Wuppertal Institute
for Climate, Environment
and Energy

The potential of heat and grid orientated block CHP on the minute reserve market and its impacts on CO_2 emissions

Prospects for the German energy market up to 2030

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4DH
4th Generation District Heating
Technologies and Systems

Technical potentials of combined heat and power units at the minutes reserve market

Motivation, energy political background in Germany and object of investigation

Expansion of CHP:

- CHP aim for 2020: 25 % of the net power generation* (2013: 18.1%)
- High expansion potentials of decentralised combined heat and power units in the field of residential (RB) and non residential buildings (NRB)
  (e.g. >17 millions of single-family and small multi-family houses in Germany)

Expansion of Renewable Energies:

- Great expansion of photovoltaics and wind
  (RES in the electricity sector: 2014: 26,2% / aim 2025: 40-45%)
- Fluctuations or forecast errors need compensation through balancing power
- The minutes reserve market is most suitable for heat and power units because of the tender arrangements

→ Focus on **pooling decentralised CHP units** and **balancing power markets** (MR)

*originally: with regard to total power production, currently in discussion: with regard to adjustable power generation

Research questions for the investigation

- What are the technical **potentials** of CHP units at the **minutes reserve market**?
- Which and how much **flexibility** is appropriate regarding the operation of CHP units for the **participation** at the **minutes reserve market?**
- Which **implications** has the flexibility on **CO_2 emissions**?
  → **Presentation's focal point**
  (by the example of „Residential Buildings")
- Which **constraints** bar the way towards a flexibility and a participation at the minutes reserve market?

Technical potentials of decentralised CHP units at the minutes reserve market

Key assumptions and input parameters – overview

Decentralised CHP (Stirling + Internal Combustion Engine)

$1\ kW_{el}$ | $50\ kW_{el}$ | $1\ MW_{el}$ | $18\ MW_{el}$

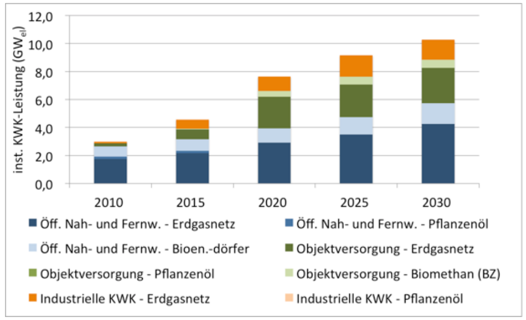
10 Residential Buildings (RB)

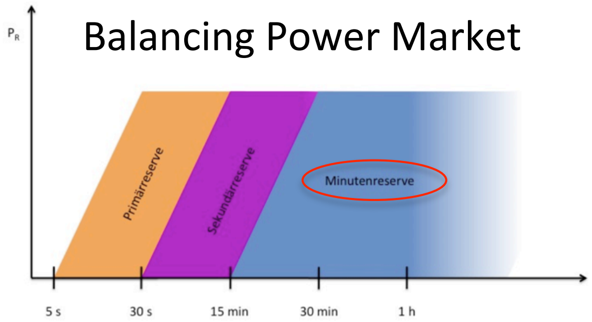
5 Non Residential Buildings (NRB)

1 Industry (exemplary)

1 Heat network (exemplary)

CHP Expansion Scenario (Lead Study 2011)





Design of 7 CHP modules for 10 residential building types

with a classical heat-orientated mode of operation

		Building		CHP Module					Boiler	Storage
		Heat demand	Heat load	Techn. principle	Capacity electr.	Capacity therm.	Power-to-heat ratio	Full load hours	Capacity therm.	Volume
		kWh/a	kW_{th}	-	kW_{el}	kW_{th}	-	h/a	kW_{th}	Litre
Existing Build.	**1 SFH**	22 700	14	Stirling	**1.0**	**5.6**	0.18	3 570	20	300
	2 MFH (small)	76 700	44	Otto	**5.5**	**12.5**	0.44	4 470	40	750
	3 MFH (big)	127 000	62	Otto	**5.5**	**12.5**	0.44	5 650	55	1 000
	4 High rise	883 900	466	Otto	**50.0**	**82.0**	0.61	5 670	440	3 000
EnEV 2007	**5 MFH (small)**	27 400	16	Stirling	**1.0**	**5.6**	0.18	4 050	20	300
	6 MFH (big)	49 300	26	Otto	**3.0**	**8.0**	0.38	4 810	26	500
	7 High rise	404 400	206	Otto	**34.0**	**66.0**	0.52	4 680	206	3 500
Passive H.	**8 MFH (big)**	23 600	20	Otto	**1.0**	**2.5**	0.40	5 940	20	500
	9 High rise	193 200	89	Otto	**15.2**	**30.0**	0.51	5 390	90	2 000
	10 Terraced H.	85 100	75	Otto	**5.5**	**12.5**	0.44	5 140	75	1 100

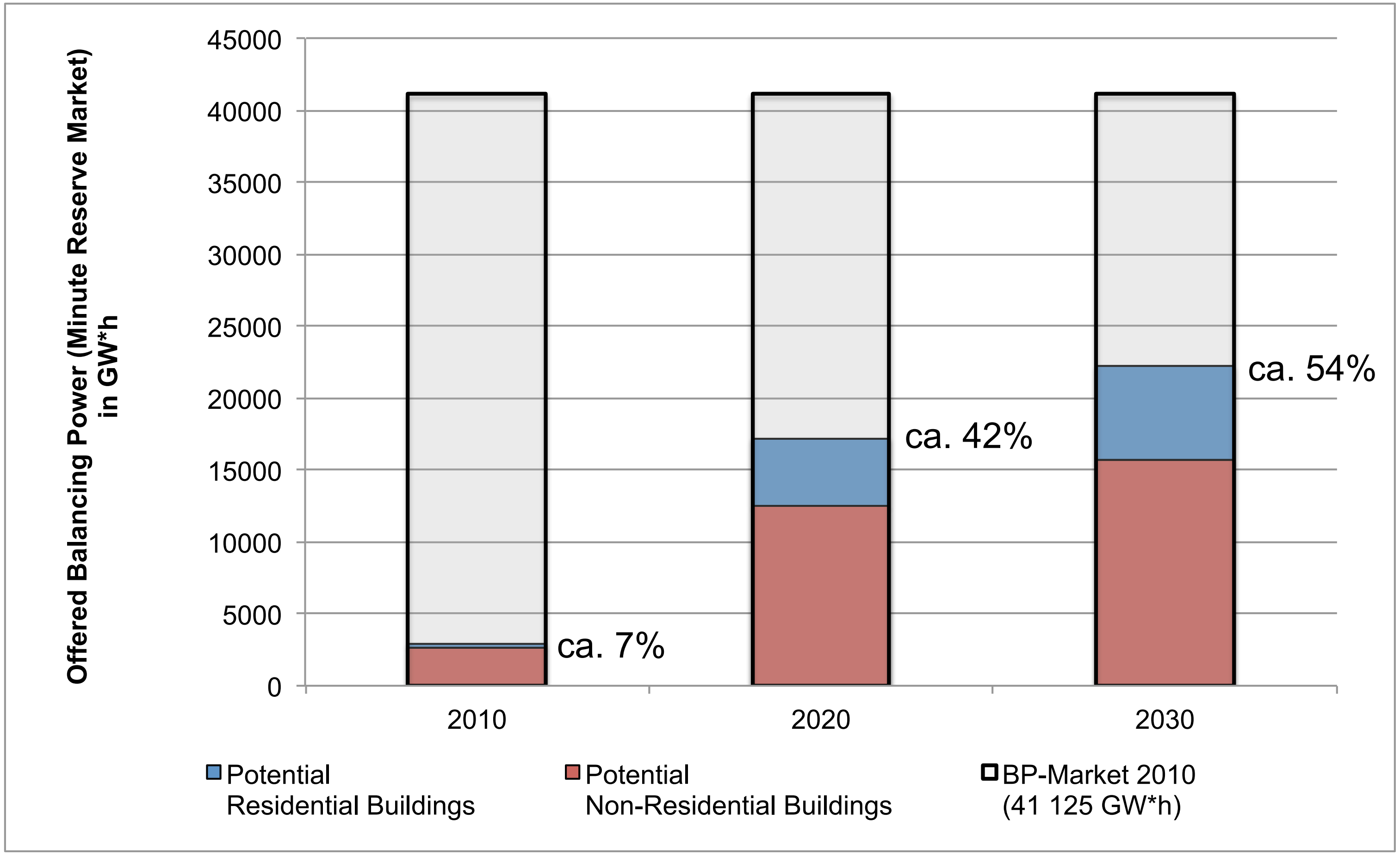
Energy performance of buildings (specific useful energy demand for heating in kWh/m^{2}a):

Existing buildings: 129 until 214
EnEV 2007: 50
Passive house: 15

EnEV = German Energy Saving Ordinance

Simulation results for potentials at the minutes reserve market

- **68 % of the installed CHP capacity** can be used for the provision of minutes reserve in annual average.
- In the future, CHP units for RB and NRB types could theoretically **cover about half of the German market of 2010** (without additional measures for the flexibilisation)



Flexibilisation of combined heat and power units

The effects vary heavily depending on the plant dimensioning

Three types of investigation:

- **Flex-1: Enlargement of the plant (Doubling CHP plant *including storage*)**
  - Enlargement of the supply potential (plus 10 to 56%) particularly in the winter
  - The lower the cover ratio of the thermal load, the higher the increase of provision of balancing power
  - Doubling of the storage losses (alternative solution: only enlargement of the CHP unit)

- **Flex-2: Enlargement of the buffer storage (4 times)**
  - Enlargement of the supply potential (plus 6 to 24 %) particularly in the transition period and for plants with high cover ratio of the thermal load

- **Flex-3: Deployment of emergency coolers**
  - Enlargement of the (pos.) supply potential (plus 12 to 97 %) particularly in the summer and for plants with low thermal cover ratio of the thermal load (e.g. RB1)
  - Additional loss of heat is low (high) for positive (negative) supplies

Balancing of CO_2 emissions

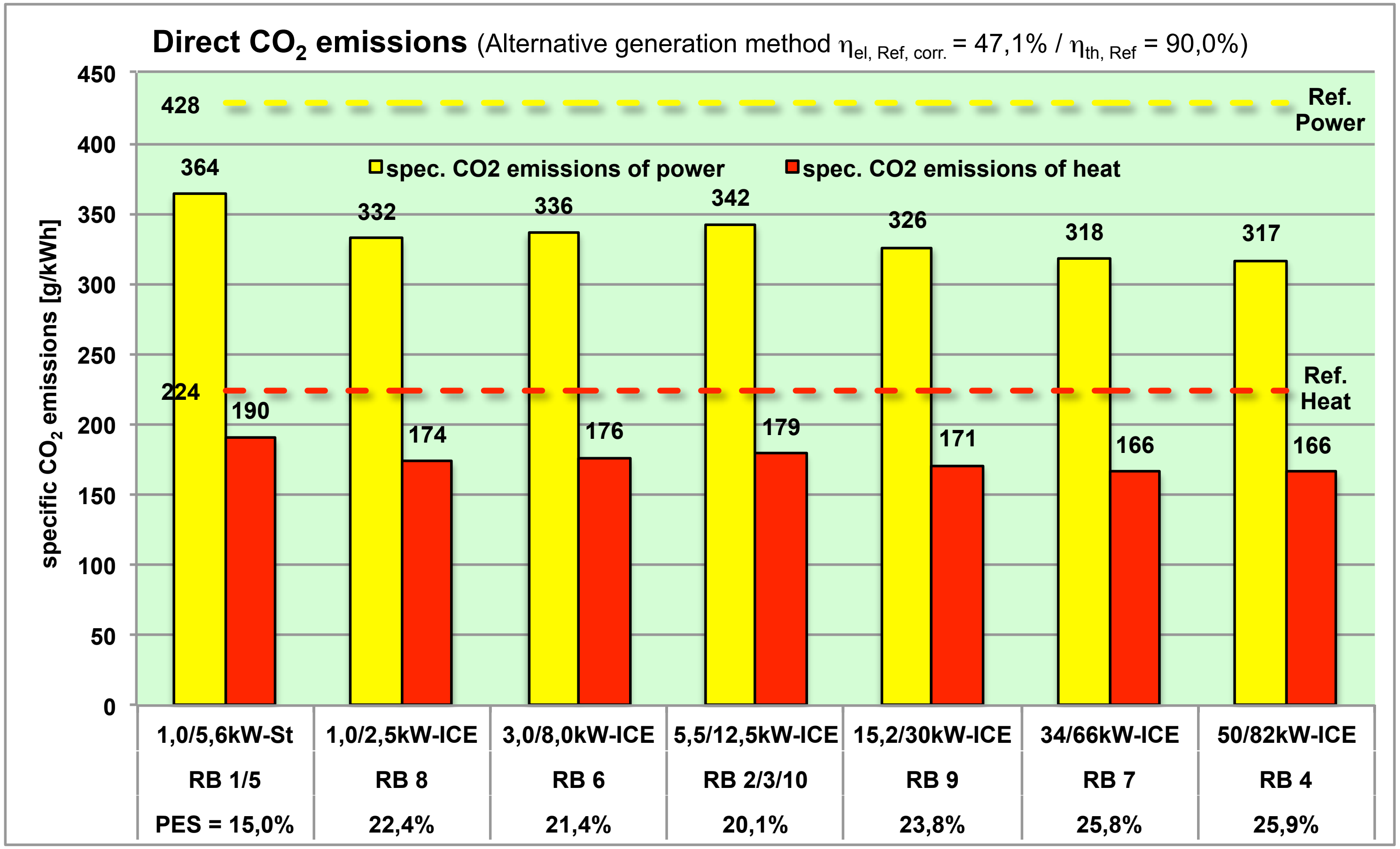
Principal proceeding

1. Calculation of **primary energy savings** vs. separate generation and allocation of **specific CO_2 emissions in g/kWh** to co-products power and heat for 7 selected CHP modules
   Chosen allocation method:
   Alternative Generation Method according to CHP EU directive 2004/8/EG
2. Calculation of **absolute CO_2 emissions per supply object in kg/a**;
   comparison of CHP mode of operation
   - "**Separate generation**"
   - **"Heat-orientated"**
   - **"Grid-orientated"**
   - **"Flexible"** (Flex 1 to 3)

   for all types of residential buildings RB 1 to RB 10
   (balance limit: total heat and power demand of supply entity)
3. **Upscaling** of CO_2 emissions **in t/a** with CHP quantity structure according to BMU "Lead Study 2011" for **2010, 2020 and 2030**

Primary energy savings vs. separate production and allocation of specific emissions to coproducts of power & heat

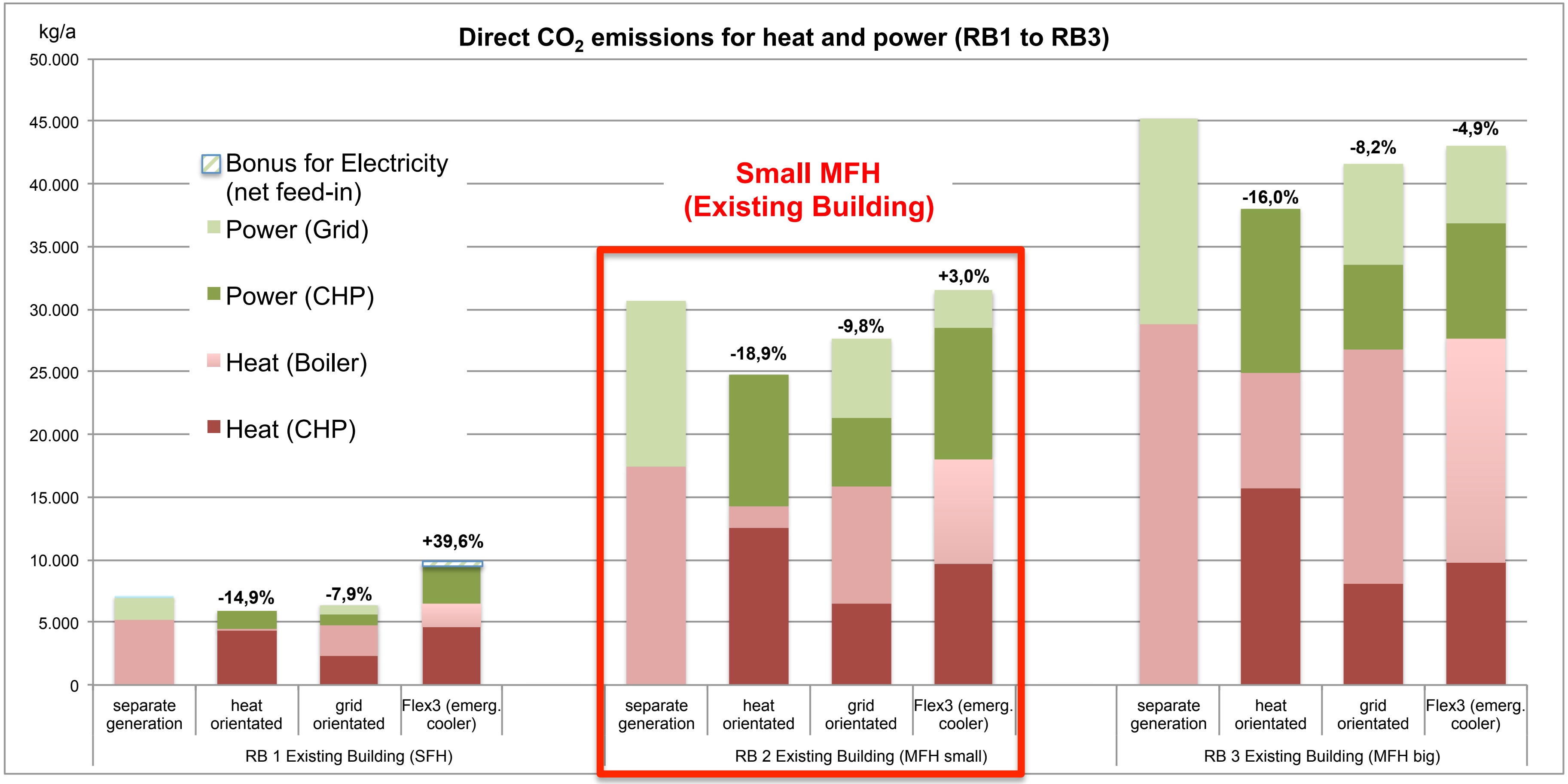
Results for Residential Building CHP (RB)



- Even a comparison with natural gas combined cycle plant (+ gas boiler) shows that all CHP modules are both primary-energy wise (PES of 15 to 26%) as also regarding CO_2 emissions for power and heat better than under separate production
- Bigger CHP aggregations (with higher electr. efficiency) tend to show better results

Object-related absolute CO_2 emissions

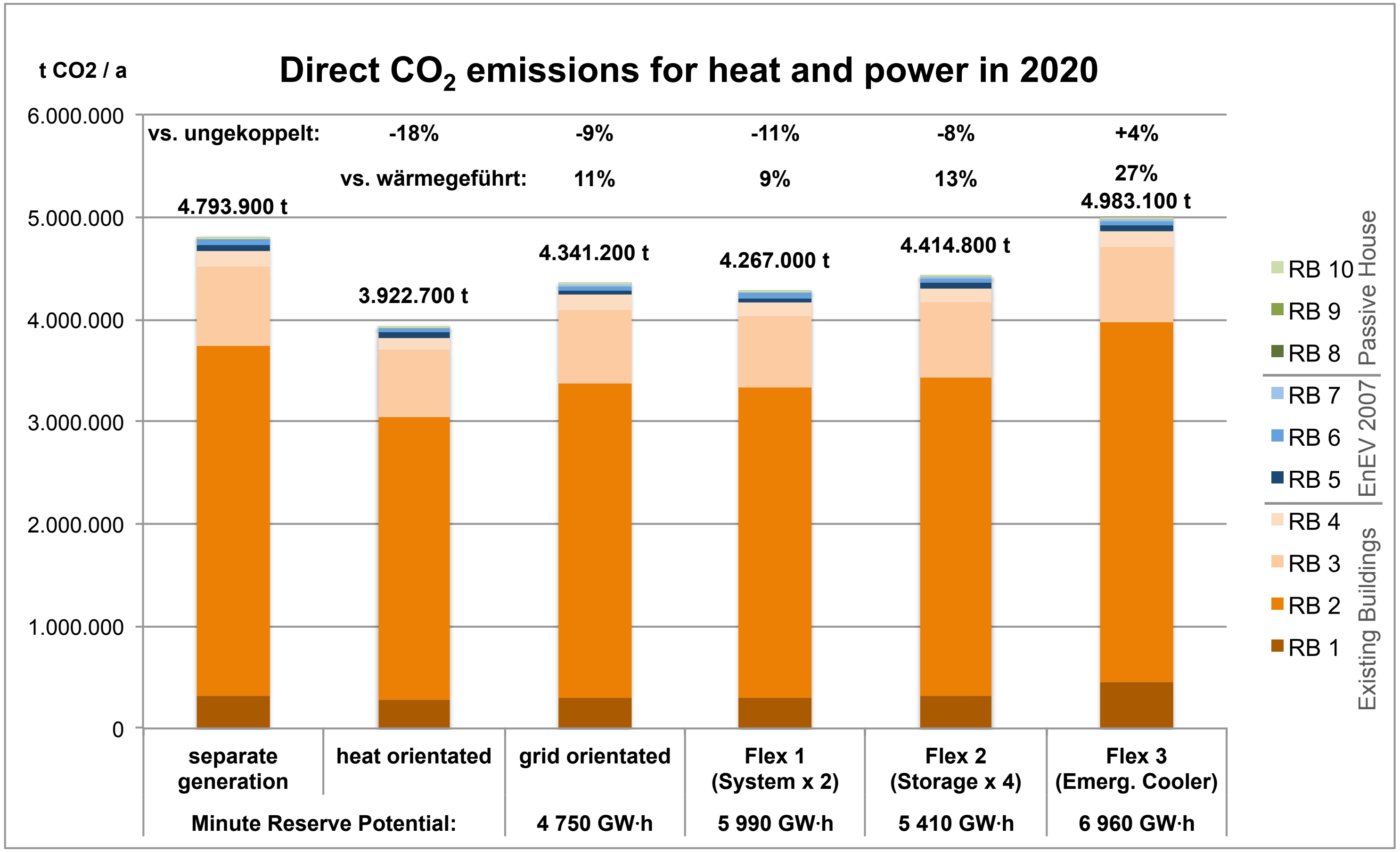
Comparison of CHP operation modes
(Selection of 3 existing building types: SFH, small MFH, big MFH)



- CO2 emissions increase if operation mode is changed from heat-orientated to grid-orientated or flexible mode (here: type „emergency cooler“) ; savings vs. separate production decrease or change sign towards more emissions
- The increases varies depending on building type / CHP load proportion / power-to-heat ratio of CHP plant
- Reasons for increase: decreasing CHP operation → increasing peak load boiler operation and additional power procurement out of grid

Sum of absolute CO_2 emissions of all types of Residential Buildings

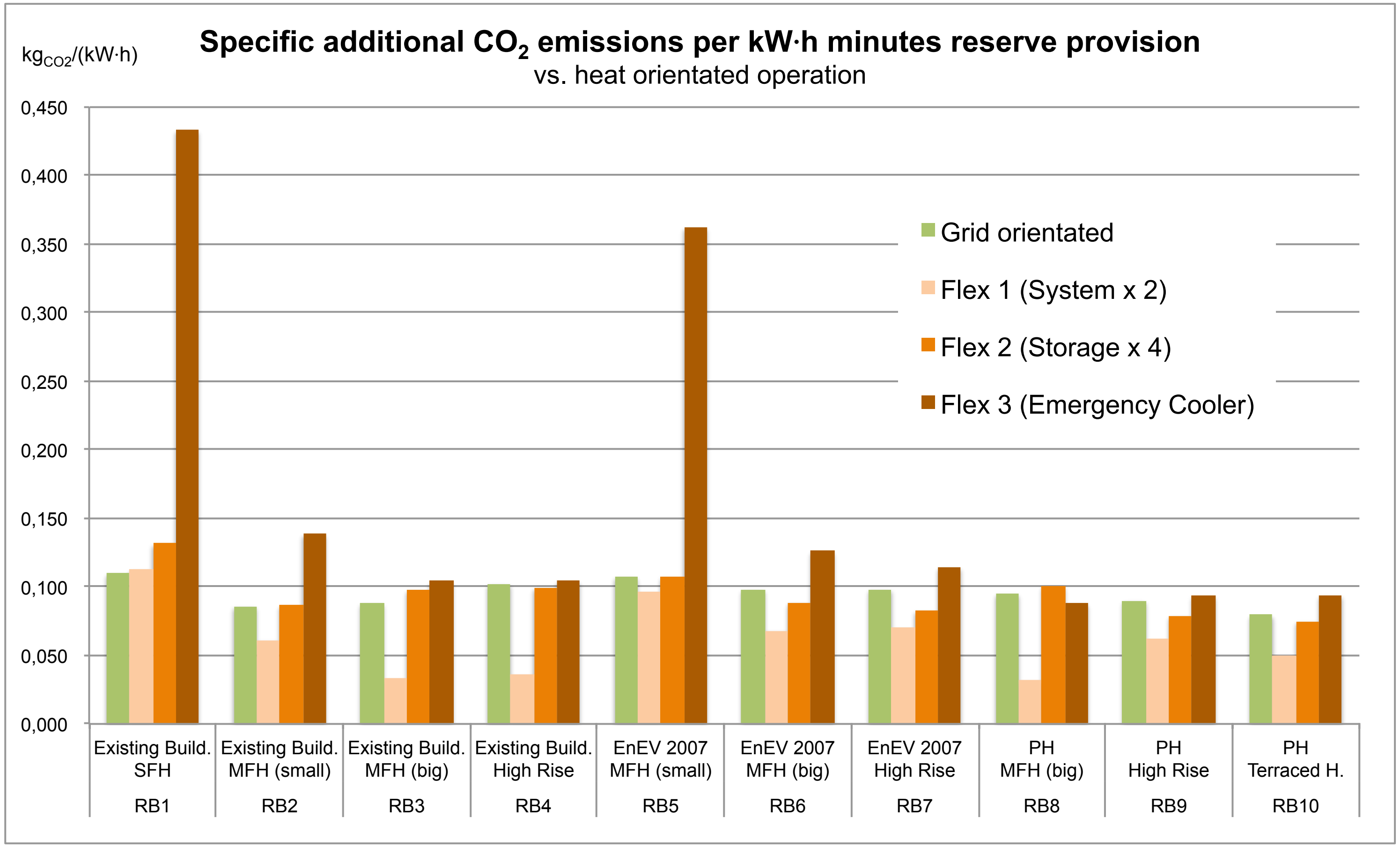
CHP quantity structure for 2020 (acc. to BMU Lead Study 2011)



- Increase of emissions compared to heat-orientated operation mode by +9% (flexible with doubling of plant size) up to +27% (flexible with emergency cooler)
- Savings vs. separate generation diminishes from -18% to -11% (Flex1) or +4% (additional emissions under emergency cooler)
- 97,4% of emissions are linked to existing buildings (Type 1 to 4), 2,5% to EnEV-2007-building (Type 5 to 7) and only 0,05% to Passive House buildings (Type 8 to 10).

Specific additional emissions versus heat-orientated operation mode

Related to benefit (provision of one kW*h minutes reserve)



- Flex1: Best ratio of additional emissions to MR potential, but option with most expenditure
- Flex2: Lower MR potential at higher storage losses → in all cases above Flex1-option
  → room for improvement through efficient storage insulation
- Flex3: In RB1/RB5 emissions almost triplicated; cause: low PtH-ratio (0,18) of 1 kW-Stirling engine
  → excessively strong discharge of CHP heat by emergency cooler (28% or 21%)

Conclusion: CO_2 emissions

Essential results about participation in the minute reserve market (for RB)

- CO_2 emissions increase significantly while **transitioning** from **heat-orientated to grid-orientated operation** (CO_2 saving potential decreases by half from -18% to -9% compared to separate production)
- Nevertheless this operation mode **still scores distinctly higher than the reference of separate generation**, in both primary energy wise and regarding CO_2 emissions
- **Flexibility options** can significantly increase the balancing power potential, but additional costs and CO_2 emissions have to be taken into account
- **Innovative heat storage technologies** (PCM / latent heat, vacuum insulation...) and plants with **high CHP coefficient** (≥ 1 to 2, also for smaller units) are crucial driver for the development of flexibility options

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Thank you for your kind attention!

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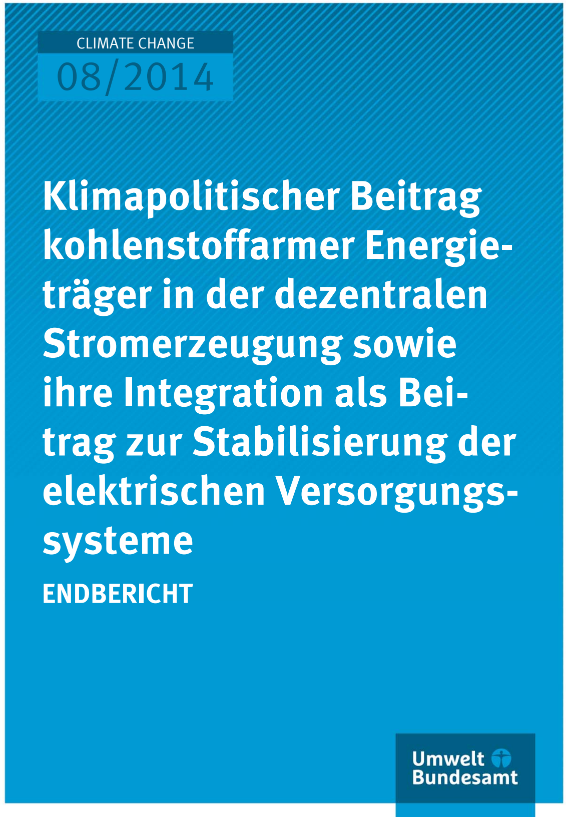
CLIMATE CHANGE
08/2014
Klimapolitischer Beitrag kohlenstoffarmer Energieträger in der dezentralen Stromerzeugung sowie ihre Integration als Beitrag zur Stabilisierung der elektrischen Versorgungssysteme
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Further information and download
(German version with English short summary):

www.wupperinst.org/en/projects/details/wi/p/s/pd/358

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Annex (back-up slides)

Comparable results:
CHP units for the participation on the balancing power market

Essential results of the “Energiewende Ruhr“ Project

- Expert workshop 2015 of project „Energiewende Ruhr“ confirmed necessity to use CHP plants more flexibly through smart grids
- Embedding CHP plants in smart grid is a central condition for the vision of a „Green CHP“

Results table of 6 consistent scenarios from an expert workshop on deriving qualitative scenarios of action for „Green CHP“ (method: cross-impact-analysis)

Scenario	1	2	3	4	5	6
Consistent value	0	0	0	0	0	0
Total impact score	50	52	50	52	27	8
Descriptor	**Forms**					
Centrality degree	District supply of quarters					
Smart grid	Successful					
LowEx	Integration into return flow of district heating grids				Cold local heating	
Storage capacity	Heat storage				Gas storage	
Acceptance	Increases				Constant	
Trigeneration	Industry, trade & commerce		Public buildings		No roll-out	
Renewables	Solar thermal	Deep geothermal	Solar thermal	Deep geothermal	Biogas/Biomethan	

energiewende ruhr

www.energiewende-ruhr.de
www.wupperinst.org/en/projects/details/wi/p/s/pd/402

Technical potentials of decentralised CHP units at the minutes reserve market

Aim and input parameters of the modelling

- Aim:
  Analysis of the technical potential of decentralised CHP units for residential buildings (1 until 50 kW_{el}) and non-residential buildings (18 until 1 200 kW_{el}) for the participation at the minutes reserve market

- Hourly resolved modelling of the maximal possible supply of minutes reserve; boundary conditions:
  - It has to be possible to cover required heat at any time (→ additional peak load boiler)
  - It should not be produced more heat than the amount which can be taken out

- In the course of time (until 2030) the design and behaviour of the minutes reserve market is assumed to be constant (like in 2010) in order to simplify the modelling

- Development of the CHP park, taking into account the renewable energy long-term scenario 2011, only considering the supply for residential and non-residential buildings ("Lead Study" of the German Federal Ministry for the Environment BMU, scenario A)

Design of 5 CHP modules for 5 non-residential building types

with a classical heat-orientated mode of operation

Model Nr.	Non-Residential Building type	HEC* [GWh/a]	Heat load [kW_{th}]	CHP output [kW_{th}]	CHP output [kW_{el}]	Share of load [%]	PtH* ratio –	VLH* [h/a]	Peak boiler [kW_{th}]	Heat storage Volume [Litre]	Heat storage S/R * [°C]
NRB 1	Hospitals	12,35	4.415	1.187	1.189	27 %	1,00	6.700	4.000	30.000	85/45
NRB 2	Rest home	1,24	443	114	71	26 %	0,62	6.900	400	4.500	85/45
NRB 3	Hotels	0,43	155	41	20	26 %	0,49	6.700	140	1.500	80/40
NRB 5	Offices	0,35	106	36	18	34 %	0,50	7.300	100	1.500	80/40
NRB 6	Schools	0,56	169	66	34	39 %	0,52	6.600	150	2.500	80/40

HEC = Heat Energy Consumption; PtH= Power-to-Heat; VLH = Full load hours; S/R = Supply and return temperature

Specific useful energy demand for heating of the NRB in kWh/m²a:

Nursing home: 154
Hotel: 151
Office: 95
School: 108
Hospital: 27.629 kWh/bed/a

Technical potential of decentral CHP units at minutes reserve market

Assumptions for modelling

- Temporal resolution of heat demands for different residential buildings (RB) and companies of trade and commerce (NRB)
- Plant design for 3,500 to 6,000 full load hours, peak load boiler with $P_{th,max}$ of almost 1 h of storage volume

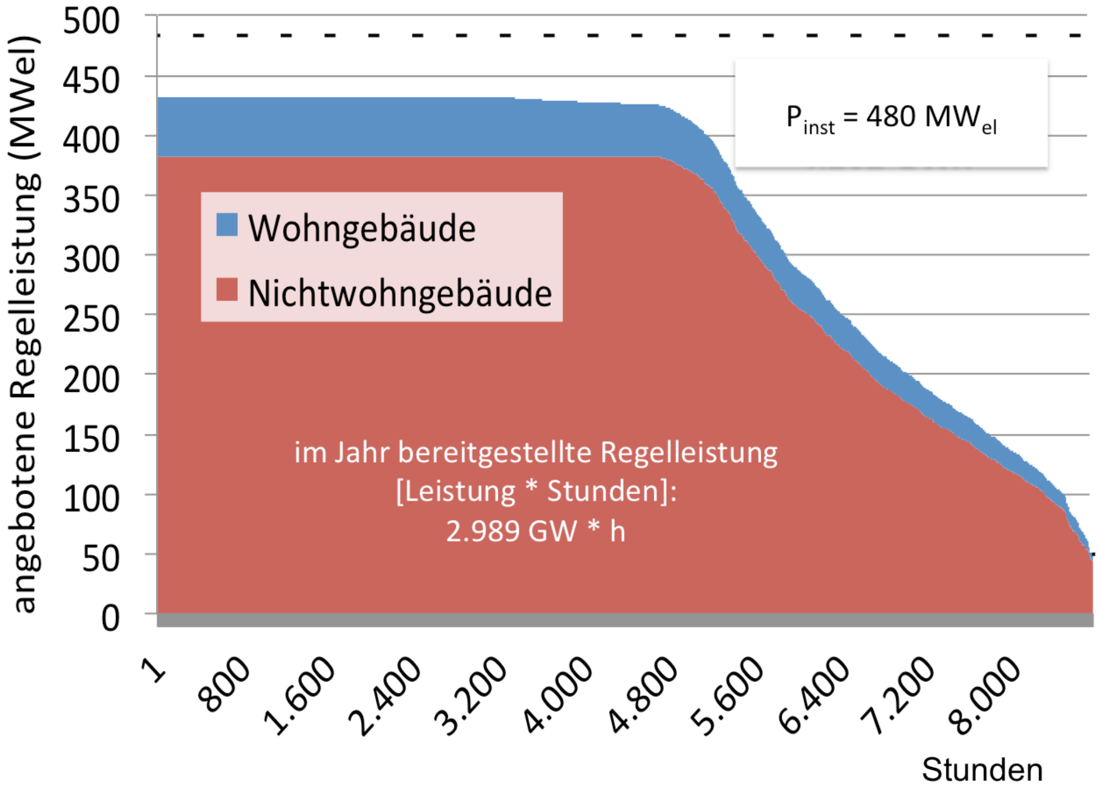
- Balancing power in 4-hour-time slices
- No differentiation of positive or negative Balancing power potentials (because retrieval through complete time slice needs to be available, CHPs units need to be able to feed-in as also to repose each time slice, independent from pos. or neg. MR offered)

in MW_{el}	2010	2020	2030
CHP in RB	56	883	1 238
CHP in NRB	424	1.953	2 467

Technical potential of decentral CHP units at minutes reserve market

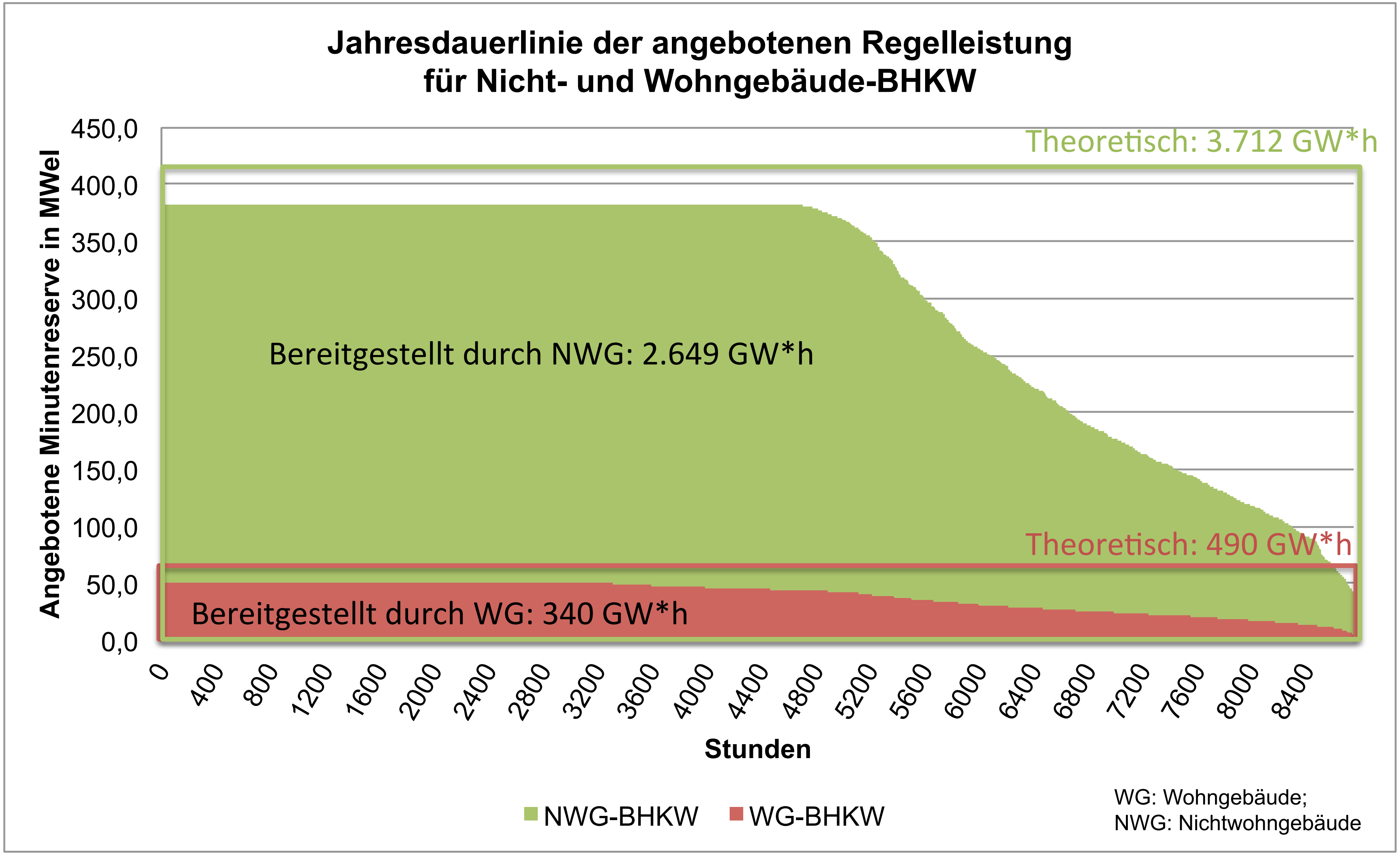
Results of modelling – Annual load curve of MR provision through CHP plants (2010)

- Per annual average, almost 70 % of CHP nominal power can be provided as balancing power
- Almost 4,000 h p.a., 90 % of total CHP nominal power can be provided as MR
- Balancing power capacity never decreases below 7 % of total nominal power during the course of year



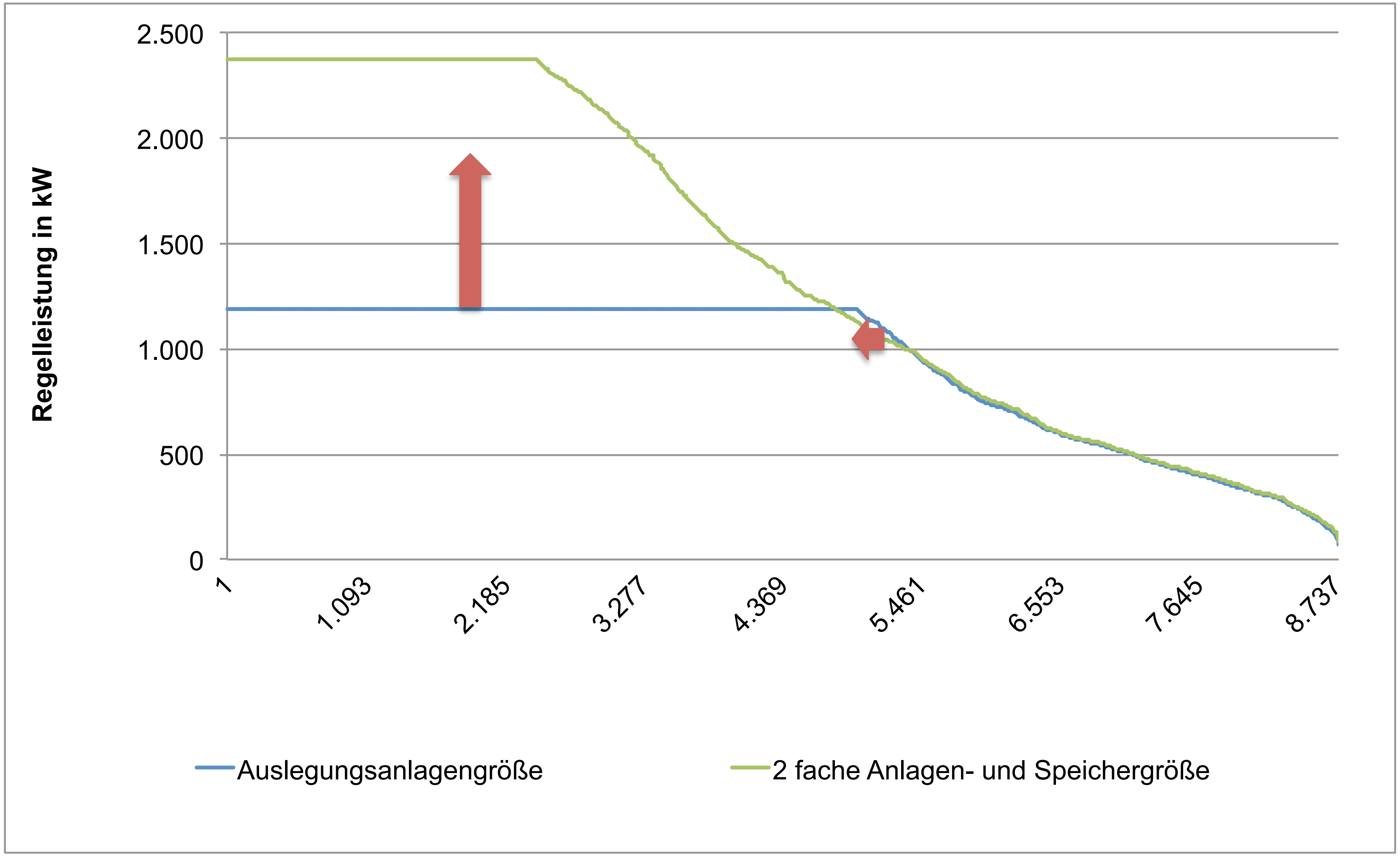
Technical potentials of CHP units at minutes reserve market

Technically, almost 2/3 of theoretic potential possible



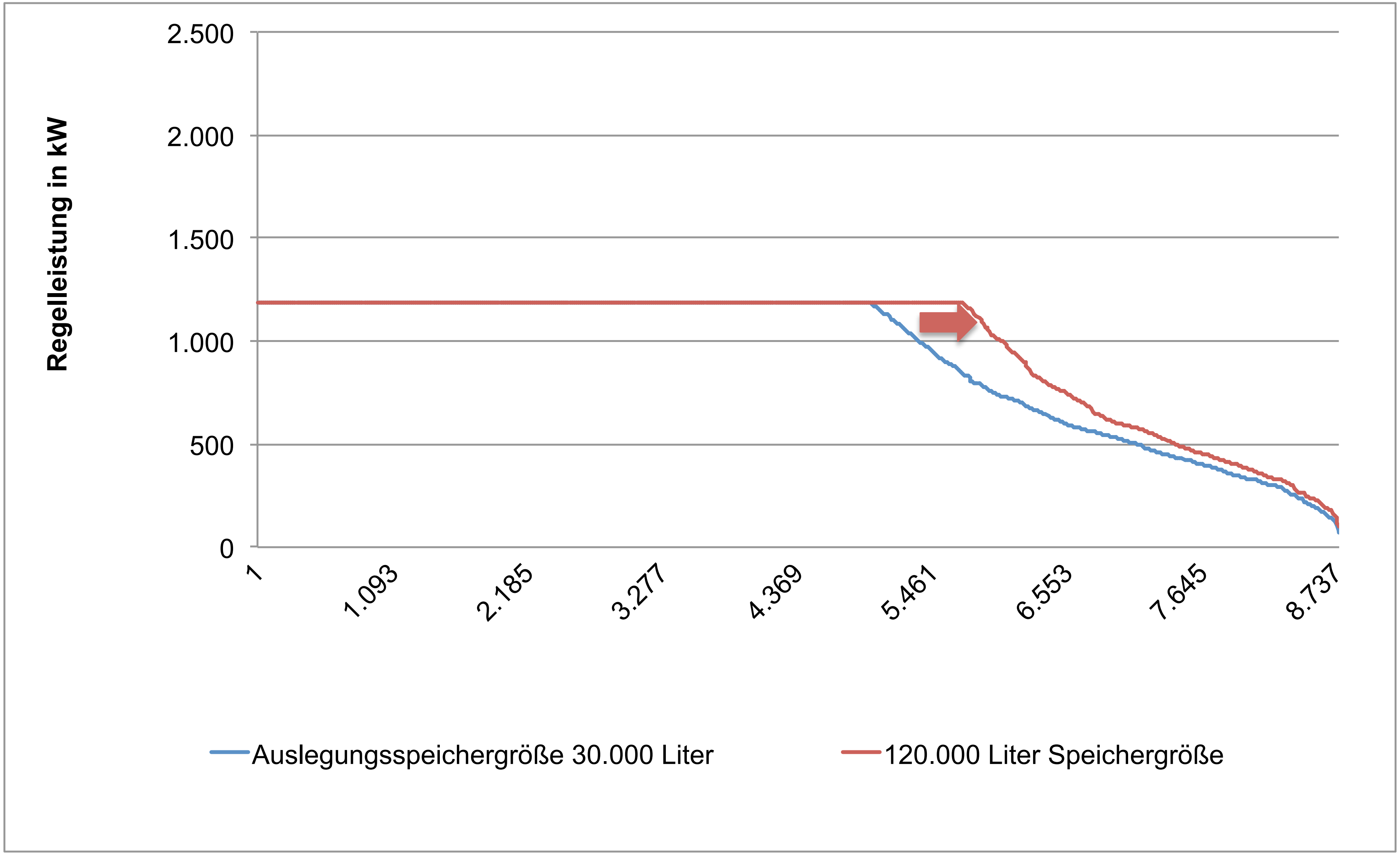
Flexibility of CHP units

Exemplary effect of **plant** expansion (CHP for hospital)



Flexibility of CHP units

Exemplary effect of **storage** expansion (CHP for hospital)



Primary energy savings vs. separate production of energy and allocation of specific CO_2 emissions to the coproducts power & heat

Allocation method

Alternative Generation Method (compliant to EU directive 2004/8/EG)

- Calculation of **primary energy savings PES** versus reference systems of separate generation:

$$PES = 1 - \left[\frac{1}{\eta_{th}/\eta_{th,Ref} + \eta_{el}/\eta_{el,Ref}} \right]$$

and distribution of PES to coproducts:

Specific fuel demand for power:

$$W_{fuel,el} = W_{fuel} \cdot (1 - PES) \cdot \frac{\eta_{el}}{\eta_{el,Ref}}$$

Specific fuel demand for heat:

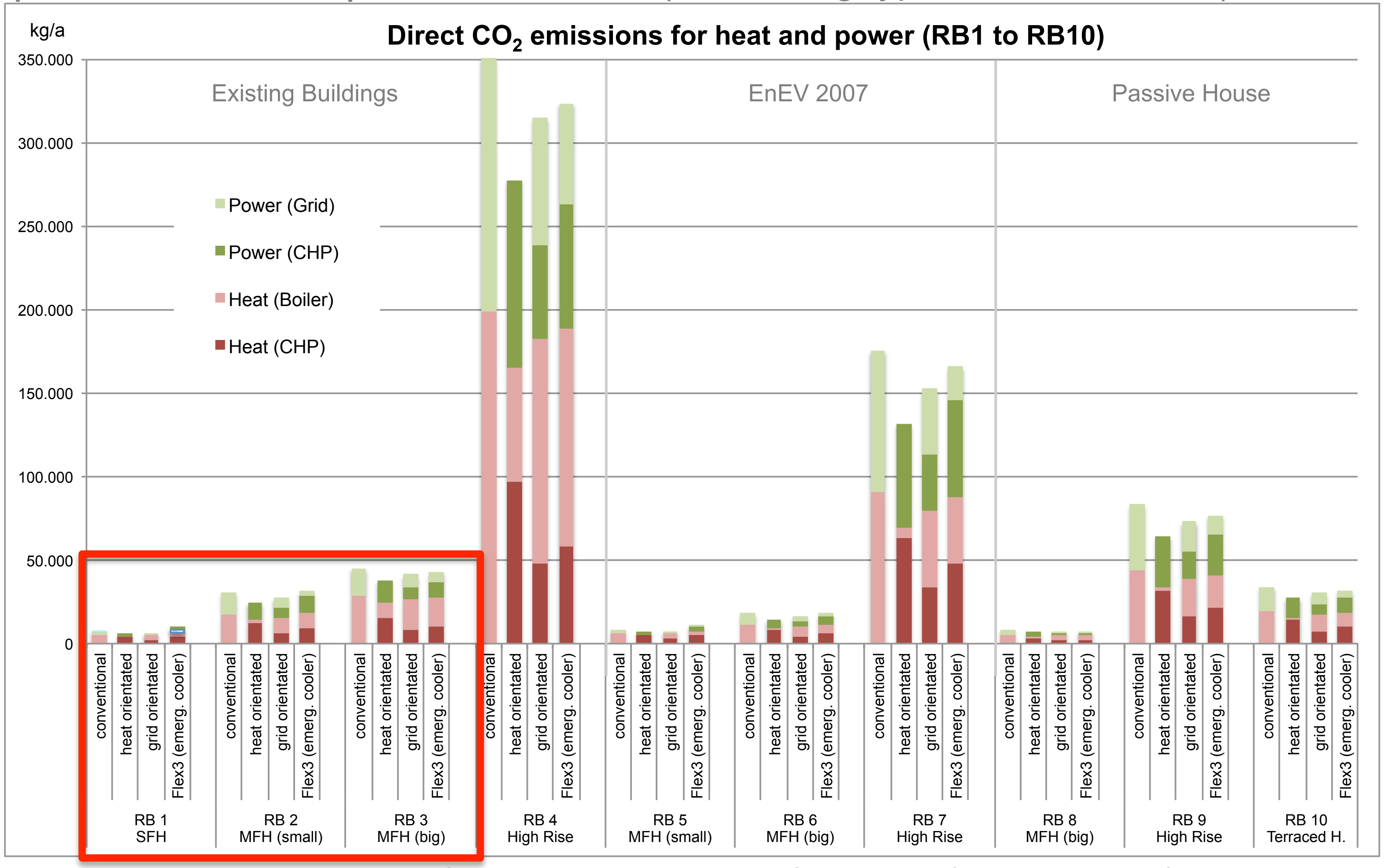
$$W_{fuel,th} = W_{fuel} \cdot (1 - PES) \cdot \frac{\eta_{th}}{\eta_{th,Ref}}$$

→ Definition of **reference systems** of separate generation of energy necessary!
(tabulated parameters for electr. / therm. efficiency and spec. fuel emissions)
here: natural gas combined cycle plant (η_{el} = 53,2%) + natural gas boiler (η_{th} = 90,0%)

- **Credit for avoided net losses** in form of corrective factor on the value of the reference power efficiency:
  - for power consumed on site (own consumption): 0,860 (< 0,4 kV)
  - for feed-in power: 0,925 (< 0,4 kV)

Object-related absolute CO_2 emissions

Comparison of CHP operation modes (all building types RB 1 to RB 10)



- Related to objects, emissions of the high-rise building CHP units (RB 4, 7 and 9) are dominant compared to all other types of residential buildings
- Emissions of existing buildings (RB1 to 4) are each significantly higher than those of the EnEV buildings (RB 5 to 7) or Passive House Buildings (RB 8 to 10)

Essential constraints

- Additional costs for investments, operation and transaction i.e. for automation, flexibility options and market participation
- Remote control technology: Availability, costs and standards
- Less revenues through reduced usage rate (less full load hours)
- Competition with power self-supply or sale with participation at power market (spot market, day-ahead or intraday)
- Unattractive prices at minutes reserve market
- Partly missing installation options for flexibility measures
- Partial-load operation or frequent starting and stopping
- Low coverage degree during summer (summer recess)
- Higher CO_2 emissions while changing from heat-orientated to grid-orientated operation
- Missing rules in KWKG regarding grid-orientated application and virtually combined BHKW
- Cease of power tax refund for virtually aligned BHKW with a total performance above 2 MWel

Conclusion:
CHP systems for the participation in the balancing power market
Essential results

- Still (relatively reviewed) high build-up potential for decentral CHP at small performance range (RB and NRB)
- Provision of system services from decentralised CHP systems is increasingly desired while electricity production from fossil fuels (condensing power plants) declines
- CHP systems can provide balancing power with significant extent (today almost 7 and up to 50% of MR market in the future) and contribute to energy efficient heat supply at the same time
- Especially economic and technical constraints (still) limit its application
- In the field of CHP systems there is a significant balancing power potential, but it competes with other market strategies and other providers

Conclusion: CO_2 emissions

Essential results on flexibility options (Residential Buildings in the year 2020)

Flex1 (Plant x 2):

- 6.000 GW*h (+26%)
- Results in almost all cases in lower emission values than under grid-orientated operation
- But: high investment necessary

Flex2 (Storage x 4):

- 5.400 GW*h (+14%)
- Heat storage important element for MR provision, but only moderate increase of MR potential
- Innovative technologies (PCM / latent heat, vacuum insulation...) decrease saving losses and CO_2 emissions (e.g. potential of vacuum insulation: minus 80 % vs. mineral wool)

Flex3 (Emergency cooler):

- 7.000 GW*h (+47%)
- Highest potential of flexibilisation, but partly significant additional CO_2 emissions
- Therefore perspectively only useful when plants with high CHP coefficient (≥ 1 to 2) are also available for smaller units
  → market launch of fuel cells (e.g. SOFC: 0.5 kW_{th} /1.5 kW_{el} / eta_{el} = 50...60 % / SKZ > 2)

Recommended actions

To increase minutes reserve potential for decentral BHKW

- Force CHP expansion
- Decrease constraints against provision of MR
- Support innovative CHP plants with high electric efficiency
- Support innovative storage concepts / insulation technologies
- Avoid ecologically negative effects from flexibility measures