Low Enthalpy Heat and Building Deep Borehole Thermal Energy Storage

EU Interreg DEG Rollout Meeting 2020, 29st September 2020

TECHNISCHE UNIVERSITÄT DARMSTADT

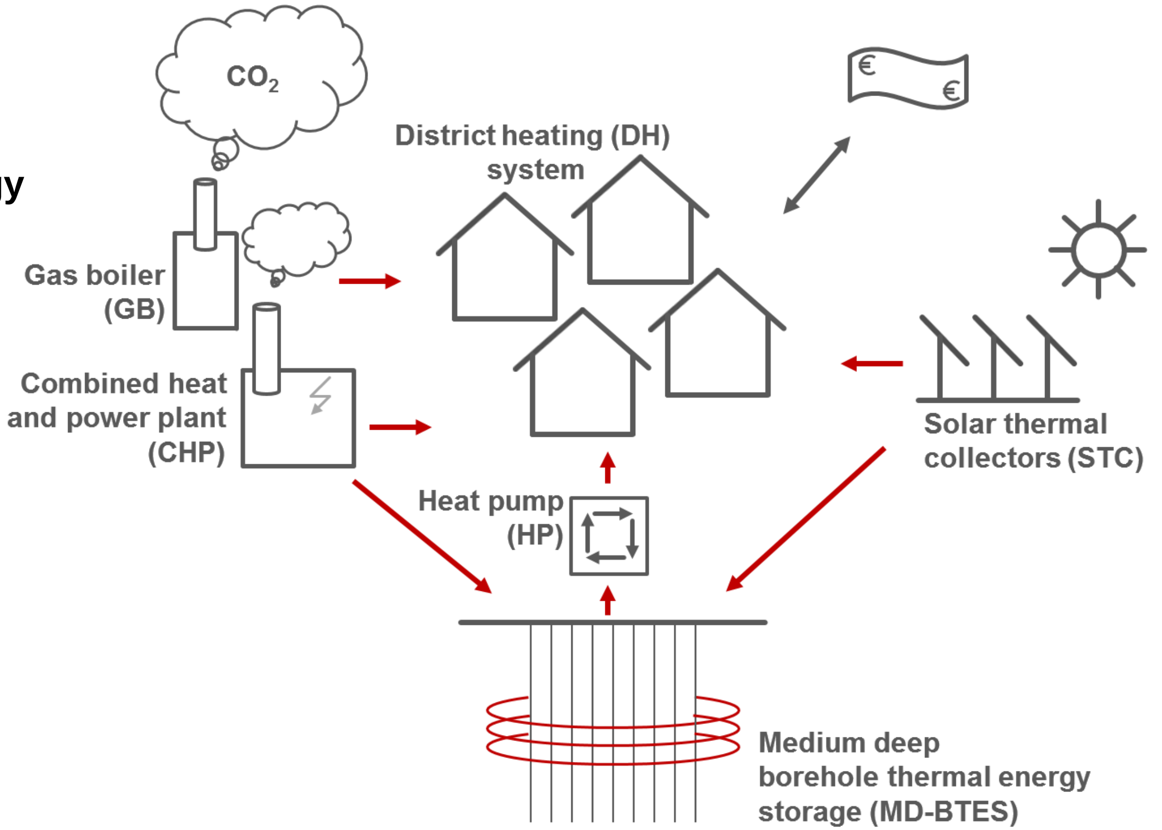
Graduate School of Energy Science and Engineering

Prof. Dr. Ingo Sass

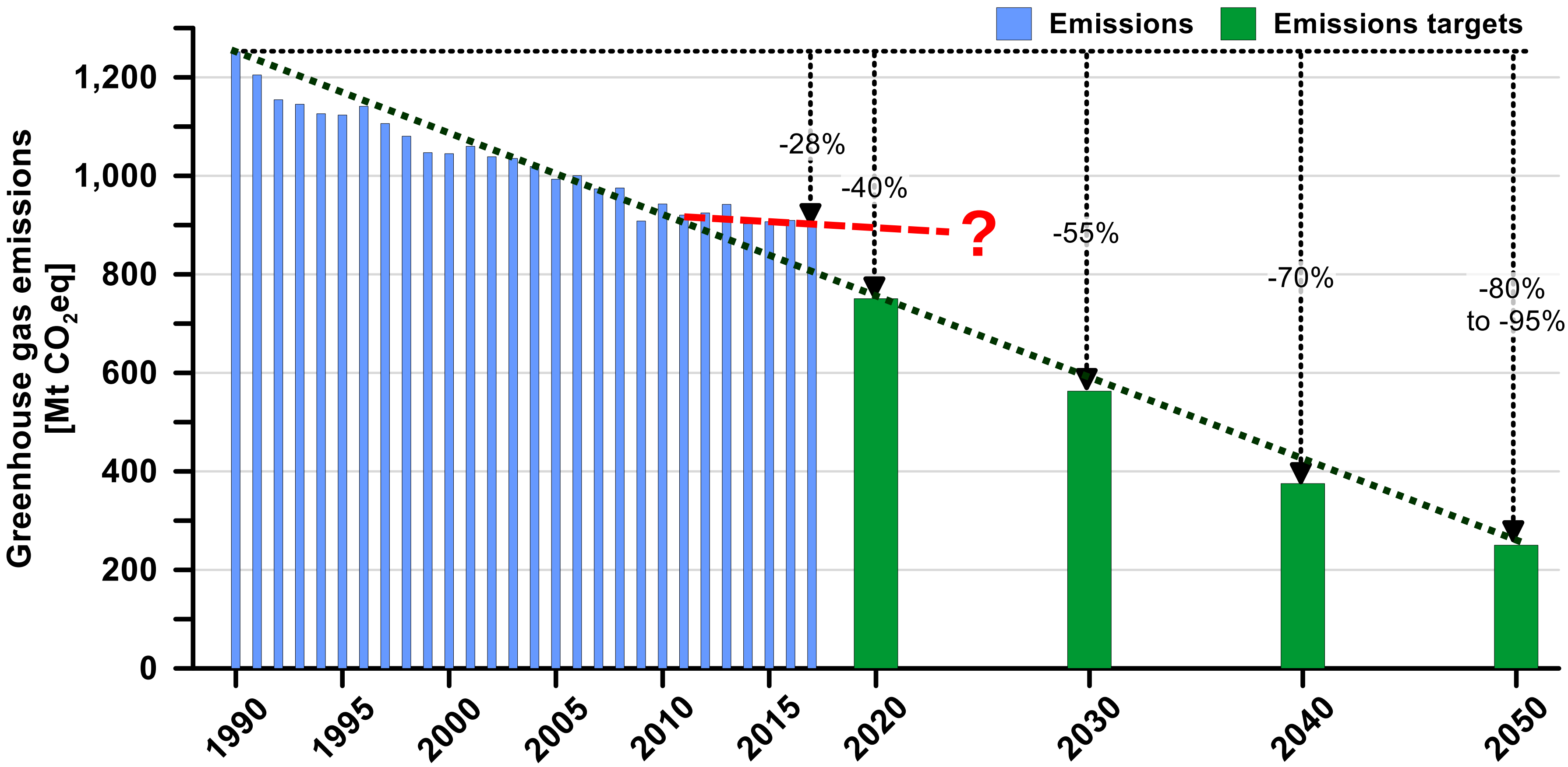
Chair of
Geothermal Science and Technology

With major contributions

Dr.-Ing. Daniel Schulte
Dr.-Ing. Bastian Welsch

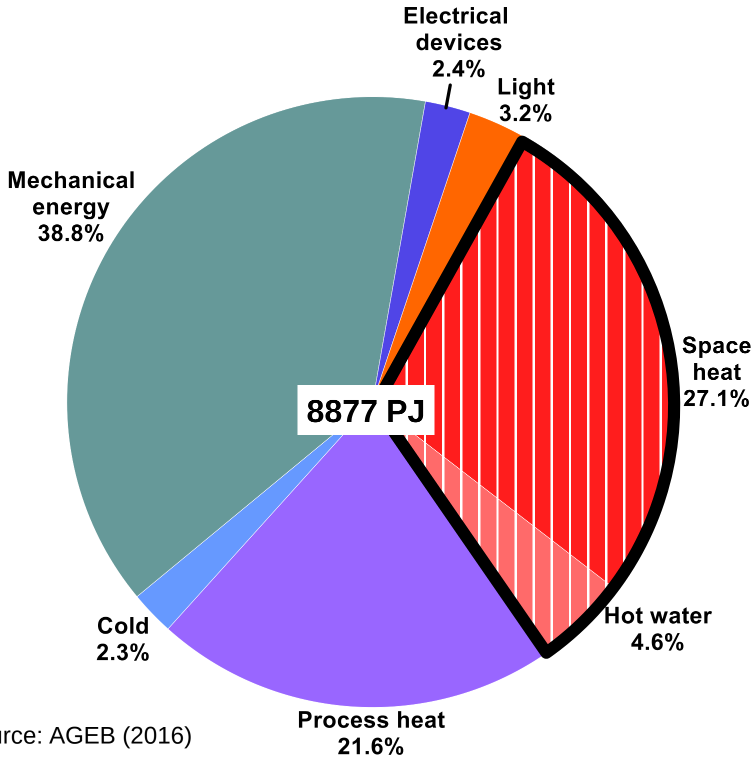


Germany Falling Short of Emissions Targets



Emissions in Germany, without LULUCF–Land Use, Land-Use Change and Forestry, data sources: UBA (2018), Aktionsprogramm Klimaschutz 2020 (BMUB 2014), Klimaschutzplan 2050 (BMUB 2016)

Final Energy Consumption in Germany 2015



Data source: AGEB (2016)

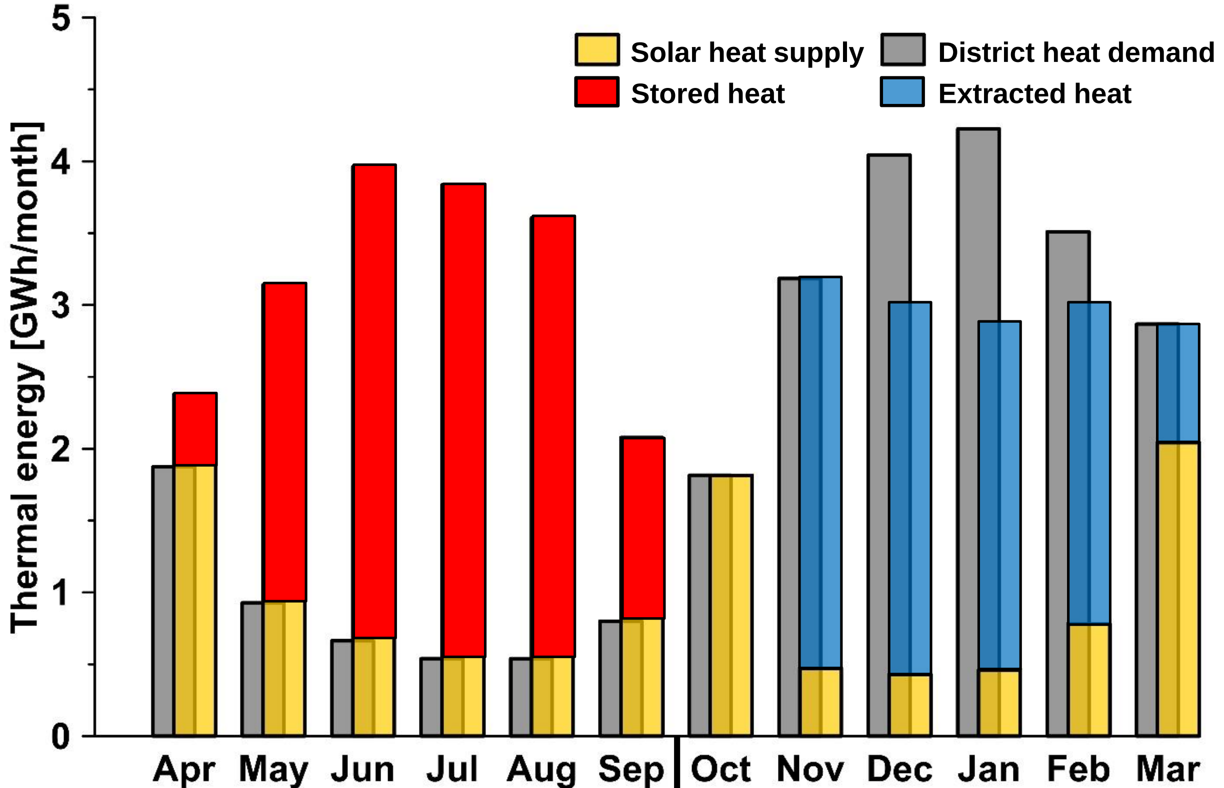
About 32% for space and water heating

Thereof more than 70% from fossil fuels

➡ High potential for greenhouse gas (GHG) emission reduction

Offset of Heat Demand and Renewable Heat Production of Solar Sources

TECHNISCHE UNIVERSITÄT DARMSTADT



Summer:
production potential exceeds demand

Winter:
demand exceeds production potential

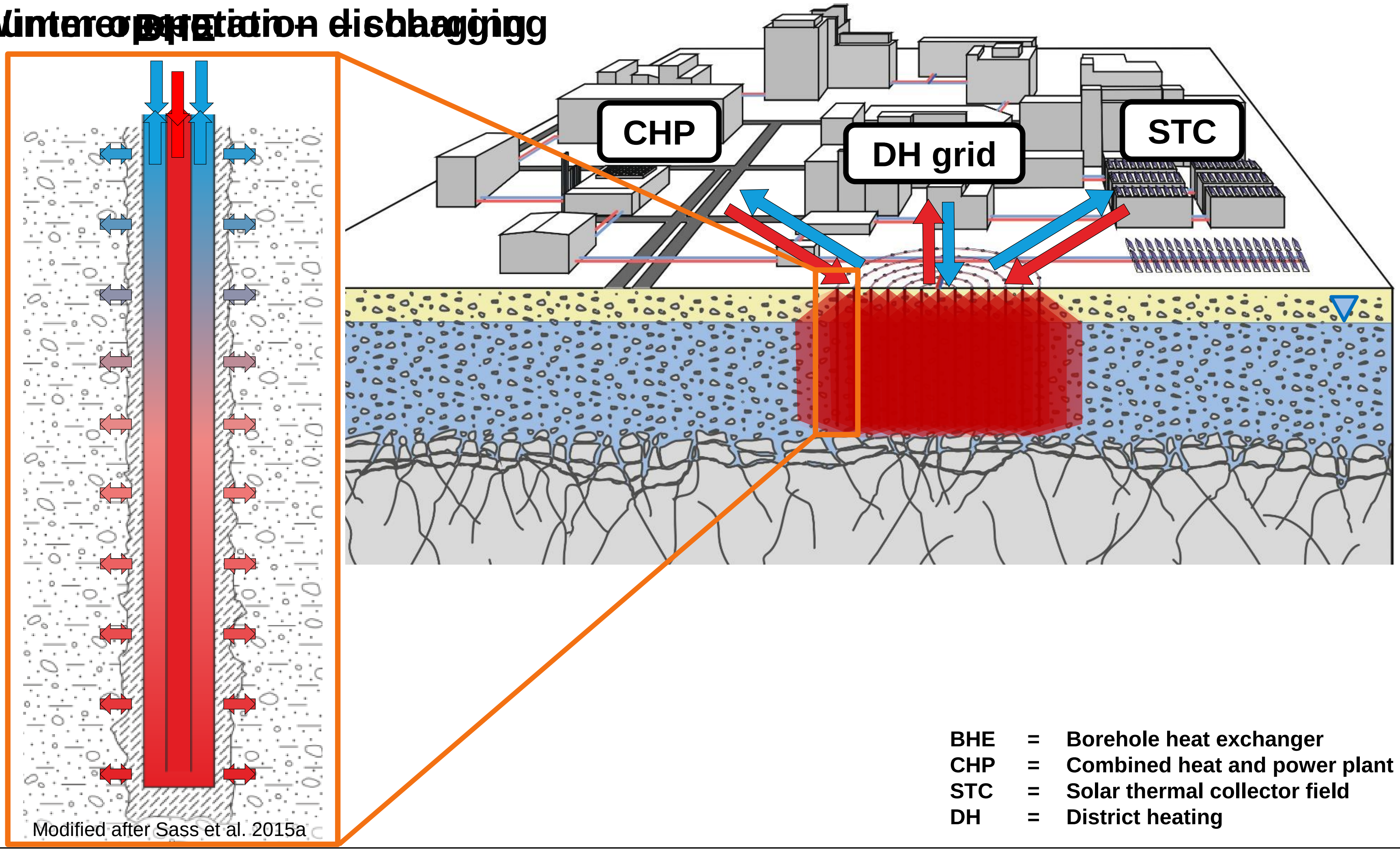
Seasonal thermal energy storage: shift excess heat to times of high heat demand

Borehole Thermal Energy Storage (BTES)

Winter operation – discharging

Summer operation – charging

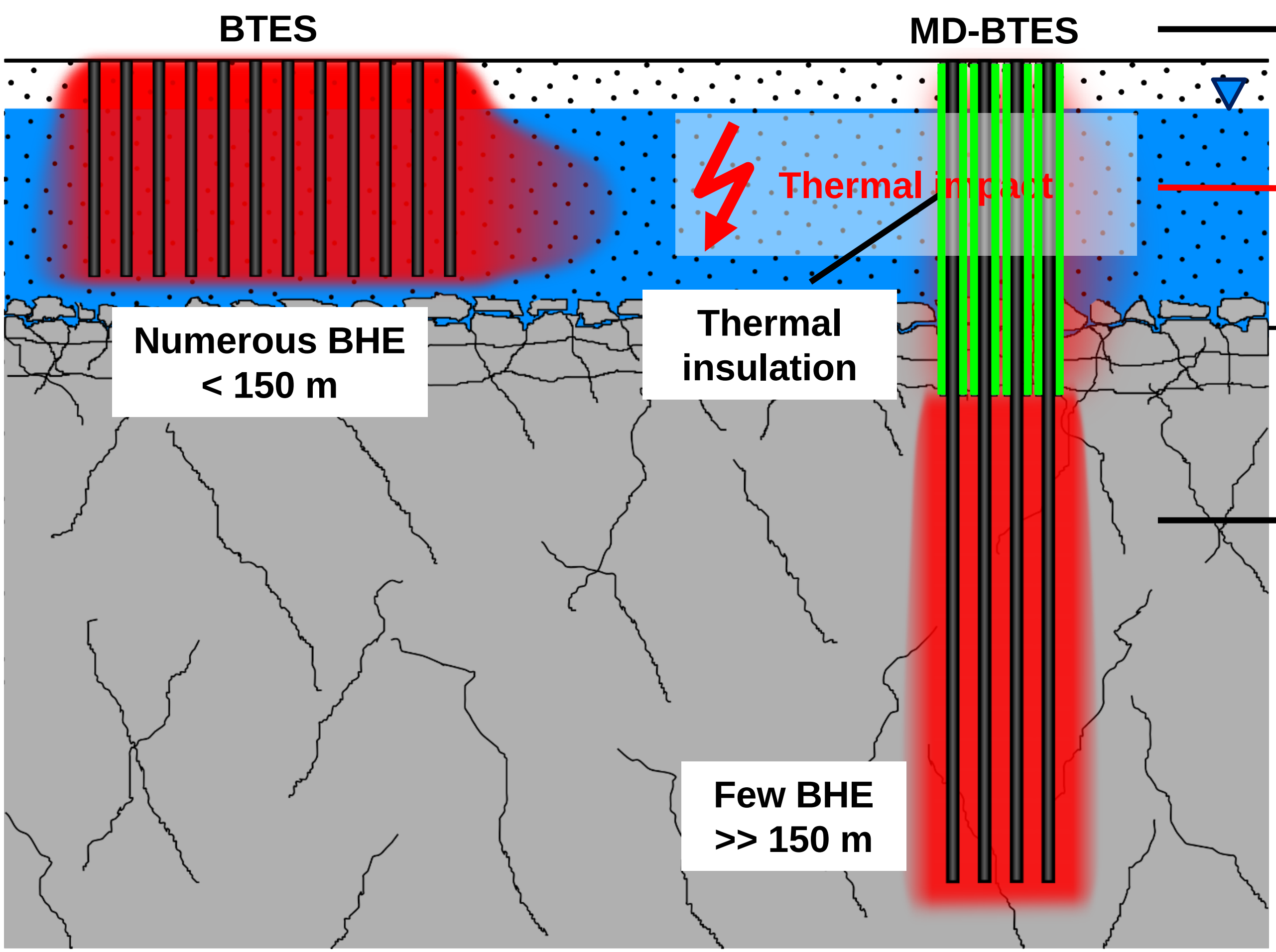
BHE



Modified after Sass et al. 2015a

BHE	=	Borehole heat exchanger
CHP	=	Combined heat and power plant
STC	=	Solar thermal collector field
DH	=	District heating

Concept of Medium Deep Borehole Thermal Energy Storage (MD-BTES)



Less building ground required

Negligible thermal impact

Aquifer

Unconsolidated rock

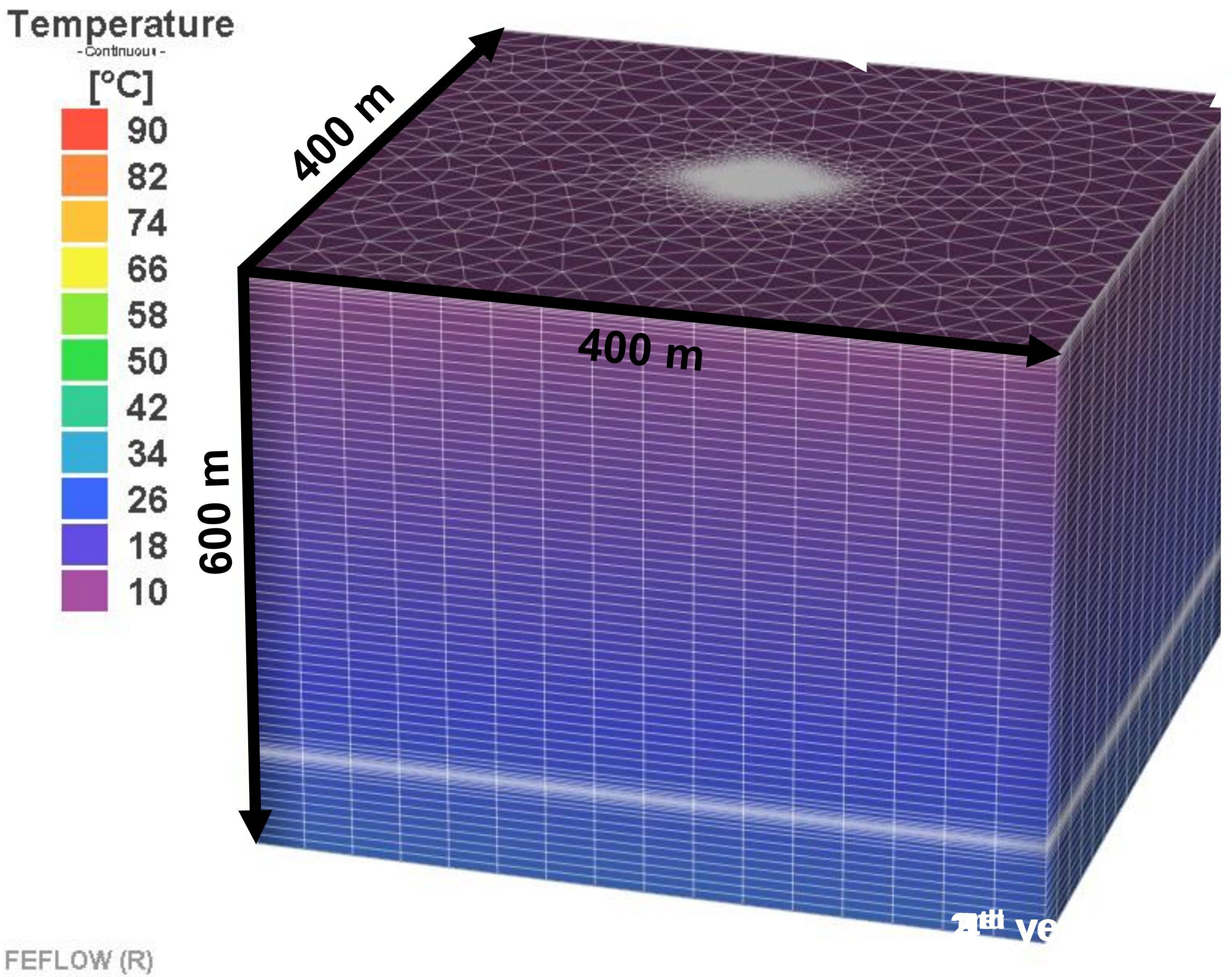
Solid rock

Low permeability

- Conductive heat transport dominant
- Reduced convective heat losses

BHE = Borehole heat exchanger

Storage in Action



Example

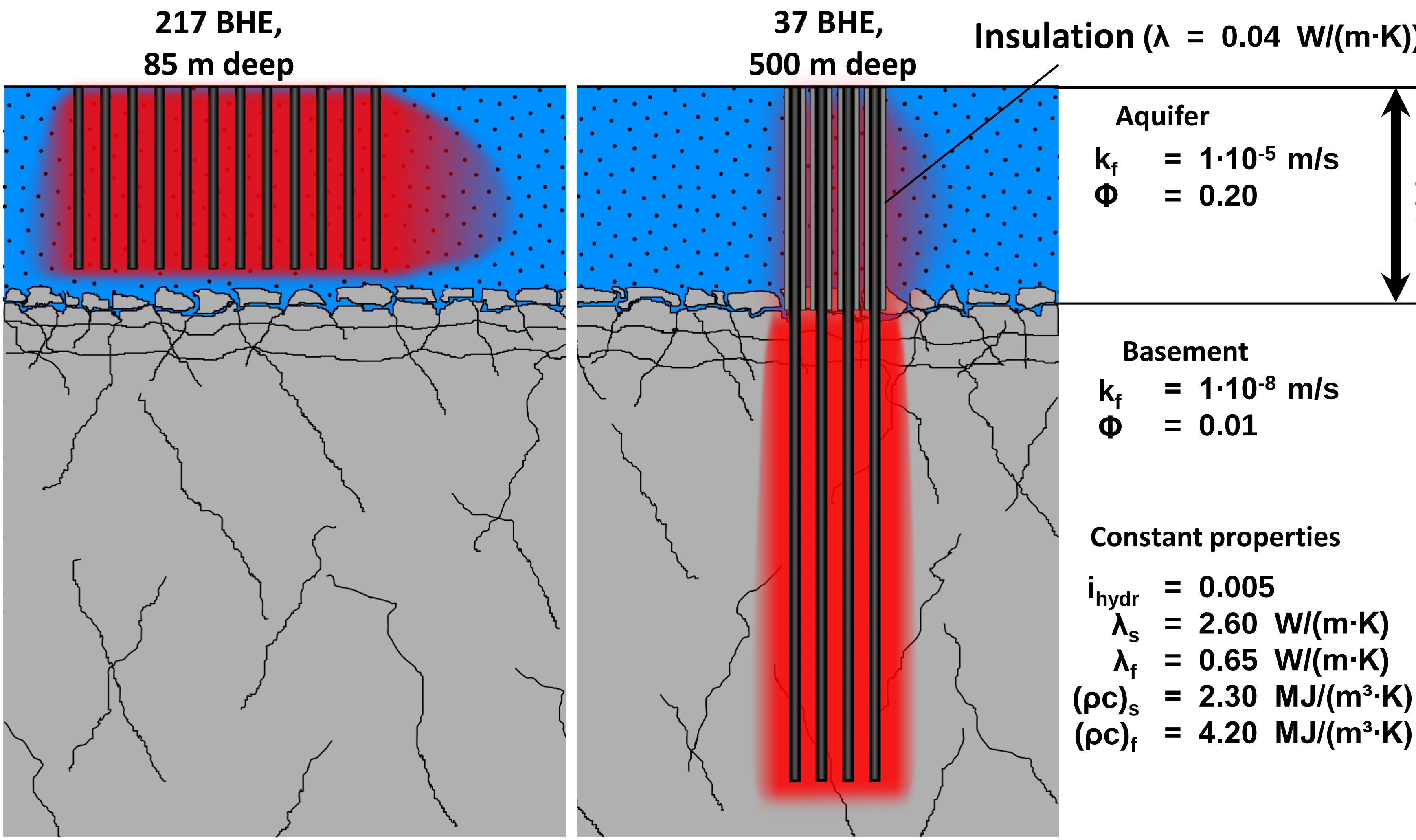
- **37 BHE**
- **500 m deep**
- **5 m spacing**

Geothermal gradient = 3 K/100 m

Material properties (e.g. crystalline basement)

k_f	=	$1 \cdot 10^{-8}$ m/s
Φ	=	0.01
i_{hydr}	=	0.005
λs	=	2.60 W/(m·K)
λf	=	0.65 W/(m·K)
$(\rho c)_s$	=	2.30 MJ/(m³·K)
$(\rho c)_f$	=	4.20 MJ/(m³·K)

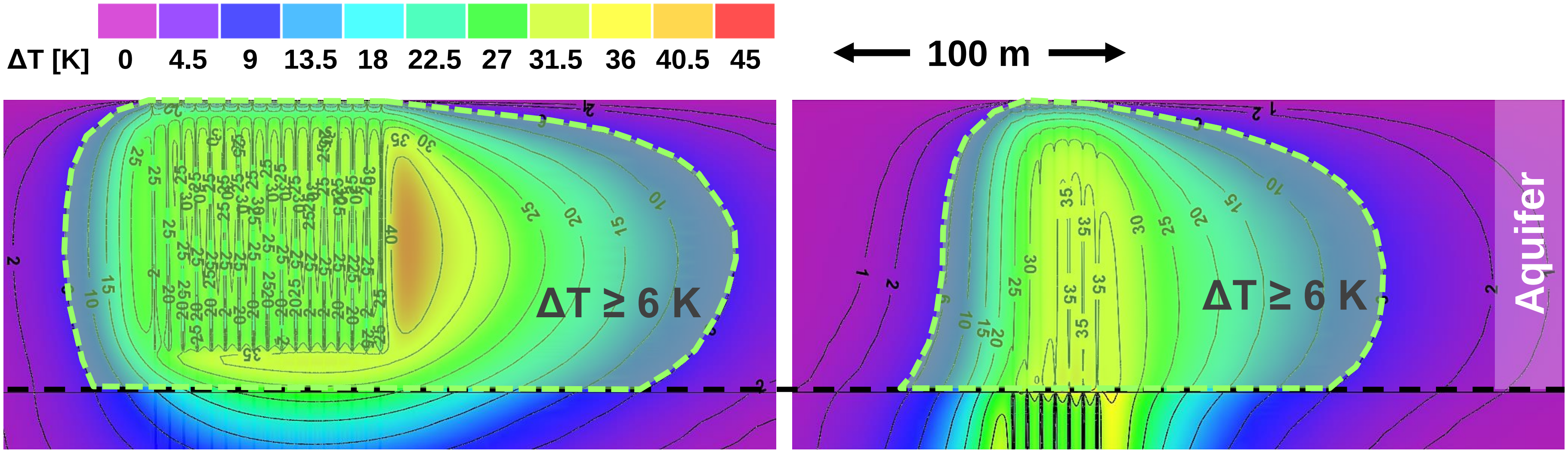
BTES versus MD-BTES – Model Setup



MD-BTES Reduces the Thermal Impact on Shallow Aquifers Significantly

TECHNISCHE UNIVERSITÄT DARMSTADT

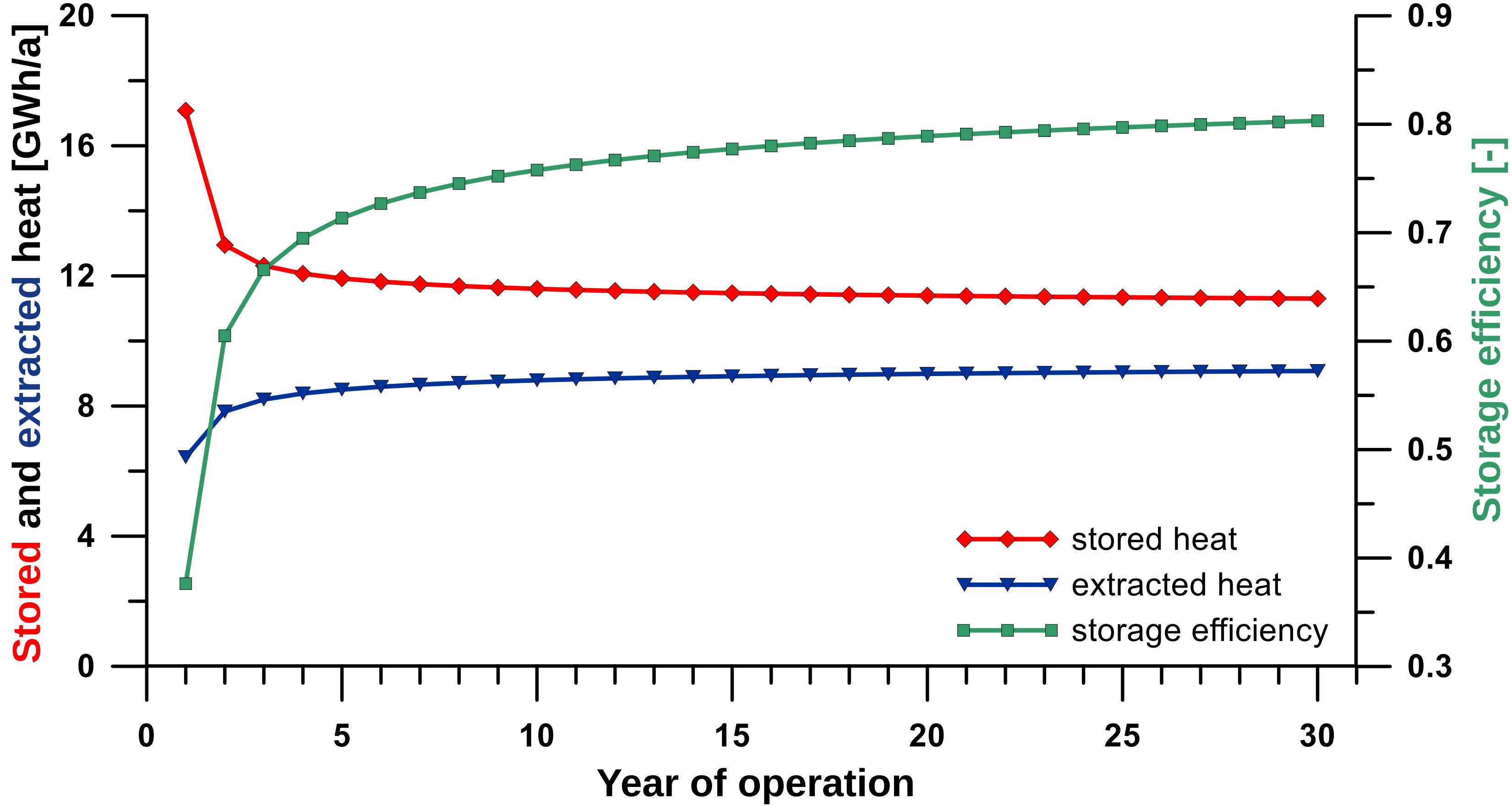
Temperature increase after 30 years of operation



	BTES	MD-BTES	Reduction
Specific heat loss to aquifer	$390 \frac{Wh}{kWh_{extr}}$	$50 \frac{Wh}{kWh_{extr}}$	-87%
Impacted aquifer volume (ΔT ≥ 6 K)	$2.7 \cdot 10^6$ m³	$0.8 \cdot 10^6$ m³	-70%

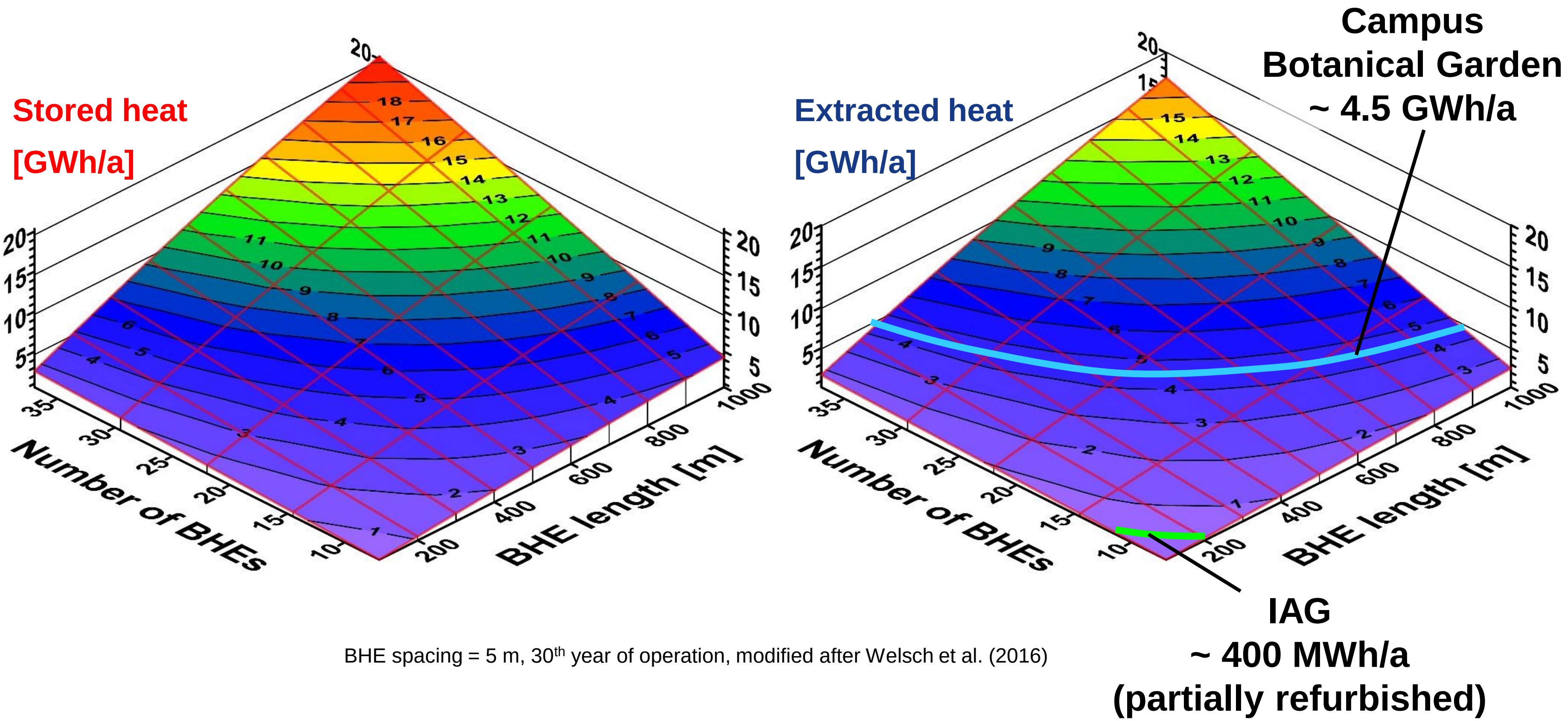
Storage Performance Improves with Time

TECHNISCHE UNIVERSITÄT DARMSTADT



37 BHE, BHE length = 500 m, BHE spacing = 5 m, Sass et al. (2015b)

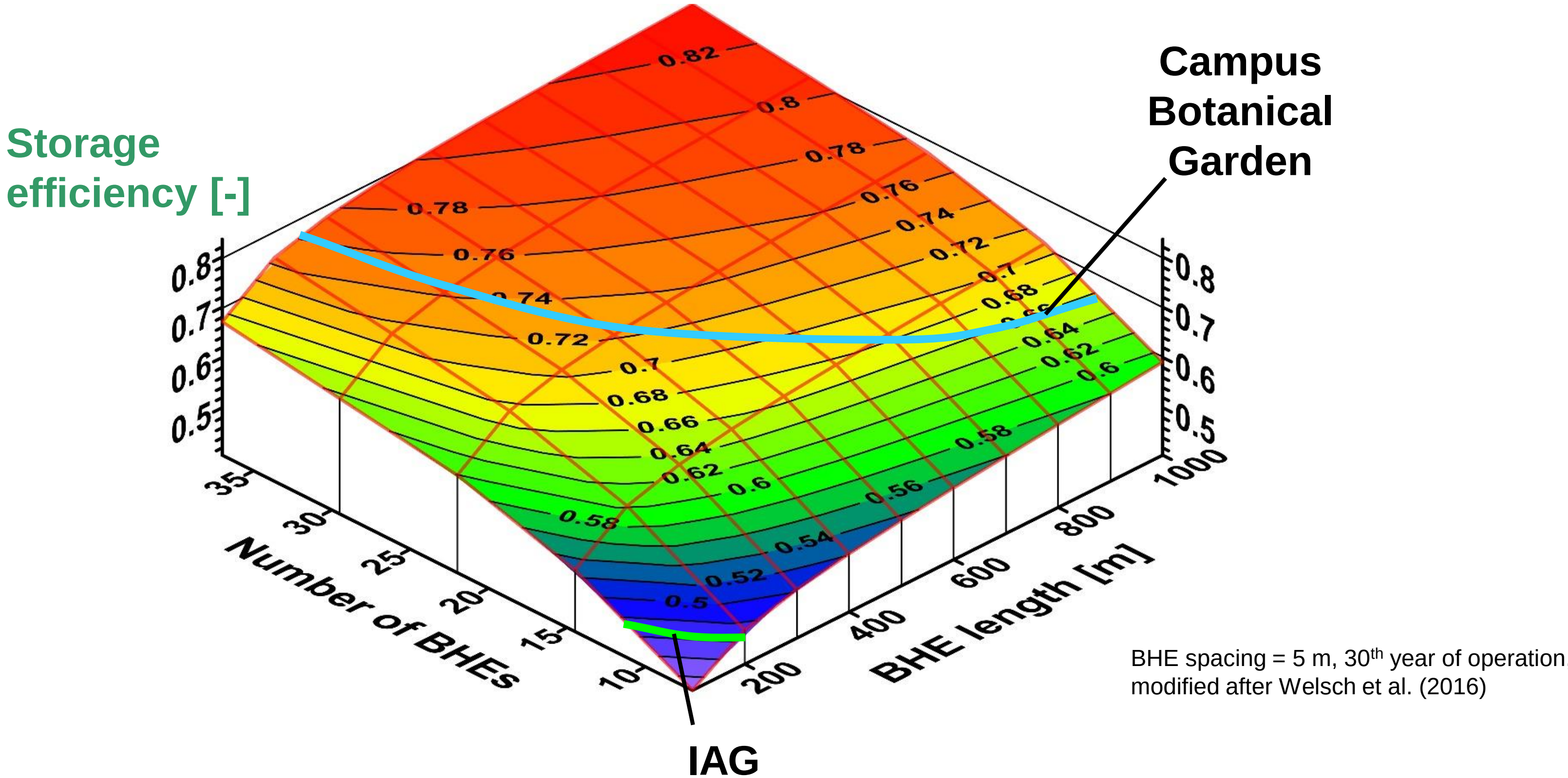
Storage Capacity Increases with BTES-Size



BHE spacing = 5 m, 30th year of operation, modified after Welsch et al. (2016)

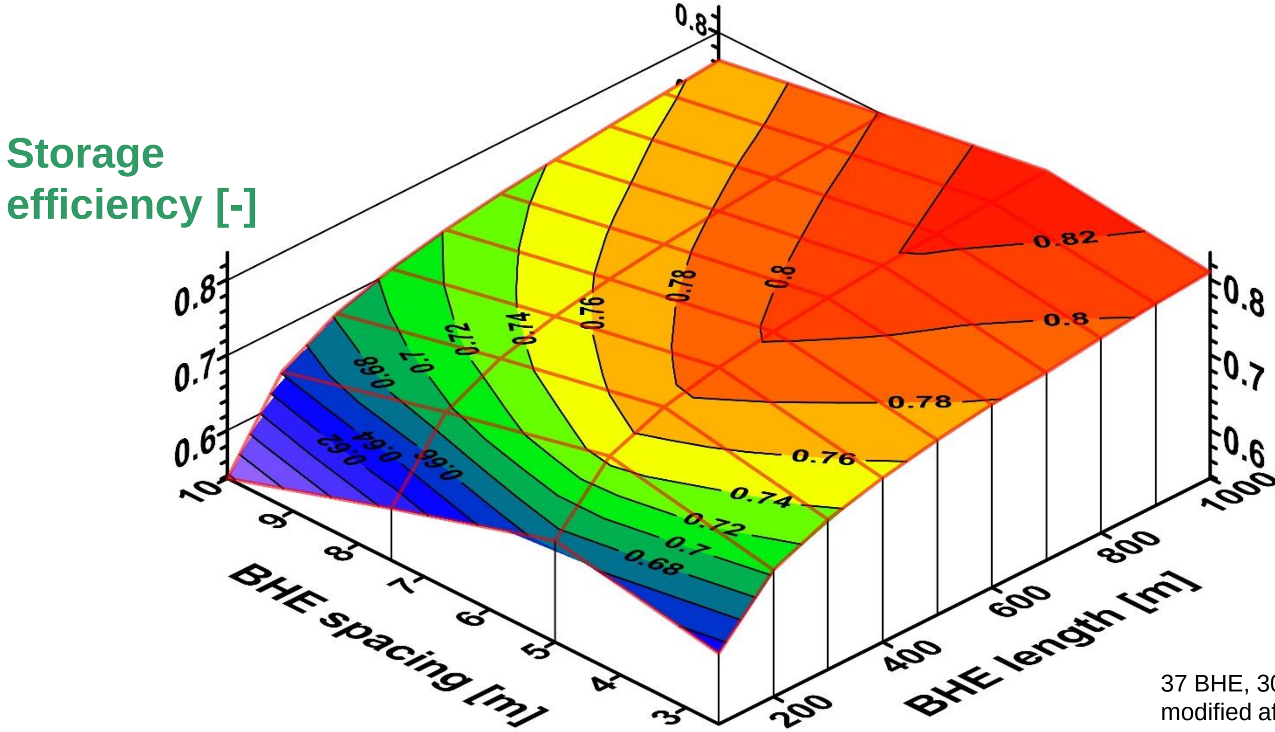
- Q_S and Q_E increase almost linear with the length and the number of BHE.

Storage Efficiencies Exceed 80%



- **Storage efficiency increases with BHE length and the number of BHE.**

Drilling Accuracy Is Crucial

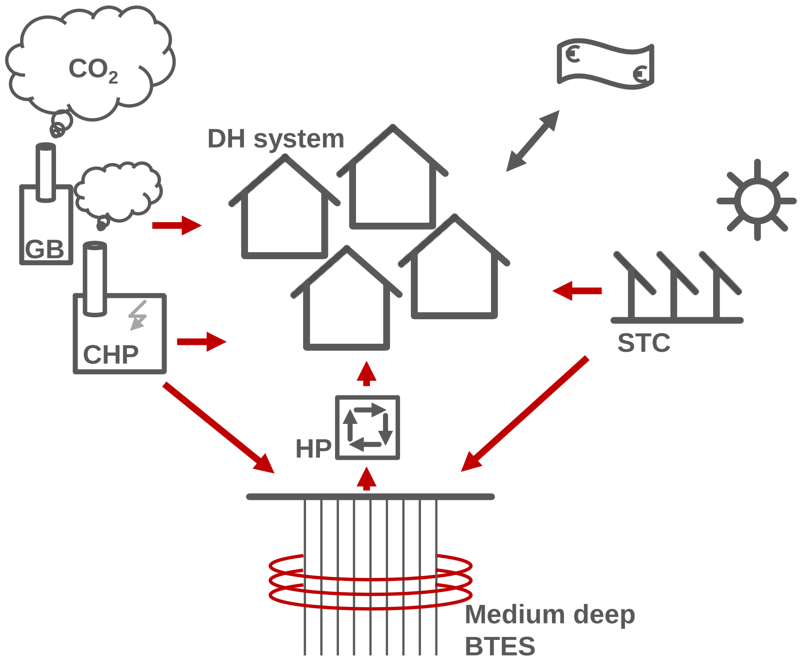


37 BHE, 30th year of operation, modified after Sass et al. (2015b)

- **Maximum of storage efficiency at a BHE spacing of 5 m**

Life Cycle Assessment

Use phase



Welsch et al. (2018)

MATLAB-Based Assessment Tool

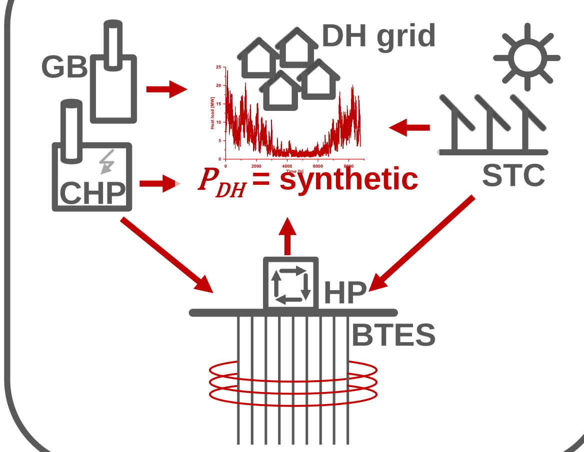
System design

Input variables

- DH demand
- CHP nominal power
- STC area
- BTES depth*

Assessment tool

Heating system model



Energy flows
Component dimensions

LCA & economic assessment routine

Economic and environmental scenario

Input variables

- Electricity price
- Gas price
- Emission factors
- Subsidies

Energy balance on an hourly basis

Results

Output variables

- Levelized cost of heat (LCOH)
- Global warming potential (GWP)

*number of BHE is kept constant at 37, spacing at 5 m

Modified after Welsch et al. (2018)

Assessment Categories

TECHNISCHE UNIVERSITÄT DARMSTADT

Levelized cost of heat

$$LCOH = \frac{\sum_{a=0}^{a_{end}}((I_a + M_a + F_a - R_a) \cdot (1+r)^{-a})}{\sum_{a=0}^{a_{end}}(Q_a \cdot (1+r)^{-a})} \cdot 100 \qquad \text{[ct/kWh]}$$

I = Investment costs

R = Revenues

a = Year of operation

M = Maintenance costs

Q = Delivered heat

F = Fuel (operation) costs

r = Interest rate

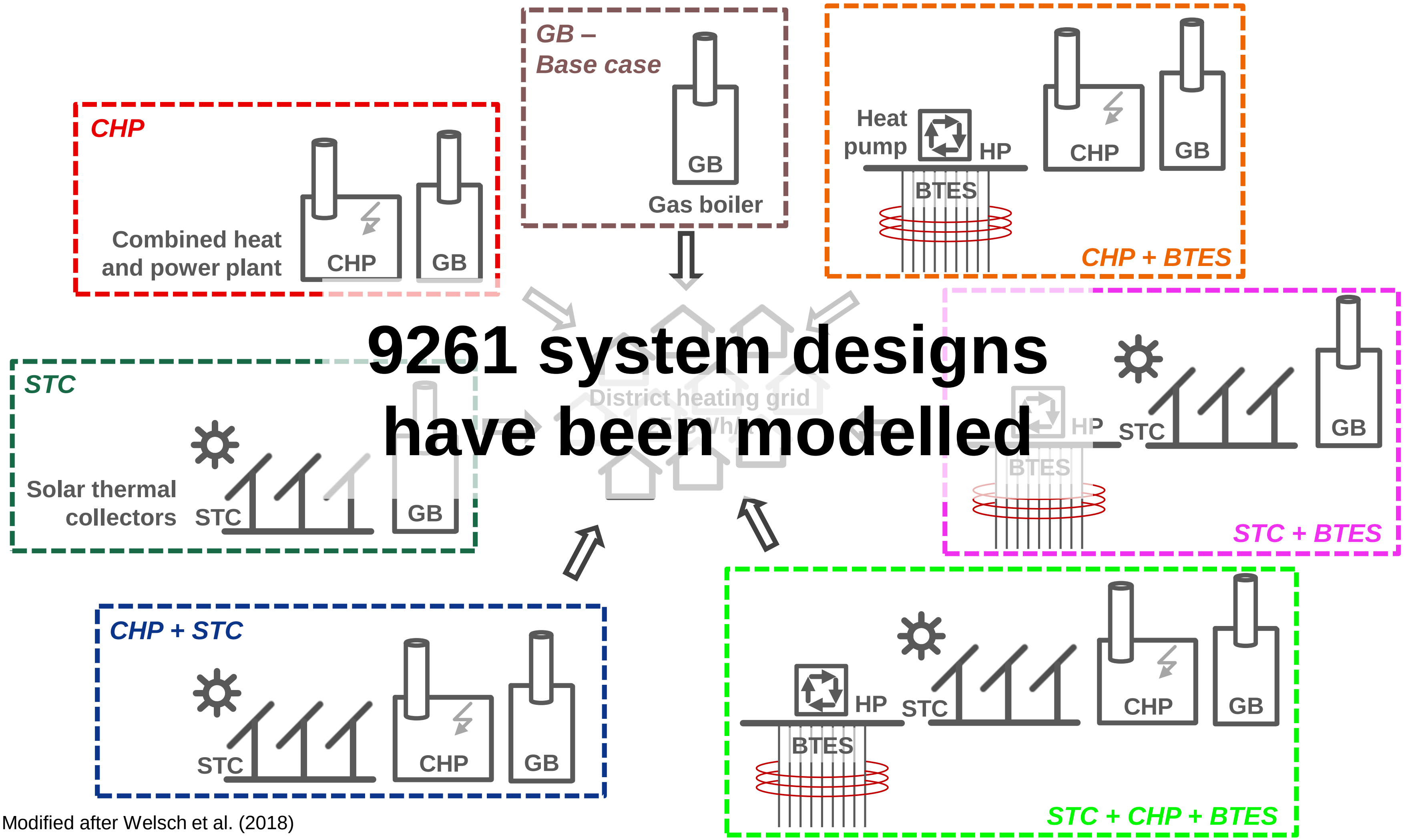
Global warming potential

$$GWP = \sum_{a=0}^{a_{end}} \left(GWP_{prod,a} + GWP_{op,a}\right) \qquad [\text{t } CO_2 \text{ eq}]$$

prod = Production phase

op = Operation phase

Comparative Assessment Study



9261 system designs have been modelled

Modified after Welsch et al. (2018)

Economical and Environmental Scenarios

Time frame 30 years

Scenario	Gas price [ct/kWh]	Electricity base price for CHP feed-in [ct/kWh]	Electricity price for industry [ct/kWh]	Emission factor grid electricity [g/kWh]	Subsidies included
BAU (Business As Usual)	3.08[1]	3.66[2]	13.08[3]	532[4]	✗
BAU SUB	3.08[1]	3.66[2]	13.08[3]	532[4]	✓
EVO (Evolution)	Projected[5] ↗	Projected[5] ↗	Projected[5] ↗	Projected[5] ↘	✗
EVO SUB	Projected[5] ↗	Projected[5] ↗	Projected[5] ↗	Projected[5] ↘	✓

[1]average gas price for industry in Germany 2015 (Statistisches Bundesamt, 2017)

[2]3.16 ct/kWh average price for baseload power at the EPEX spot 2015 (European Energy Exchange AG, 2017) plus 0.5 ct//kWh for avoided grid charges

[3]average value for 2015 (Statistisches Bundesamt, 2017)

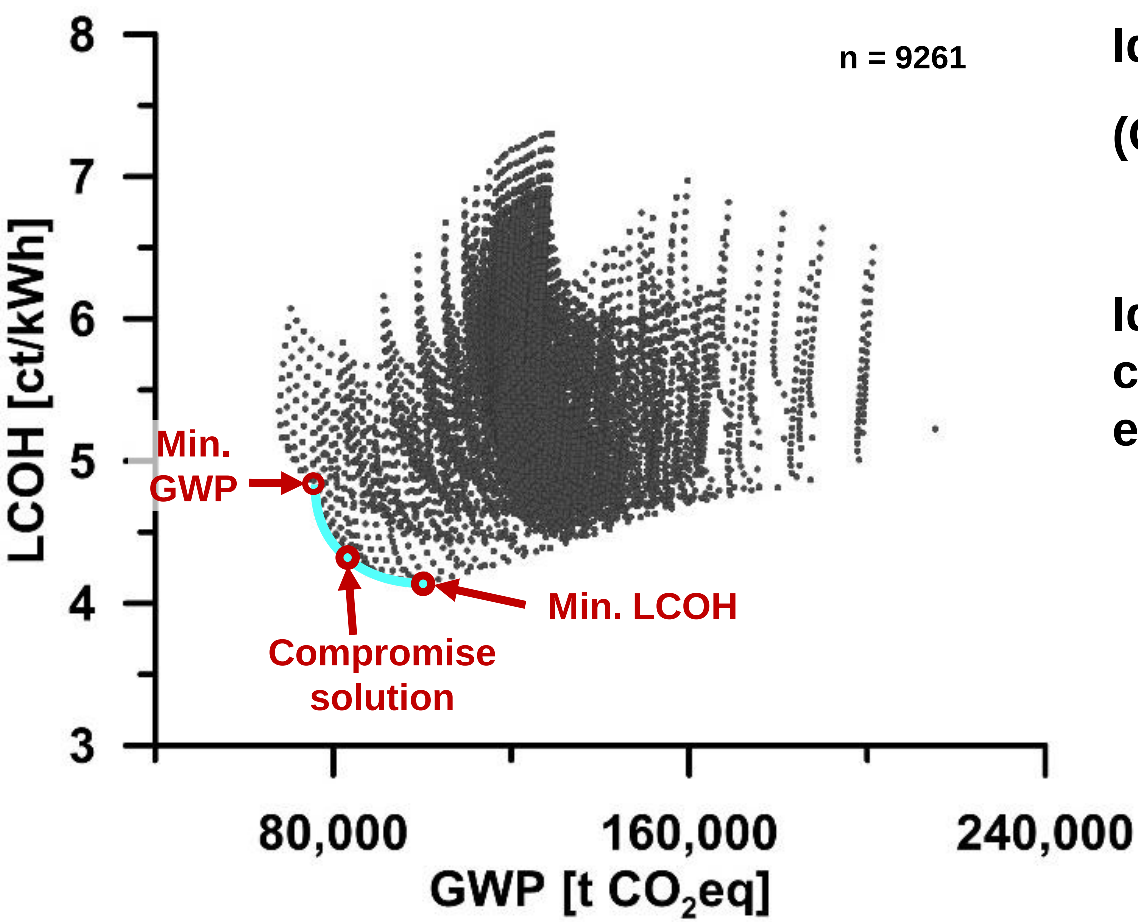
[4]current German electricity mix (IINAS, 2016)

[5]trends from Schlesinger (2014)

SUB scenarios include current German subsidies for

- **CHP electricity sales**
- **STC and heat storage installation**

Principle of Pareto Analysis as an Anti-Greenwashing-Measure



- Data points

Welsch et al. (2018)

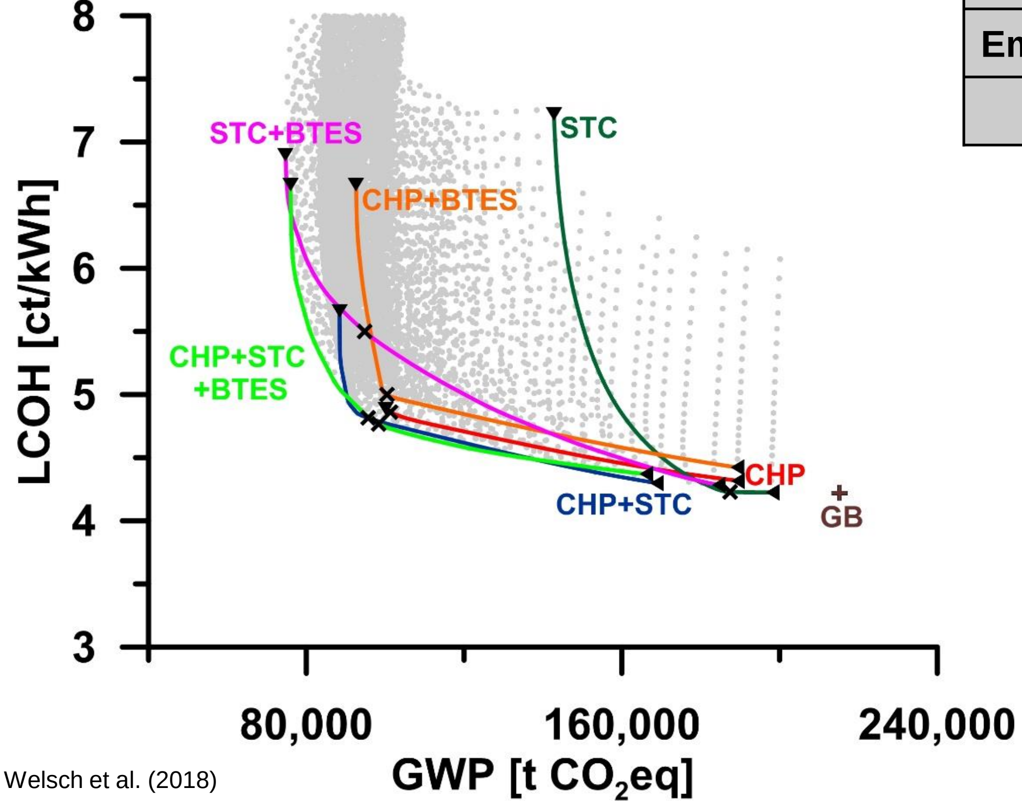
Identification of Pareto fronts

(Cost-Benefit-Analysis)

Identification of three characteristical Pareto efficient systems:

- **Minimum LCOH**
- **Minimum GWP**
- **Compromise solution**

BAU – GWP Reductions Come at a Price



Welsch et al. (2018)

Energy prices	const.
Emission factor grid electricity	const.
Subsidies	✗

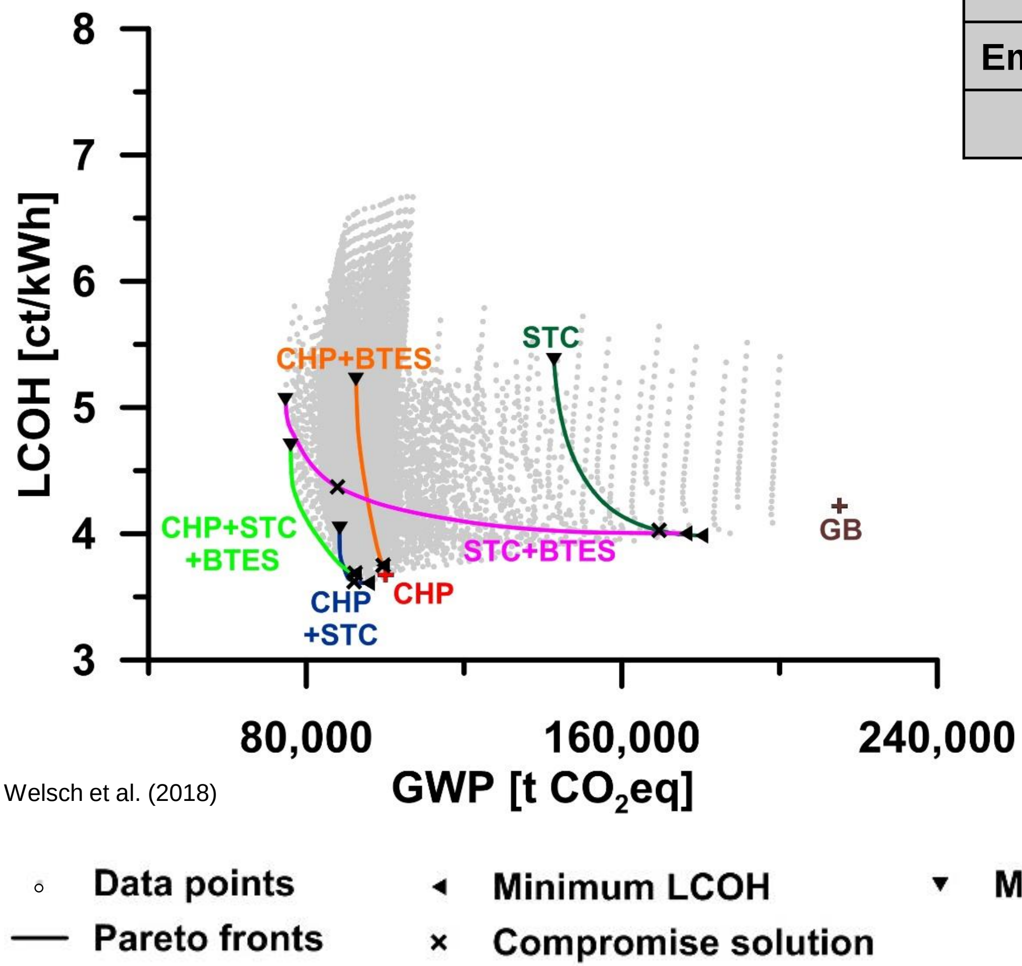
◦ Data points ◂ Minimum LCOH ▾ Minimum GWP

— Pareto fronts × Compromise solution

BAU SUB – Subsidies Benefit CHP

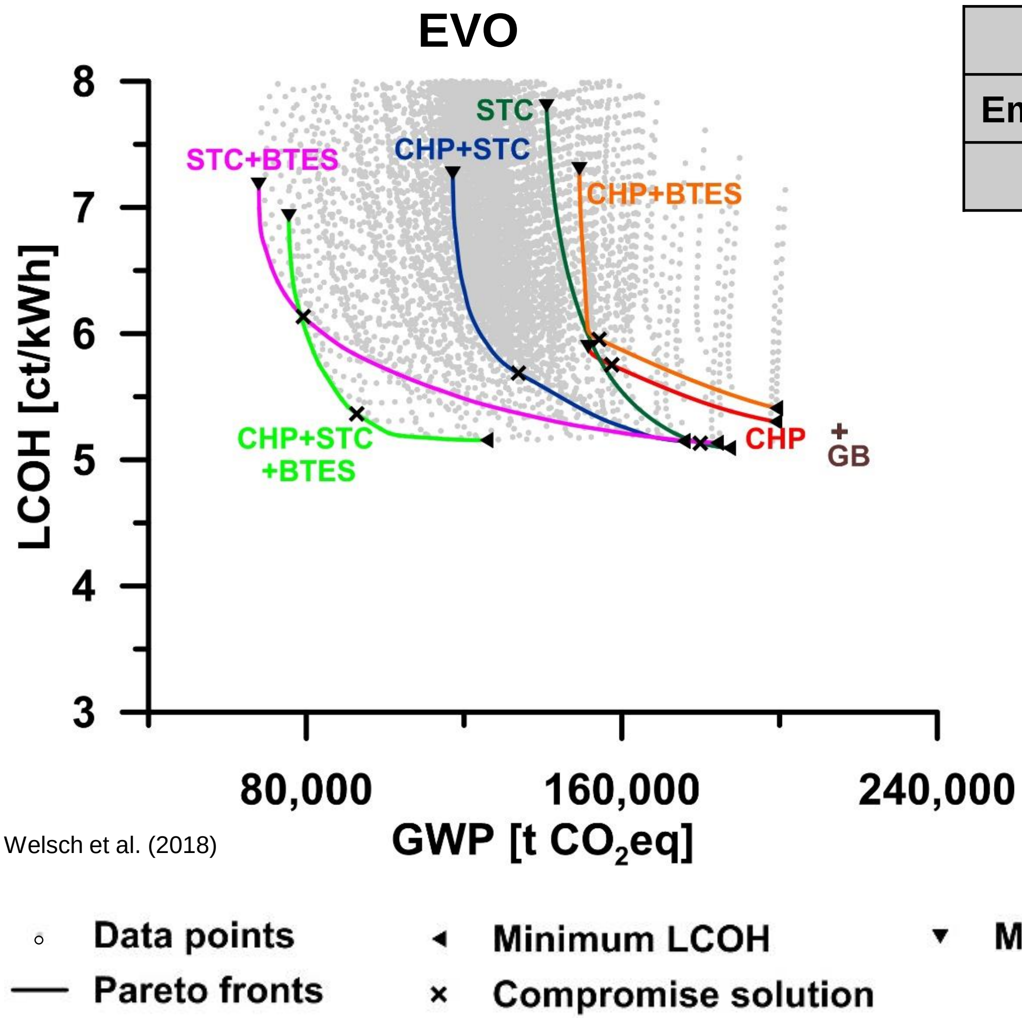
TECHNISCHE UNIVERSITÄT DARMSTADT

Energy prices	const.
Emission factor grid electricity	const.
Subsidies	✔



Welsch et al. (2018)

EVO – Evolution Benefits BTES

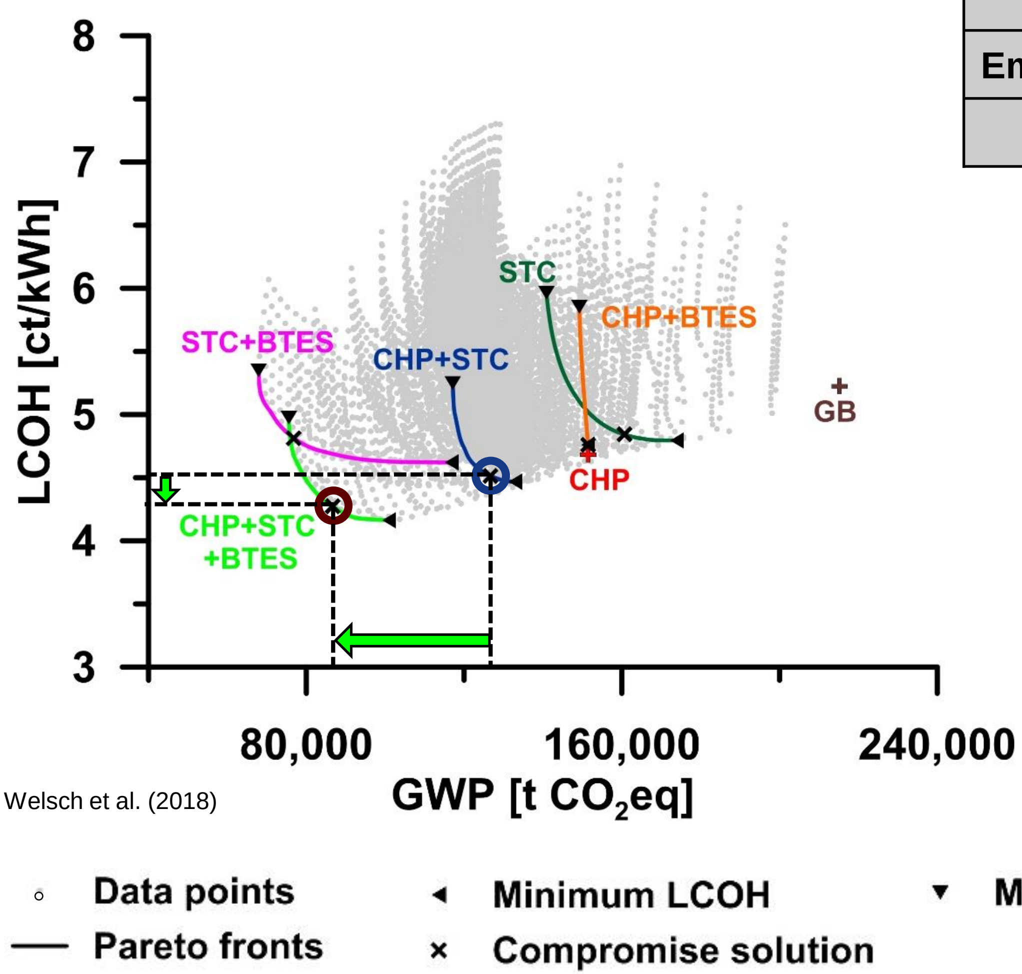


Welsch et al. (2018)

Energy prices	↗
Emission factor grid electricity	↘
Subsidies	✗

EVO SUB – MD-BTES Systems Significantly Reduce GHG Emissions and Lower Heat Costs

TECHNISCHE UNIVERSITÄT DARMSTADT



Welsch et al. (2018)

Energy prices	↗
Emission factor grid electricity	↘
Subsidies	✓

Compared to the best compromise solution without BTES

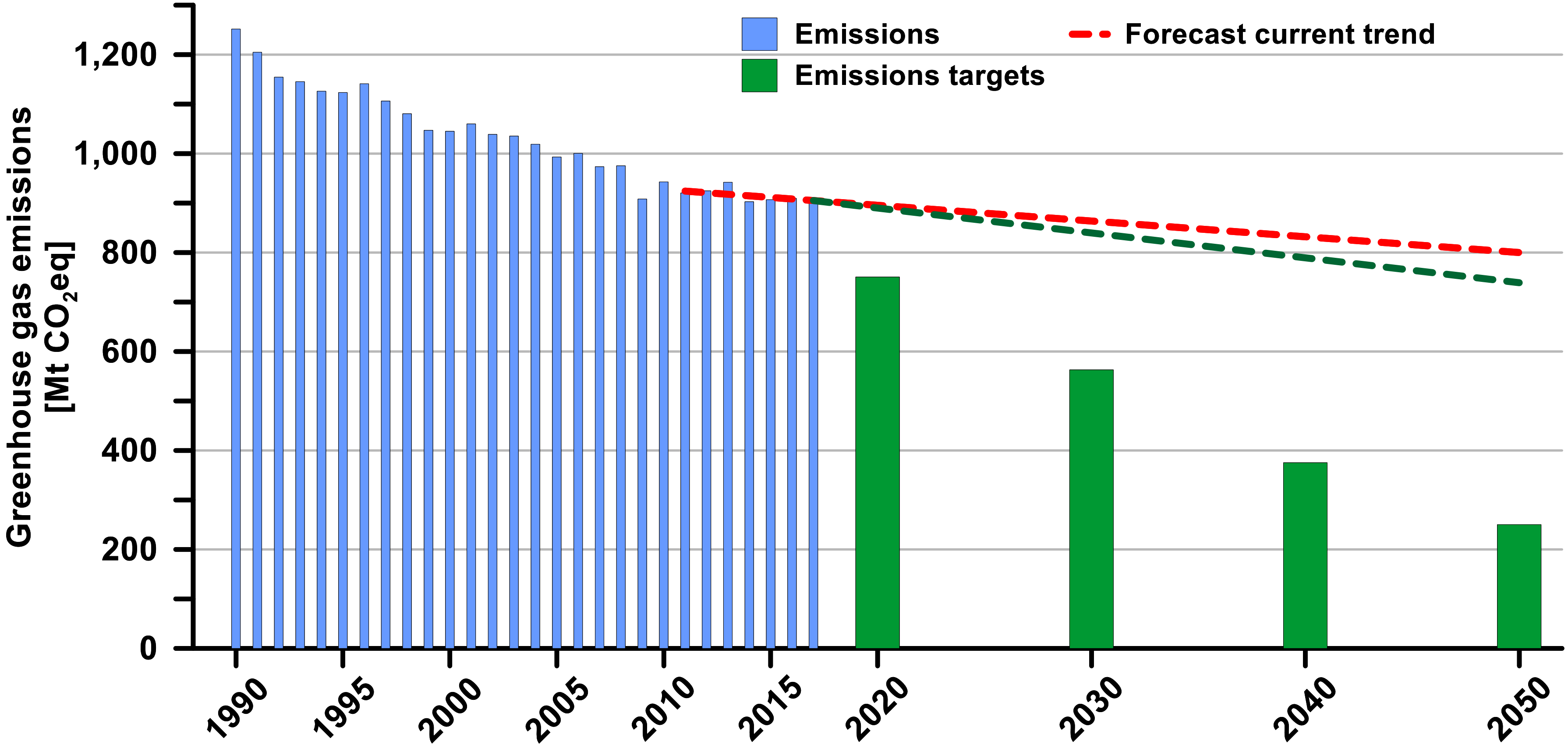
- **Reduction of the GWP by 32%**
- **Reduction of the LCOH by 5.3%**

Conclusion – Geothermalists: Think Big!

- MD-BTES are eminently suitable for seasonal heat storage.
- MD-BTES systems significantly reduce the thermal impact on shallow groundwater aquifers.
- MD-BTES are most effective on a 1 to 25 GWh/a scale (for single systems)
- MD-BTES systems are cost-effective and can significantly reduce GHG emissions.
- LCA should be a standard method in the planning process of DH systems.

Tentative Forecast of GHG Emissions Shows the Required Magnitude of Reductions

TECHNISCHE UNIVERSITÄT DARMSTADT



Assumptions:
- **Continuous increase of DH share in urban areas from 13% to 75% in 2050**
- **All DH systems are equipped with a CHP+STC+BTES combination**
- **Forecast CHP+STC+BTES based on EVO SUB**

Data sources: UBA (2018), BMUB (2014), BMUB (2016)

Thank you for your attention!

TECHNISCHE UNIVERSITÄT DARMSTADT

Funding

HESSEN Hessisches Ministerium für Wirtschaft, Energie, Verkehr und Landesentwicklung

Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

Graduate School of Energy Science and Engineering

FORUM INTERDISZIPLINÄRE FORSCHUNG

Literature

- AGEB (2016): Anwendungsbilanzen für die Endenergiesektoren in Deutschland in den Jahren 2013 bis 2015. Studie beauftragt vom Bundesministerium für Wirtschaft und Energie, Projektnummer: 072/15., Arbeitsgemeinschaft Energiebilanzen e.V.
- Bär K, Reinsch T, Sippel J, Strom A, Mielke P, Sass I (2017): P³ - International PetroPhysical Property Database. Proceedings 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 13-15
- BMUB (2014): Aktionsprogramm Klimaschutz 2020, Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
- BMUB (2016): Klimaschutzplan 2050 - Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung, Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
- IINAS - International Institute for Sustainability Analysis and Strategy (2016): GEMIS model and database, version 4.93, *in* Strategy, IIfSAa, ed., Darmstadt.
- Schlesinger M, Hofer P, Kemmler A, Kirchner A, Koziel S, Ley A, Piégsa A, Seefeldt F, Straßburg S, Weinert K, Lindenberger D, Knaut A, Malischek R, Nick S, Panke T, Paulus S, Tode C, Wagner J, Lutz C, Lehr U and Ulrich P (2014): Entwicklung der Energiemärkte – Energiereferenzprognose, Projekt Nr. 57/12, http://www.bmwi.de/Redaktion/DE/Publikationen/Studien/entwicklung-der-energiemaerkte-energiereferenzprognose-endbericht.html, accessed 07.06.2017.
- UBA (2018): National Trend Tables for the German Atmospheric Emission Reporting 1990-2016, Dessau, Umweltbundesamt.