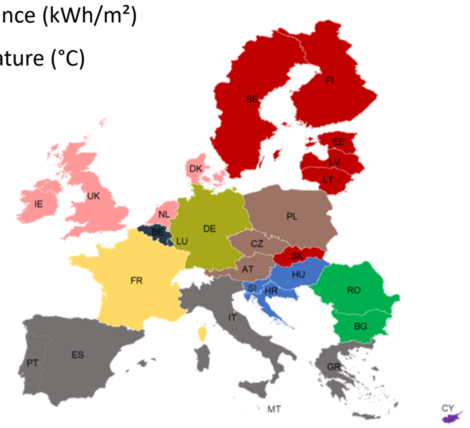
- ➢ Hierarchical clustering method
- ➢ Grouping criteria
  - Average extreme summer temperature (°C)
  - Average extreme summer irradiance (kWh/m²)
  - Average extreme winter temperature (°C)
  - Average UA-value (W/K)
  - Average roof area (m²)
  - Share of electric heating
  - Share of electric cooling



- Group 1: CY, MT
- Group 2: FR
- Group 3: PT, IT, ES, GR
- Group 4: HU, SI, HR
- Group 5: IE, NL, UK, DK
- Group 6: RO, BG
- Group 7: SE, FI, SK, LT, LV, EE
- Group 8: PL, CZ, AT
- Group 9: BE, LU
- Group 10: DE

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Developing cost functions: example application to group 5 (DK)

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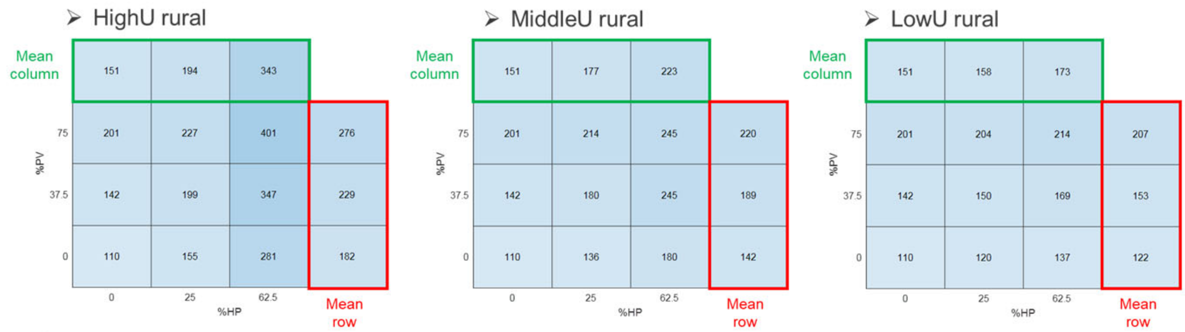
Average grid reinforcement cost per dwelling in rural area as a function of %HP, %PV, avg. U-value



By fitting we obtain:

$$LCC^*_{d,r}(DK, \%HP \;\&\; \%PV \;\&\; U) = \sum_{m,n,o} k_{m,n,o} \times (\%HP)^m \times (\%PV)^m \times (U)^o \quad (3^{\text{rd}} \text{ order polynomial}) \; \mathrm{R}^2 = 0.98\,, \mathrm{RMSE} = 11\,€$$

(similar approach for urban area)

This allows to compute the cost per country as an input for WP6:

$$LCC^*(DK, \%HP \;\&\; \%PV \;\&\; U) = D_r(DK) \cdot LCC^*_{d,r}(DK, \%HP \;\&\; \%PV \;\&\; U) + D_u(DK) \cdot LCC^*_{d,u}(DK, \%HP \;\&\; \%PV \;\&\; U)$$

Overview of the main findings

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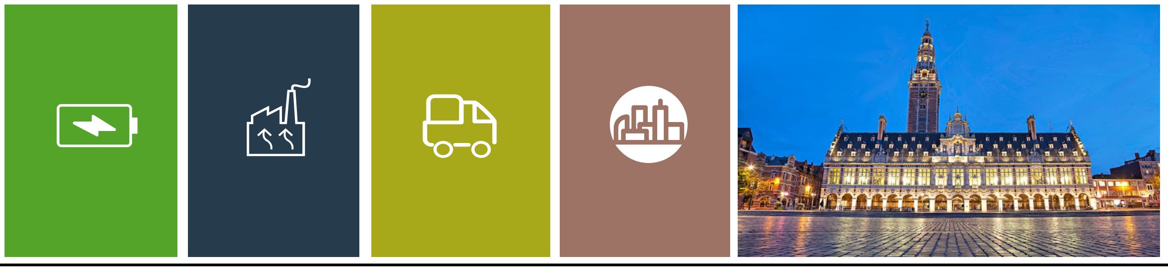
- The grid reinforcement cost is generally lower in urban versus rural areas.
  The grid reinforcement cost for urban grids is up to 360 €/dwelling, for rural grids up to 450 €/dwelling,
- The grid reinforcement cost is generally higher in badly insulated dwellings.
- The grid reinforcement cost is higher when increasing the %HP.
- The grid reinforcement cost is generally higher when increasing the %PV.
- At the worst insulation levels, the increase in grid reinforcement cost is higher for %HP than for %PV.
- At the best insulation levels, %PV tends to trigger more grid reinforcement cost than %HP.



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Spatial modelling and assessment of **thermal grids** for the EU28

Europa-Universität Flensburg, Halmstad University
Bernd Möller
Eva Wiechers
Urban Persson
Luis Sánchez García

Mapping of the heat sector 2015 → Future heat demand mapping

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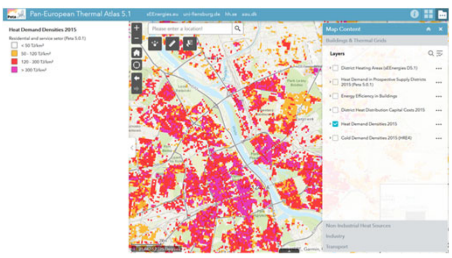
- Heat Roadmap Europe (HRE4) methodology extended to EU28 and adjusted to sEEnergies scenarios
- Current extent of DH systems
- Potential DH zoning → Prospective Supply Districts (PSD)
- Investment costs in distribution grids
- Allocation of RE and excess heat.



New version of Pan-European Thermal Atlas

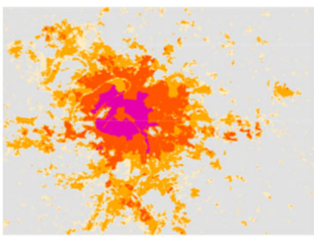
A new 100m population grid for 2030 and 2050

- Based on past urban development (JRC GHS, 1990 – 2015)
- Aligned with national population scenarios (PRIMES)
- Includes minimal expansion of urban areas

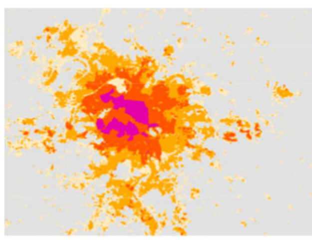
First of its kind attempt to model future population at this resolution and scale.

Future heat demand (WP1) on national level is distributed to 100m level by population and building age, adjusted to a European heating index (HRE)

Simple model that disregards urban planning and policy constraints.



heat demand: Paris, 2030

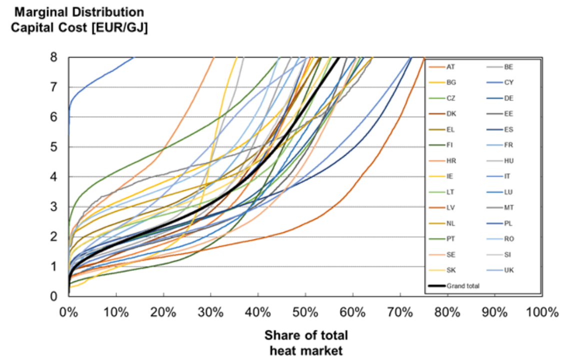


heat demand: Paris, 2050

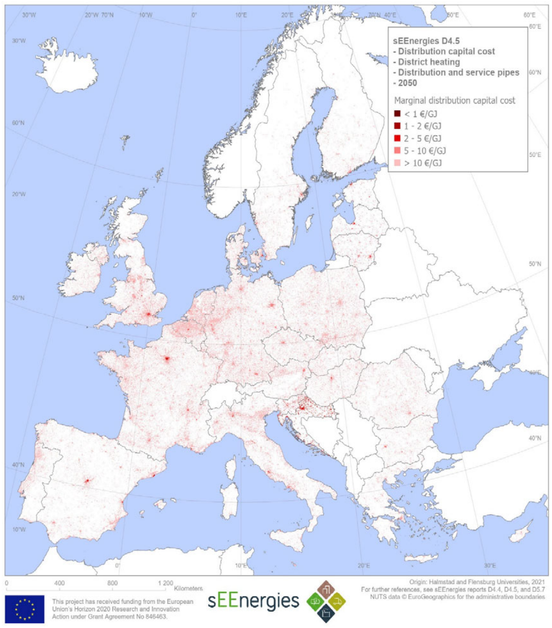
Representative thermal grids and their costs

Studies of existing district heating grids to arrive at country-specific DH grid costs

Thermal grids have been characterised by their physical suitability (representative heat demands) as well as their economic suitability (representative cost curves).



Source: Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy. 2019;176:604-22.



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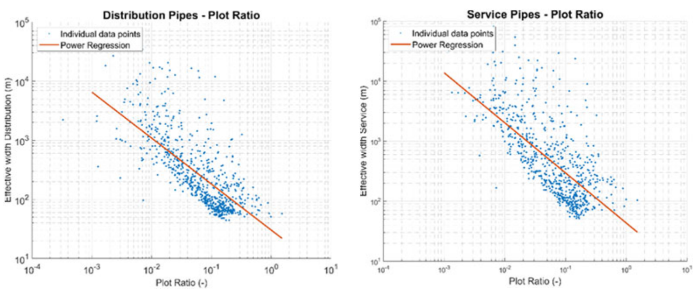
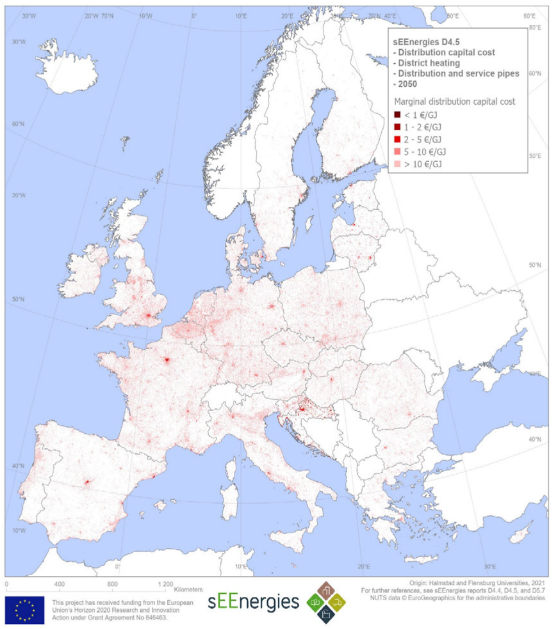


Correlation between effective width and plot ratios for distribution (left) and service (right) pipes, for the DH system of Odense, Denmark



Representative thermal grids and their costs

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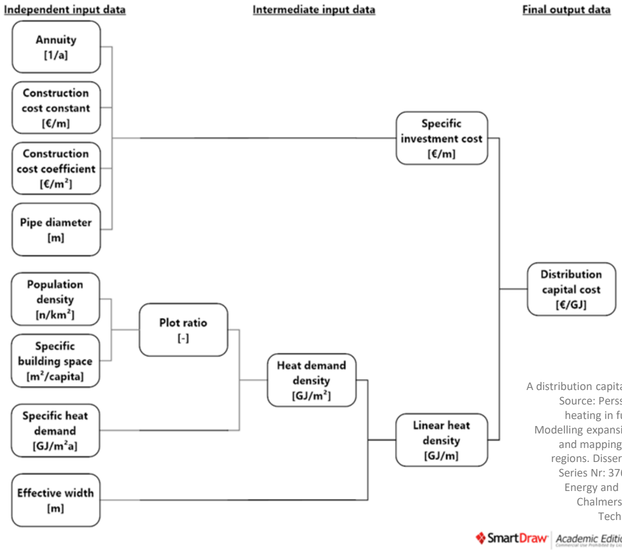
Studies of existing district heating grids to arrive at country-specific DH grid costs

- Model background:
  - Quantities and structure
    - The District Heating Distribution Capital Cost (DHDCC) model
      - Distribution system
        - Network pipes circulating a media fluid
      - Main output:
        - The specific distribution capital cost

$$\text{The specific distribution capital cost } (C_d) = a \cdot \frac{I}{Q_S} = Annuity \cdot \frac{\text{Total network investment cost } [€]}{\text{Annually sold district heat } [\frac{GJ}{a}]} \left[\frac{€}{GJ}\right]$$

- Basic equation, introducing trench length (L):

$$C_d = a \cdot \frac{I}{Q_S} = a \cdot \frac{\left(\frac{I}{L}\right)}{\left(\frac{Q_S}{L}\right)} \left[\frac{€}{GJ}\right]$$



A distribution capital cost model. Source: Persson U. District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions. Dissertation Thesis. Series Nr: 3769. Göteborg: Energy and Environment, Chalmers University of Technology, 2015.

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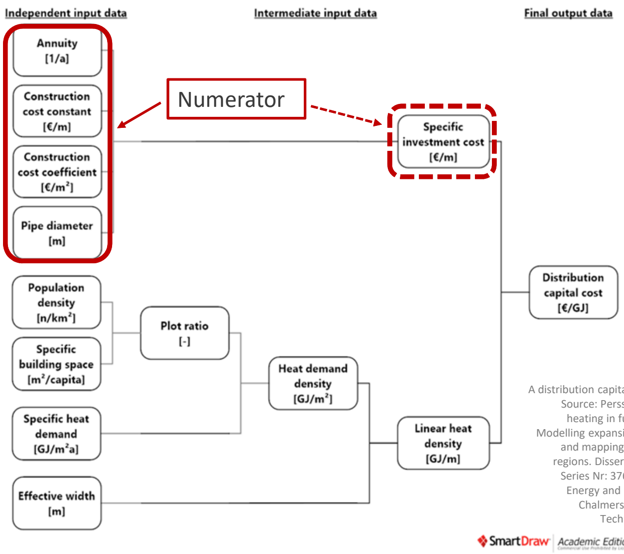
- Numerator independent input data:

$$C_d = a \cdot \frac{(C_1 + C_2 \cdot d_a)}{\left(\frac{Q_S}{L}\right)} \left[\frac{€}{GJ}\right]$$



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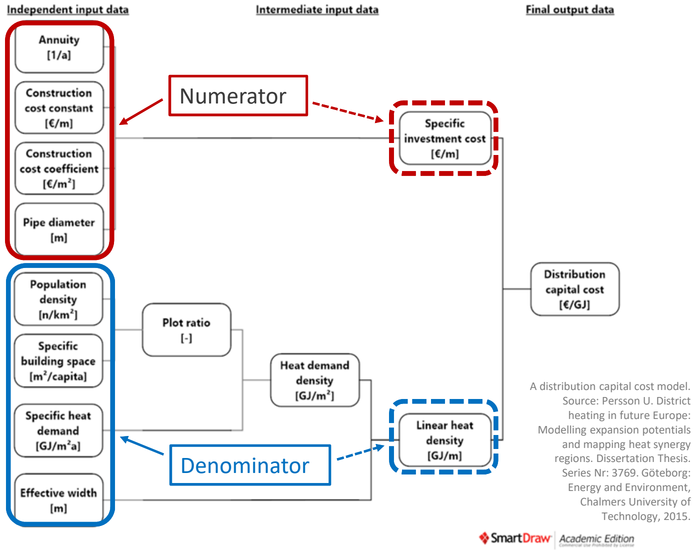
- Denominator independent input data:

$$C_d = a \cdot \frac{(C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w} \left[\frac{€}{GJ}\right]$$



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- Analytical model:

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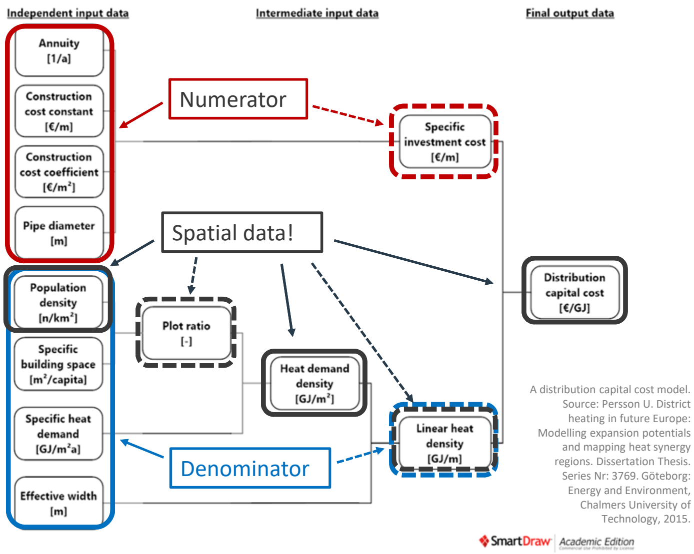

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Representative thermal grids and their costs

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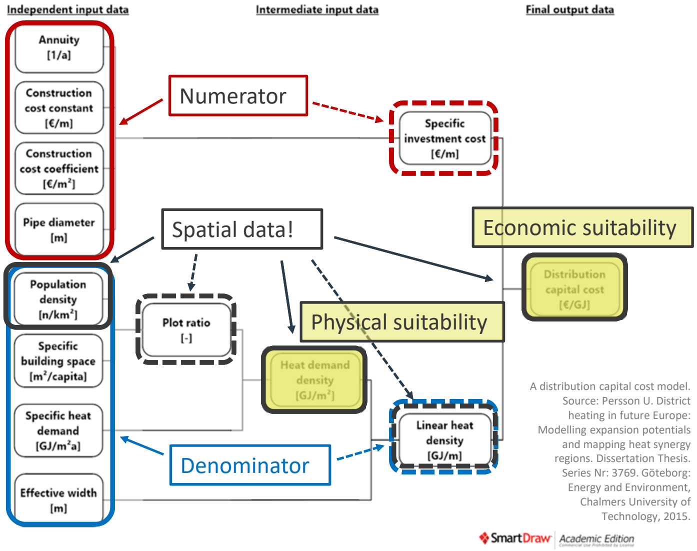

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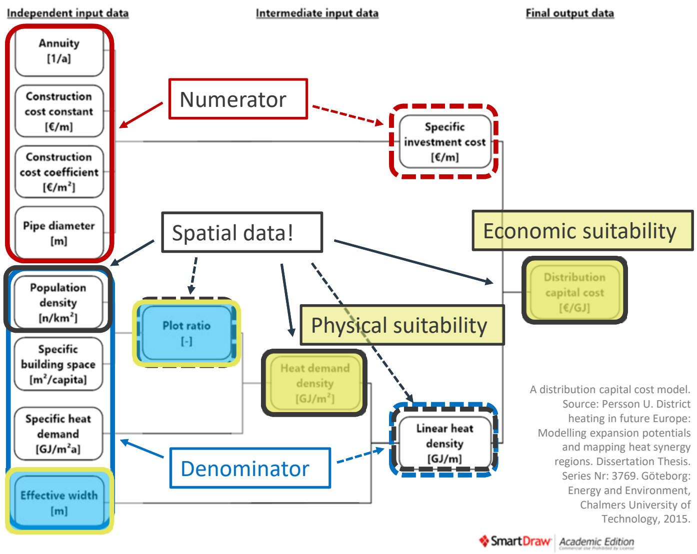

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Representative thermal grids and their costs

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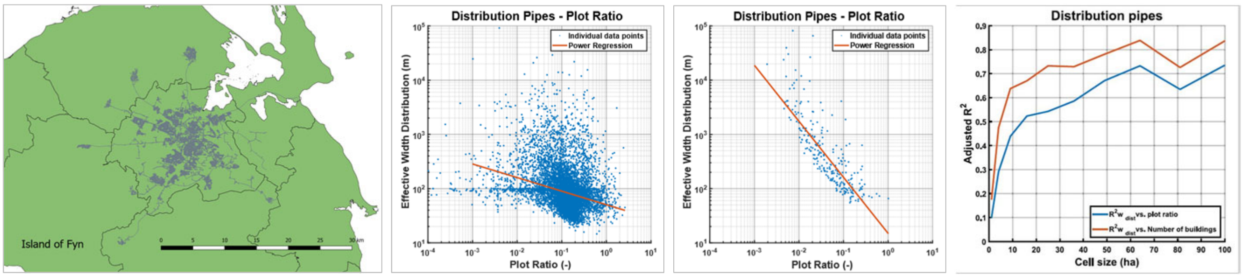
Studies of existing district heating grids to arrive at country-specific DH grid costs

- Model development:
  - Economic suitability
    - Effective width and plot ratio
      - Effective width: w, the relative demand for district heating pipe lengths (quota of land area and pipe length)
      - Plot ratio: e, a city planning parameter describing the fraction between building space area and land area (product of p and α)



Source: Sánchez-García, L., Averfalk, H., Persson, U., 2021. Further investigations on the Effective Width for district heating systems. Energy Reports 7, 351-358 (Conference presentation at the 17th International Symposium on District Heating and Cooling, Nottingham Trent University, 6–9 September 2021, Nottingham, UK).
Left: Overview image of the Odense city district heating network of Fjernvarme Fyn (Odense, Denmark), from which input data was used for 2.264 km of trench length.
Centre: Analysis of optimal cell size for assessment of effective width at low plot ratio conditions (cell size of 1 hectare at centre left, cell size of 100 hectare at centre right)
Right: Distribution of adjusted coefficients of determination for different cell sizes to assess optimal cell size. Effective width as function of plot ratio and of number of buildings.

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Representative thermal grids and their costs

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Studies of existing district heating grids to arrive at country-specific DH grid costs

$$w = \max(\kappa \cdot x^{\eta}, w_{min})$$

Pipe Type	Plot Ratio		Number of Buildings per ha		wmin [m]
	η	κ	η	κ	
Distribution	-0.7541	28.2	-0.7903	696.4	~55
Service	-0.8366	35.35	-0.9917	1 592	~45

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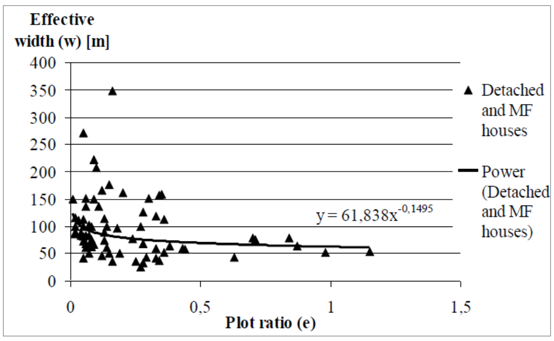
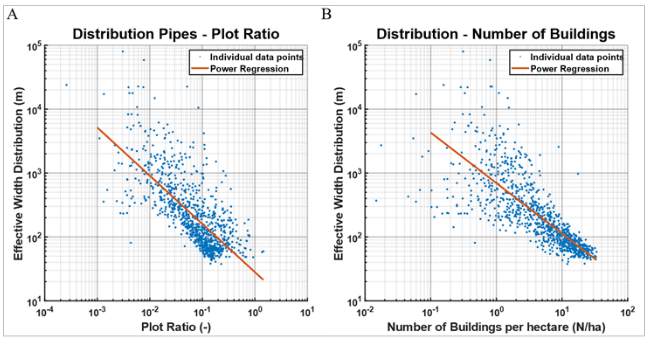


Source: Persson U, Werner S. Effective Width - The Relative Demand for District Heating Pipe Lengths in City Areas. 12th International Symposium on District Heating and Cooling, 5th to 7th of September, Tallin 2010. p. 128-31.



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Representative thermal grids and their costs

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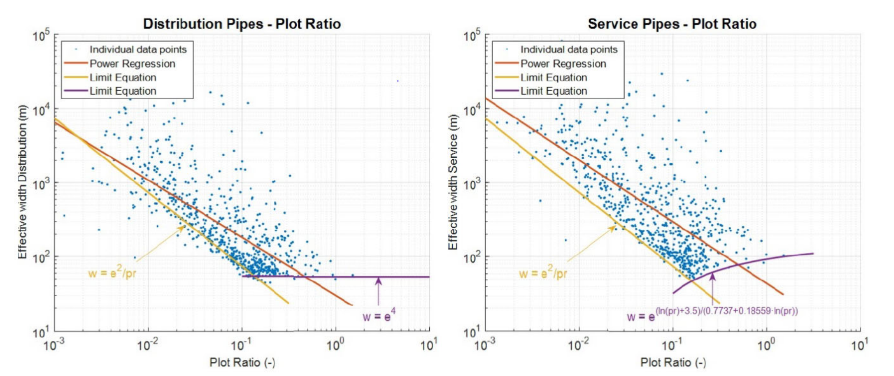
- Model development:
  - Economic suitability
    - Distribution and service pipes
    - Effective Width for a cell size of 16 ha with limit equations



Effective width as a function of plot ratio; for distribution pipes at left and for service pipes at right. Source: Persson U, Möller B, Sánchez-García L, Wiechers E. D4.5 District heating investment costs and allocation of local resources for EU28 in 2030 and 2050. sEEnergies - Quantification of Synergies between Energy Efficiency First Principle and Renewable Energy Systems. Horizon 2020 Project No. 846463. https://doi.org/10.5281/zenodo.48922712021

Representative thermal grids and their costs

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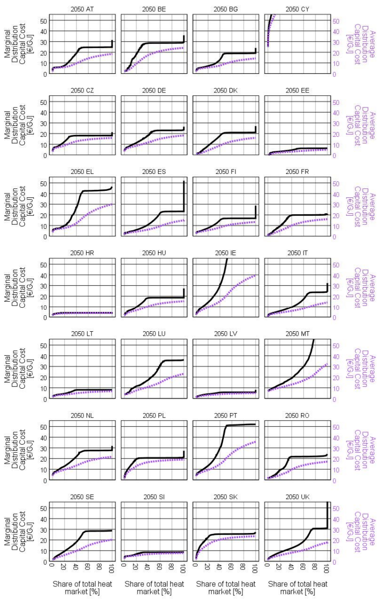
Studies of existing district heating grids to arrive at country-specific DH grid costs

- DH Distribution capital cost graphs for 2030 and 2050
  - National level cost curve aggregates
  - NUTS3 regional level cost curve aggregates
  - Calculated at the 1 ha-level
    - Heat demand density (driven by population density and building characteristics)
    - Construction cost functions for pipe networks (nation-specific where available)
    - Distribution and service pipes
    - Model development and first assessments in D4.5.

Table 1. Construction cost curve parameters for ten European Countries[2]

Country	Range validity (pipe diameter [mm])		Intercept	Slope	Source
	Min	Max	€/m	€/m²	
Germany	25	300	349	4213	(Besier, Klöpsch, & Wagner, 2009)
Spain	65	125	354	4314	(Cuesta, 2020)
France	65	450	*	*	(Roger, 2020)
Croatia	25	250	*	*	(Dorotić, 2020)
Italy	50	400	540	2087	(Denarie, 2020)
Lithuania	70	600	71	3262	(Gurklienė, 2020)
Hungary	25	200	*	*	(Edit, 2020)
Netherlands	65	250	549	3370	(Schepers et al., 2019)
Sweden	50	400	439	4073	(Sánchez-García, 2017; Svensk Fjärrvärme AB, 2007)
United Kingdom	25	500	549	2236	(AECOM et al., 2017)



Distribution capital costs for district heating by EU Member States.
Distribution and service pipes.
Source: sEEnergies D4.5 deliverable report, 2021

Potential DH by extent and cost, allocation of excess heat and RE potentials

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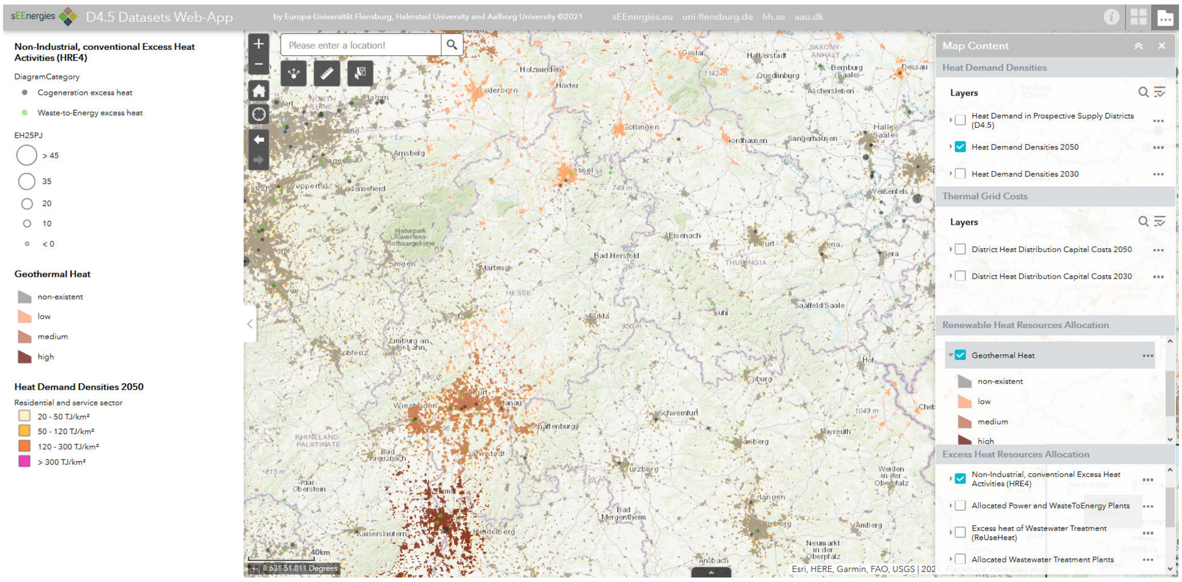
Published and visualised by means of a Web-based Map



Potential DH by extent and cost, allocation of excess heat and RE potentials

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Task 4.3: Spatial modelling and assessment of **thermal grids** for the EU28

- A model of the future population distribution (physical suitability for district heating)
  - Development and testing of a novel approach based on time series data for population developments, local linear regression, adjustment to national and regional (NUTS3) population forecasts, emphasis on densification.
- Modelling of future distribution capital costs (economic suitability for district heating)
  - Development of distribution capital cost model:
    - Detailed study of effective width on the basis of high-resolution data from existing large-scale system (Odense)
    - Nation-specific construction costs where available
    - Model scope: Both distribution and service pipes considered
- Challenges
  - Heat demand distribution at low densities in rural areas
  - Raster data type for physical suitability (float, not integer)

Further development in WP5!

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Assessment of role and costs of **gas grids** and storages

Aalborg University
Iva Ridjan Skov
Noémi Schneider

Objectives & scope

- Present **the state of play of the different types of gas grids and storages** in Europe (key technologies, performance indicators, and costs)
- Analyze the impact of **renewable technologies** on the different types of gas grids and storages in future perspectives.

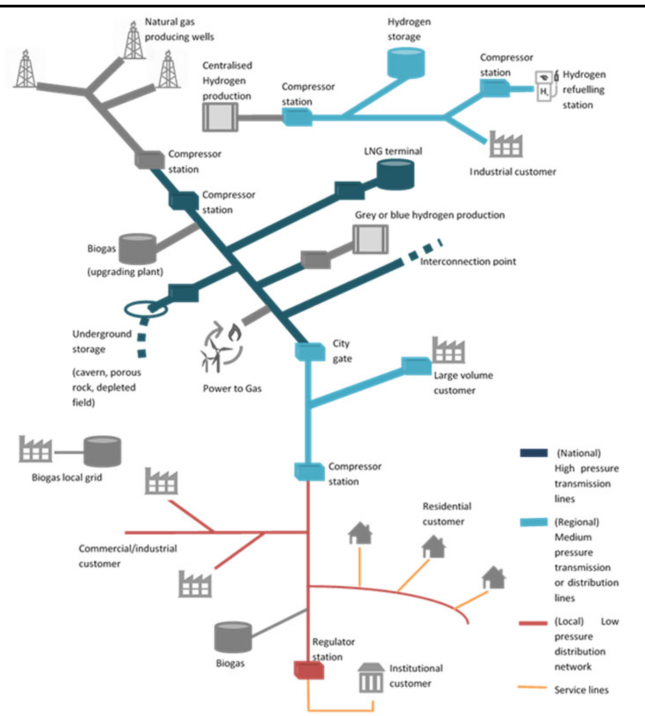
Methodology

Assessment of the role and costs of the existing gas grids

- Data collection on state-of-play of existing gas grids
- Investment costs are derived for all EU countries by adjusting the share of the costs associated with the installation of the technology according to the country labour costs
- Outputs review
  - European survey: few answers
  - Supplemented by literature review

Future role of gas grids and types of gases

- Literature review



Assessment of the role and costs of the existing gas grids and storages

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- Overview of the current status of European gas grids, interconnections and storages
  - ✓ **Natural gas** infrastructure is well-developed and interconnected and provides Europe with around 1,500 TWh of cross-seasonal flexibility.
  - ✓ Existing **hydrogen** transport infrastructures correspond to industrial clusters. The permitted concentration of hydrogen in the natural gas grid varies significantly between countries.
  - ✓ So far, the **greening of the gas system**, based on biogas and biomethane, has proceeded to a share of about 4%.
- Data sheet (cost database) with more than 800 cost estimates
  - ✓ Investment costs for **natural gas** transmission, distribution and service lines
  - ✓ Investment costs for dedicated **hydrogen** grid or retrofitting of natural gas grids for hydrogen transportation
  - ✓ **Biogas** upgrading investment costs

Main outputs (Deliverable 4.3 & 4.4)

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Take away messages

KU Leuven, Europa-Universität Flensburg, Halmstad University, Aalborg University
Dirk Saelens, Rui Guo, Simon Meunier, Christina Protopapadaki,
Bernd Möller, Eva Wiechers, Urban Persson, Luis Sánchez García
Iva Ridjan Skov, Noémi Schneider

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Summary and main conclusions

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Electricity grids

- Developed a **techno-economic methodology** to estimate the low-voltage **grids reinforcement cost** as a function of the residential **low-carbon technologies** integration and **dwelling insulation level scenario**.
- The methodology has been applied to **EU countries.**

Thermal grids

- Applied and **extended** mapping of **current** and **future heat demands** and potentials of district heating to **EU28**.
- Studied **representative thermal grids** and included **country-specific costs** to identify DH suitability across Europe.
- **Mapped** potential DH by extent and cost, and **allocated excess heat** and **RE potentials** using online mapping.

Gas grids

- Presented key **techno-economic data** on existing European **natural gas**, **biogas**, **biomethane**, **syngas** and **hydrogen** infrastructures.
- Analyzed the potential to use the **existing natural gas grids** for biogas, biomethane, syngas and hydrogen.

Energy efficiency matters!

- **Grid related results strongly depend on the chosen scenarios**

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Thank you for your attention

KU Leuven, Europa-Universität Flensburg, Halmstad University, Aalborg University
Dirk Saelens, Rui Guo, Simon Meunier, Christina Protopapadaki,
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Iva Ridjan Skov, Noémi Schneider

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