Smart power-to-heat concepts for district heating system based on data-energy network

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

HOCHSCHULE LANDSHUT

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Background and Motivation
Heat Transition

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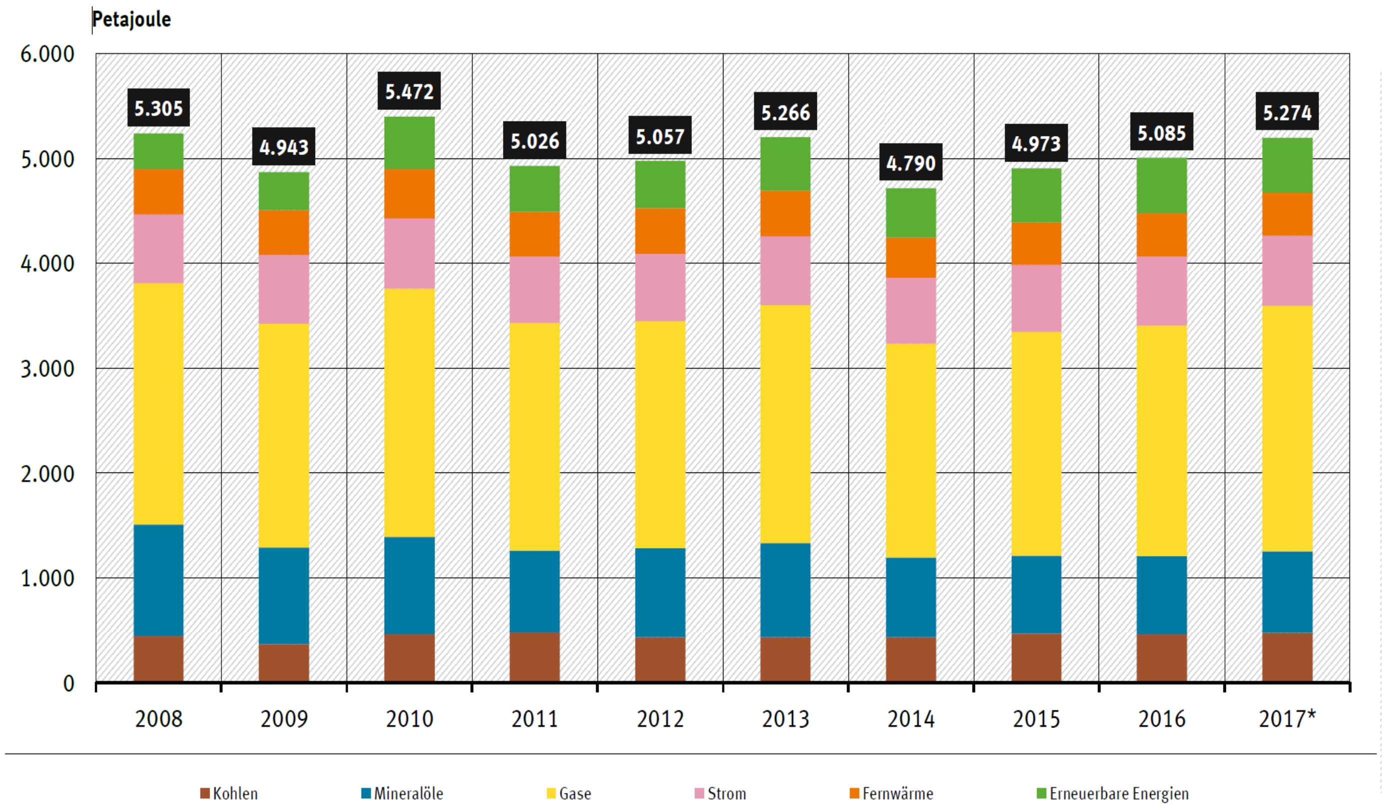
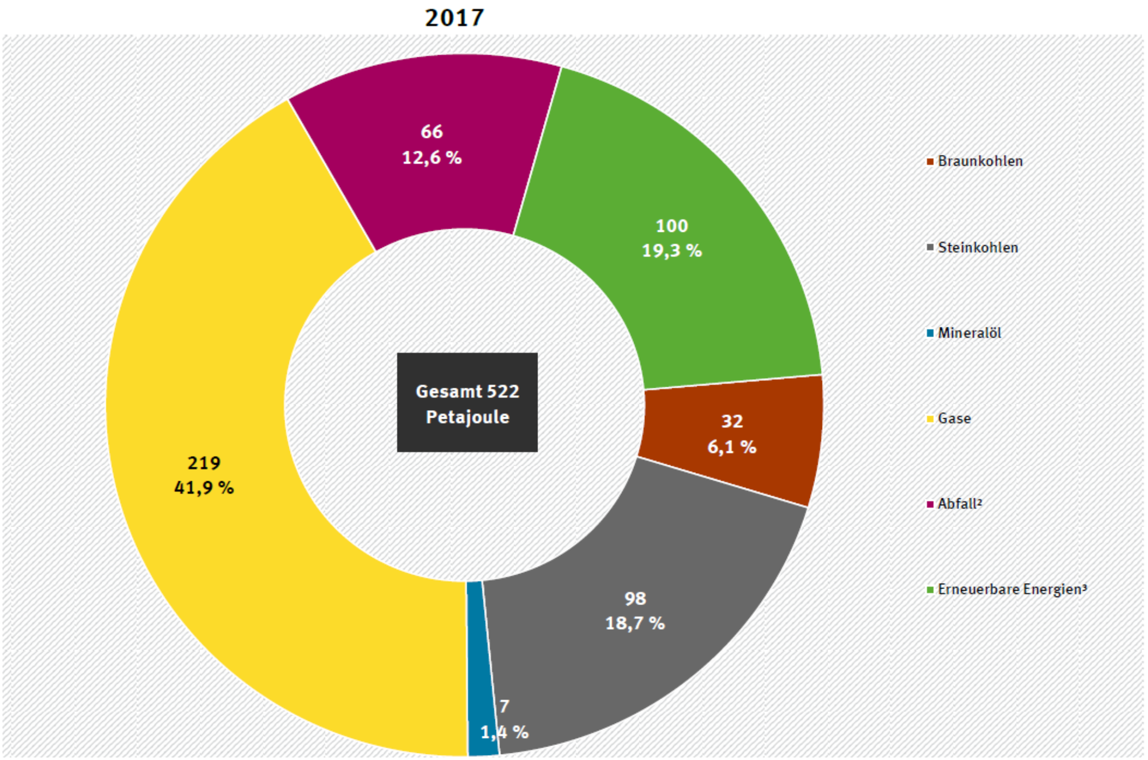


Quelle: Arbeitsgemeinschaft Energiebilanzen, Anwendungsbilanzen, Stand 11/2018

Figure 1: Heat consumption (incl. cooling applications) by energy source



Quelle: Arbeitsgemeinschaft Energiebilanzen, Anwendungsbilanzen, Stand 08/2018

Figure 2: Energy source of district heating system (DHS)

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P2H in Germany

- At the beginning of 2019, 36 larger P2H modules with an electrical output of between **0.5 and 60 MW** were installed in Germany.
- The total output amounts to approximant **555 MW**.

Table 1: Example of P2H Modules in Operation in Germany

Betreiber	Leistung	Inbetriebnahme
BTB Berlin	6 MW	2015
Energieversorgung Offenbach	2x5 MW	2014
ENRO Ludwigsfelde	15 MW	2014
FHW Berlin-Neukölln	10 MW	2015
Heizkraftwerke Mainz	5 MW	2013
Mainova	8 MW	2015
N-ERGIE	50 MW	2015
Stadtwerke Flensburg	30 MW	2012
Stadtwerke Lemgo	5 MW	2012
Stadtwerke Schwerin	15 MW	2013
Stadtwerke Tübingen	5 MW	2014
VVS Saarbrücken	10 MW	2012

Quelle: Power-to-Heat plants in Germany, Power-to-Heat, http://www.power-to-heat.eu/power-to-heat/

Methodology
P2H Concept for DHS

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Challenges of Implementation P2H in DHS

- Complex Options of Implementation P2H
- Cost-effective and Eco-friendly
- Combining P2H and Heat Load Forecasting

P2H Concept for DHS

Location
- Centralized
- Decentralized

Power source
- Renewable Power Plants: PV, Wind Power, Biomass
- Green Power from Grid

Conversion Technology
- Electrical Resistance Heating: Heat Rod, Electric Boiler
- Heat Pump

Storage
- Active: Internal, External
- Passive

Figure 3: P2H Concept in DHS

Methodology
Data Analysis

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Example of DHS

- Biomass Cogeneration Plant (CHP) since 2012
- Biomass CHP supplies:

  Electricity: **16 GWh/a** (4500 households)

  Heat: **60 GWh/a** (4700 households)
- Line Length: 30 km

Annual Load Duration Curve

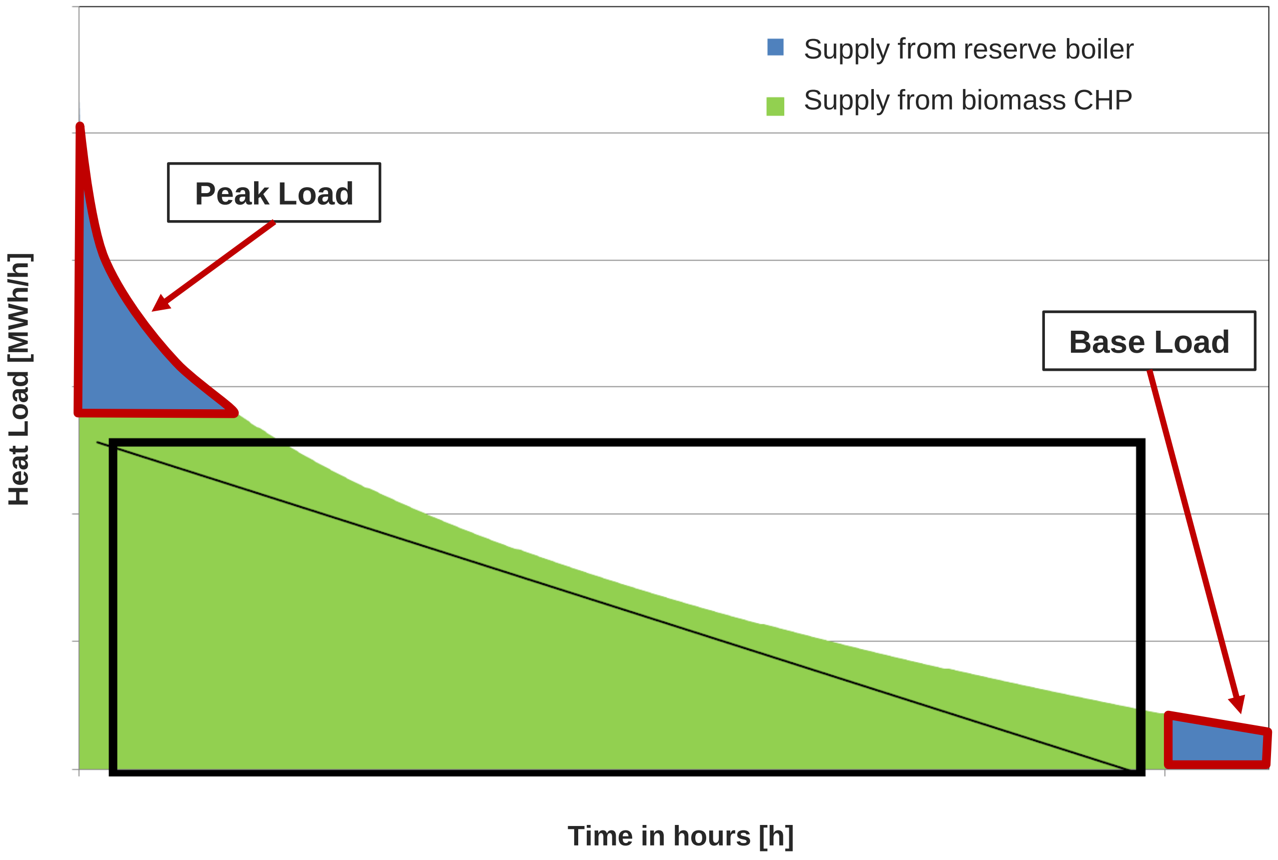

Figure 4: Annual load duration curve of DHS

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Heat Load Characteristics

- Thermal Load inversely proportional to outdoor temperature
- Heat load in summer is 20%-30% in winter
- Heat load fluctation in summer (about 10%) is much smaller than in winter (30%)
- Two peaks: 6:00 - 8:00, 18:00 - 21:00
- Two drops: 14:00 - 16:00, 22:00 - 04:00

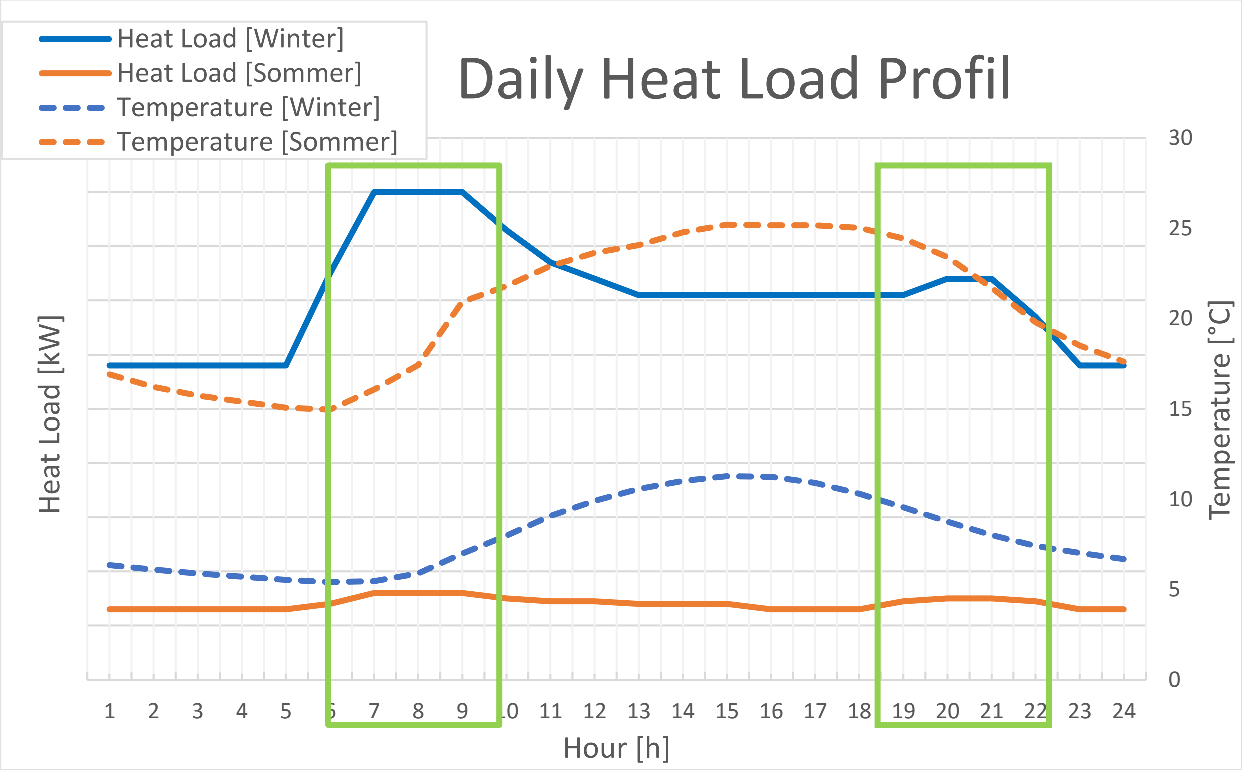

Figure 5: An Example Daily Heat Load Profile for DHS over One Year with Corresponding Outside Temperature

Methodology and P2H Concept
Heat Load Forcasting — Data Pre-Processing

Most ML models are not able to handle categorial variables, so we choose the following cyclic encoding:

$$x_{\sin} = \sin\left(\frac{2 \times \pi \times t}{T}\right)$$

$$x_{\cos} = \cos\left(\frac{2 \times \pi \times t}{T}\right)$$

For $t \in T$, with $T = 12$ for months, $T = 7$ for weekdays and $T = 365$ for day in year.

Normalization of numerical values by following equation:

$$z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}$$

All numerical values are transformed to be between $\min = 0$ and $\max = 1$

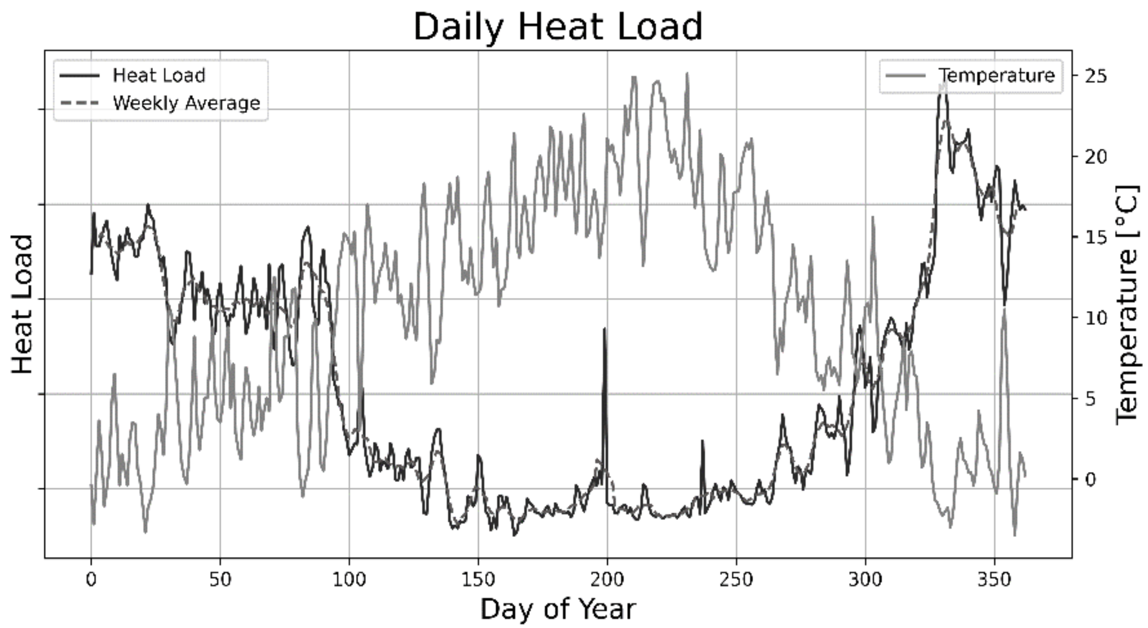

Figure 6: Daily heat load demand for one example building over one year with corresponding outside temperature.

Methodology and P2H Concept

Heat Load Forcasting — Model Development and Evaluation

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1.095 daily values: 80% for train and 20 % test

Training phase:

- approximate a function $f: \mathbf{X} \rightarrow \mathbf{Y}$,
- $\mathbf{X}$ is composed of the features *yesterday's heat load, temperature, humidity, month, weekday, day of year*
- $\mathbf{Y}$ is the day-ahead prediction of the building's heat load.
- three models *Random Forest, Neural Network, Support Vector Machine*

trained models are evaluated with the remaining 20 % data

Table 2: Model evaluation metrics on test set.

	Random Forest	Support Vector Machine	Neural Network
R^2	**0.98**	0.96	0.95
MAE	**18.21**	28.27	32.50
RMSE	**34.75**	49.25	52.51

Model evaluation metrics

$$\mathrm{R}^2 = \frac{\sum_{n=0}^{N}(\widehat{y_n} - \overline{y_n})}{\sum_{n=0}^{N}(y_n - \overline{y_n})},$$

$$\mathrm{MAE} = \frac{1}{N}\sum_{n=0}^{N}|\widehat{y_n} - y_n|,$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{n=0}^{N}(\widehat{y_n} - y_n)^2}{N}}.$$

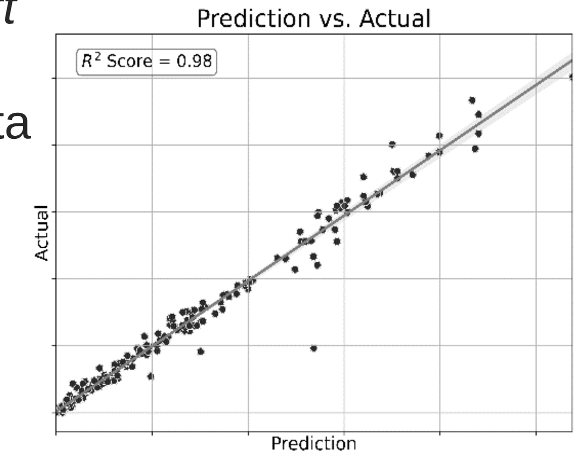

Figure 7: Accuracy of model prediction with an R^2 score of 0.98

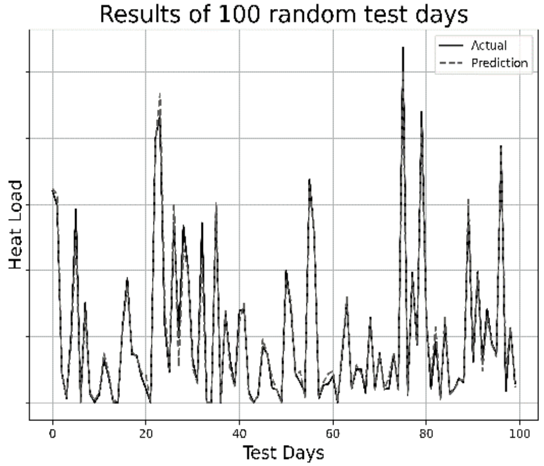

Figure 8: Comparison between actual heat load and predicted value for 100 random days

Methodology and P2H Concept
Implementation P2H Concept

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- Decentralized systems:
  - Purchase, installed, maintained cost
  - Retrofitting difficulty
  - Installed additional meters
  - Space requirement
  - Contract adjustment

  => Heat boilers, heat rods
- Centralized systems:
  - Heat losses in heat transfer

  => Superpower Heat pump, multiple small heat pumps

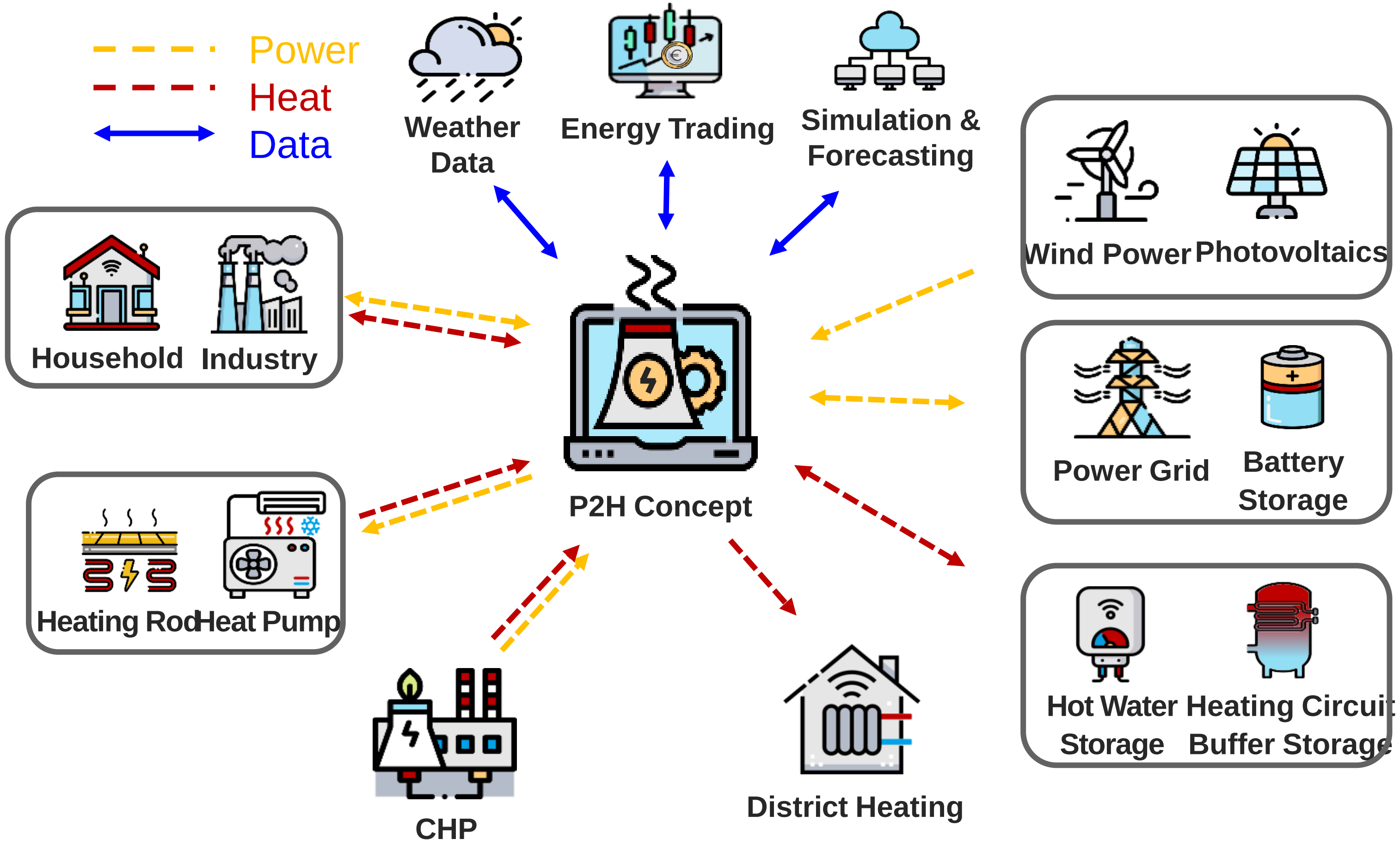

Figure 9: P2H Concept for DHS Including Data and Energy Flows

Results
Cost Analysis

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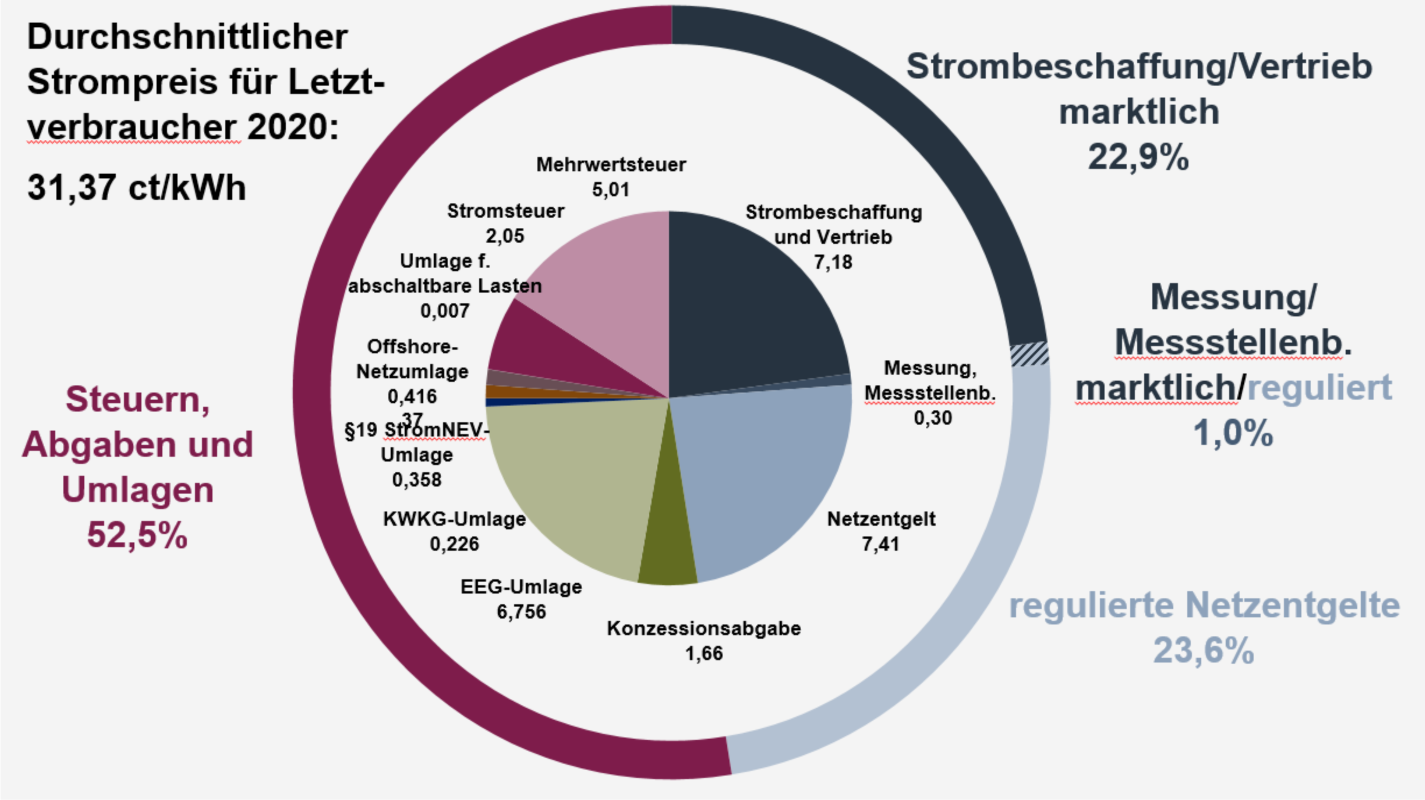
Cost Analysis

- Purchase cost of heat pump is about **7 times** that of a heat boiler
- Cost-balancing electricity price (over 5 years) for heat pumps and electric boilers is **23 cents/kWh**
- The replacement of gas boiler with P2H technology is **NOT** cost-effective in the current situation



Quelle: BDEW, Angaben in ct/kW bei einem Verbrauch von 3.500kWh/a, Stand: 01/2020

Figure 10: Average Electricity Price for P2H Operators

Thanks for your attention!

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