Optimal diversification of large-scale district heating generation portfolios in Austria

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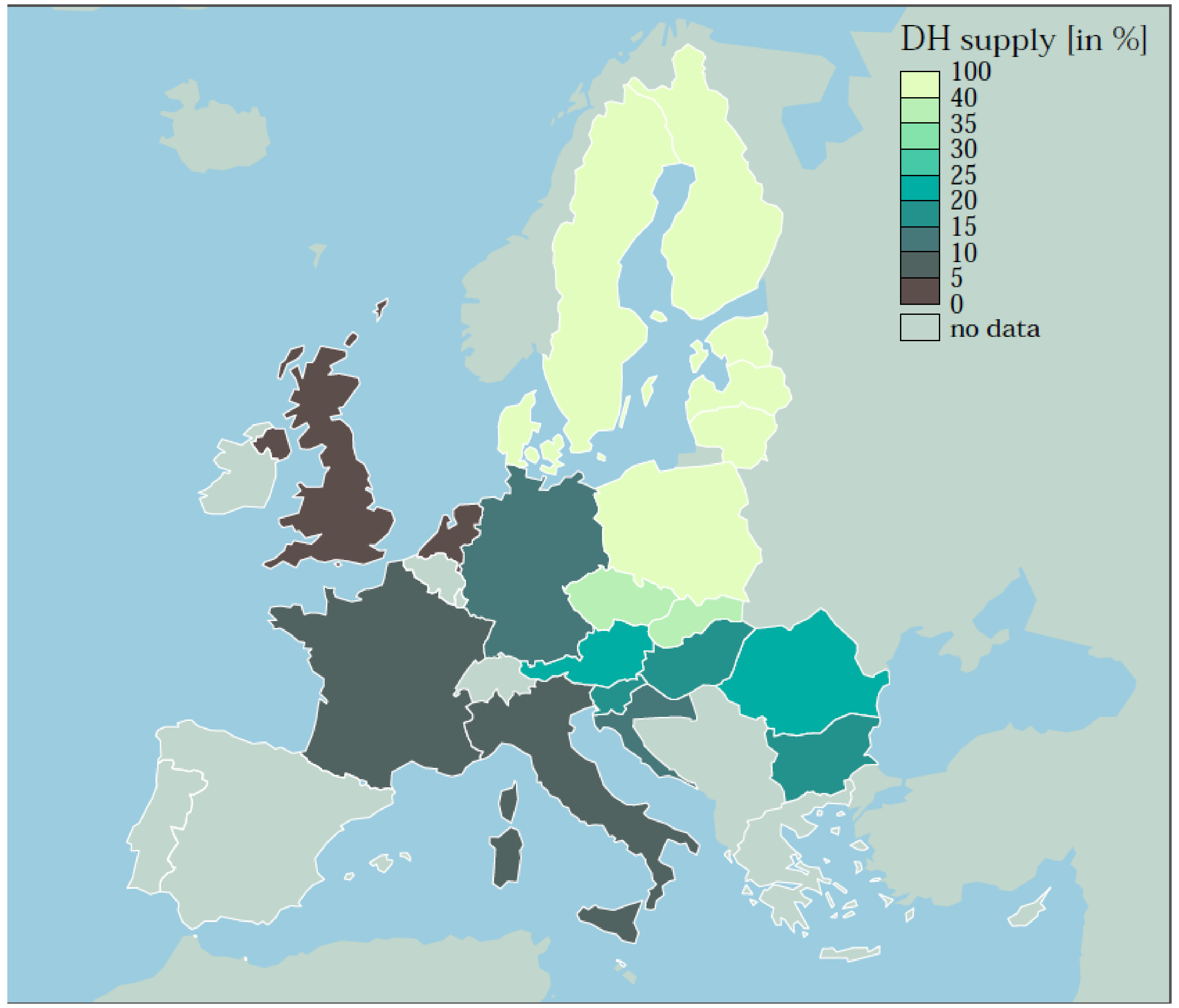
Motivation

In Austria 28% of its citizens are supplied by DH, but **economic viability** has been **challenged** in the past years as natural gas power plants turned unprofitable. In 2010 61% of the DH demand in Vienna was supplied from waste heat from natural gas power plants.

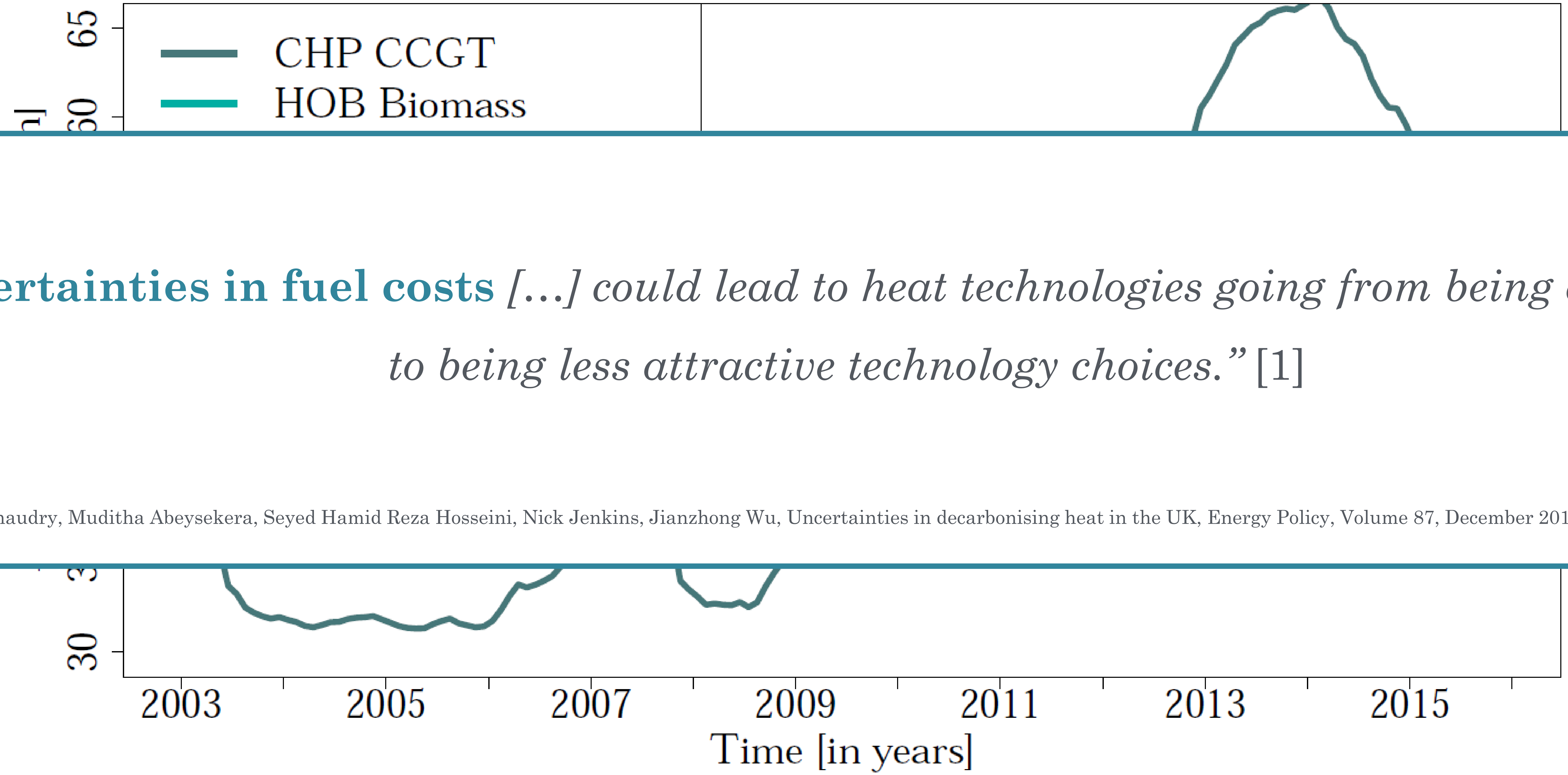
Diversification of heat sources and fuels for District Heating (DH) is fundamental for enabling long-term stable and competitive prices. **Uncertainty of fuel prices** can be identified as the **key cause** of DH plant **investment risk**.

TARGET: Optimal Transformation of existing DH generation portfolios towards portfolios with **competitive *and* low-volatile generation costs**.



Share of DH generation in total heat generation per EU member country

Why is Diversification Fundamental?



"**Uncertainties in fuel costs** *[…] could lead to heat technologies going from being cost effective to being less attractive technology choices."* [1]

[1] Modassar Chaudry, Muditha Abeysekera, Seyed Hamid Reza Hosseini, Nick Jenkins, Jianzhong Wu, Uncertainties in decarbonising heat in the UK, Energy Policy, Volume 87, December 2015, Pages 623-640

Average costs of DH generation of the past 12 months with a utilization of **5.000 full load hours**.

Methodology

- The generation portfolio selection is based on **minimizing expected LCOH adjusted by some level of risk**, defined as variance (*Risk-Averse Two-Stage Stochastic Programming*).

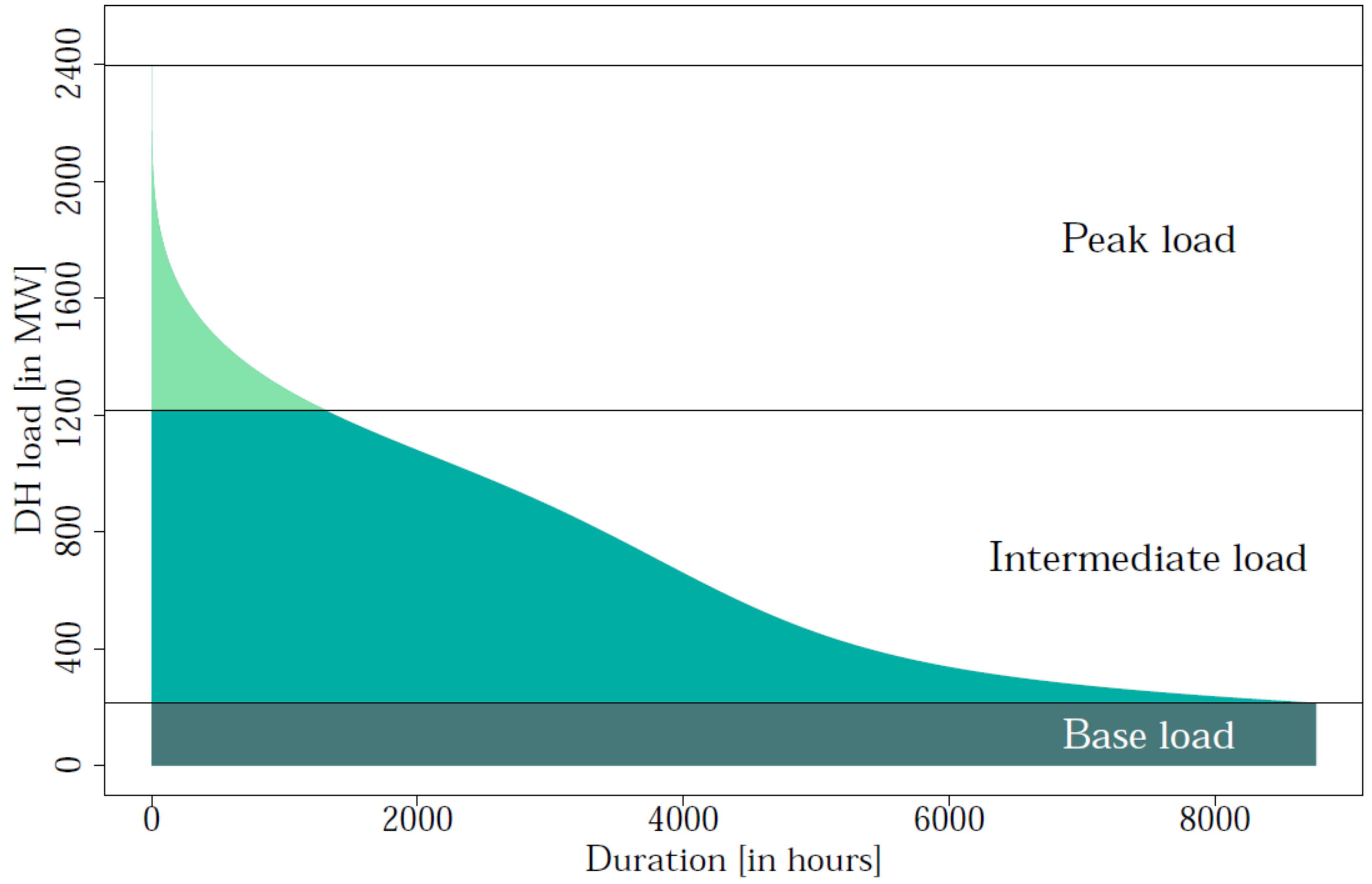
- More precisely the DH operator's utility from an uncertain pay-off P is given as:

$$\mathcal{U}(P) := \mathbb{E}(P) - \frac{\beta}{2}\mathbb{V}\mathrm{ar}(P),$$

  where **beta** is a parameter reflecting the **risk aversion**.

- **Fuel costs** are modelled as **stochastic processes** (multivariate Geometric Brownian Motion).

- **DH demand** and **merit orders vary strongly over time**, which is explicitly accounted for in the approach.

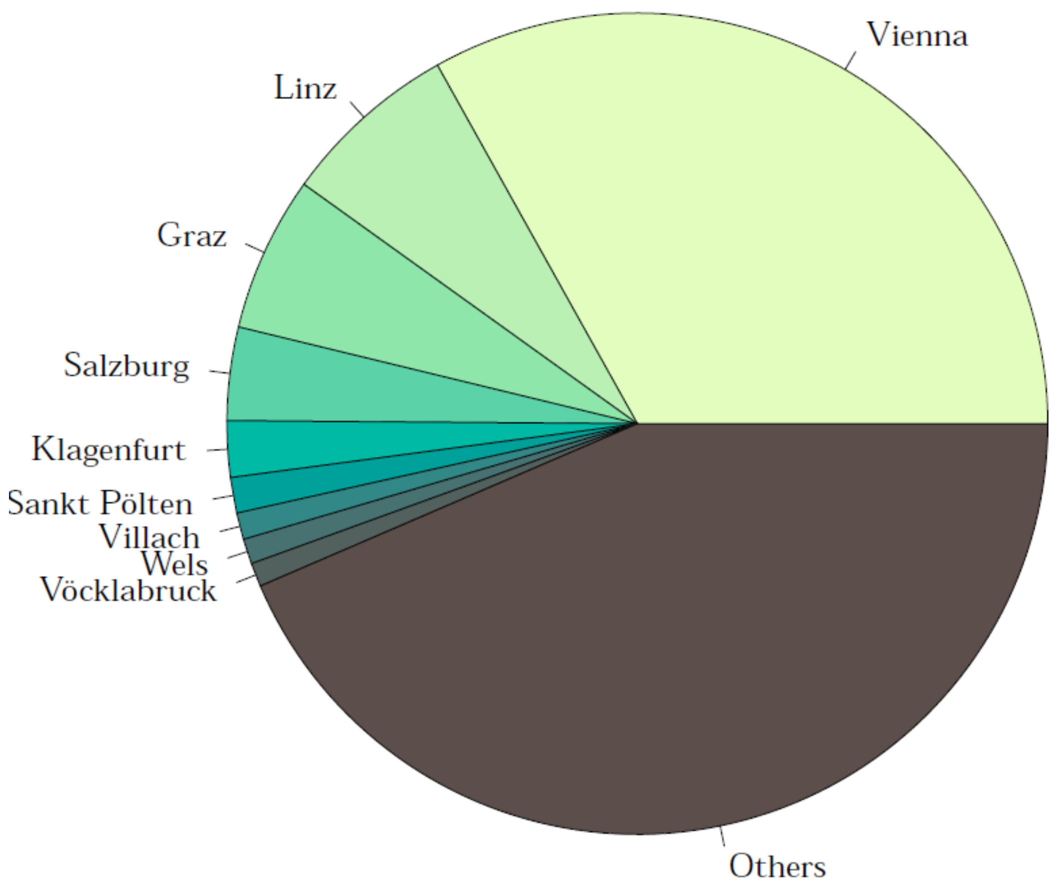


Case study

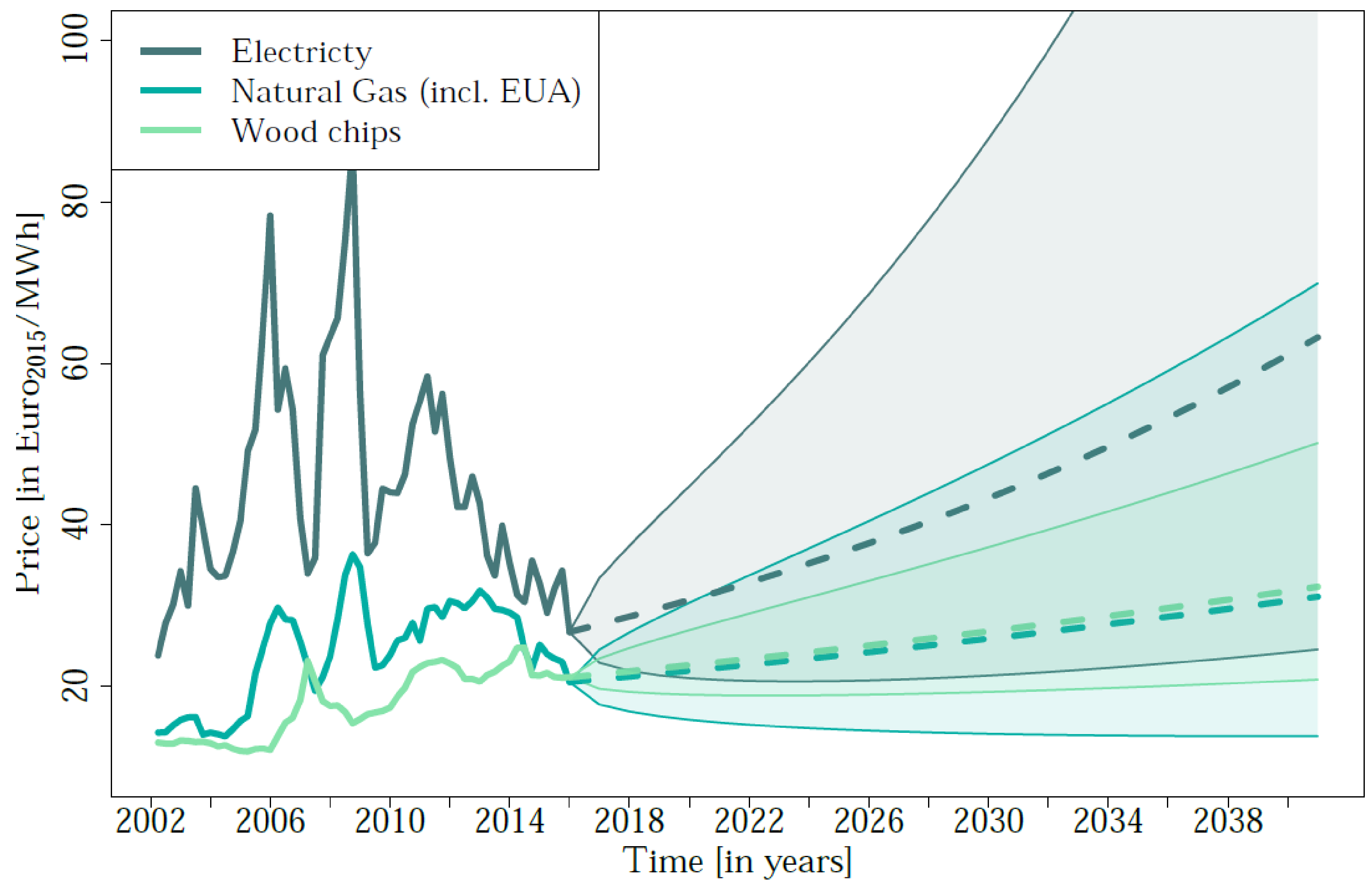
Mean-variance optimal generation portfolios in 2030 for the **three largest DH systems in Austria**: Vienna, Linz and Graz based on the existing generation park in 2015.

Energy Price Data (Electricity and EUA: EXAA spot, natural gas: EIPI, wood chips: Wiener Warenbörse):

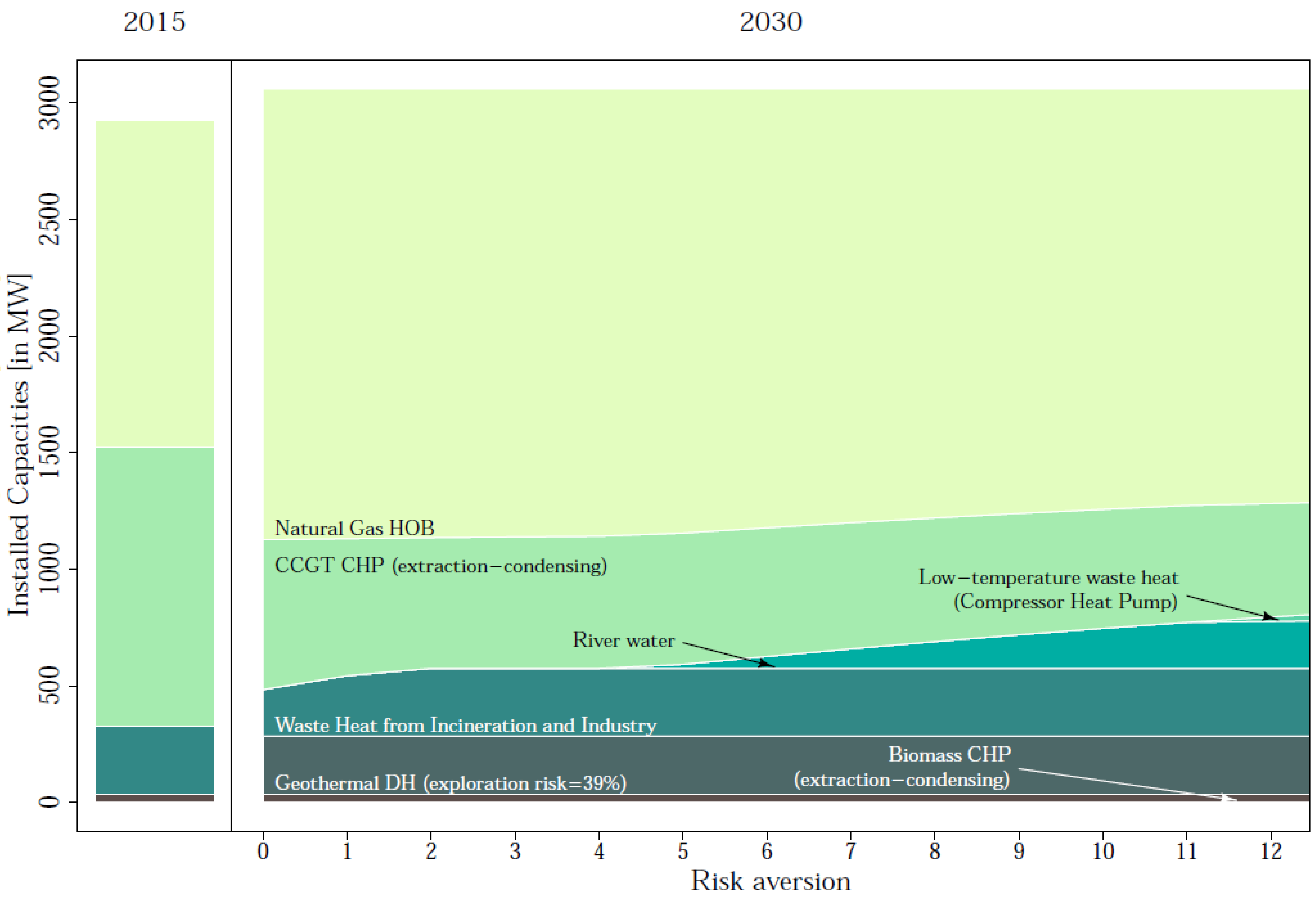
- Transmission/transportation costs and taxes: as of 2015.
- Volatility and correlations: historic values (2002-2015).
- Expected value: Energieszenarien 2050 (WIFO).



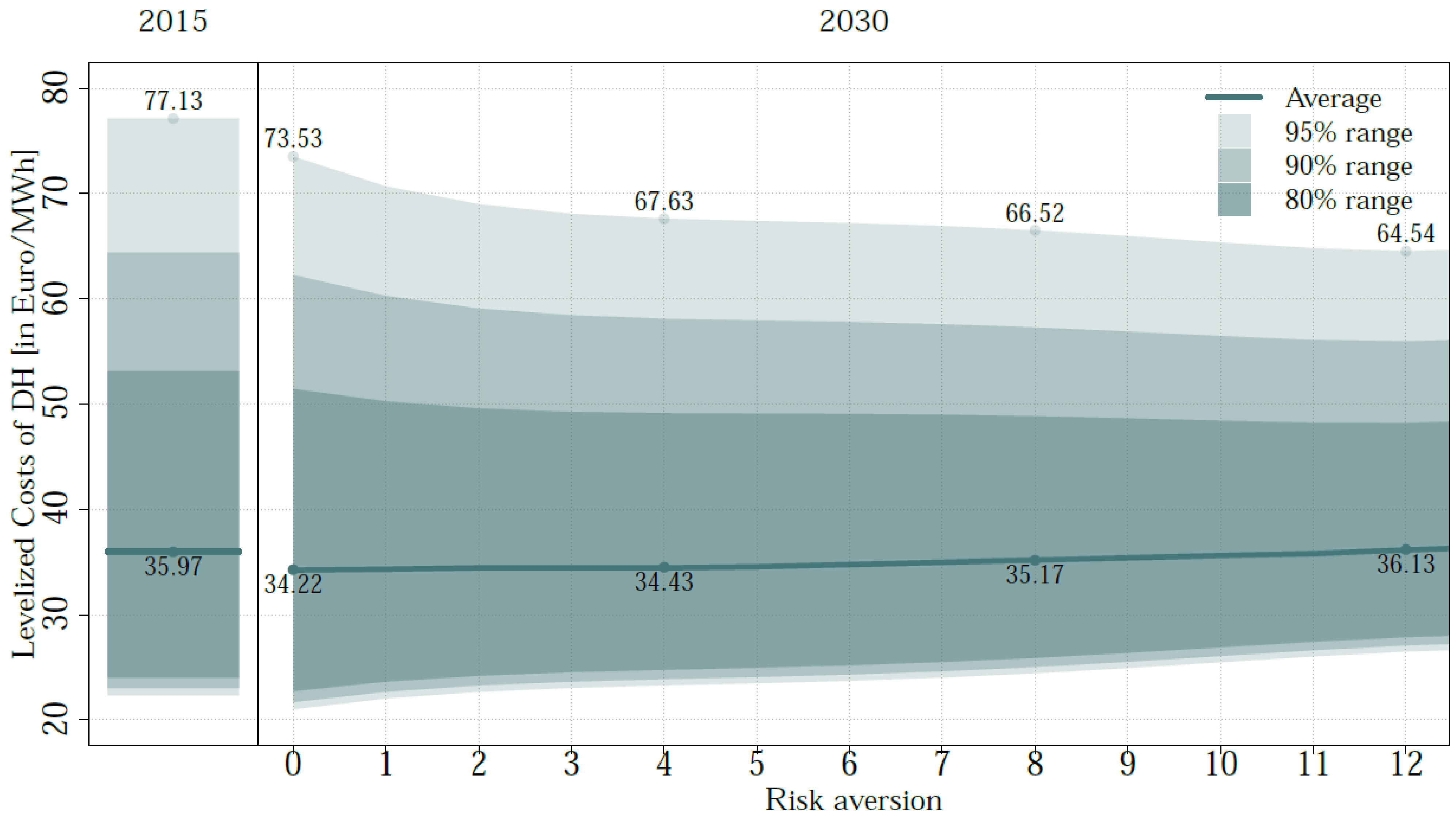
Share in annual DH generation in Austria.



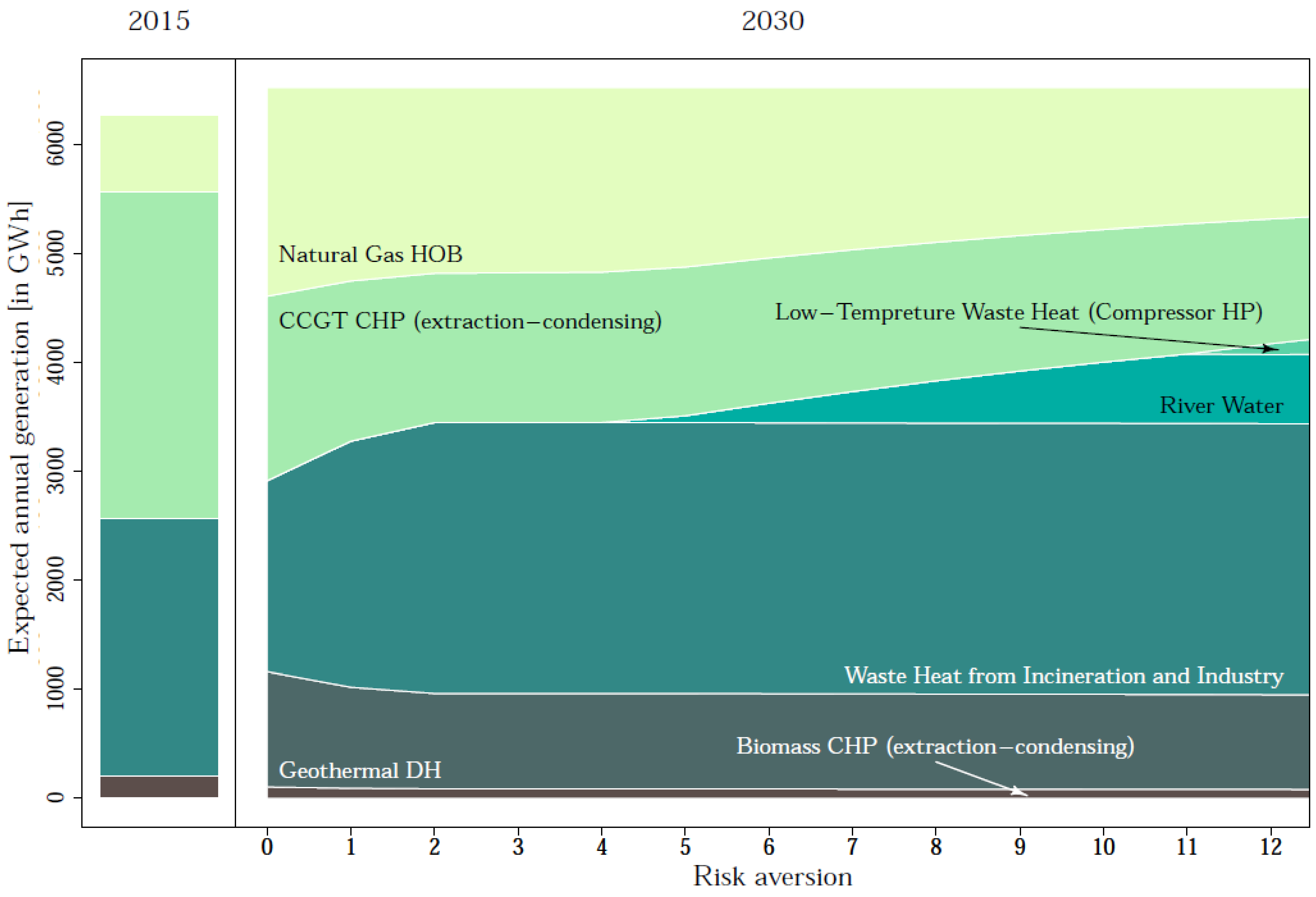
Vienna: Installed capacities



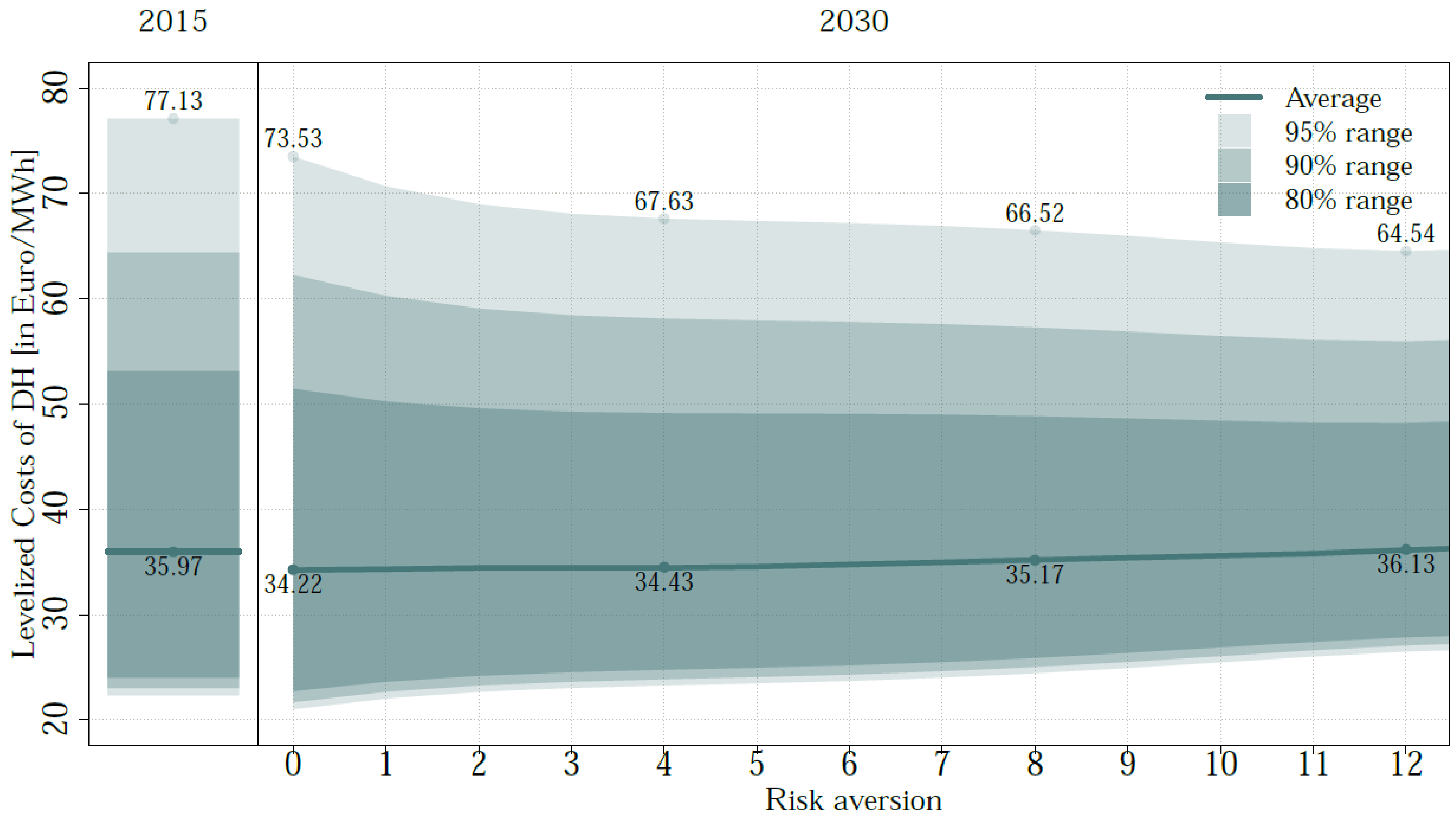
Distribution of generation costs



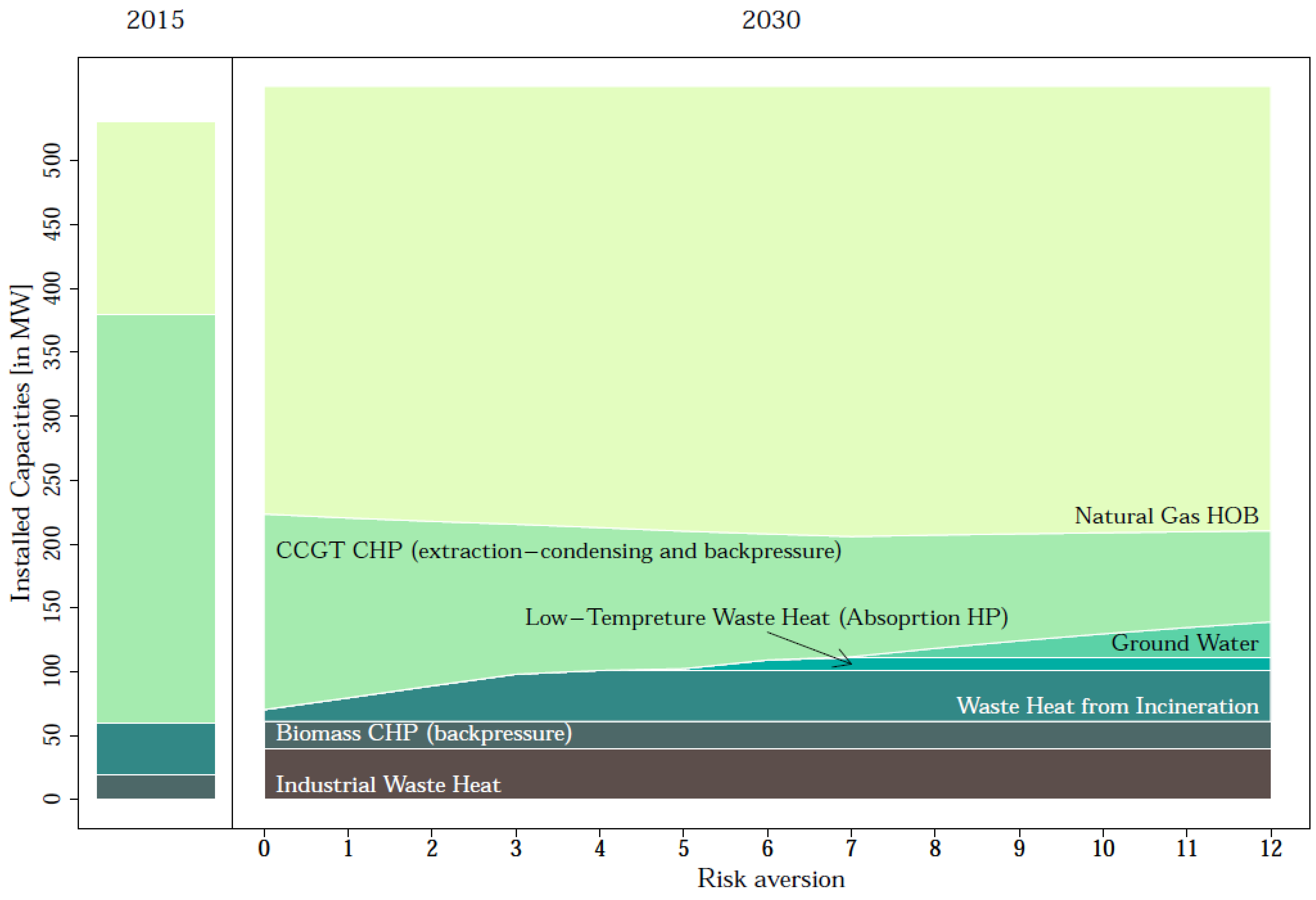
Vienna: Expected annual generation

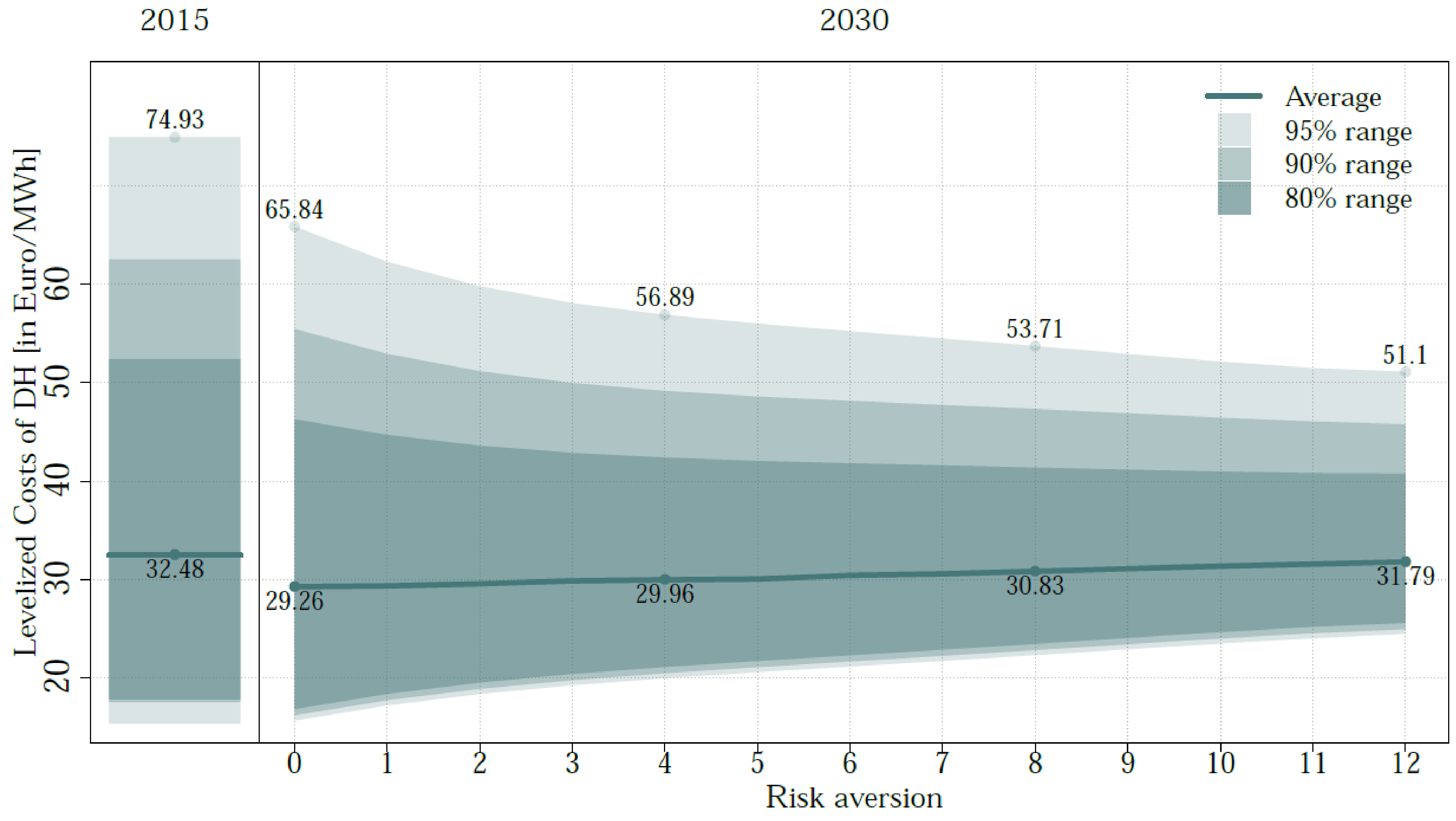


Distribution of generation costs

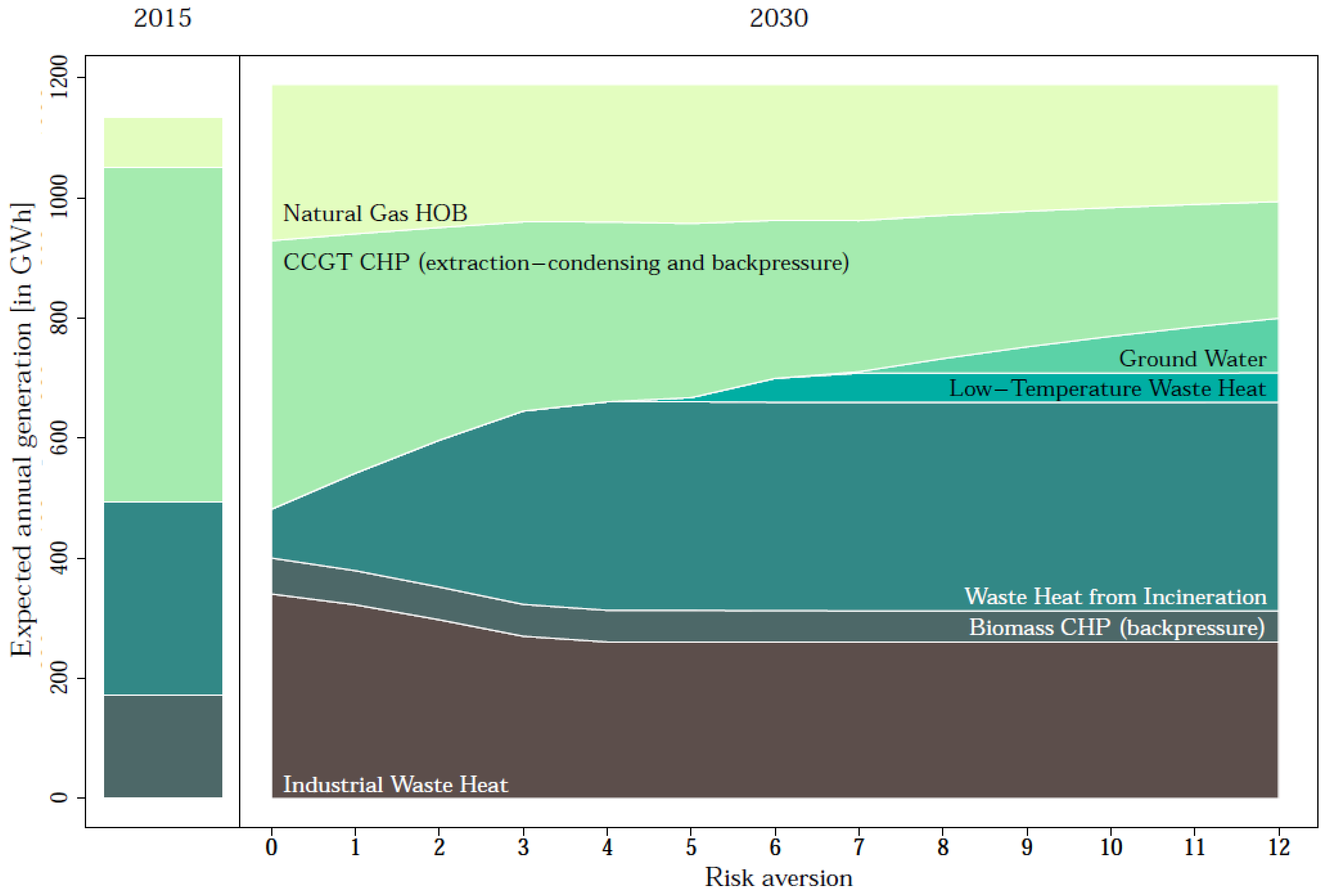


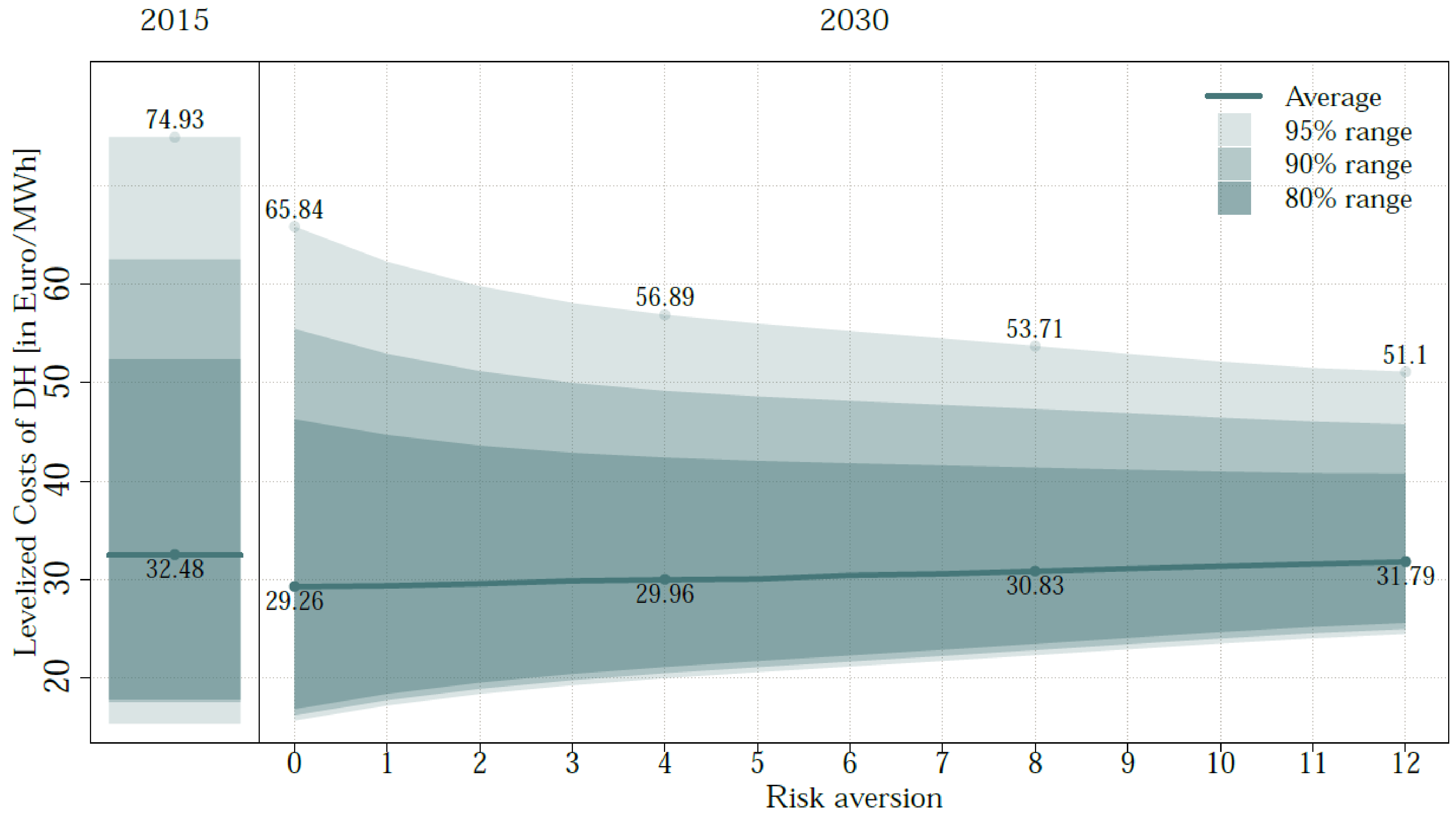
Linz: Installed capacities



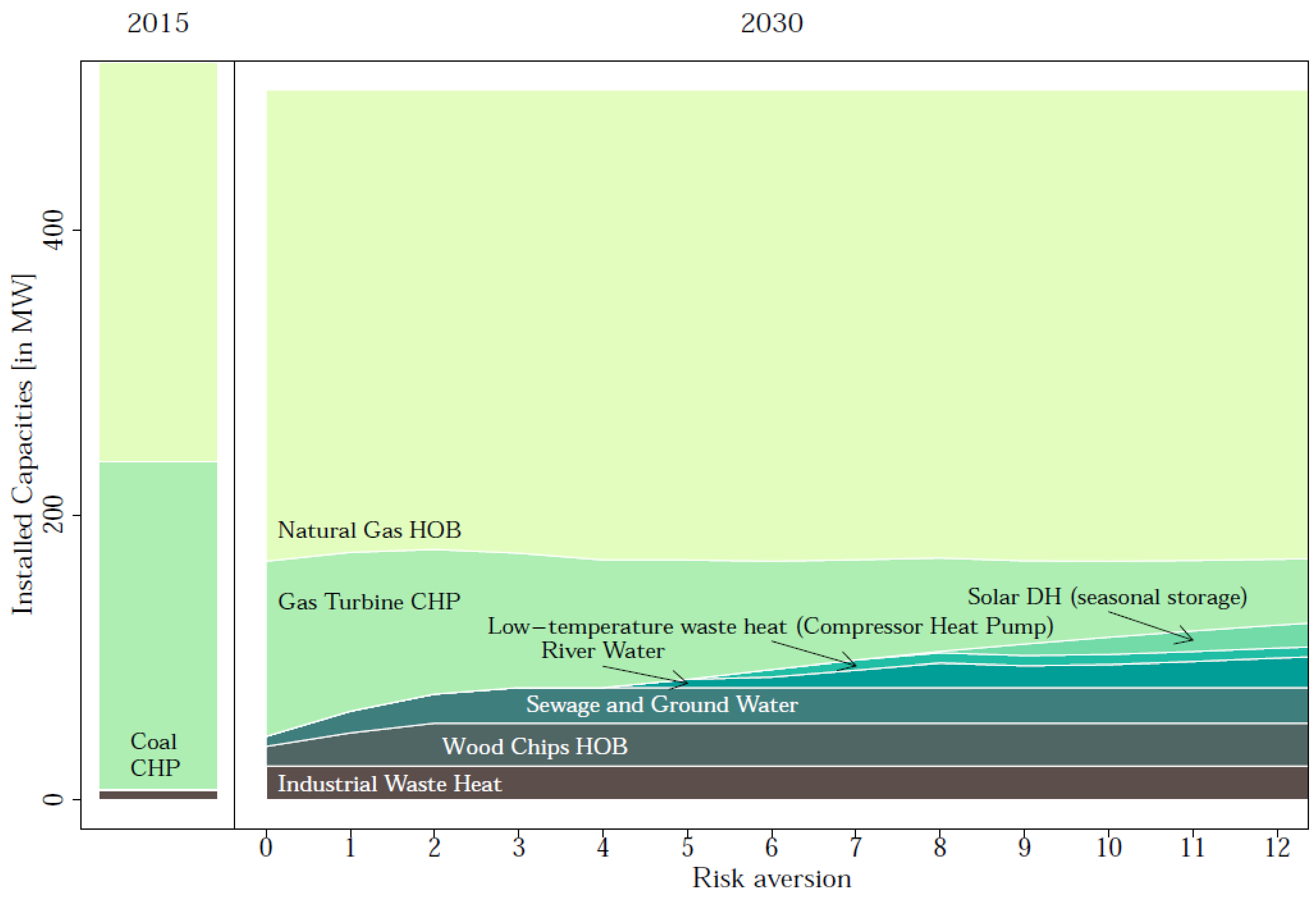


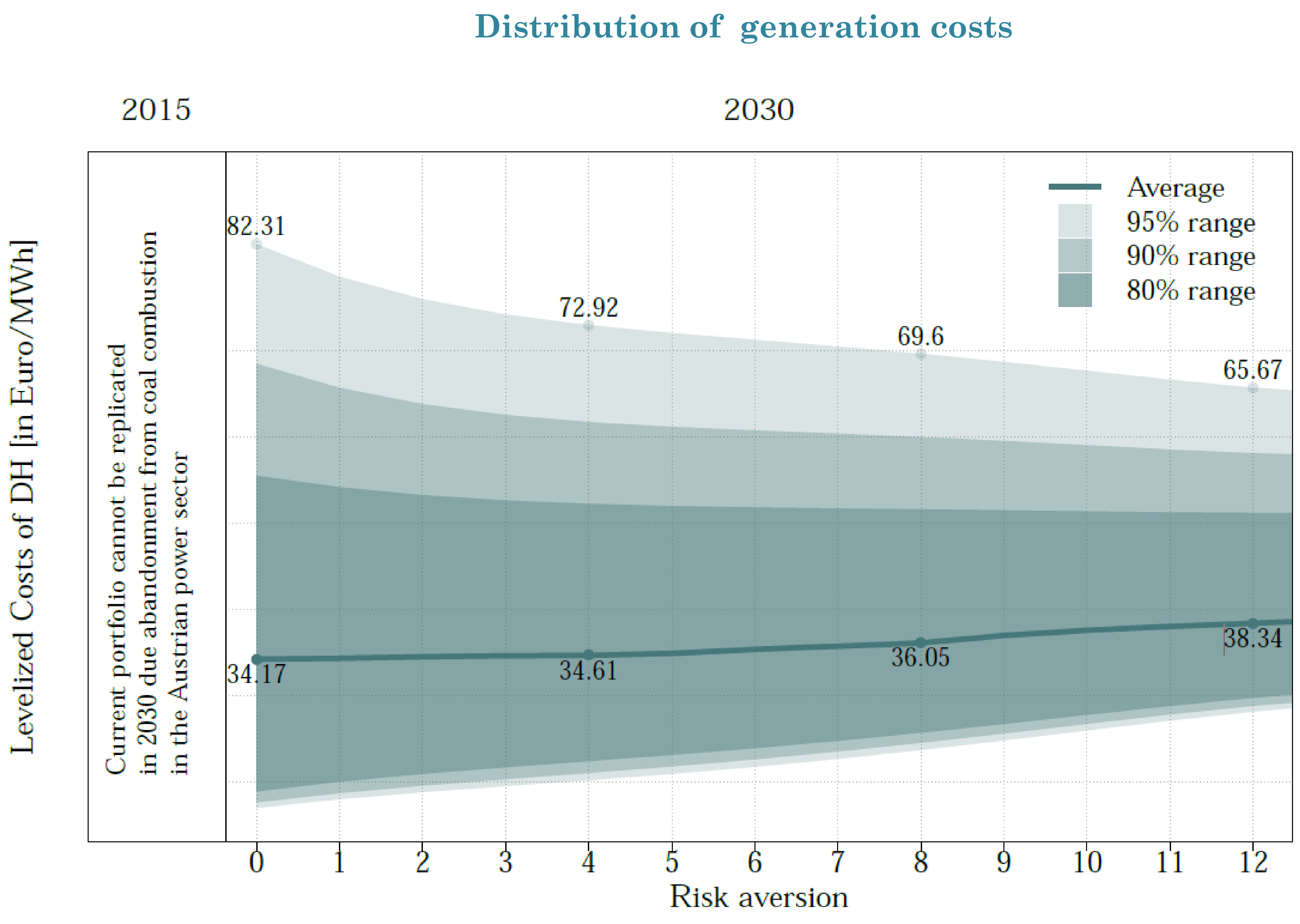
Linz: Expected annual generation



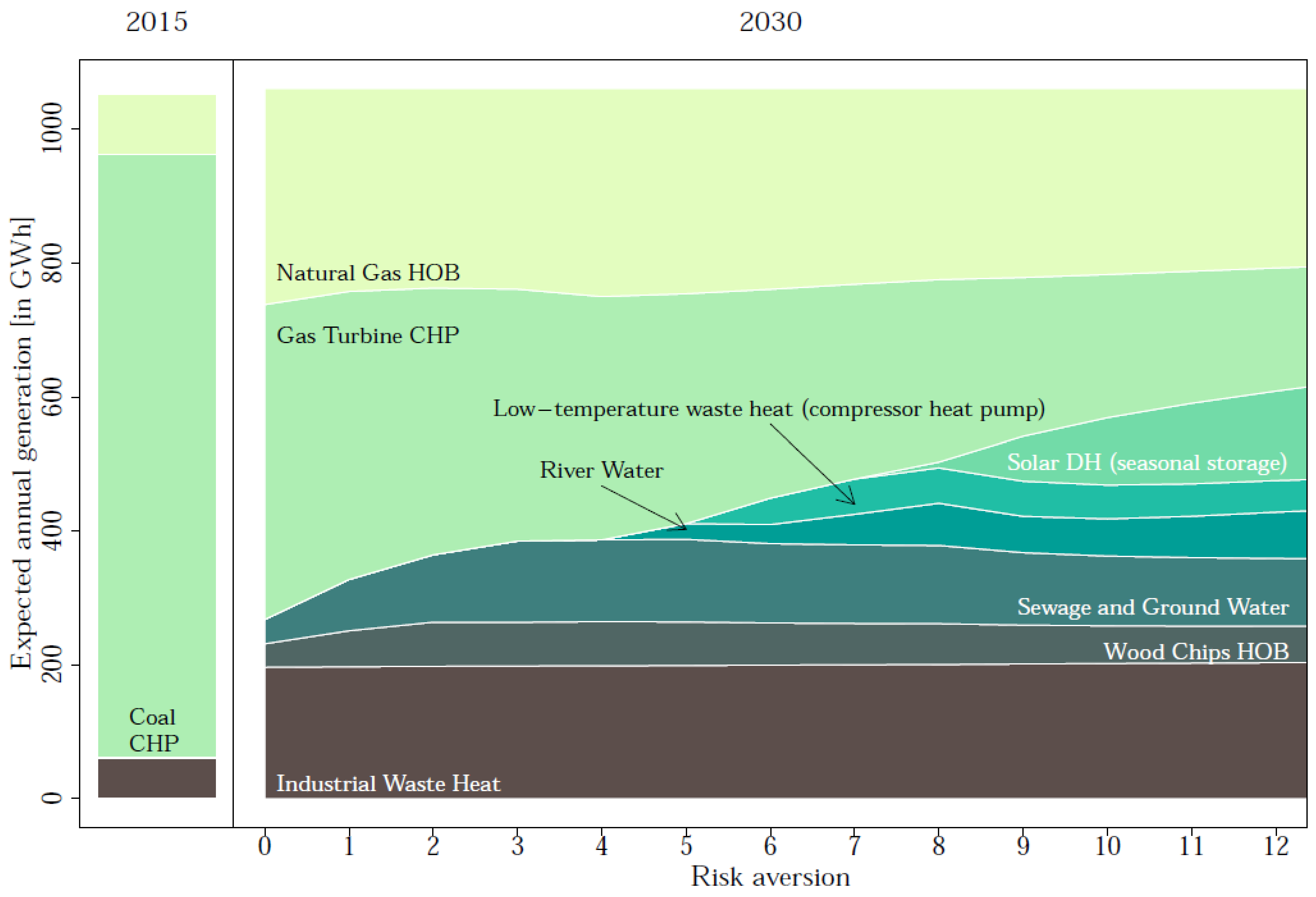


Graz: Installed capacities

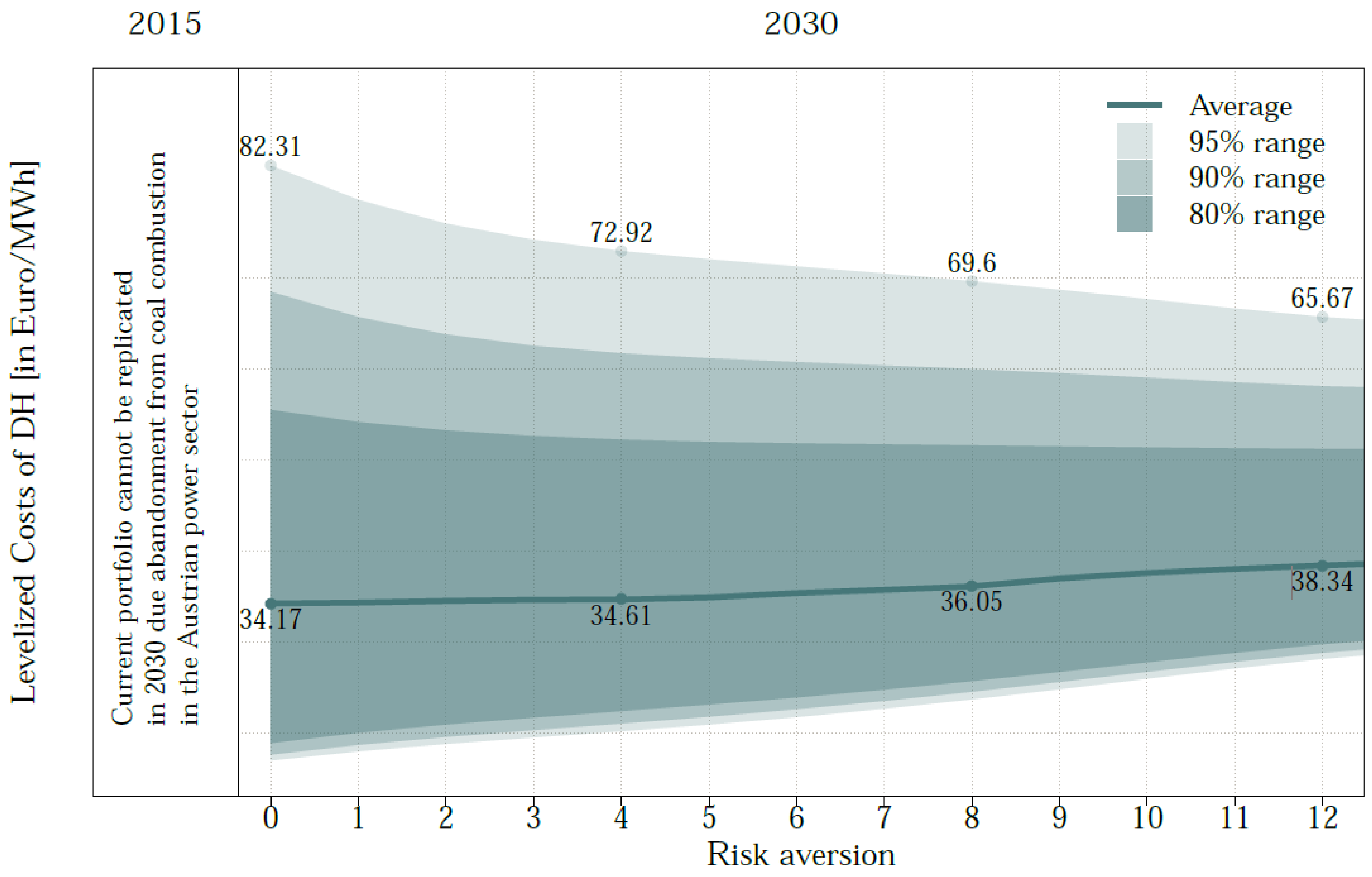




Graz: Expected annual generation



Distribution of generation costs



The role of heat pumps

- When minimizing expected generation costs is the only target, heat pumps are typically **not part of the least-cost portfolios** for 2030 in Austria. However least-cost portfolios are very vulnerable to unfavourable price developments , i.e. economic not viable in these scenarios.

- Heat pumps are **used for diversification purpose** in mean-variation optimal generation portfolios, in particular when gas CHP plants are present. Compared to least-cost portfolios, **expected generation costs are slightly higher, but their volatility is much lower**.

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Methodology (backup)

Program 7 (Integral portfolio problem)

$$
\begin{aligned}
\min_{c} \varphi &\left(\boldsymbol{F}^\top \boldsymbol{c} + (P_\sigma \bar{\mathbf{V}})^\top Q(P_\sigma \boldsymbol{c}) \right) \\
&= \boldsymbol{F}^\top \boldsymbol{c} + \sum_{\sigma \in \mathcal{S}_n} \mathbb{P}(\sigma) \left(\bar{\mathbf{V}}_{|\sigma}\, Q(P_\sigma \boldsymbol{c}) + \frac{\beta}{2} Q(P_\sigma \boldsymbol{c})^\top \Sigma_{|\sigma}\, Q(P_\sigma \boldsymbol{c}) \right), \\
s.t. \quad & \bar{\boldsymbol{c}} \geq \boldsymbol{c} \geq \boldsymbol{0}, && (\forall t \in [0,T]) \\
& \boldsymbol{1}^\top \boldsymbol{c} \geq D(0). && (\forall t \in [0,T])
\end{aligned}
$$

where we have that

$$
\begin{aligned}
\mathbb{P}(\sigma) &:= \mathbb{P}(V_{\sigma(1)} < V_{\sigma(2)} < \cdots < V_{\sigma(n)}), \\
\bar{\mathbf{V}}_{|\sigma} &:= P_\sigma\, \mathbb{E}(V | V_{\sigma(1)} < V_{\sigma(2)} < \cdots < V_{\sigma(n)}), \\
\Sigma_{|\sigma} &:= P_\sigma \left[\mathbb{C}\mathrm{ov}(V | V_{\sigma(1)} < V_{\sigma(2)} < \cdots < V_{\sigma(n)}) \right] P_\sigma^\top + (\bar{\mathbf{V}}_\sigma - \bar{V})(\bar{\mathbf{V}}_\sigma - \bar{V})^\top
\end{aligned}
$$

and $\mathcal{S}_n$ denoting the set of all $n!$ permutations of $\{1, 2, \ldots, n\}$.

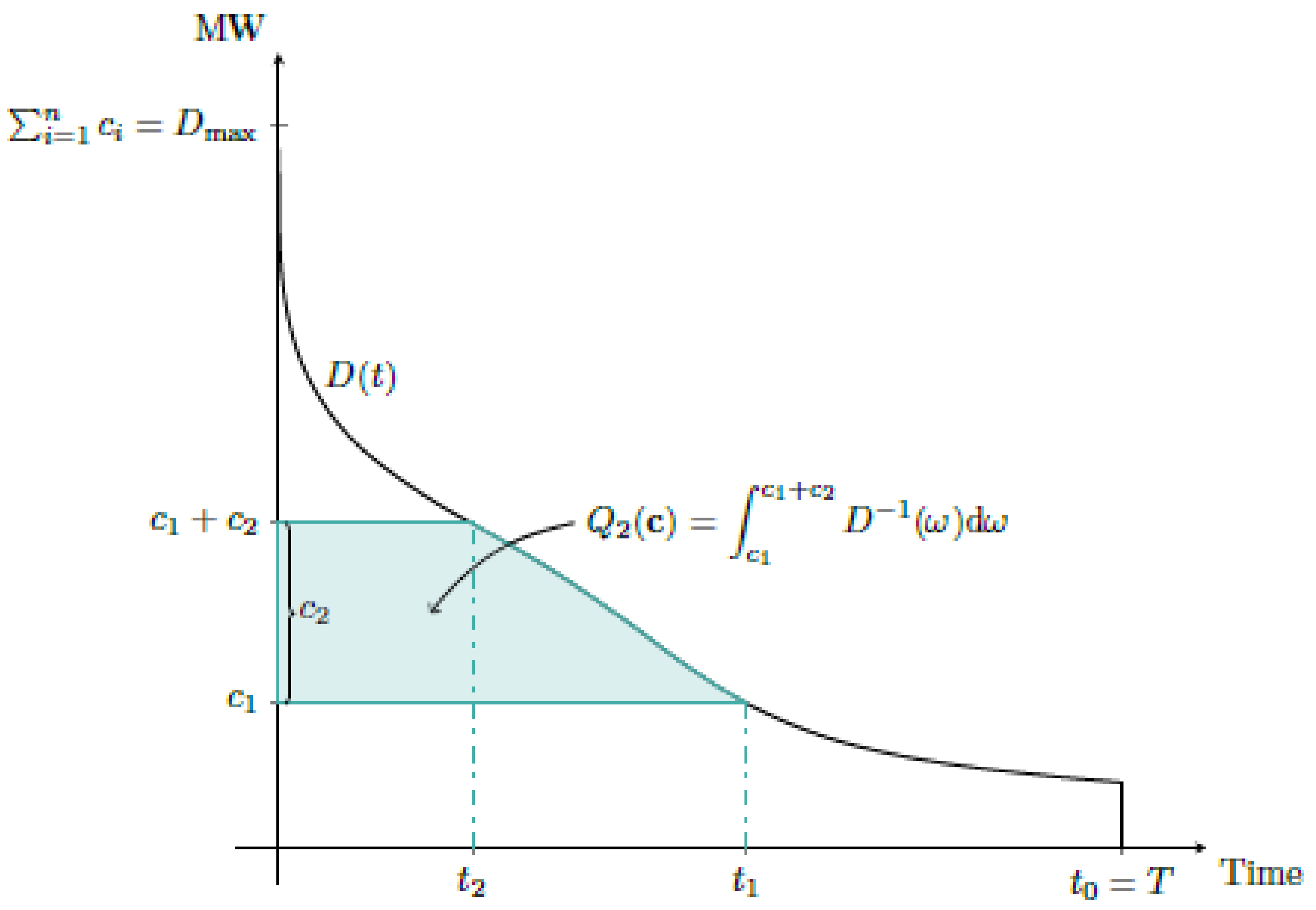

Figure 5.1: Load duration curve $D(t)$ with notion for the GEP with merit-order dispatching. For district heating technology 2 the corresponding capacity is given by c_2 and the corresponding DH generation by $Q_2(\mathbf{c})$ (surface of red area). (Source: Own illustration)