Developing a Model for Consumer Management of Decentralised Options

A working paper in progress, co-authored with Broghan Helgeson

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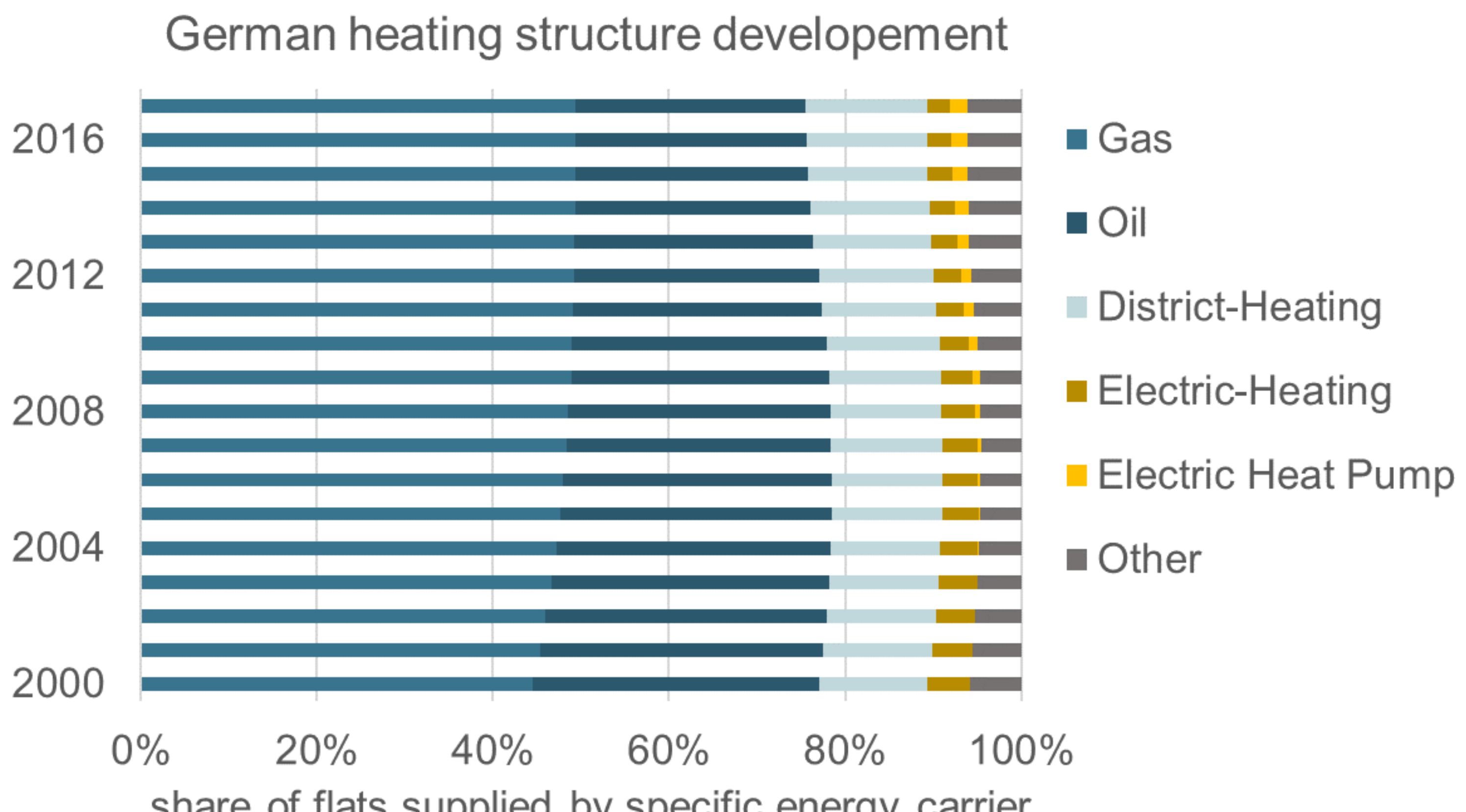
Decarbonisation amidst a slowly changing heat sector

Motivation

- Decarbonisation target in the building sector: (-40% by 2050[1])
- > 75% of flats heated w/ fossil fuels in 2017 (~50% gas, >25% oil)[2]
- Low (~3.4% in 2015) system replacement rate in heating market [3]



Research Questions

Modelling household energy consumption and behaviour

Methodological

i) How can linear programming methods be used to **simulate investment in and operation of** distributed generation and storage technologies to optimize the **total energy use** of end consumers?

ii) What **technological, regional and regulatory aspects** must be accounted for in order to model the decisions surrounding end consumers' energy use and provision?

Applied

iii) What role may **emerging technologies** play in helping end consumers in Germany achieve a cost-minimal **energy mix**?

iv) How may **variations in the electricity price and remuneration structures** due to an increasing share of renewable electricity sources affect the consumer's energy decisions?

A Glance into Consumer Modelling Literature

Existing applications and methodologies

Various **Distributed Energy Resource/Systems** (DER/DES) models are used for **Decentralised Energy Planning** (DEP) most of which apply either:

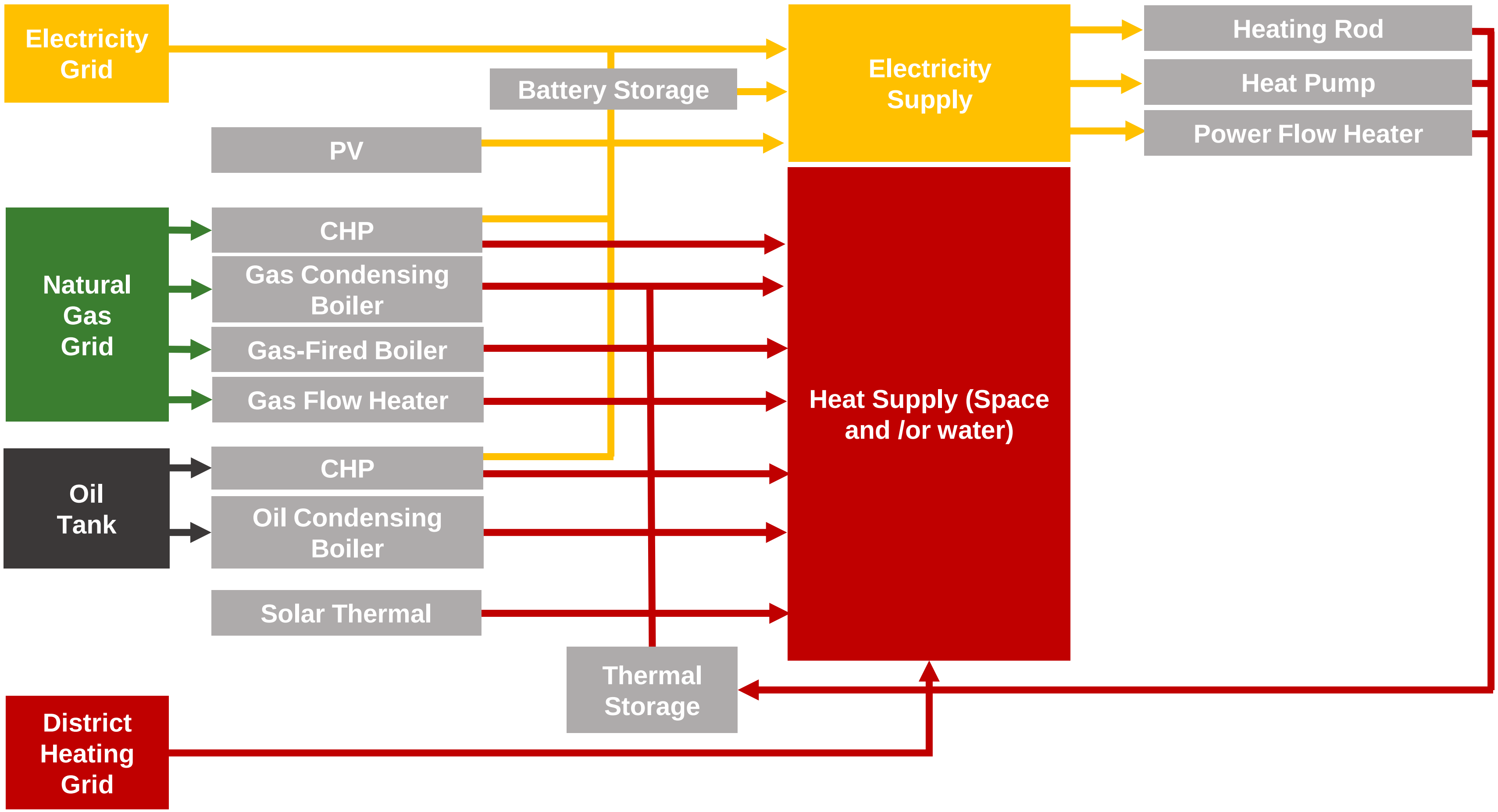
- Simulation models (e.g. Balcombe et. al.(2015))
- Optimisation models
  - Mostly Mixed-Integer Linear Programming (MILP) models
  - Most cover electricity, combined water and space heating as well as cooling
  - Many focus on specific technology mix (e.g. Ashouri et. al. (2013))
  - Others have specific (stand alone) neighbourhood application including microgrid operation for rural or newly-built areas (e.g. Bracco et.al. (2016))

COMODO

- Variable consumer definition (load & production profiles) allow for the inclusion of **newly-built as well as stock buildings** for urban as well as rural areas
- Differentiation of energy use types: **electricity, warm water heat, space heat**
- Wide **range of technologies** and installation capacities: Application for households, trade, commerce and services (as well as small-scale industry)
- **Flexible design** of energy tariffs, remuneration, subsidy and costs to allow for an extensive range of **regulatory frameworks**

COMODO:
consumer management of decentralised options

COMODO Model Overview – Energy Flows



- Currently **20 technologies**
- **Hourly PV and solar thermal potentials** calculated according to technical norms[1,2,3] with standardised regional weather data[4]
- Coefficient Of Performance (COP): **hourly variable efficiency** of heat pumps depending on the source temperature[4,5] and the desired temperature of the heat supplied.

1: Eicker(2012), 2: Mertens(2013), 3: ESTIF(2007), 4: DWD(2017), 5: Benkert/Heidt(2000)

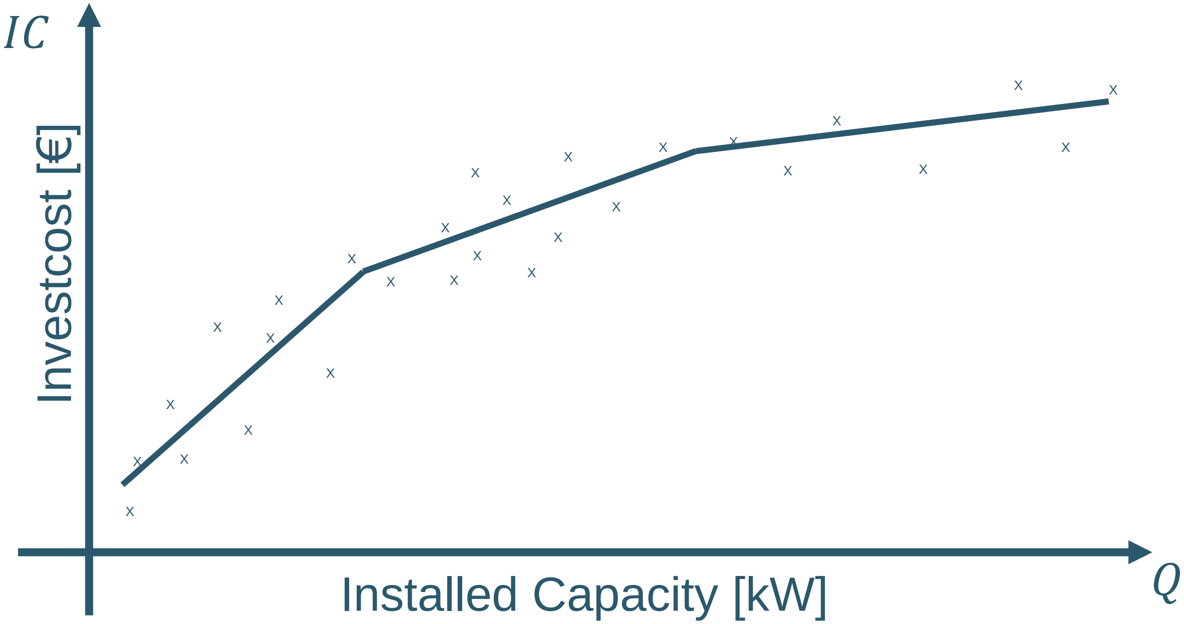
Model Overview

Mixed Integer Linear Problem

$$min!\boldsymbol{TC} = \sum_{y} \left[\frac{1}{(1+i)^{(y-y_0)}} \cdot \left(\sum_{x} \left[\boldsymbol{AIC}_{y,x} + \boldsymbol{FOMC}_{y,x} - \sum_{EUT} \boldsymbol{R}_{y,x,EUT} \right] + \boldsymbol{EBC}_{y} + \sum_{f} \left[\boldsymbol{CBC}_{y,f} \right] \right) \right]$$

Annualised Investment Cost (IC) reduced by Subsidy (S)

Variables		
$\boldsymbol{TC}$	€	Total Costs
$\boldsymbol{AIC}$	€/a	Annualised Investment Costs
$\boldsymbol{IC}$	€	Investment Costs
$\boldsymbol{S}$	€	Subsidy
$\boldsymbol{FOMC}$	€/a	Fixed Operation & Maintenance Costs
$\boldsymbol{R}$	€/a	Revenues, Remuneration
$\boldsymbol{EBC}$	€/a	Energy Based Costs
$\boldsymbol{CBC}$	€/a	Capacity Based Costs
Parameters		
i	-	interest rate
y	-	year
y_0	-	start year
Sets		
y	-	year
x	-	technology
f	-	fuel
EUT	-	Energy Use Type



Model Overview

Mixed Integer Linear Problem

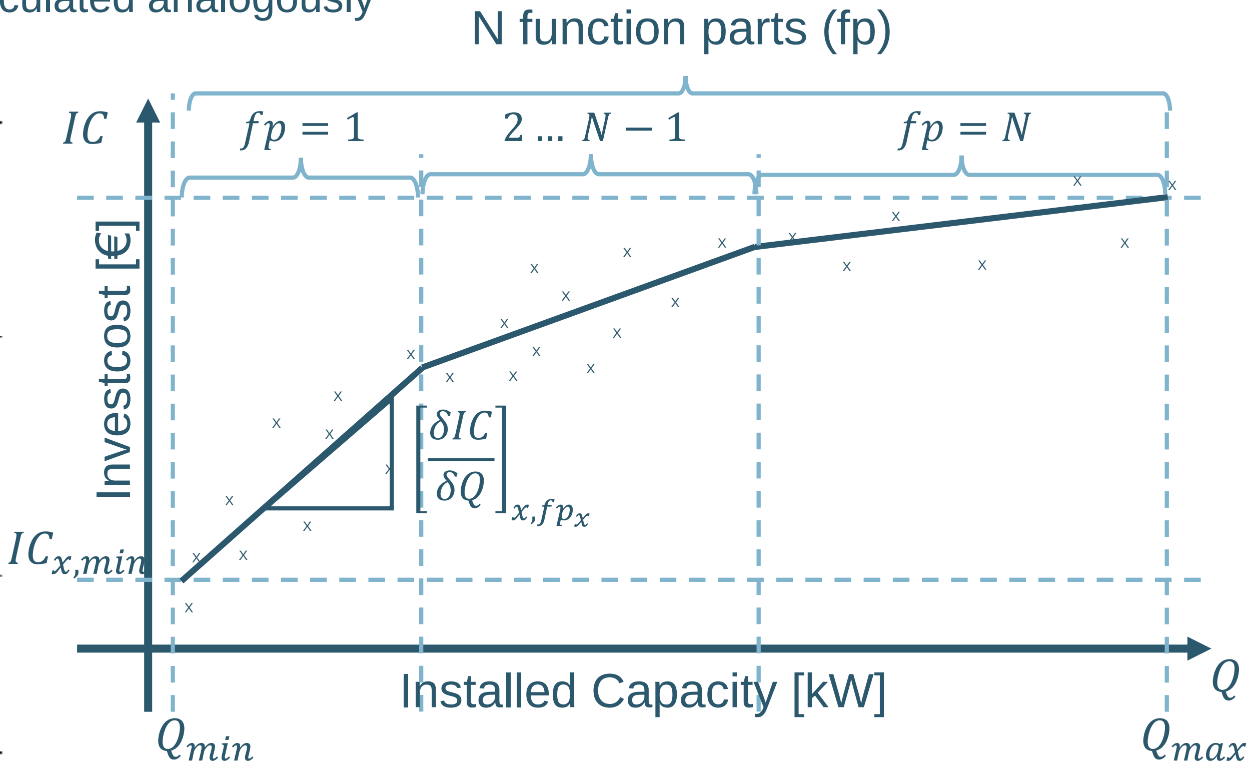
$$\boldsymbol{IC}_{y_x,x} = IC_{x,min} \cdot \gamma_{y_x,x,min} + \sum_{fp_x=1}^{N} \left[\boldsymbol{\Delta Q}_{y_x,x,fp_x} \cdot \gamma_{y_x,x,fp_x} \cdot \left[\frac{\delta IC}{\delta Q}\right]_{x,fp_x} \right]$$

$$\boldsymbol{Q}_{y_x,x} = \sum_{fp_x=1}^{N} \boldsymbol{\Delta Q}_{y_x,x,fp_x}$$

$\boldsymbol{FOMC}_{y,x}$ and $\boldsymbol{S}_{y_x,x}$ are calculated analogously

$\boldsymbol{FOMC}_{y,x}$ with $\gamma = 1$

Variables		
$\boldsymbol{IC}$	€	Investment Costs
$\boldsymbol{S}$	€	Subsidy
$\boldsymbol{FOMC}$	€$/a$	Fixed Operation & Maintenance Costs
$\boldsymbol{Q}$	kW	Capacity
Parameters		
i	-	interest rate
y	-	year
y_0	-	start year
γ	-	learning factor
$IC_{x,min}$	€	Min. Invest. Costs
$\delta IC/\delta Q$	€$/kW$	Specific Invest. Costs
Sets		
y	-	year
y_x	-	installation year
x	-	technology
fp	-	function part



A Glace at an Application: Variable Electricity Prices

On the Way to a Efficient Market Solution

Preliminary Results

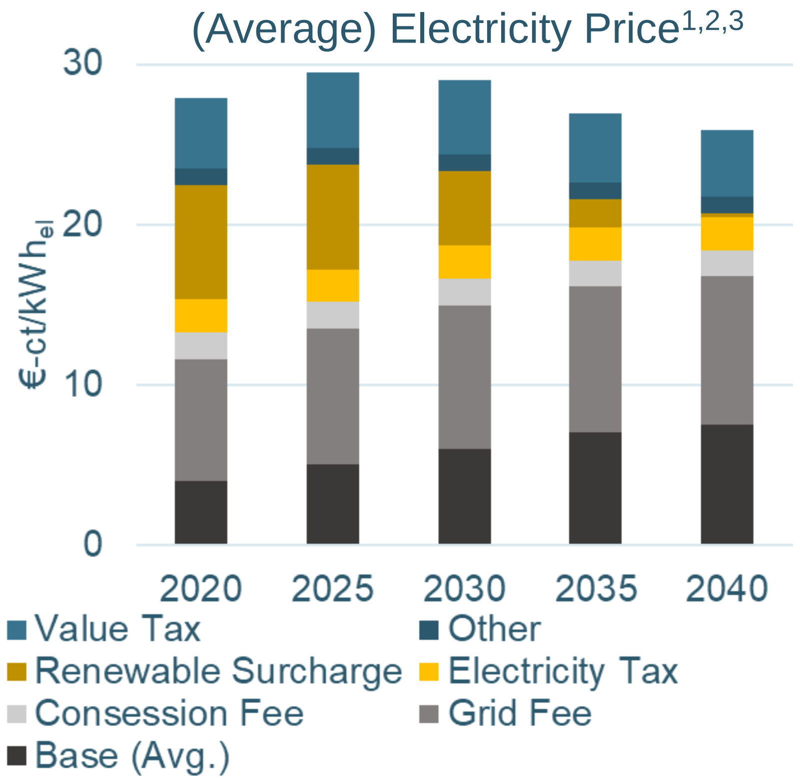
Consumer and Scenario

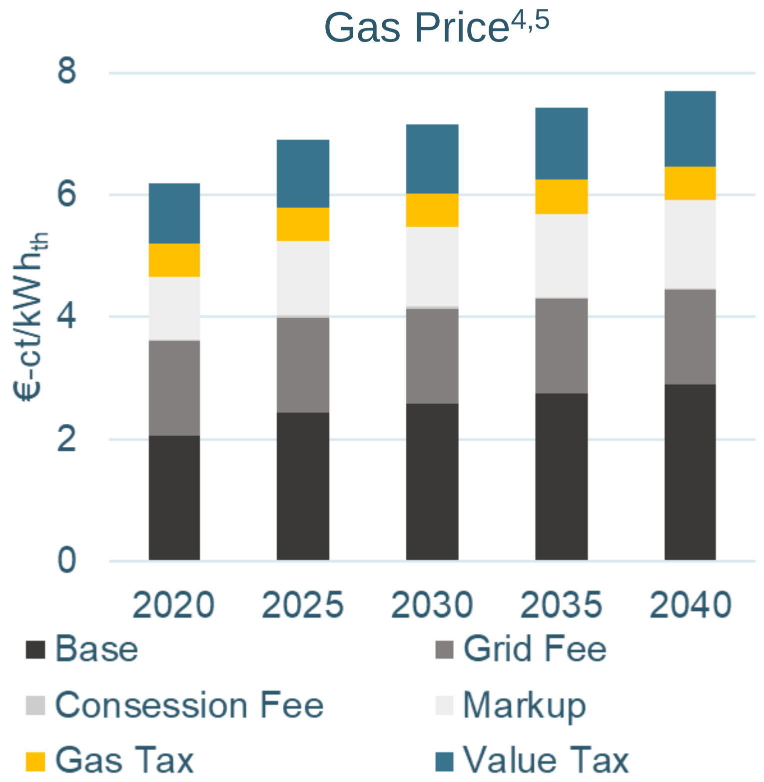
	Name	SFH1	SFH2	
Consumer	Description	Newly built	1984-1994	Clustering according to building typology in 2015[1]
	Region	Cologne	Cologne	Relevant for Load Profile generation based VDI4655[2] and regional weather[3]
	Dwelling area [m²]	160	137	According to building typology in 2015[1]
	Investment Phase	**2025-2040**	**2025-2040**	
Demand [kWh/a]	Electricity	5101	5101	Based on typical days of VDI4655[2] (#residents = 3) and regional weather[3]
	Water Heat	1868	1868	Based on building typology in 2015[1]
	Space Heat	13510	18084	According to building typology in 2015[1]
Technical specifics	Roof Area [m²]	60	60	Assumption
	PV Potential [kW_p]	10	10	Assumption
	Flow Temperature [°C]	35	55	Assumption
	Economic lifetime for technologies [years]	15	15	Assumption for all technologies except batteries (10 years), technological lifetime differs from economic lifetime

Scenarios	Status Quo	Efficiency Boost	Market Solution
Electricity Price	Constant	Variable	Variable
RES Support	Yes	Yes	No
RES Share in 2030	60%	60%	60%

1: IWU(2015), 2: VDI4655(2015) , 3: DWD(2017)

Market definitions - business as usual





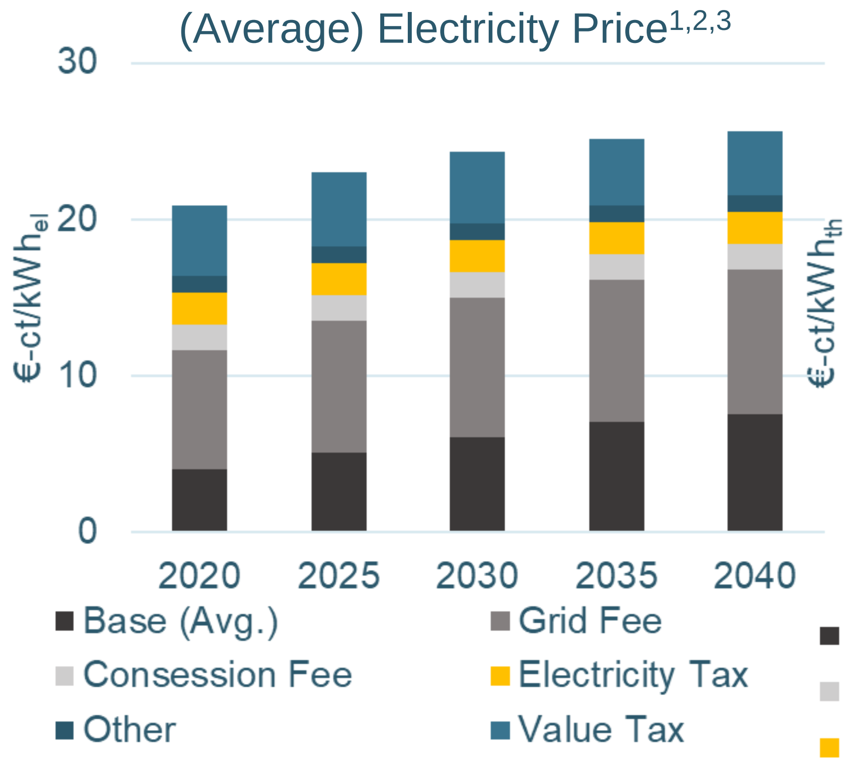
Market	Year	2020	2025	2030	2035	2040
	Delta (max-min) of hourly electricity price [€-ct/kWh]	20.1	22.1	25.5	28.7	31.3
	Share renewable electricity generation (%)	38	52	61**	64	67
	Avg. CO_2 emissions of grid electricity [gCO_{2eq}/kWh_{el}]	390	332	238	146	96

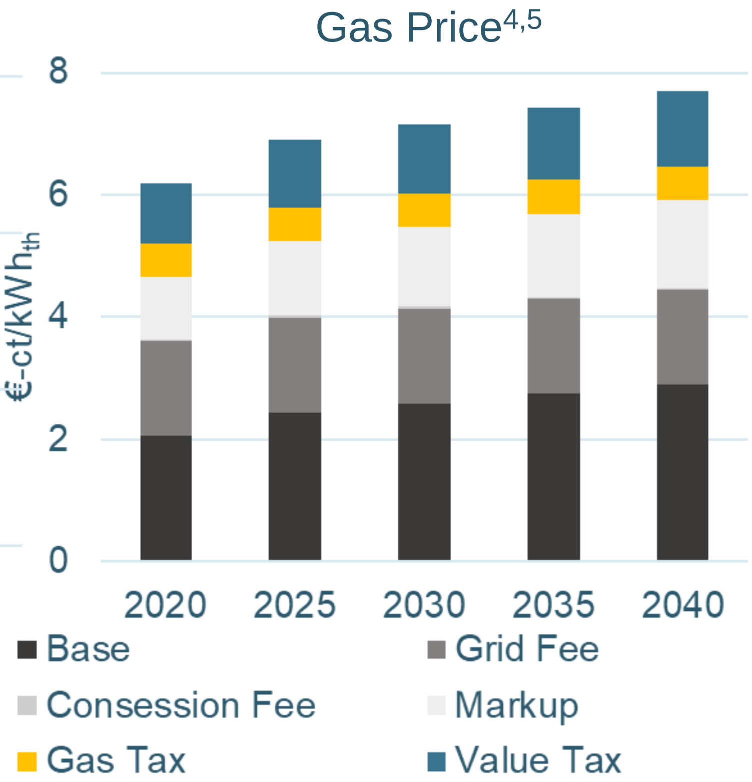
**60% target in 2030 set in model

- Current subsidy schemes annually reduced following the expected cost reduction
- FIT for CHP and market premium for PV are assumed to be constant

1: EWI model DIMENSION, 2: Estimation, 3: BDEW(2019)a, 4: BDEW(2019)b, 5: WEO(2018)

Market definitions – no RES support





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	Avg. CO_2 emissions of grid electricity [gCO_{2eq}/kWh_{el}]	390	332	238	146	96

**60% target in 2030 set in model

- No subsidies
- CHP and PV sell electricity at base price

1: EWI model DIMENSION, 2: Estimation, 3: BDEW(2019)a, 4: BDEW(2019)b, 5: WEO(2018)

Variable Electricity Prices

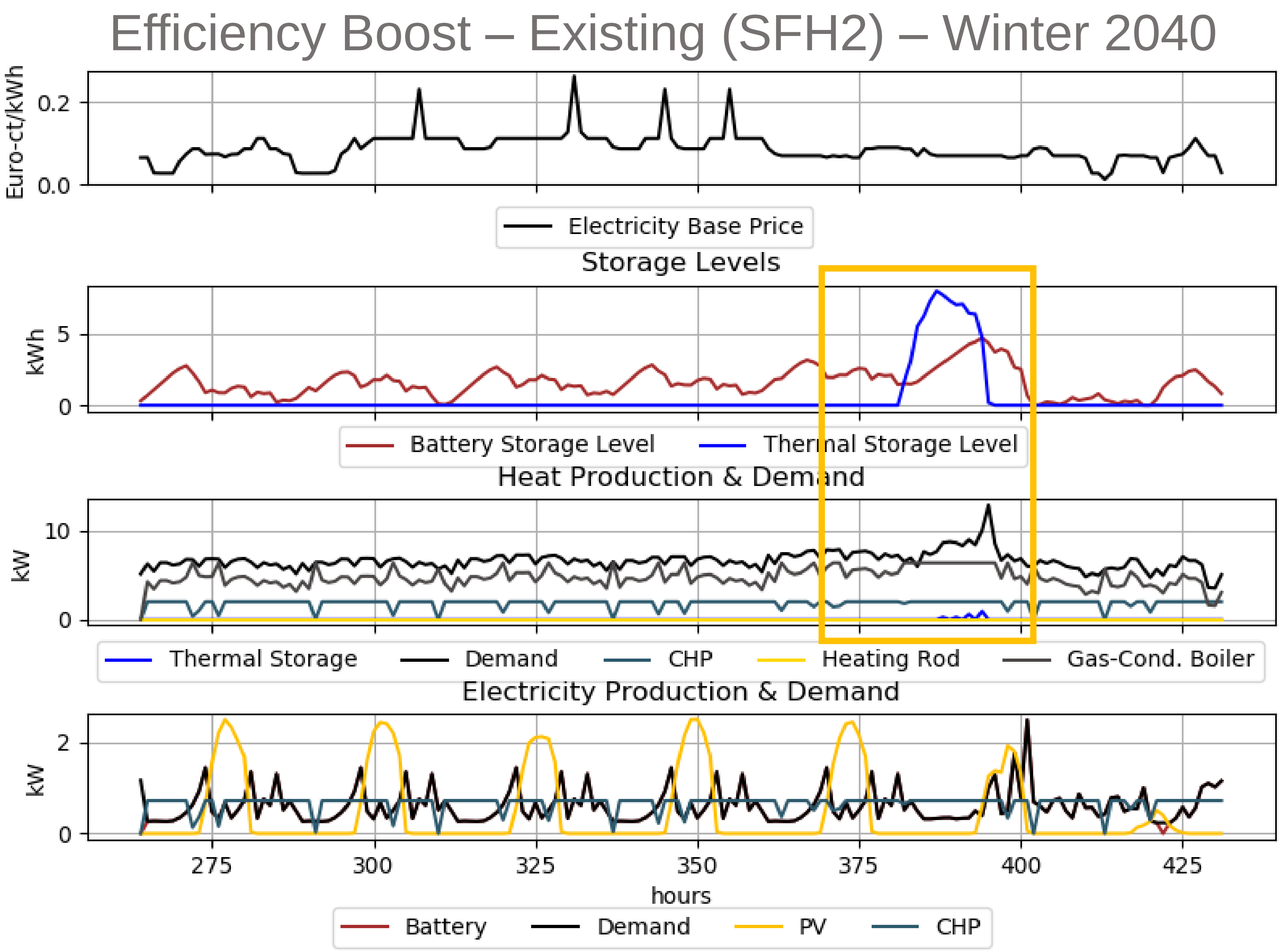
On the Way to a Efficient Market Solution

- Variable prices have minimal effect on investment
- Gas-based supply
- Heating rod as peak technology, for which the operation is influenced by the electricity price in 2025
- Self-sufficient electricity supply from 2040 onwards
- Self-sufficiency triggered by reduced costs (-18%) for Combined Heat and Power (CHP)

Scenarios	Status Quo	Efficiency Boost	Market Solution
Electricity Price	Constant	Variable	Variable
RES Support	Yes	Yes	No

Existing (SFH2)		2025-2039			from 2040		
		Status Quo	Efficiency Boost	Market Solution	Status Quo	Efficiency Boost	Market Solution
Gas Boiler	kW_{th}	6,4	6,4		6,4	6,4	
Heating Rod	kW_{th}	1,4	1,9		1,4	1,9	
Thermal Storage	l	300	300		300	300	
CHP (Gas Motor)	kW_{th}	-	-		2,0	2,0	
PV	kW_{peak}	-	-		4,7	4,7	
Battery	kWh_{el}	-	-		7,3	7,3	

Variable Electricity Prices



Variable Electricity Prices

On the Way to a Efficient Market Solution

- Variable prices have minimal effect on investment
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- Self-sufficient electricity supply from 2040 onwards
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Market solution:

- No renewable surcharge leads to lower electricity prices
- Higher heating rod capacity allows for lower gas boiler capacity

Scenarios	Status Quo	Efficiency Boost	Market Solution
Electricity Price	Constant	Variable	Variable
RES Support	Yes	Yes	No

Existing (SFH2)		2025-2039			from 2040		
		Status Quo	Efficiency Boost	Market Solution	Status Quo	Efficiency Boost	Market Solution
Gas Boiler	kW_{th}	6,4	6,4	6,2	6,4	6,4	6,2
Heating Rod	kW_{th}	1,4	1,9	2,4	1,4	1,9	2,4
Thermal Storage	l	300	300	264	300	300	264
CHP (Gas Motor)	kW_{th}	-	-	-	2,0	2,0	2,0
PV	kW_{peak}	-	-	-	4,7	4,7	4,7
Battery	kWh_{el}	-	-	-	7,3	7,3	7,3

Variable Electricity Prices

On the Way to a Efficient Market Solution

- Newly build (SFH1) shows similar results, with reduced capacities due to lower heating demand
- Electricity makes up larger share of total energy demand, making CHP more profitable
- Overall, the changes in costs as well as emissions due to the introduction of variable prices are insignificant (<1%)
- Self-sufficient electricity supply in 2040 causes results to converge

Scenarios	Status Quo	Efficiency Boost	Market Solution
Electricity Price	Constant	Variable	Variable
RES Support	Yes	Yes	No

Existing (SFH2)		2025-2039			from 2040		
		Status Quo	Efficiency Boost	Market Solution	Status Quo	Efficiency Boost	Market Solution
Gas Boiler	kW_{th}	6,4	6,4	6,2	6,4	6,4	6,2
Heating Rod	kW_{th}	1,4	1,9	2,4	1,4	1,9	2,4
Thermal Storage	l	300	300	264	300	300	264
CHP (Gas Motor)	kW_{th}	-	-	-	2,0	2,0	2,0
PV	kW_{peak}	-	-	-	4,7	4,7	4,7
Battery	kWh_{el}	-	-	-	7,3	7,3	7,3

Newly build (SFH1)		2025-2039			from 2040		
		Status Quo	Efficiency Boost	Market Solution	Status Quo	Efficiency Boost	Market Solution
Gas Boiler	kW_{th}	5,0	5,0	5,0	-	-	5,0
Heating Rod	kW_{th}	2,1	2,1	1,2	2,1	2,1	1,2
Thermal Storage	l	300	300	261	300	300	261
CHP (Gas Motor)	kW_{th}	-	-	-	4,1	4,1	2,0
PV	kW_{peak}	-	-	-	4,8	4,8	4,6
Battery	kWh_{el}	-	-	-	8,1	8,1	7,7

Key Findings & Outlook

Main Findings

Investment and operation are closely linked

- Larger investment in more expensive capacity is avoided by installing storages and simple electric heating rods
- High electricity prices drive self-sufficient investment behaviour as soon as a technology reaches a certain cost level

Variable electricity prices show limited impact on investment

- Hybridisation via investment in larger heating rod
- Combined heat and power (CHP) in 2040 dominant
- Investment in CHP makes further hybridisation via PV and battery storage lucrative

Outlook:

- Consumer profiles update: New VDI 4655 in in September 2019
- Further robustness checks, further scenarios?

Thank You!

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