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Energy Efficiency in Smart Energy Networks and Smart Grids
Estimating grid investments in the EU

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

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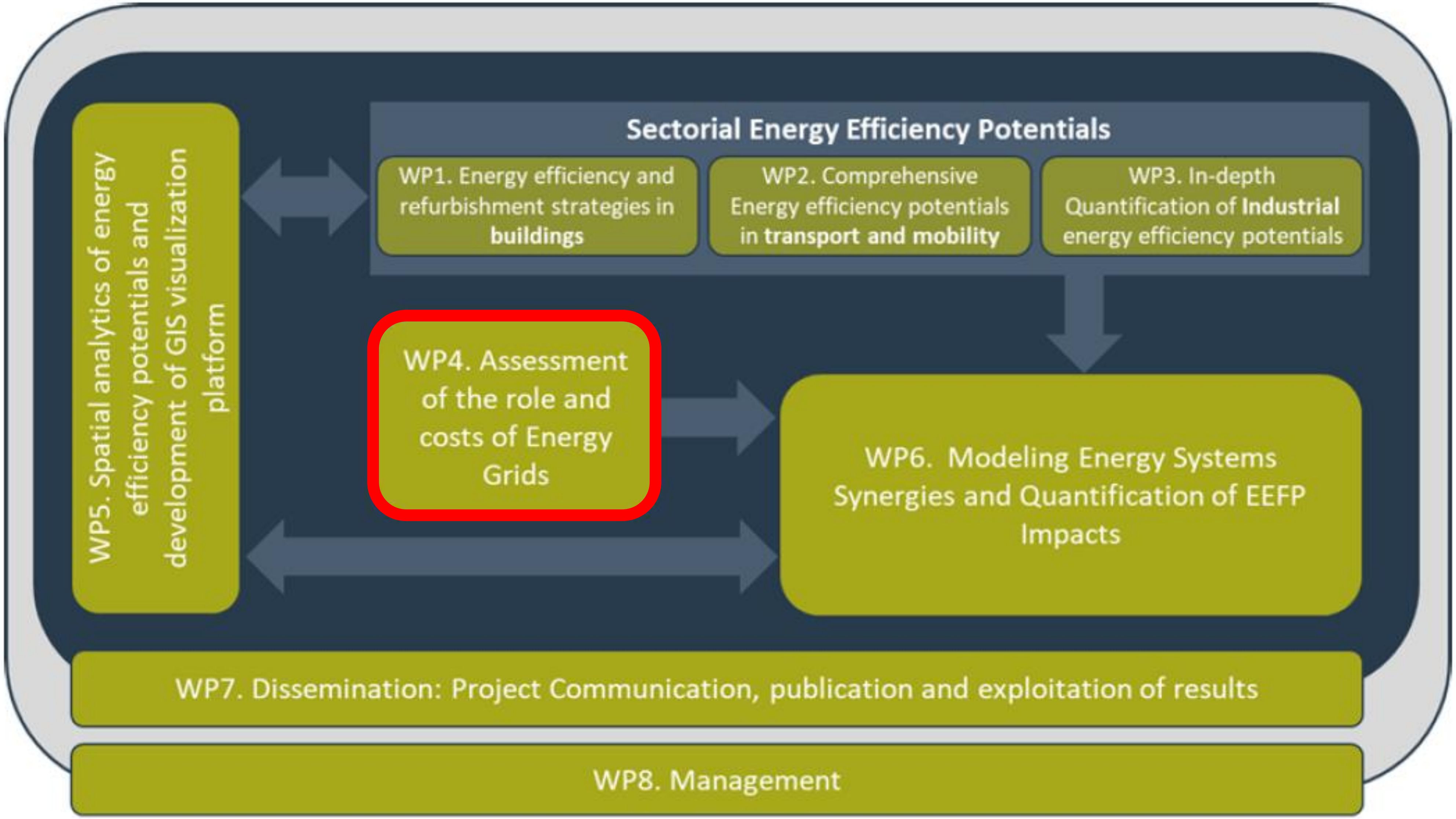
sEEnergies: overview of workpackages

Focus of WP4 is on the role of Energy Grids



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

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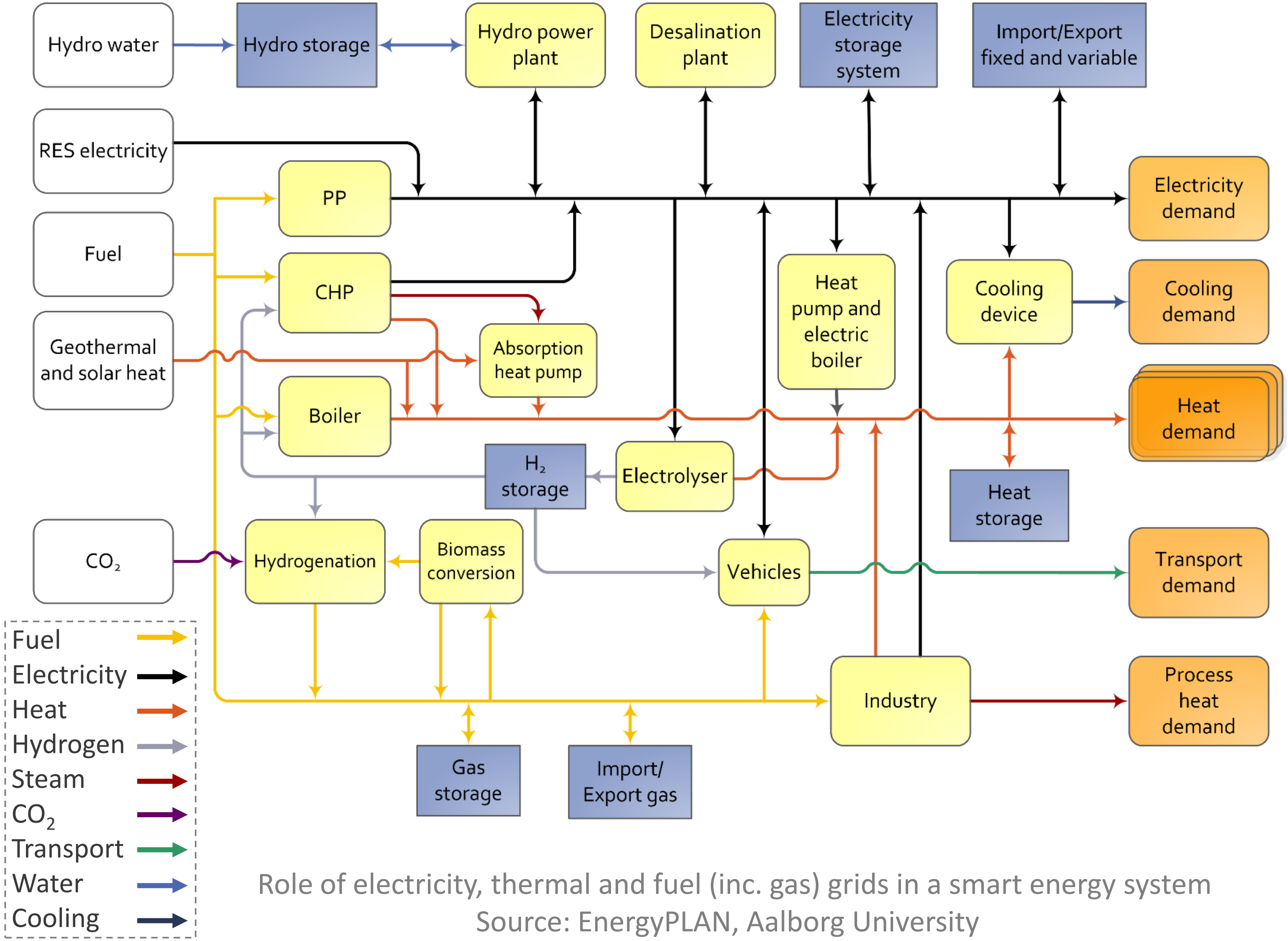
Problems

- **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:** How to modify energy grids 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

WP 4 – Task 4.1 & 4.2

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

KU Leuven
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Simon Meunier
Christina Protopapadaki
Dirk Saelens

Challenges for the electricity grid

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

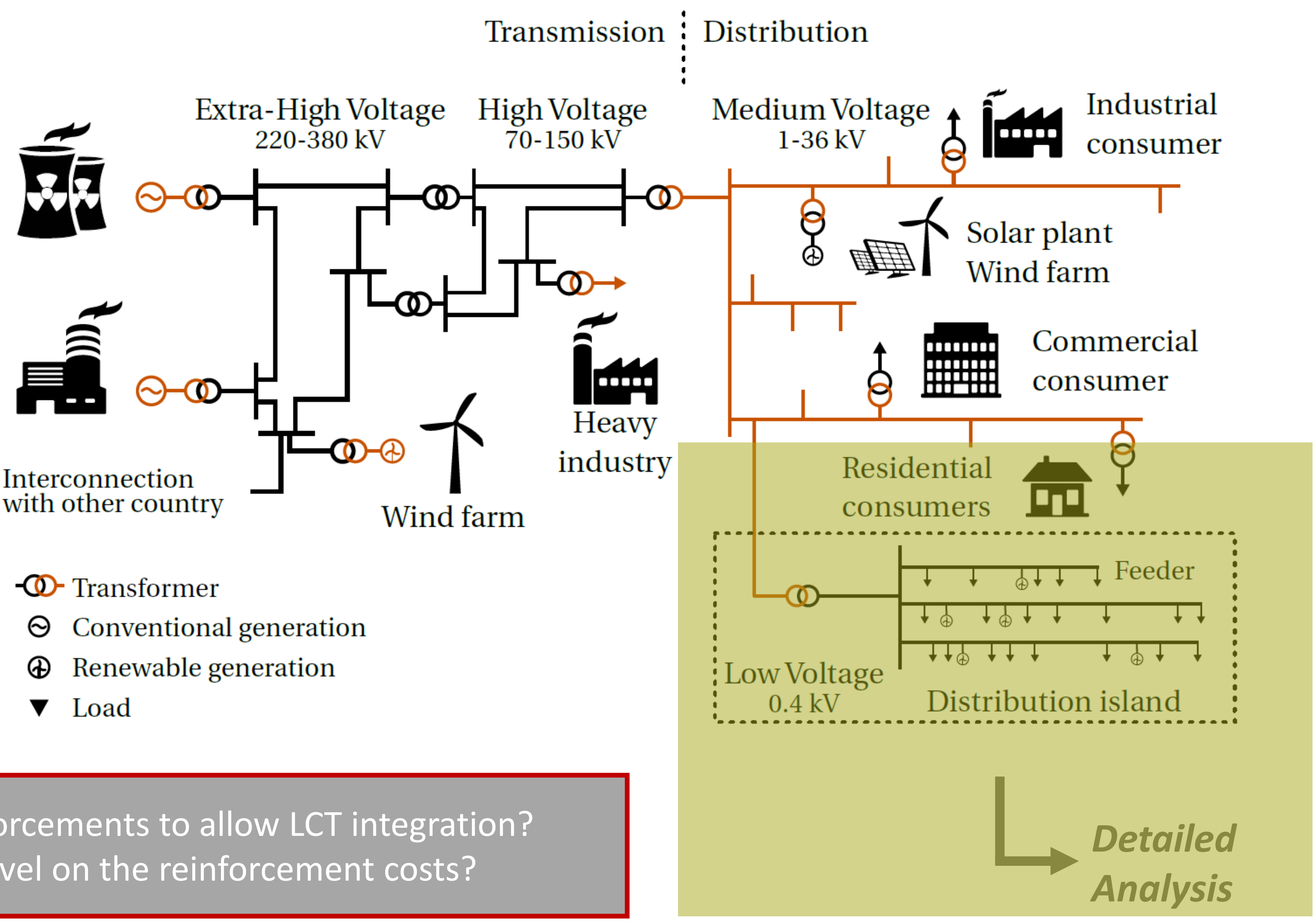
However, it triggers
grid stability problems:

- 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.



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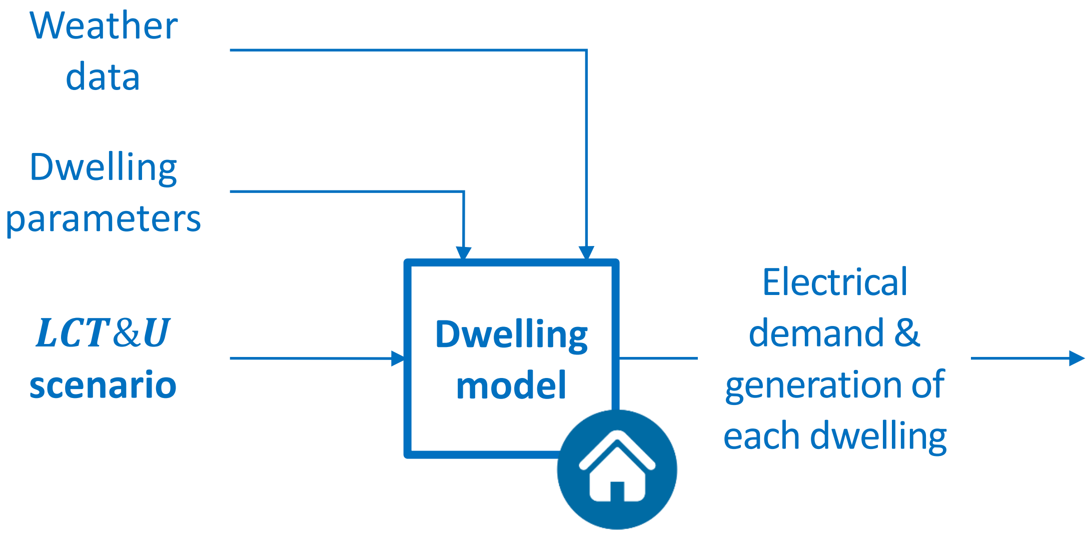
Life-cycle cost of reinforcing the grid for a given low-carbon technology integration and building insulation scenario $LCT\&U$ in a given *country*

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



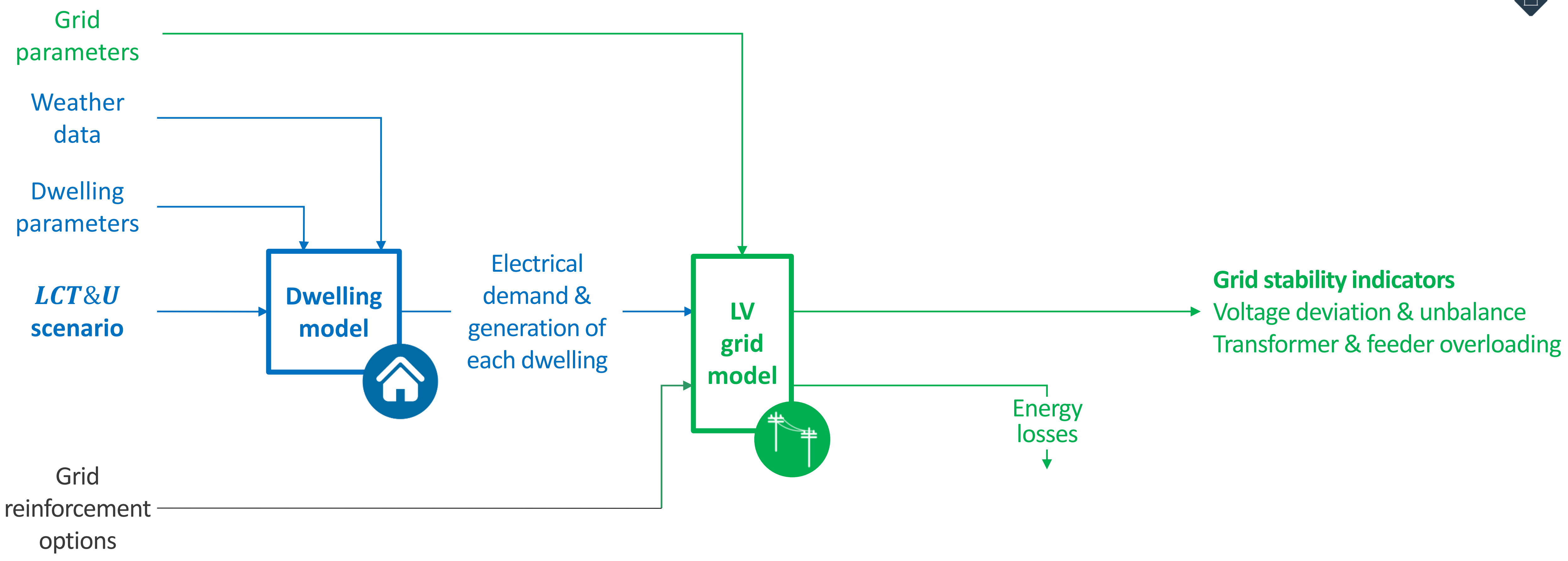
Dwelling model

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

MODELICA

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

Low-voltage grid model

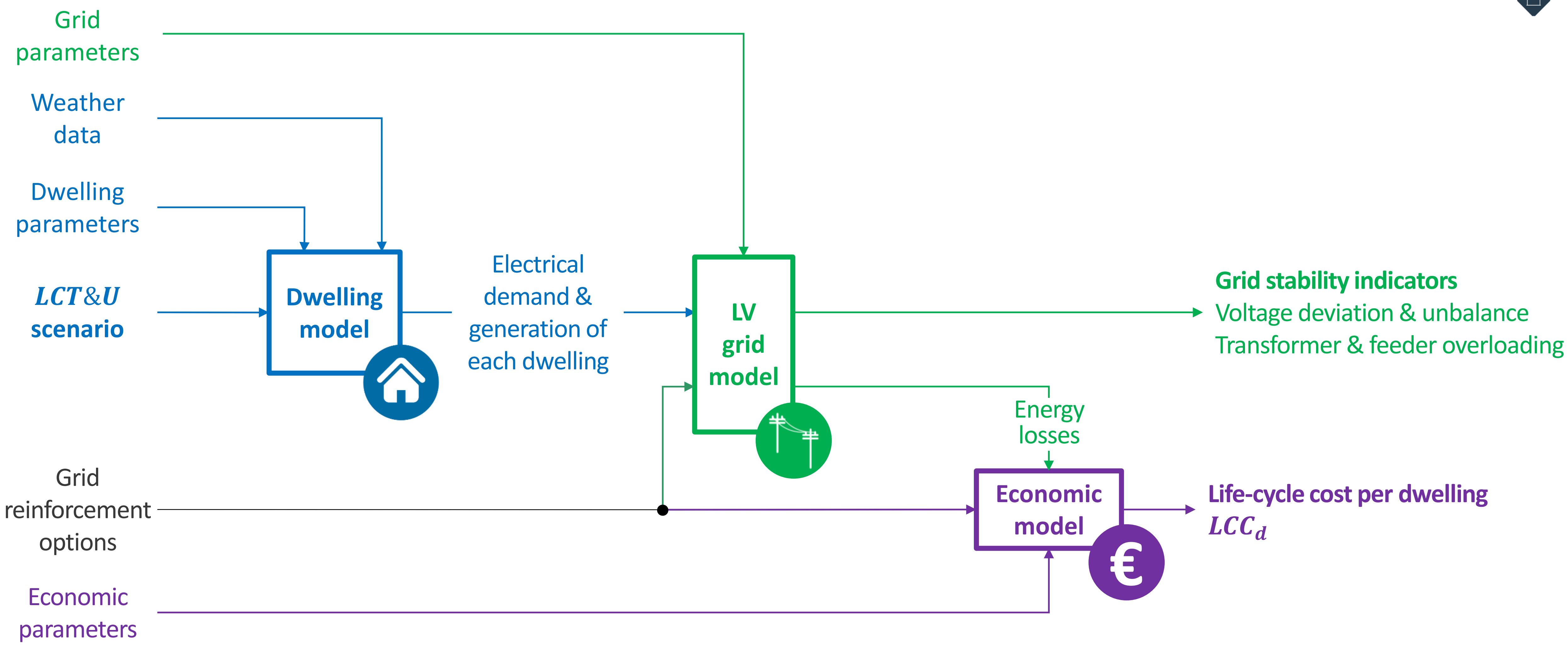


LV grid model

- 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

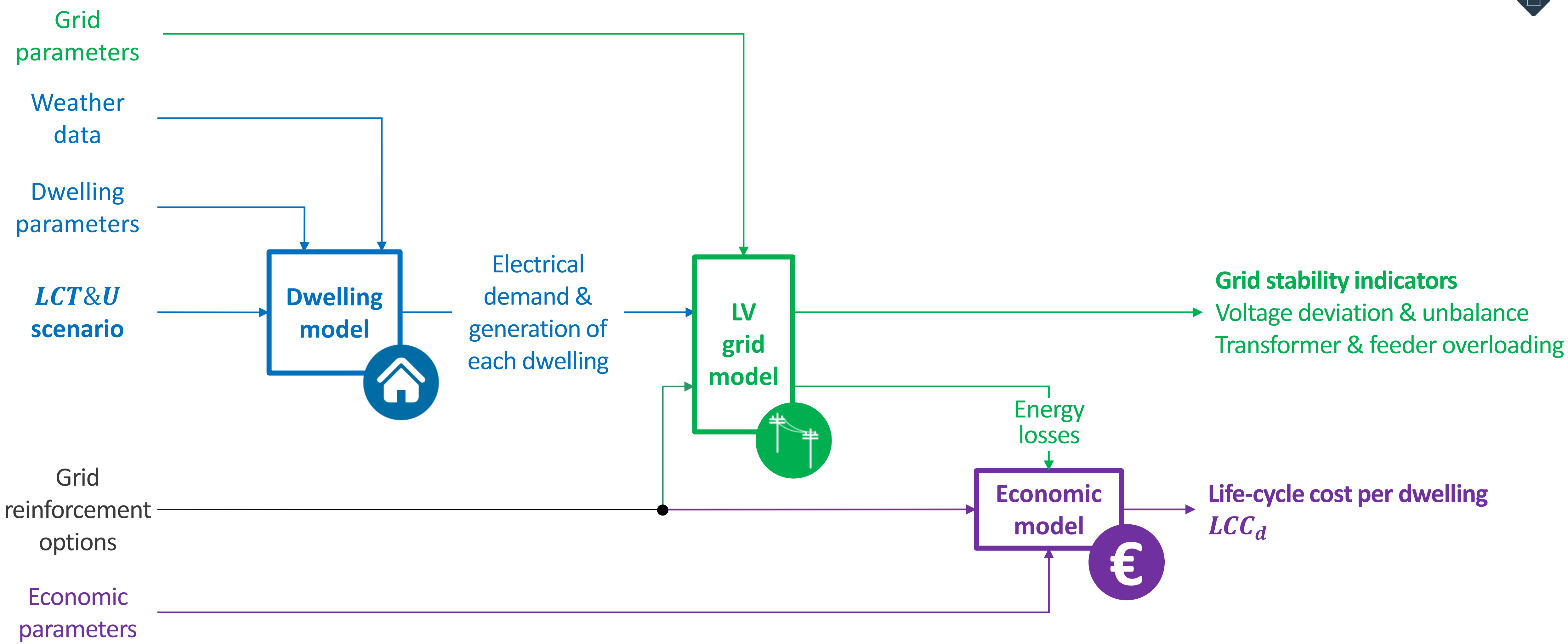


Economic model

- Investments in reinforcements
- Operating costs related to energy losses

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

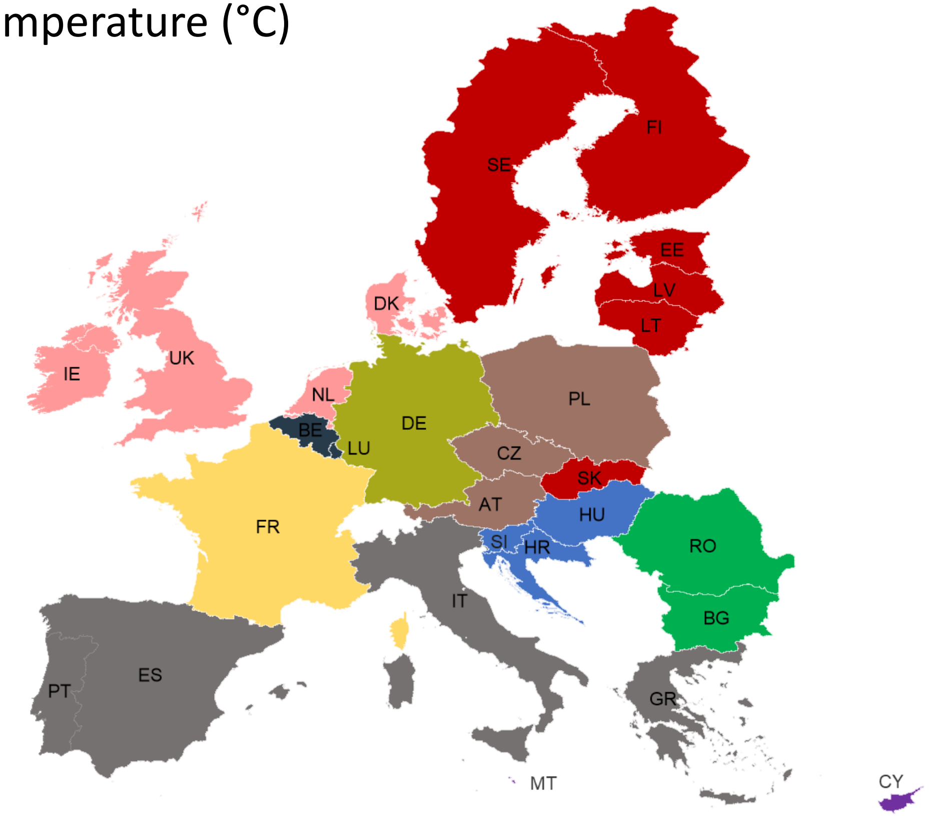
Computing the reinforcement cost per dwelling for representative grids



- 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^*.

Application to all EU countries – Country grouping

- 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



simulation status

		simulation status
	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	✓

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

➢ HighU rural

%PV \ %HP	0	25	62.5	Mean row
Mean column	151	194	343	
75	201	227	401	276
37.5	142	199	347	229
0	110	155	281	182

➢ MiddleU rural

%PV \ %HP	0	25	62.5	Mean row
Mean column	151	177	223	
75	201	214	245	220
37.5	142	180	245	189
0	110	136	180	142

➢ LowU rural

%PV \ %HP	0	25	62.5	Mean row
Mean column	151	158	173	
75	201	204	214	207
37.5	142	150	169	153
0	110	120	137	122

By fitting we obtain:

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

(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

- 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.

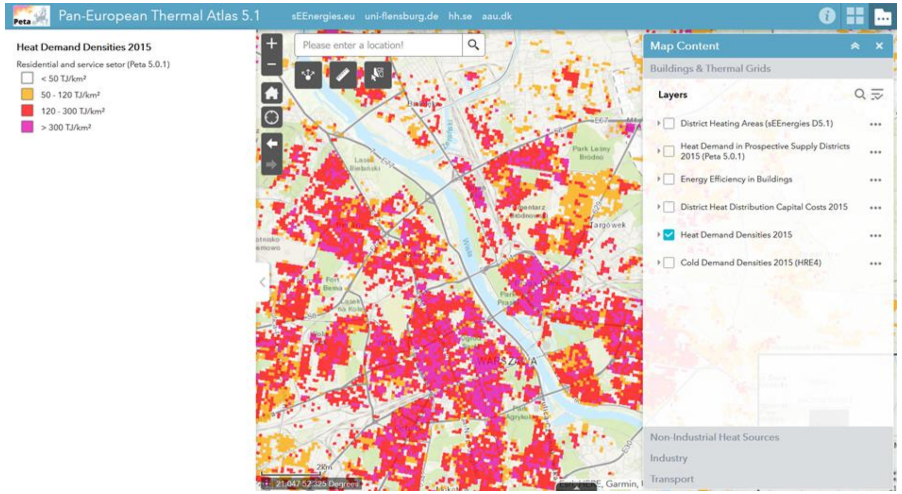
WP 4 – Task 4.3

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

- 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

Future heat demand mapping

A new 100m population grid for 2030 and 2050

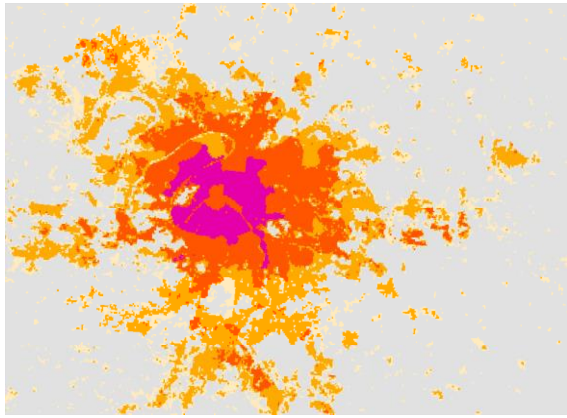
- Based on past urban development (JRC GHS, 1990 – 2015)
- Aligned with national population scenarios (PRIMES)
- Includes moderate expansion of urban areas

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

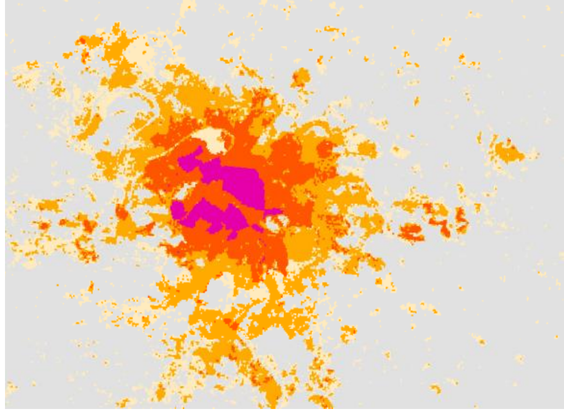
Future heat demand (WP1) on national level is distributed to 100m level by population, adjusted to heating index (HRE)

Simple model that disregards sectoral distribution, age of buildings and urban planning and policy constraints.

Information will be made available through web app



heat demand: Paris, 2030

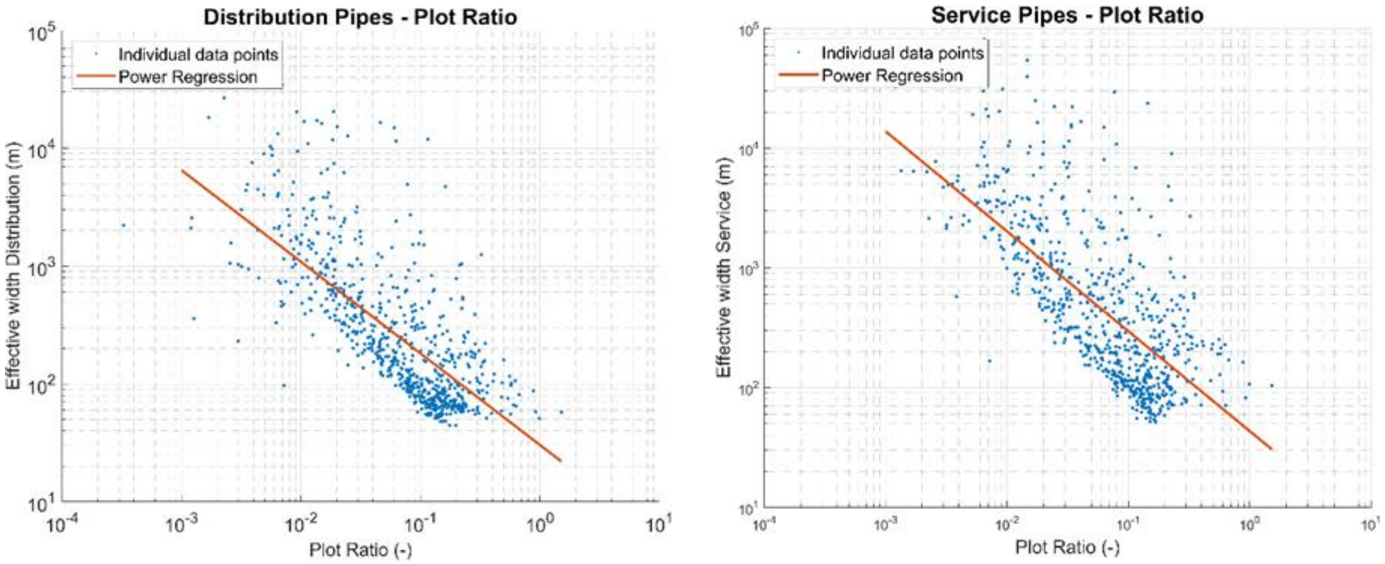


heat demand: Paris, 2050

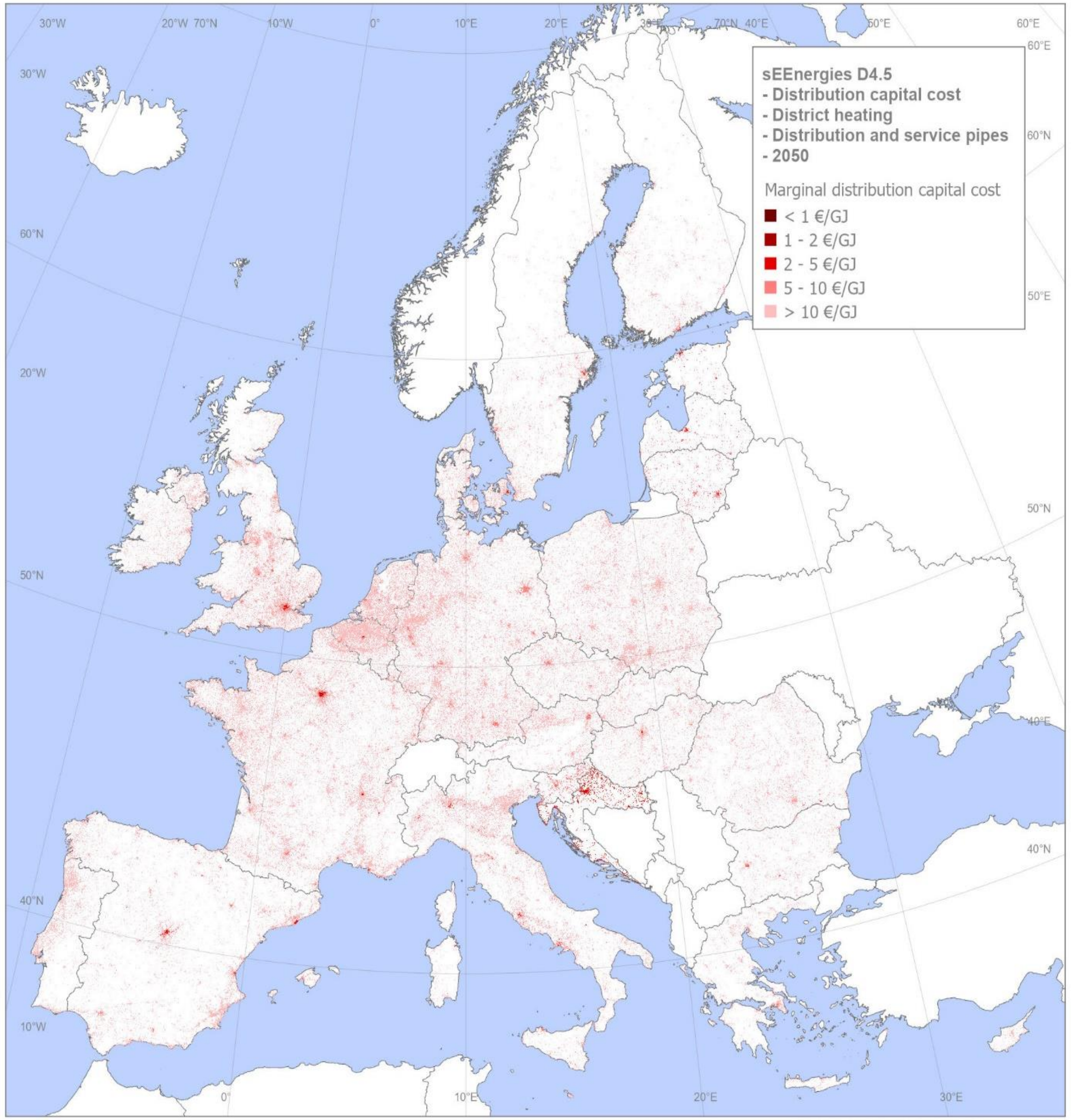
Representative thermal grids and their costs

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).



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



0 400 800 1 200 Kilometers

Origin: Halmstad and Flensburg Universities, 2021
For further references, see sEEnergies reports D4.4, D4.5, and D5.7
NUTS data © EuroGeographics for the administrative boundaries

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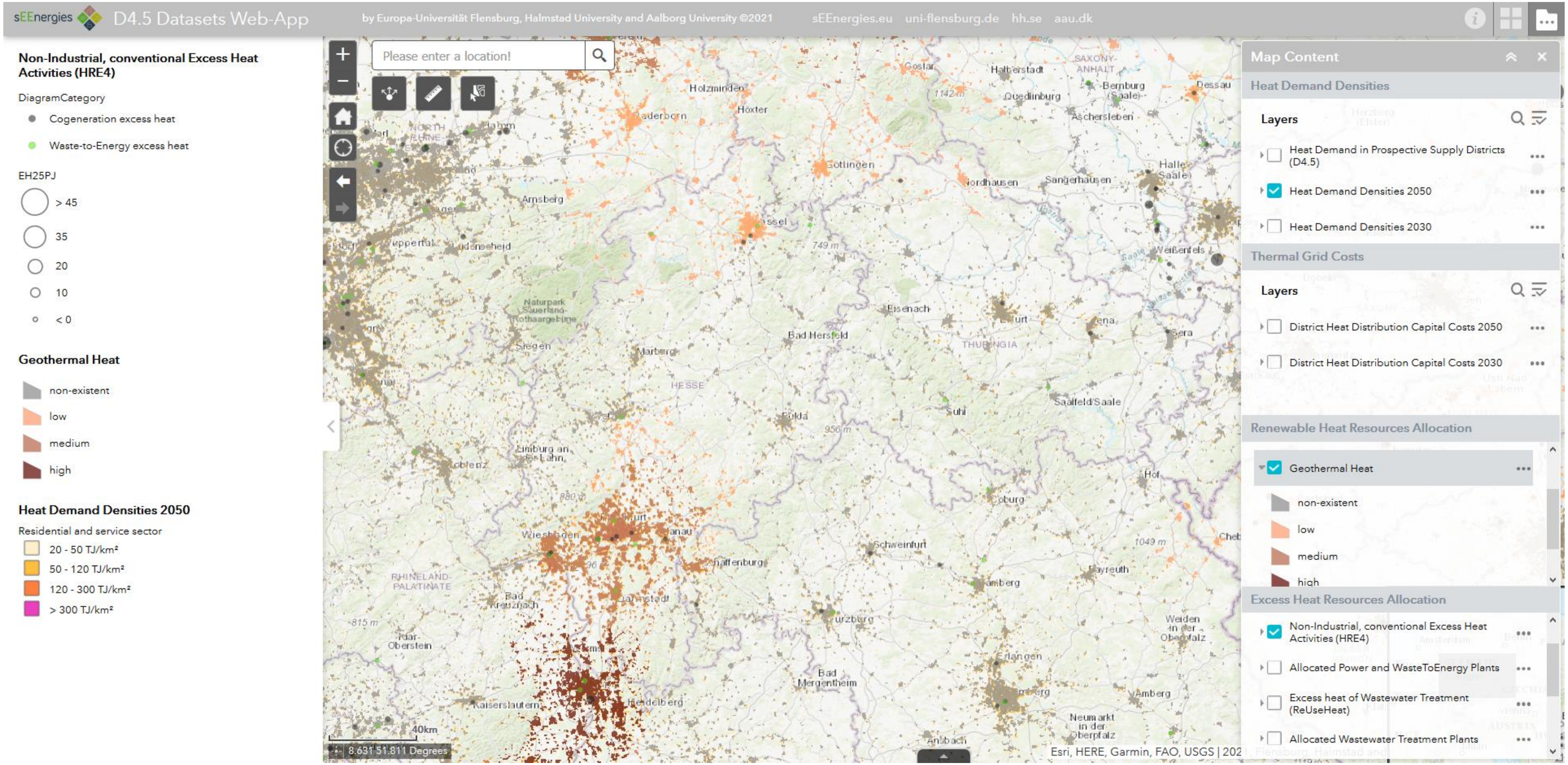
Potential DH by extent and cost, allocation of excess heat and RE potentials

Published and visualised by means of a Web-based Map



WP 4 – Task 4.4

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.

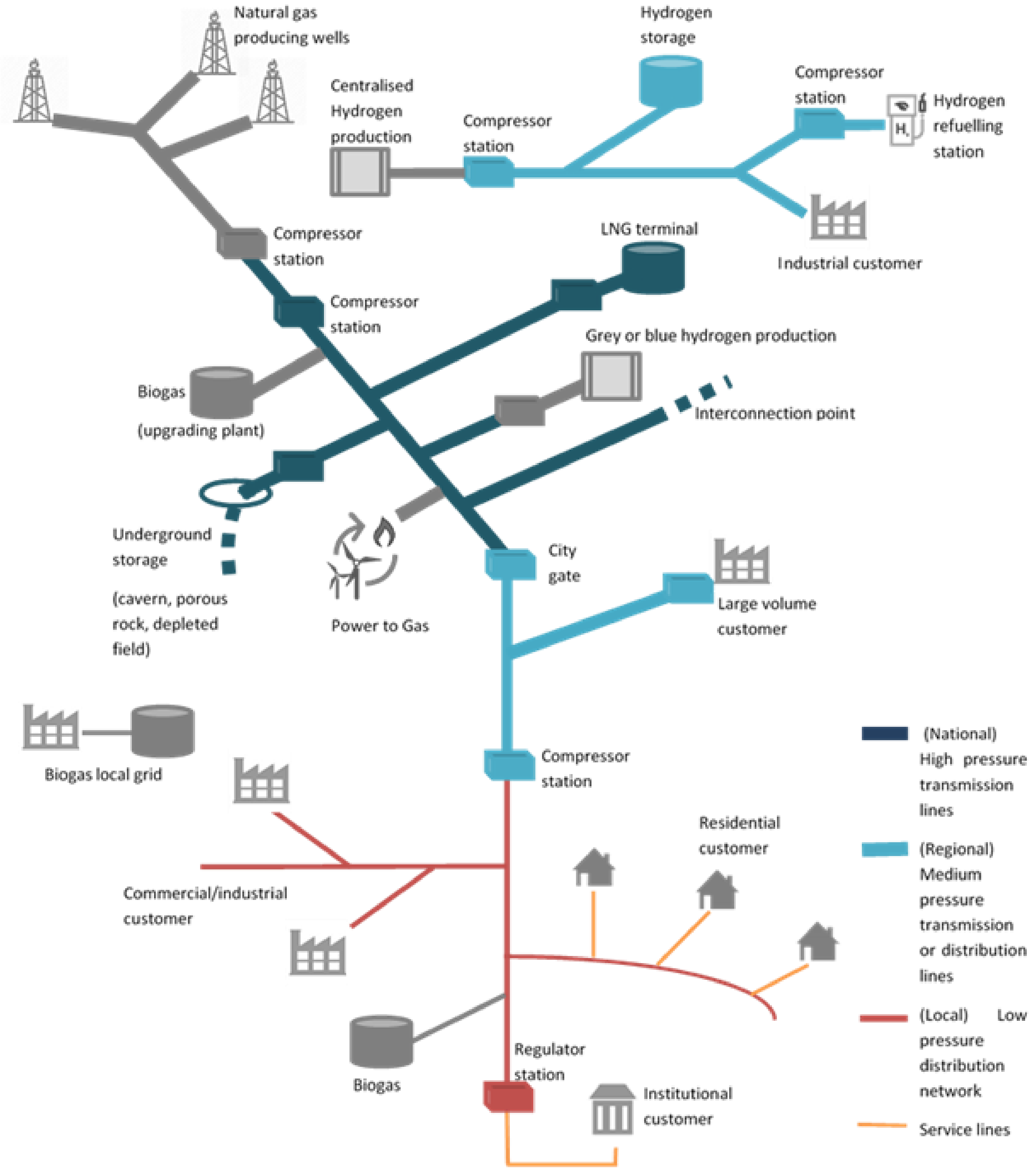
Methodology

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)

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

Take away messages

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**