Modeling the technical and economic feasibility of district cooling networks

Strategic Planning and Viability Assessment for Implementing District Cooling Networks

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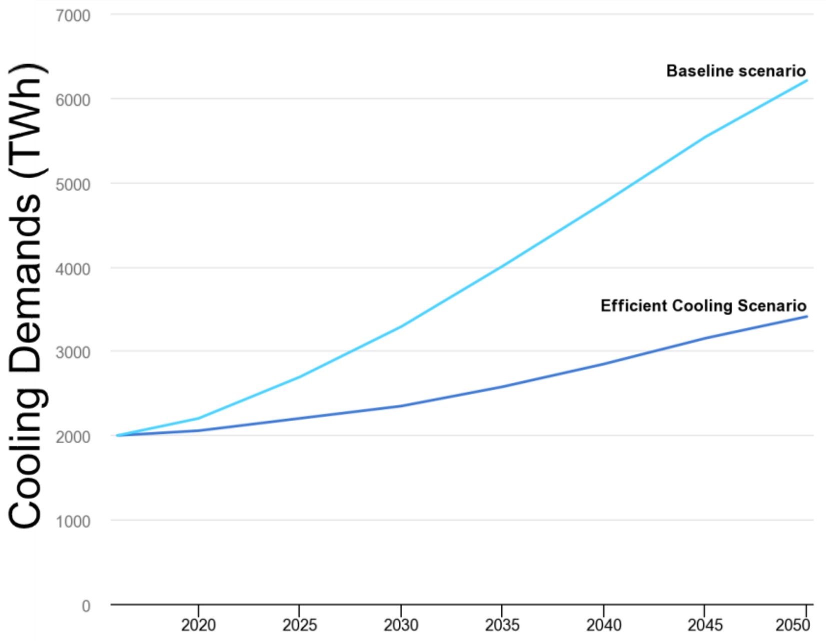
Contents

Motivation

- Increasing cooling demand
- District Cooling has the potential to provide an economic and sustainable cooling solution under different demand development scenarios
- District Cooling's better opportunity for RE integration
- Success of other network-based supply system
- The lack of models/tools for a techno-economic evaluation of the District Cooling Network potential

Global Increasing Cooling Demands (IEA,2019)



Research Question

How feasible are District Cooling networks considering the pumping, pipe, and supply costs under baseline demand conditions?

District Cooling Grid

- **Distribution System** → Where does it make sense to have the district cooling networks?
  - Transmission Grid
  - Distribution Grid
  - Service Pipes

- **Cooling source** → Free cooling sources; are these available in the region?

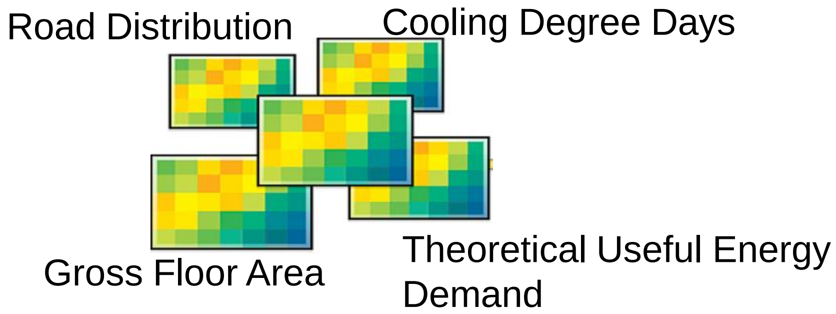
- **Energy transfer system**
  - Building specific energy transfer systems

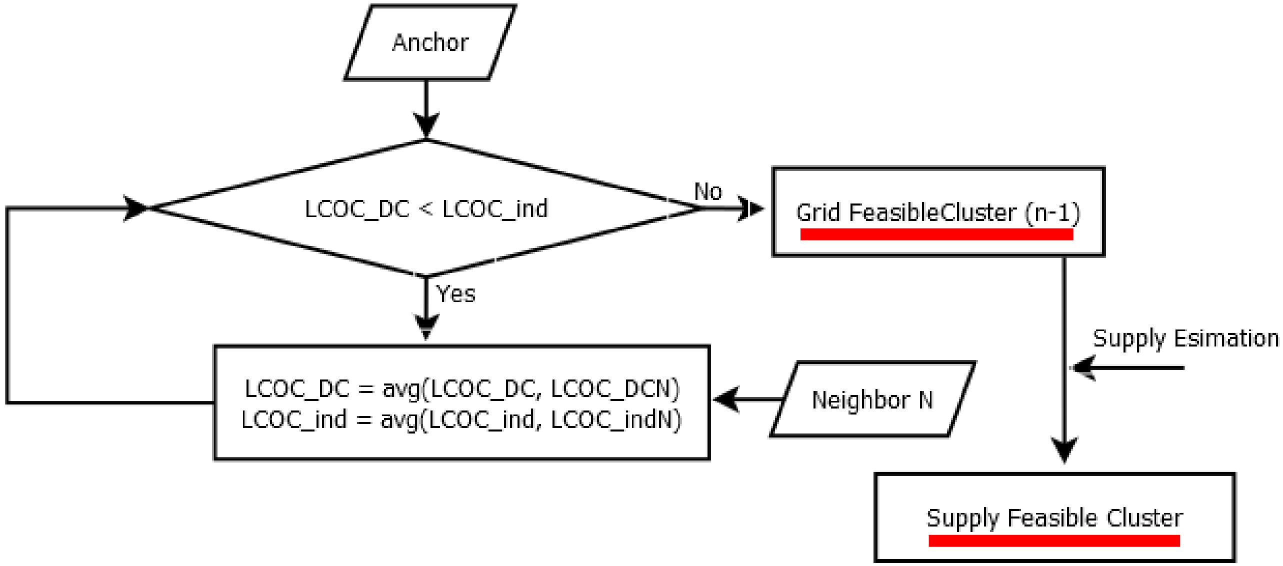
Feasibility Assessed with consideration of:
- Grid Costs
- Pumping Costs
- Supply Costs

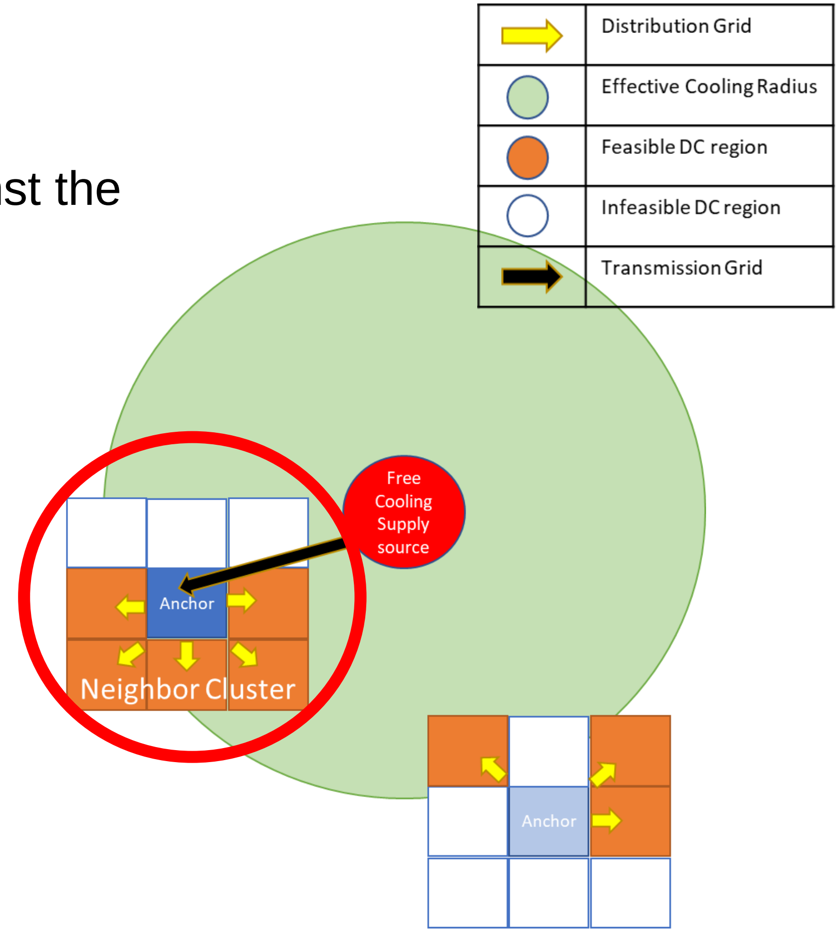
METHODOLOGY

Methodology (1 of 2)

- Working Resolution: Spatial: 100 * 100 m (hectare cell) →**CELL**
  Temporal: Annual
- Definition of the **anchors** (*High consistent demand points*)
- Estimation of the average pipe diameter and pump sizes
- Assess feasibility by comparing the LCOC of the distribution network against the corresponding individual supply
- Assess demand coverage potential and its sensitivity to electricity prices







Methodology (2 of 2)

- **Estimation of the *Peak Cooling Load* per cell [1]**

$$PCL_i = \frac{UED_{th_i}}{T_{op} \cdot AF \cdot CF}$$

$\mathrm{i:\ Grid\ \ raster\ \ cell,}\ \ i \in 1,2,3,\ldots,n$
$\mathrm{PCL}_i : Esitmated\ peak\ load\ in\ cell\ i\ in\ MW$
$UED_{th_i} : Annual\ Theoretical\ Useful\ energy\ demand\ in\ cell\ i\ in\ MWh$
$T_{op} : Technology\ Operation\ hours\ in\ hrs.$
$AF : Technology\ Availability\ Factor$
$CF : Technology\ Capacity\ Factor$

- **Calculating the *Volume Flow rate (w)* and *Theoretical Diameter* [2]**

$$TR_i = 3.51X10^{-3} \cdot PCL_i$$

$$w = \frac{24 \cdot TR_i}{1.8 \cdot \Delta T}$$

$$\mathrm{D}_{th} = \sqrt{\frac{4w}{V\pi}}$$

$\mathrm{TR}_i : Tons\ of\ Refrigeration\ in\ TR$
$w : Volume\ flow\ rate\ in\ m^3/sec$
$TR_i : Tons\ of\ Refrigeration\ in\ TR$
$\Delta T : Operating\ Temperature\ of\ DC\ network\ in\ F$
$D_{th} : Average\ Theoretical\ pipe\ Diameter\ in\ m$
$V : Average\ Water\ flow\ Rate\ in\ m/sec$

- **Calculating the Grid Costs**

$$LCOC_{grid} = \frac{FR_i \cdot PC_{D_i} \cdot crf}{UED_{th_i}}$$

$\mathrm{LCOC}_{grid} : Levelized\ cost\ of\ Cooling\ Eur/MWh$
$PC_{D_i} : Pipe\ cost\ for\ diameter\ in\ cell\ i\ in\ Eur/m$
$FR_i : Feasible\ road\ length\ for\ network\ in\ cell\ i\ in\ m$
$crf : Capital\ Recovery\ Factor$

- **Calculating the Individual System Costs**

$$\mathrm{FED}_i = \frac{UED_i}{COP_t}$$

$$\mathrm{LCOC}_{ind} = \frac{C_{ti} \cdot crf + M_t + FED_i \cdot P}{UED_{th_i}}$$

$\mathrm{C}_{ti} : Capital\ costs\ technology\ t\ to\ cover\ peak\ demand\ of\ cell\ i$
$M_t : Maintenance\ costs\ in\ a\ year\ for\ technology\ t$
$FED_i : Energy\ consumed\ in\ year$
$P : Average\ Electricity\ price$
$COP_t :\ Coefficient\ of\ Performance\ of\ Technology\ T$

- **Pump Size estimation**

$$headloss = \frac{f \cdot l \cdot v^2}{2 \cdot d \cdot g} \qquad CAPEX_i = 38.365 \cdot 10^3 \cdot e^{0.006 \times \mathrm{PumpSize}}$$

$$PumpSize = \frac{Q \cdot \rho_{water} \cdot g \cdot headloss}{\eta \cdot 1000 \cdot 3600}$$

$\mathrm{headloss:\ Pressure\ \ head\ \ in\ \ m}$
$\mathrm{f:\ friction\ \ coefficient}$
$\mathrm{l:\ Length\ \ in\ \ m}$
$\mathrm{v:\ Fluid\ \ flow\ \ velocity\ \ in\ \ m\ per\ s}$
$\mathrm{d:\ Average\ \ Pipe\ \ Diameter\ \ in\ \ m}$
$\mathrm{g:\ \ Acceleration\ \ due\ \ to\ \ gravity\ \ in\ \ m\ per\ s^2}$
$PumpSize : Pump\ Power\ in\ MW$
$Q :\ Volume\ flow\ rate\ m^3\ per\ h$
$\rho_{water} :\ Water\ Density\ kg\ per\ m^3$
$\eta :\ Pump\ efficiency$

- **Supply Sizing**

$$\mathrm{LCOC}_{DC} = \frac{\sum_{c=1}^{n} Cost_{grid}^c + Cost_{pump}^c + Cost_{supply}^c}{UED_c}$$

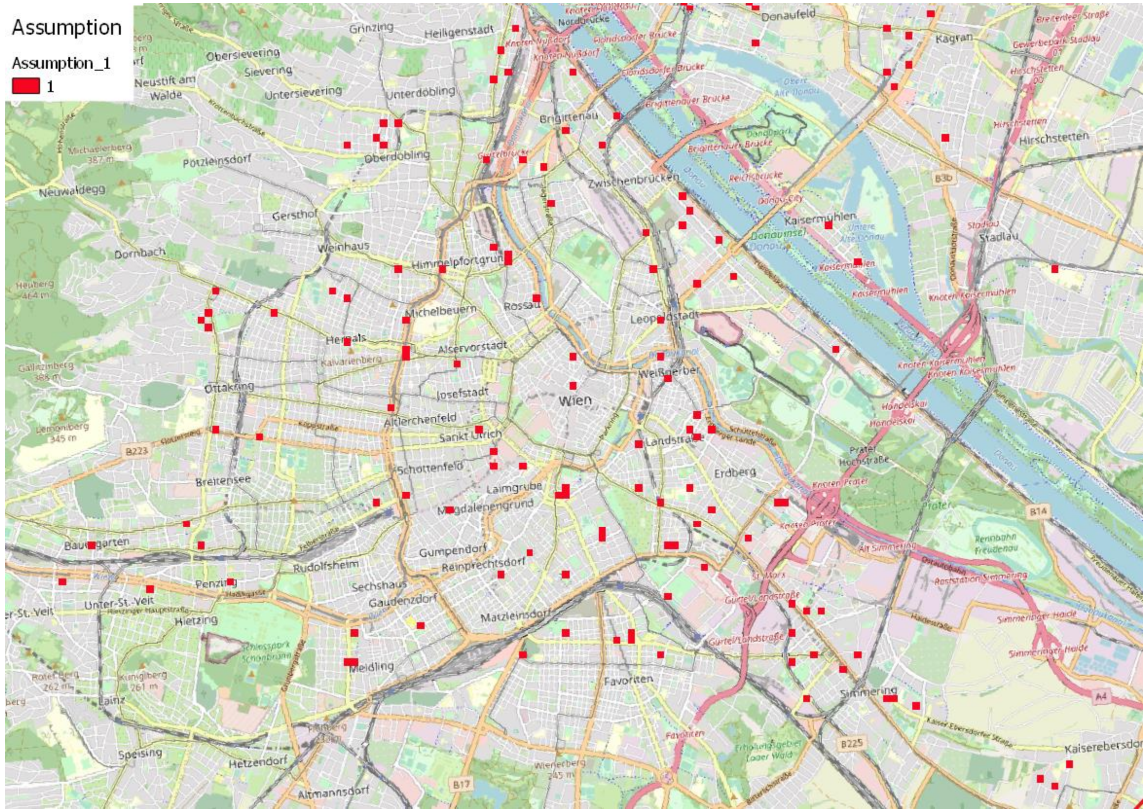
$\mathrm{c:\ Identified\ \ clusters\ \ with\ \ DC\ \ feasibility}$
$\mathrm{Cost}_{grid}^c : Total\ annualized\ grid\ costs\ in\ cluster\ c$
$Cost_{pump}^c : Total\ annualized\ pipe\ costs\ in\ cluster\ c$
$Cost_{supply}^c : Total\ annualized\ supply\ costs\ in\ cluster\ c$
$UED_c : Total\ supplied\ cooling\ demand\ in\ cluster\ c$

[1] Li et.al., A life cycle analysis techno-economic assessment framework for evaluating future technology pathways, 2021
[2]Lisaba et.al., Pipe sizing of district cooling distribution network including in energy transfer station, 2021

Assumptions

	Assumption 1	Assumption 2
Anchor Definition	• Highest 25% energy demand • Lowest 25% GFA • Peak Demand > 1 MW [3] e.g. Warehouses, supermarket	• Highest 25% energy demand • Highest 25% GFA • Peak Demand > 1 MW e.g. hospitals, offices

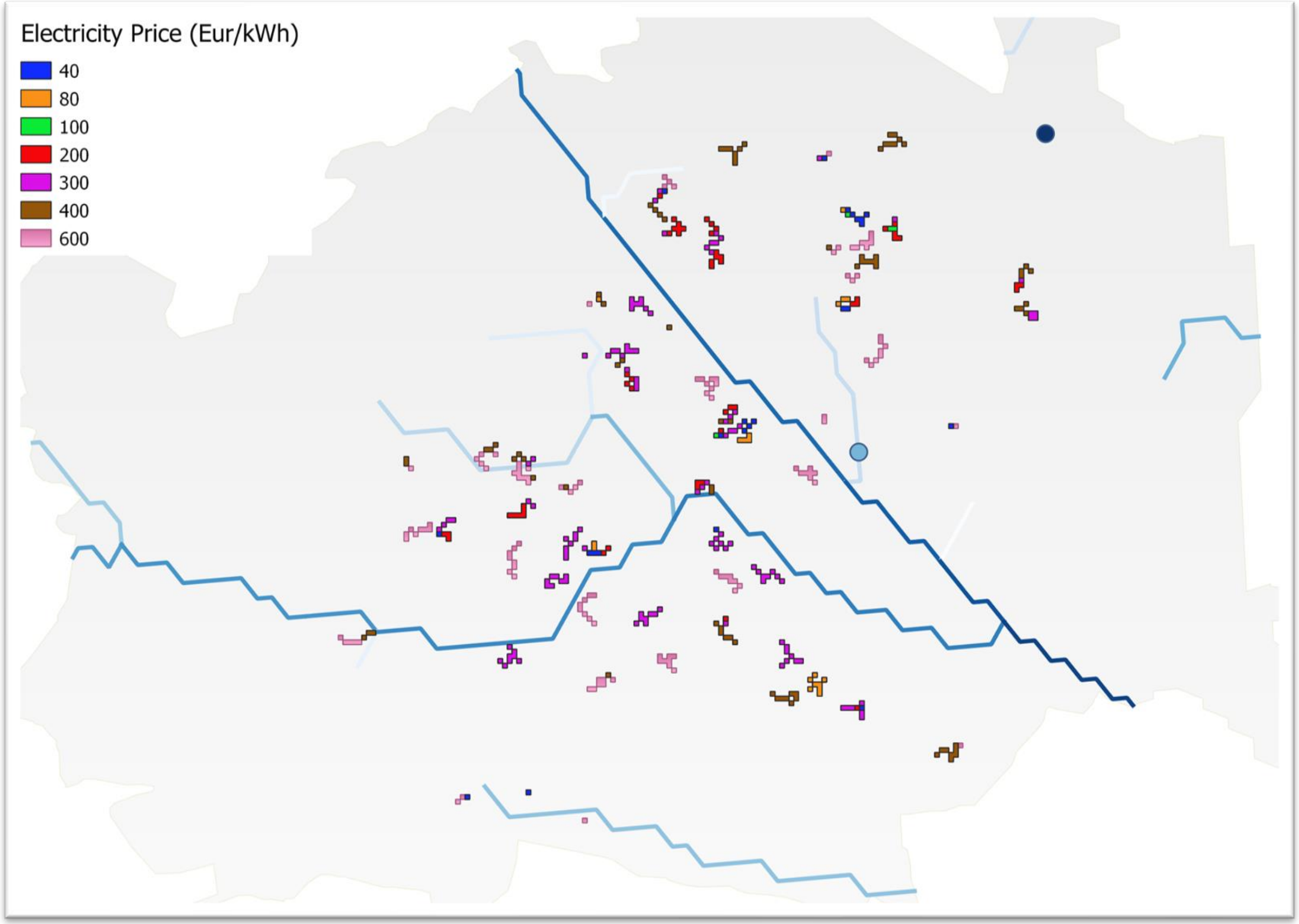
- No existing grids (heating and cooling)
- 30% of demand met by individual supply systems
- Inter-building connection is not considered
- 100% of cooling demand within a grid is connected (no market share)
- All potential grids start from an **anchor cell**

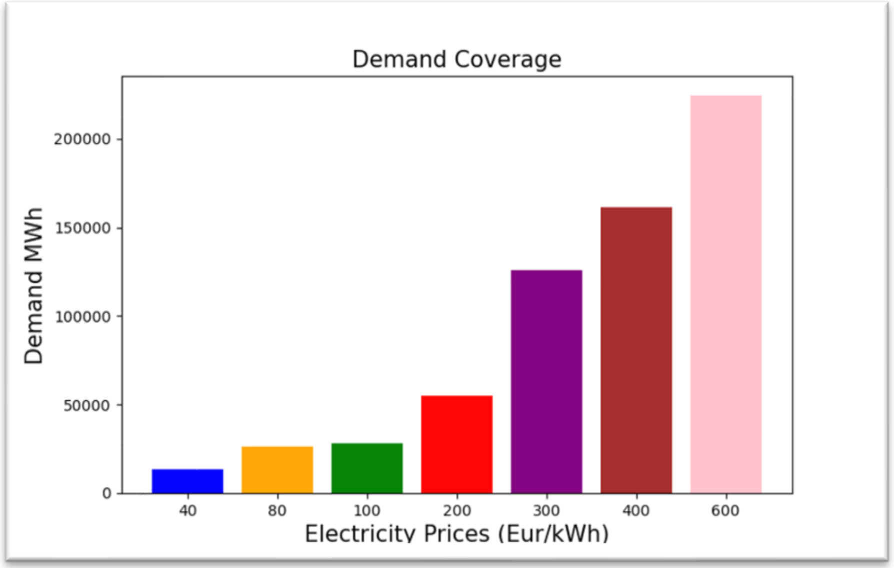


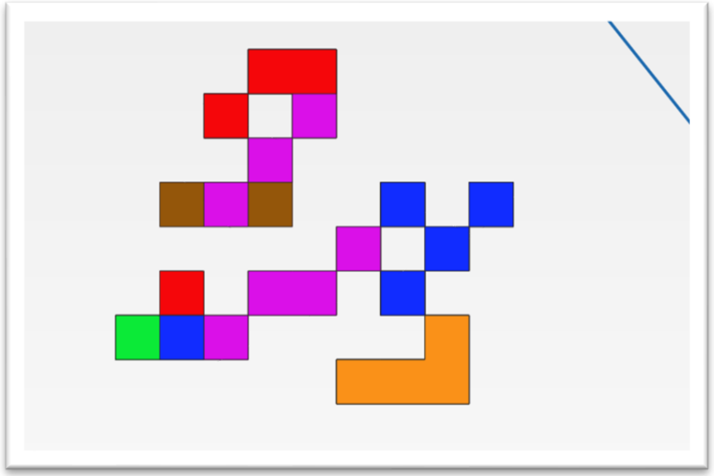
[3] A. Volkova, A. Hlebnikov, A. Ledvanov, T. Kirs, U. Raudsepp, and E. Latõšov, “District Cooling Network Planning. A Case Study of Tallinn,” IJSEPM, vol. 34, pp. 63–78, May 2022, doi:10.54337/ijsepm.7011.

RESULTS

Spatial Layout-Exemplary Results

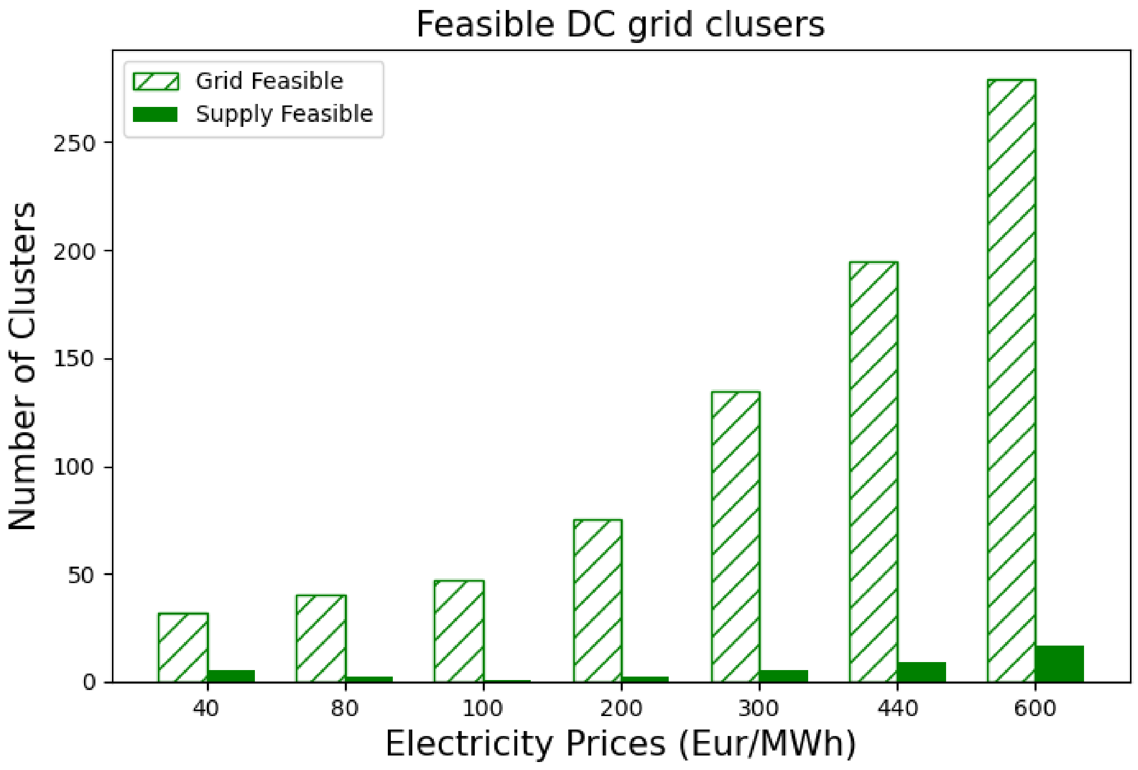


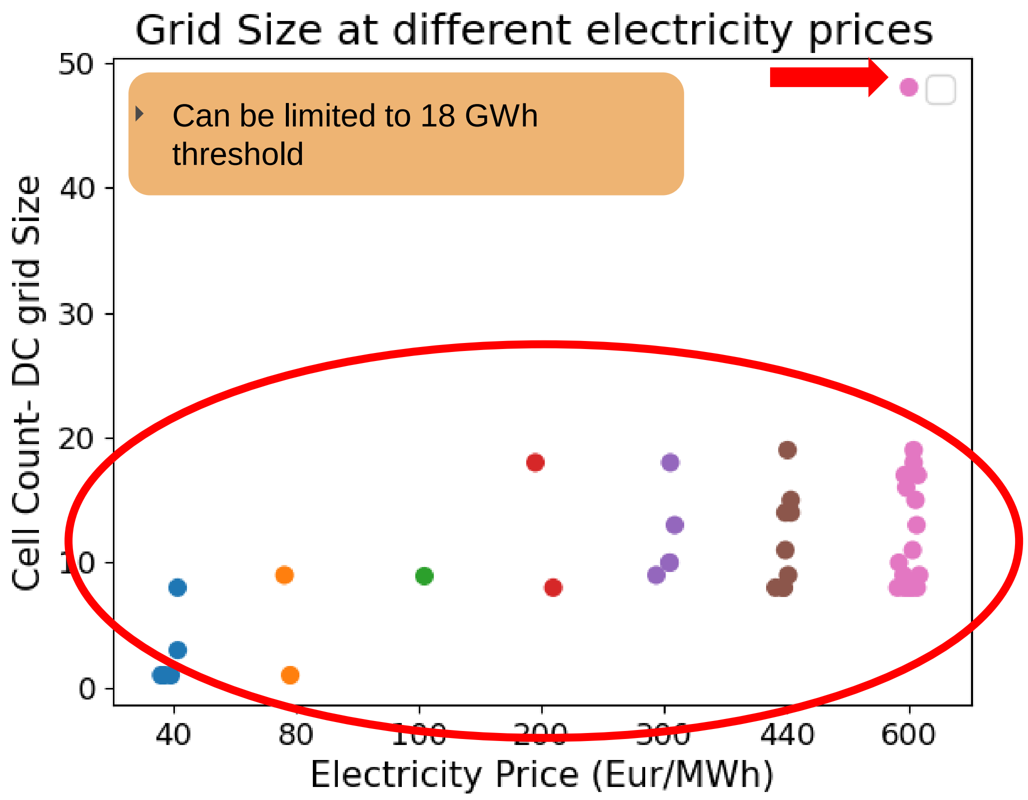




Identified Potential Grids

Assumption 2





Assumption 2

Parameters Influencing the DC Feasibility:

- Linear Demand Density
- Investment per gross floor area
- Investment Per unit demand met

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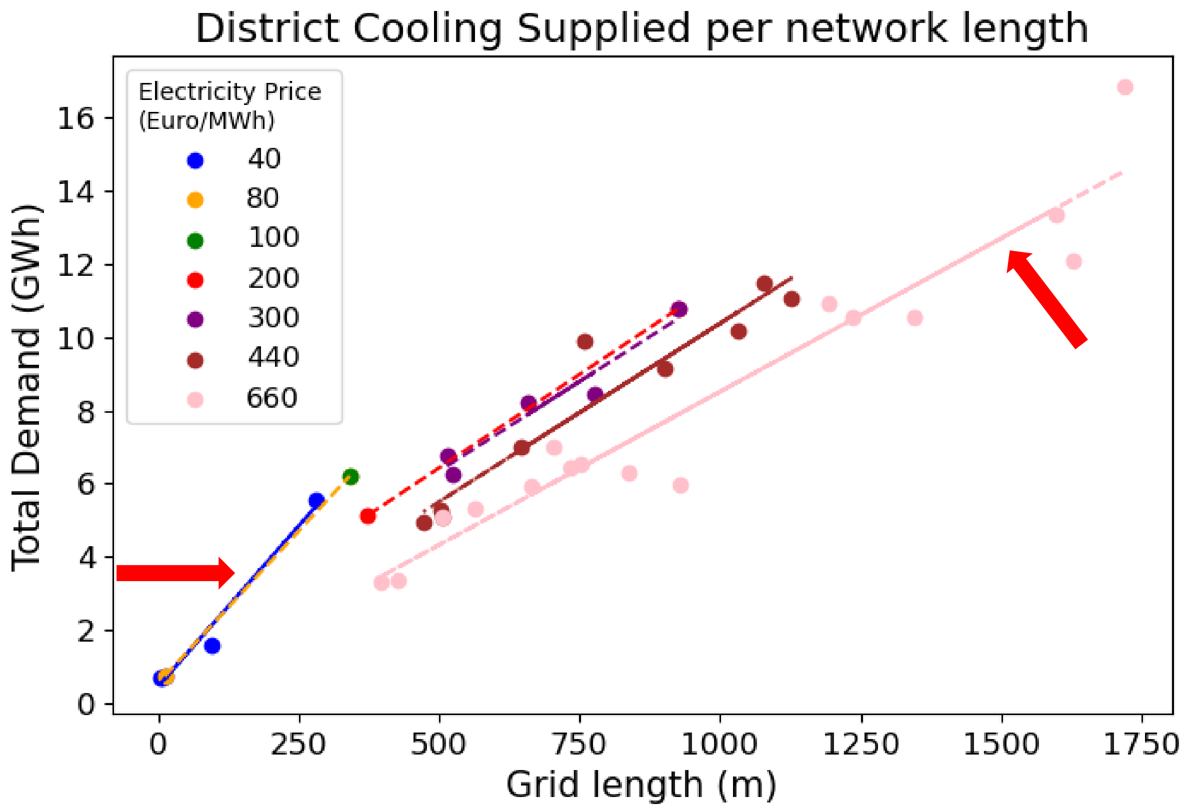
- Low prices only include anchors which are areas with high demand density
- At high prices low demand density areas are also included
- As grids get larger the coverage becomes more expensive
- Anchors are ideal locations for DC supply

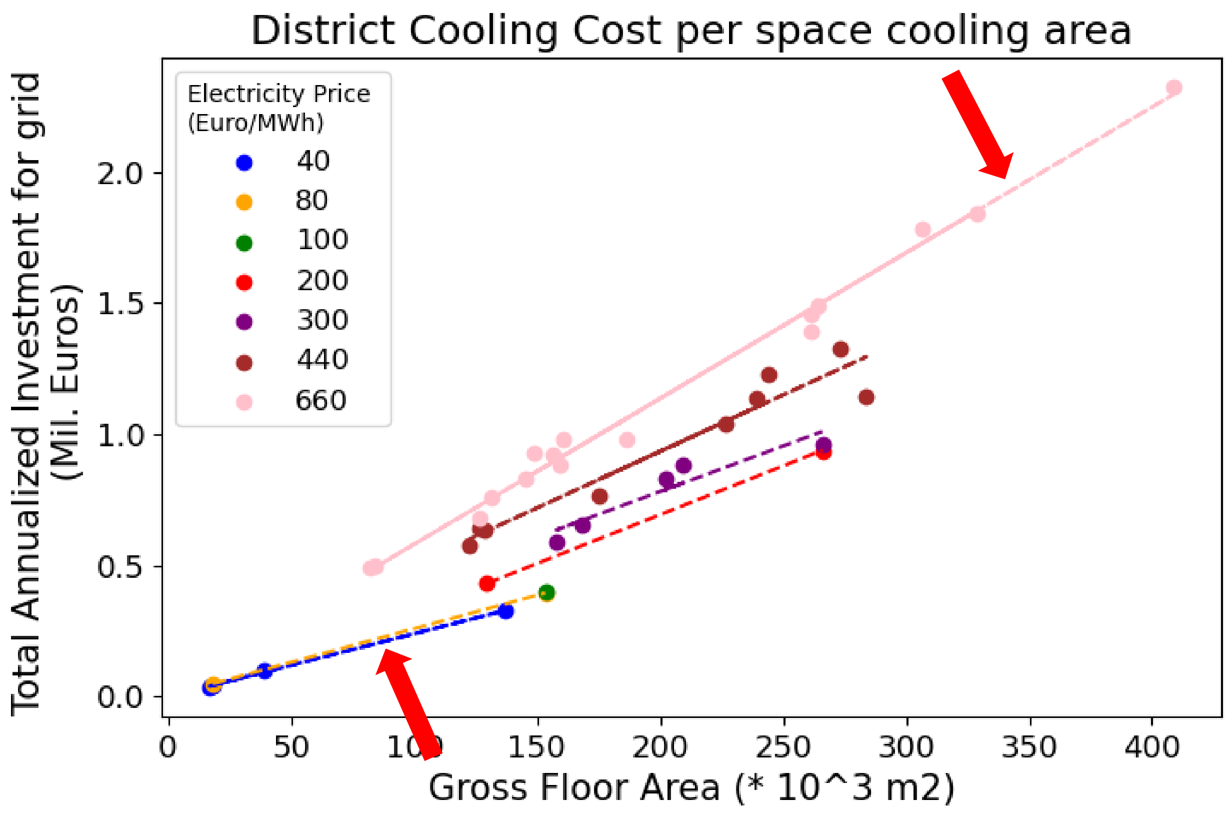


Assumption 2

Parameters Influencing the DC Feasibility:

- Linear Demand Density
- Investment per gross floor area
- Investment Per unit demand

- Marginal costs are higher for larger network due to the inclusion of a larger number of neighbors
- The increase in GFA/demand is not proportional to the increase in the estimated pipe costs
- In lower demand cells the ratio of increase in demand coverage to pipe lengths is much higher



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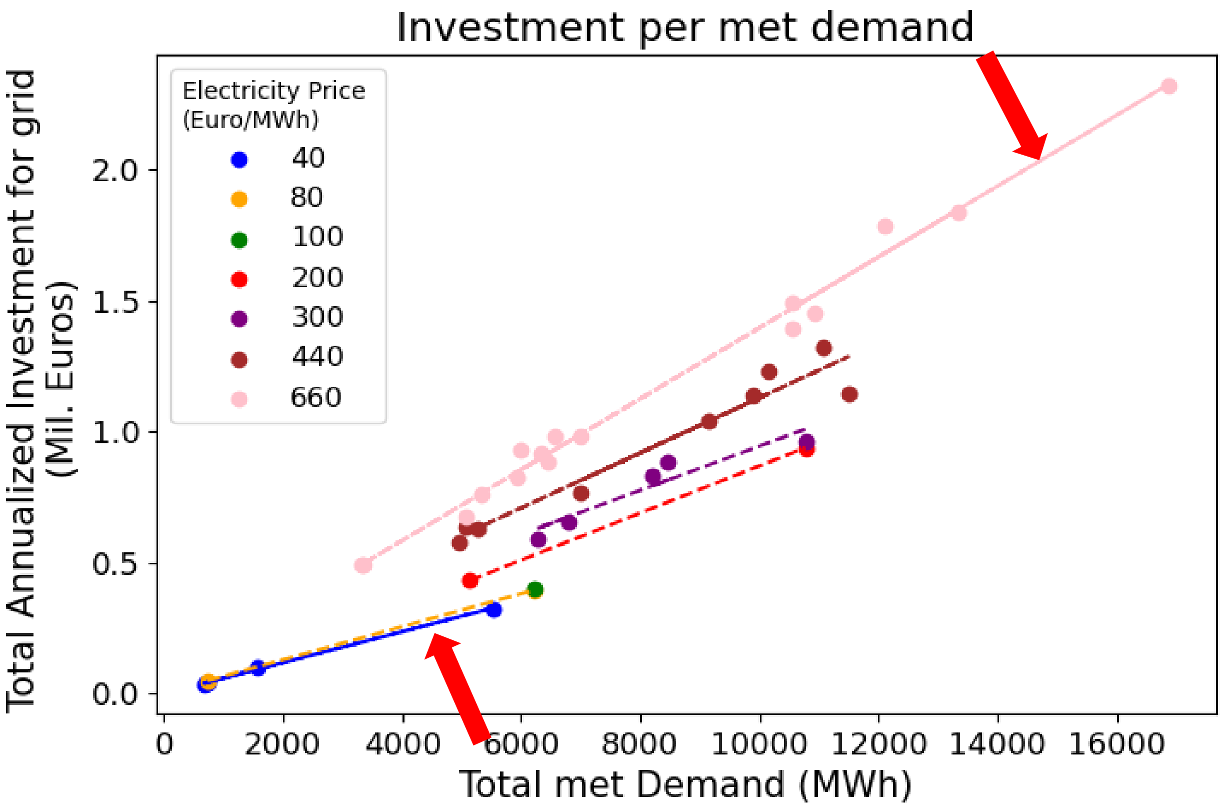
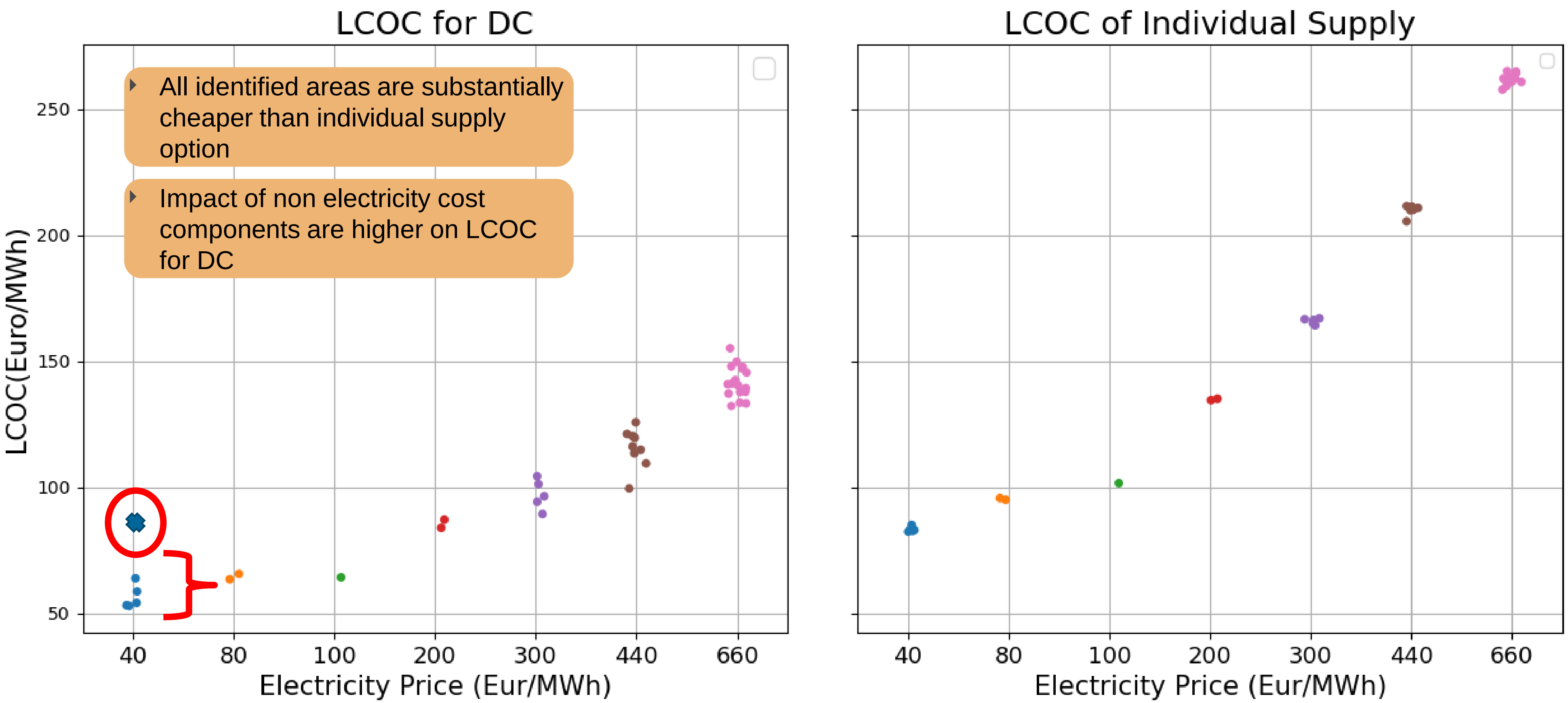


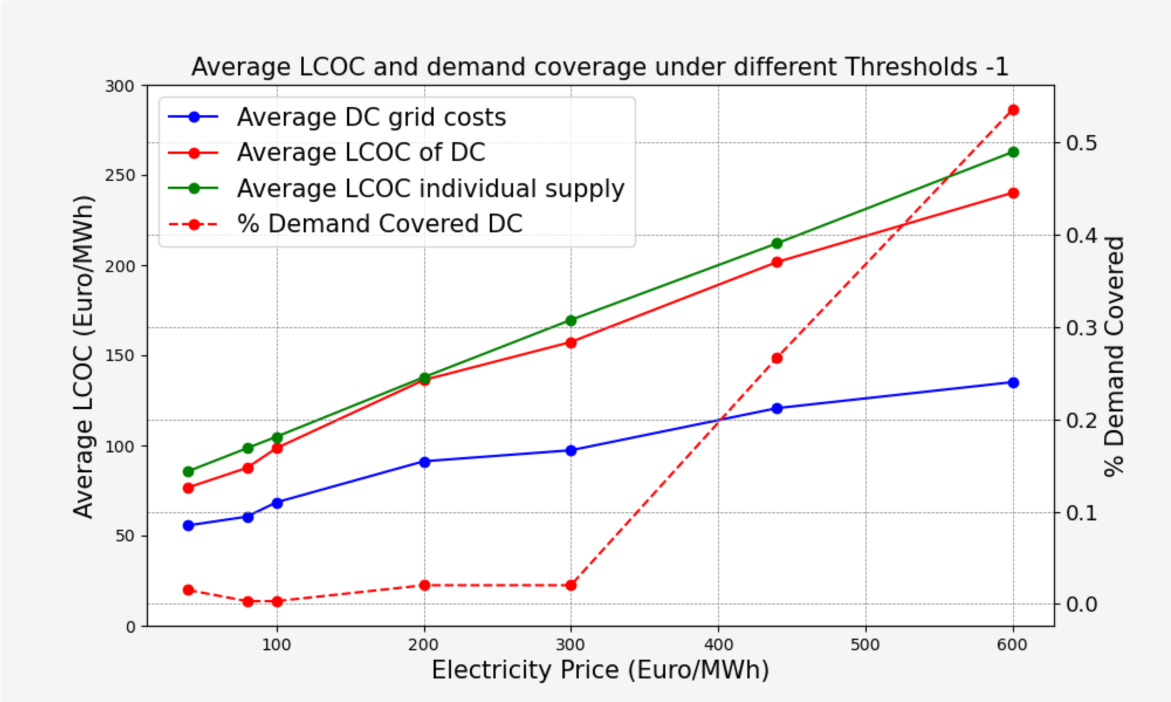
Assumption 2 – Comparing the levelized cost of cooling

- All identified areas are substantially cheaper than individual supply option
- Impact of non electricity cost components are higher on LCOC for DC



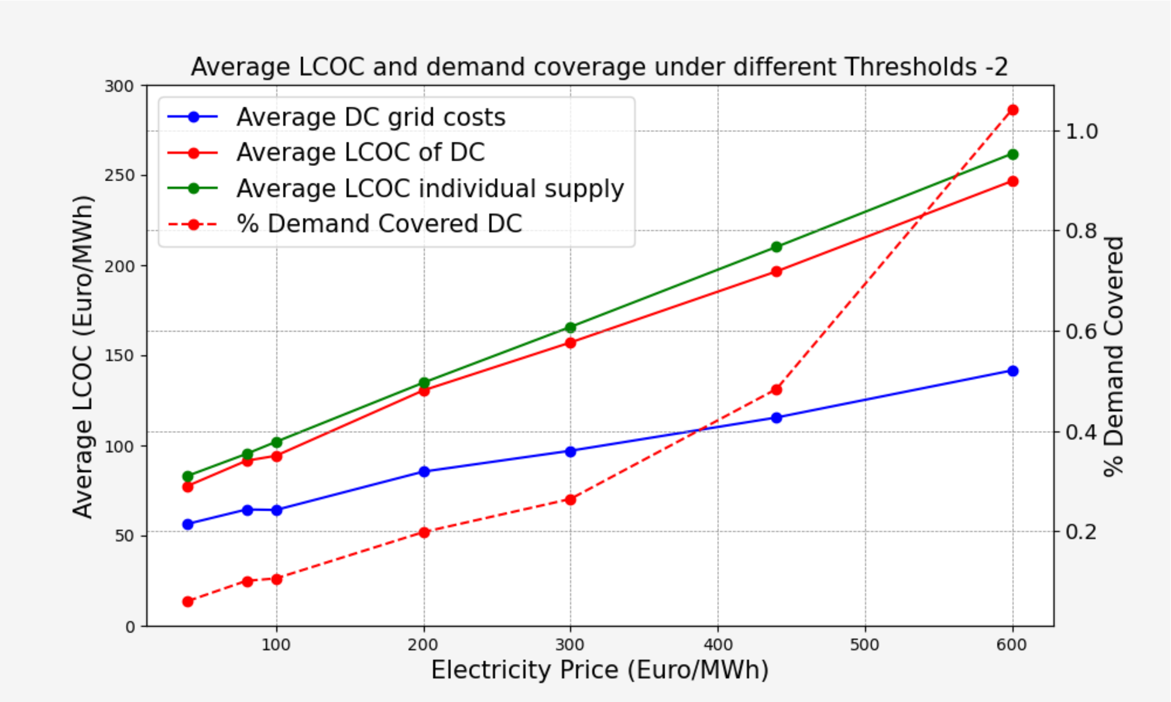
Overall Comparison –Aggregated Clusters

Assumption 1



Low costs due to the initial low number of anchors

Assumption 2



Result Summary

- Assumptions on the selection of the anchor largely influence the results.
- The identified sizes of the networks vary from 0.01 – 0.5 km2.
- Demand coverage in the ranges of 5-30GWh of theoretical useful energy demand is observed. (on average DC grids are seen with a coverage size of < 18 GWh)
- At larger electricity prices larger DC grids are seen as viable
- Levelized cost of cooling for the networks are highly price sensitive and ranges from 50-150 Euros/MWh for feasible networks
- High cost of DC supply results in infeasibility in high cooling demand urban areas – need for supportive policies

Limitations and Uncertainities

- Geospatial granularity
- Assessment based on theoretical cooling demand; Accuracy of the theoretical cooling demand
- Other sustainable cooling supply technology competitors are not considered for the assessment
- 100% supply per grid considered

- Dehumidification aspects not covered (types of DC network)

Outlook

- Inclusion of (free) supply sources – spatially defined
- Inclusion of the supply market share sensitivities into the model
- Assessment of increasing demand scenarios
- Validation of the model based on real data for actual grids and demand
- Assessment for different CO2 factors for electricity generation and reduction potential with DC

- Expansion of the model to other regional levels and to EU-27
- Multi-stage cooling network
- Selection of the anchor points based on the use of the buildings

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Thank you.

Questions, comments, recommendations?

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