ETH zürich

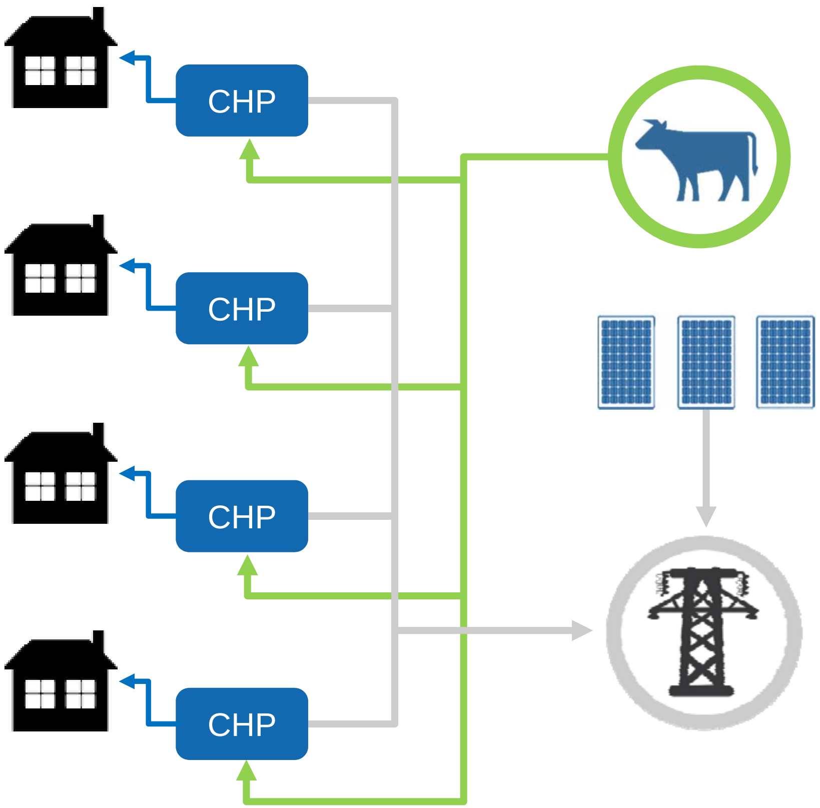
Project CHPswarm:

Potenzialanalyse eines Schwarms biogener Wärmekraftkoppelungsanlagen zur Kompensation fluktuierender erneuerbarer Stromquellen

PAUL SCHERRER INSTITUT

Distributed, biogenic CHPs → compensate for missing PV input

Research question: potentials within a Swiss region



- Combined heat and power plants
- Thermal power for buildings and industry
- Arrays of plants (a.k.a. swarm)
- Distributed power generation
- Fluctuating production from renewables
- Fuel → only biogas

Potentials:
- technological → regional case-studies
- economical → national energy scenarios

Sponsors, Research partners and participating Swiss regions:

Sponsors:

Swiss Electric Research

swisselectric research

Bundesamt für Energie

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Swiss Federal Office of Energy SFOE

Research partners:

Laboratorium für Aerothermochemie und Verbrennungssysteme ETH (LAV)

LAV

Projektleitung
Modellierung WKK-Anlagen
Wärmebedarf Gebäude und Industrie

Geoinformation Engineering ETH (GIE)

Biomasseverfügbarkeit
Standorte Biogasanlagen
Gebäudestruktur

Forschungsstelle Energienetze ETH (FEN)

FEN forschungsstelle energienetze

Stromnetzsimulation
PV-Erzeugung

Energy Economics Group PSI (EEG)

PAUL SCHERRER INSTITUT PSI

Zukunftsszenarien 2050
Marktanteile

Partnering regions:

Kanton Luzern

Centralschweizerische Kraftwerke (CKW)
Energie Wasser Luzern (EWL)
Wasserwerke Zug (WWZ)

Kanton Thurgau

Abteilung Energie des Kt. Thurgau

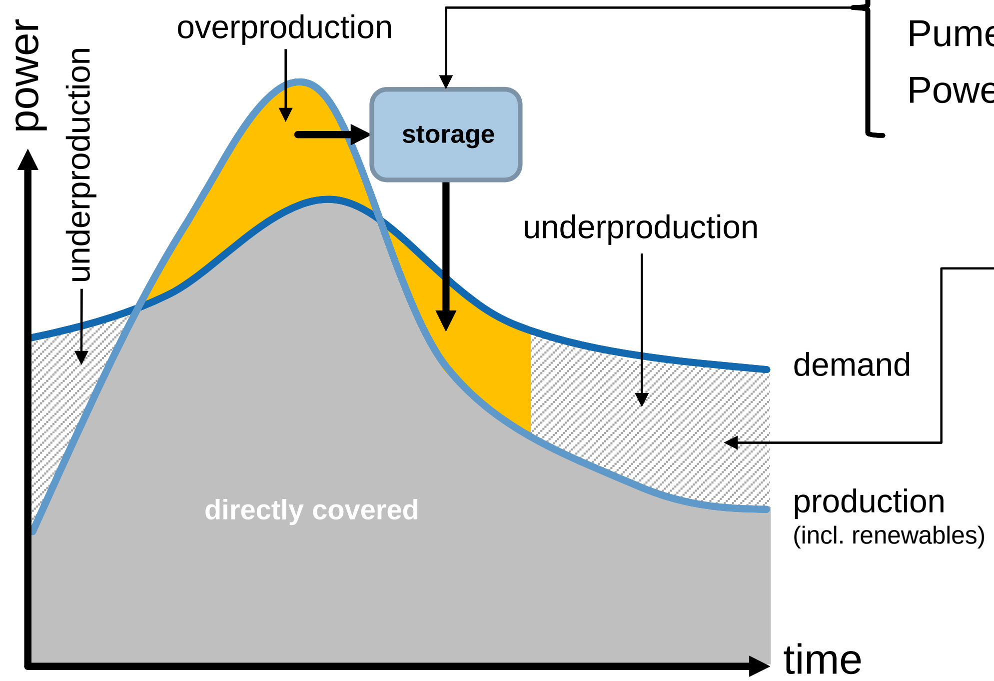
Kanton Basel-Stadt

Industrielle Werke Basel (IWB)

The bigger picture:
role of biogenic CHP-plants in future energy systems

Why CHPs? → compensation of fluctuating renewables

→ need for fast-switchable production (and loads)



Storage (absorption of overproduction)

Batteries (~80%, hours)

Pumed hydro (~75%, days)

Power-To-Gas-To-Power (~30-40%, months)

On-demand production

Pumped hydro / P2G2P (within 1 minute)

Gas-engine CHP plants (within ~3 minutes)

Gas and steam powerplants (within ~20 minutes)

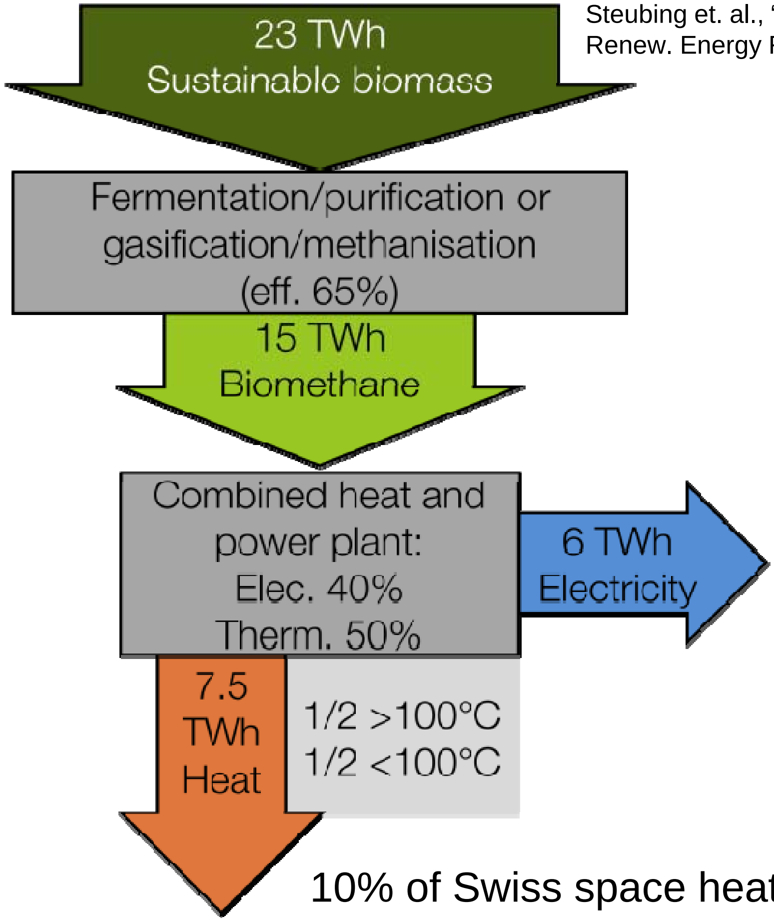
Hydro (run of the river)

Solar & wind

Thermal (excl. nuclear)

others

From biomass potentials → biogenic CHPs can make an impact



Steubing et. al., "Biogenergy Switzerland", Renew. Energy Reviews, 2010

10% of Swiss electricity demand
roughly 90% of production in winter

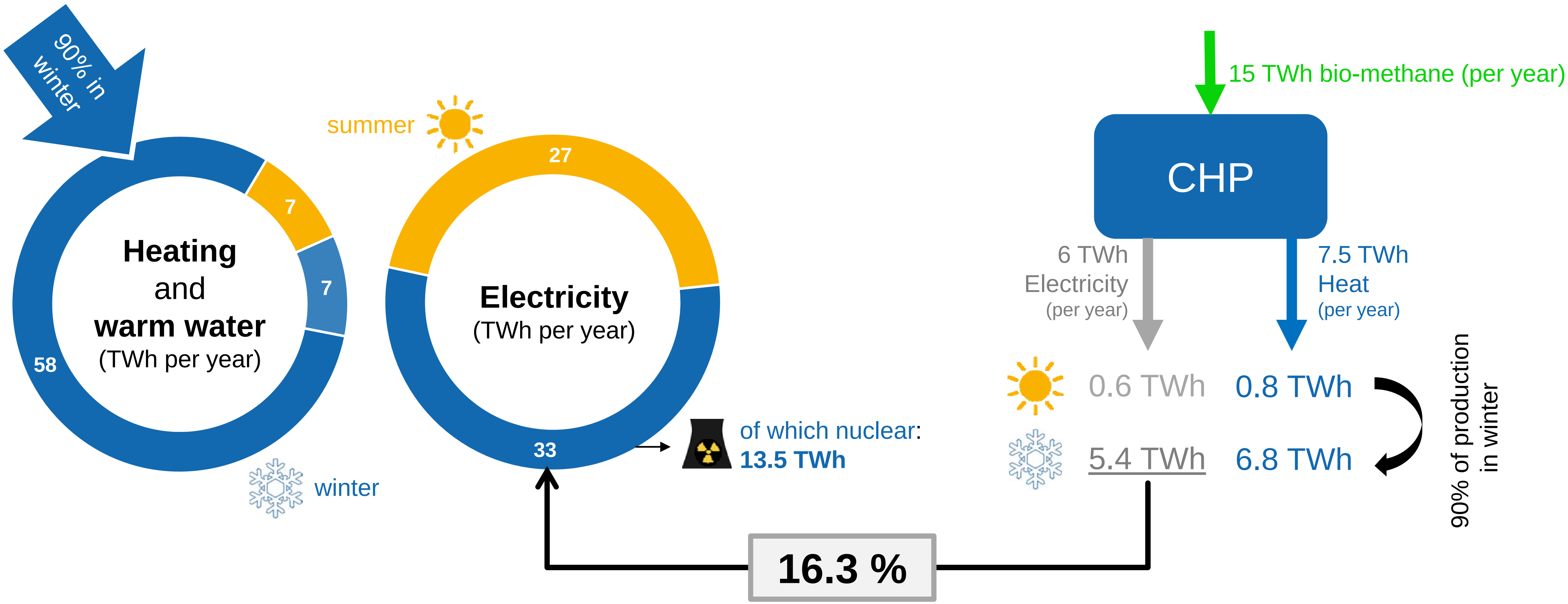
~33% of peak-power demand
assuming 2000h/year → 3GW (of ~9GW CH peak demand)

BFS, Energiestatistik 2014

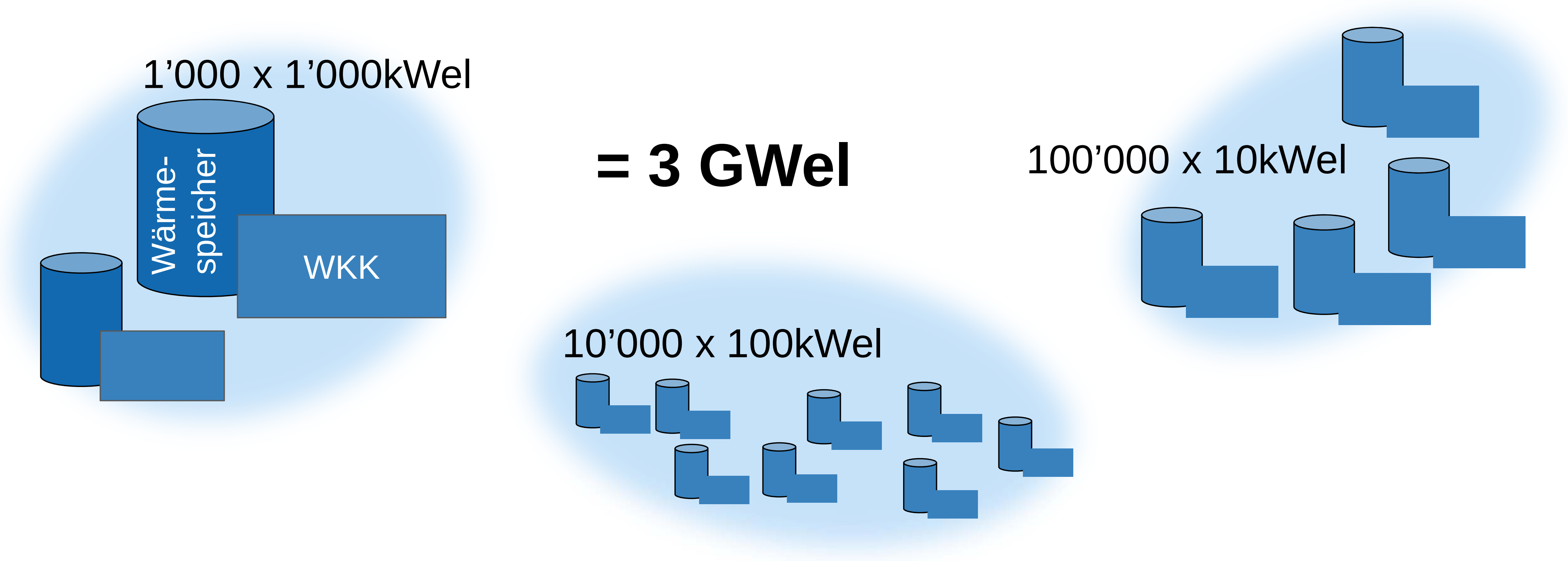
10% of Swiss space heating / warm water demand

Bulk of heat demand in winter → CHP production

electricity production of CHPs → largely in winter (→ seasonal fluctuations)



A swarm of plants
Portfolio of different plant sizes



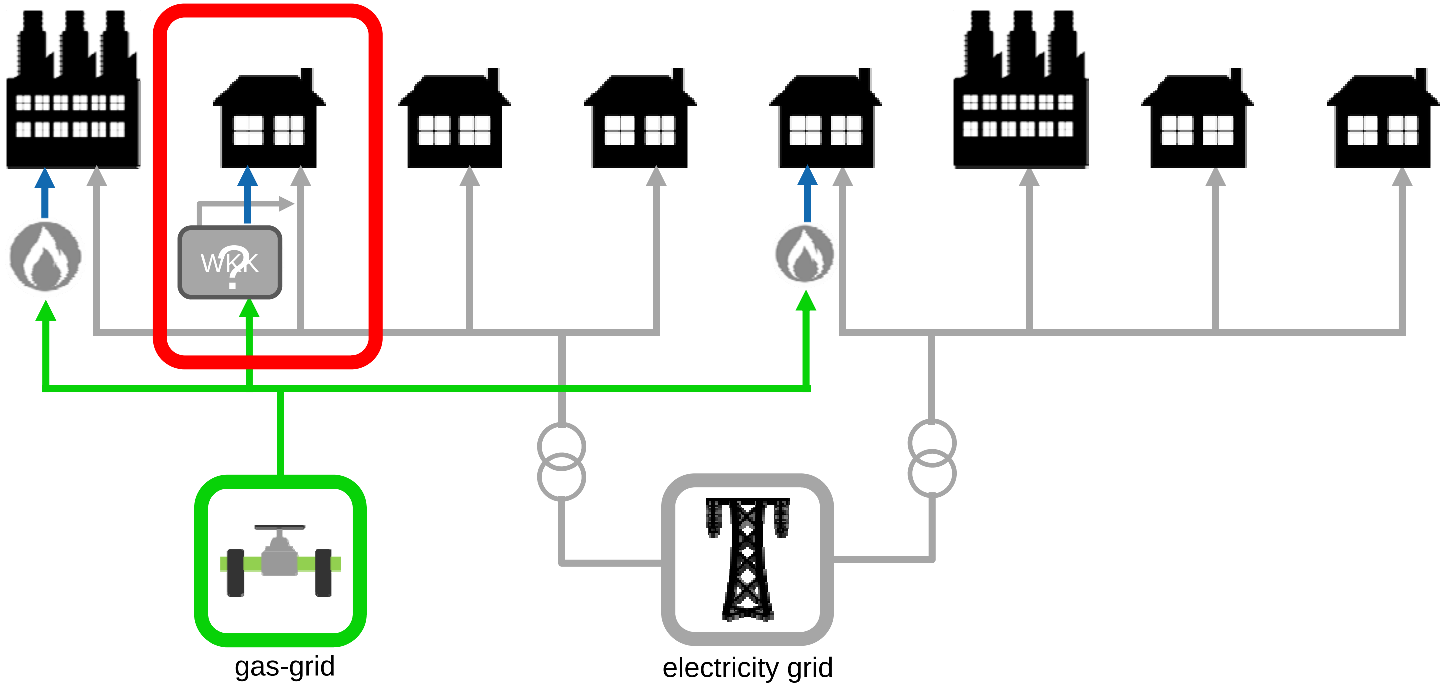
ETH zürich

The methodology

Regional case-studies focusing on technical limitations

Step 1: Design of individual CHP plants

Heat and electricity consumers

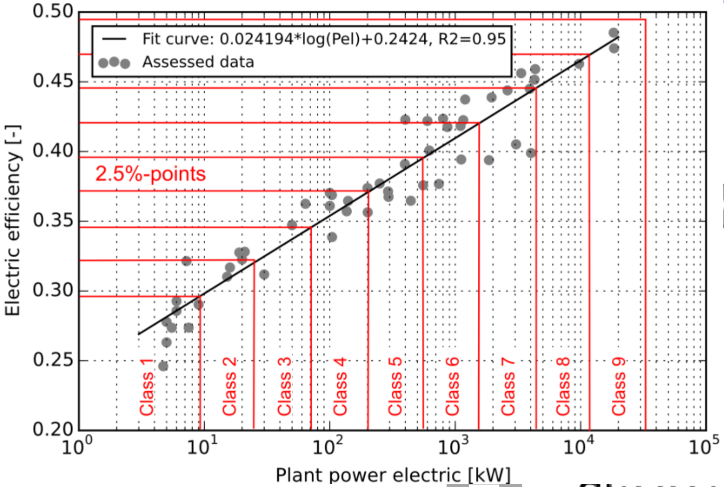


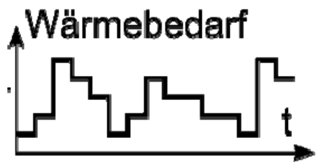
Designing a plant for a given building / industry

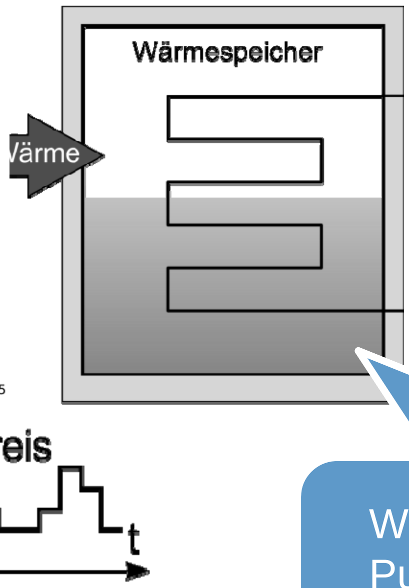
Paradigm for design and operation pattern: maximum profits (from power and heat sales)

Efficiency generally increases with plant-size; for the same heat-sink → shorter production → larger storage

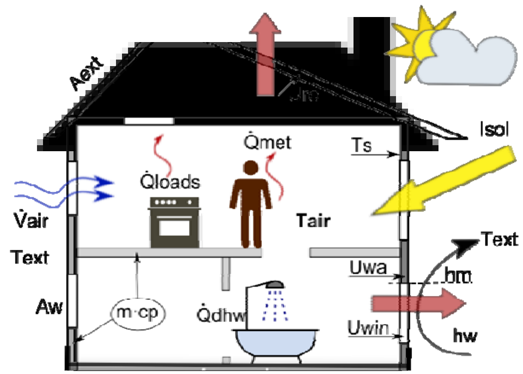
Gas



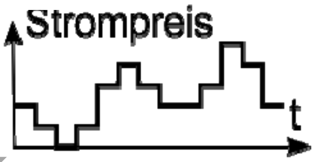




heat



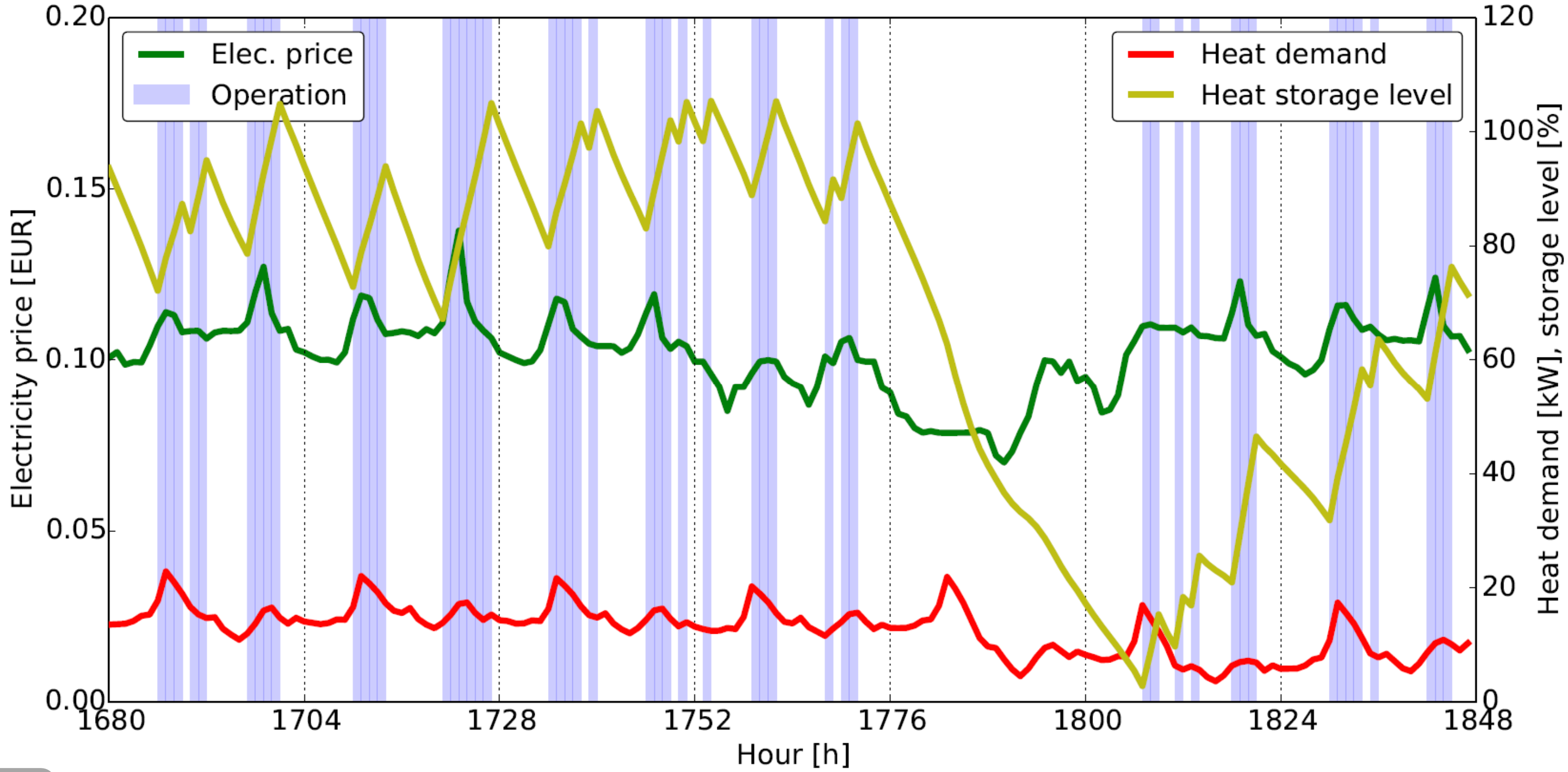
ISO13790 – SIA380



Revenues of electricity sales vary according to momentary market prices

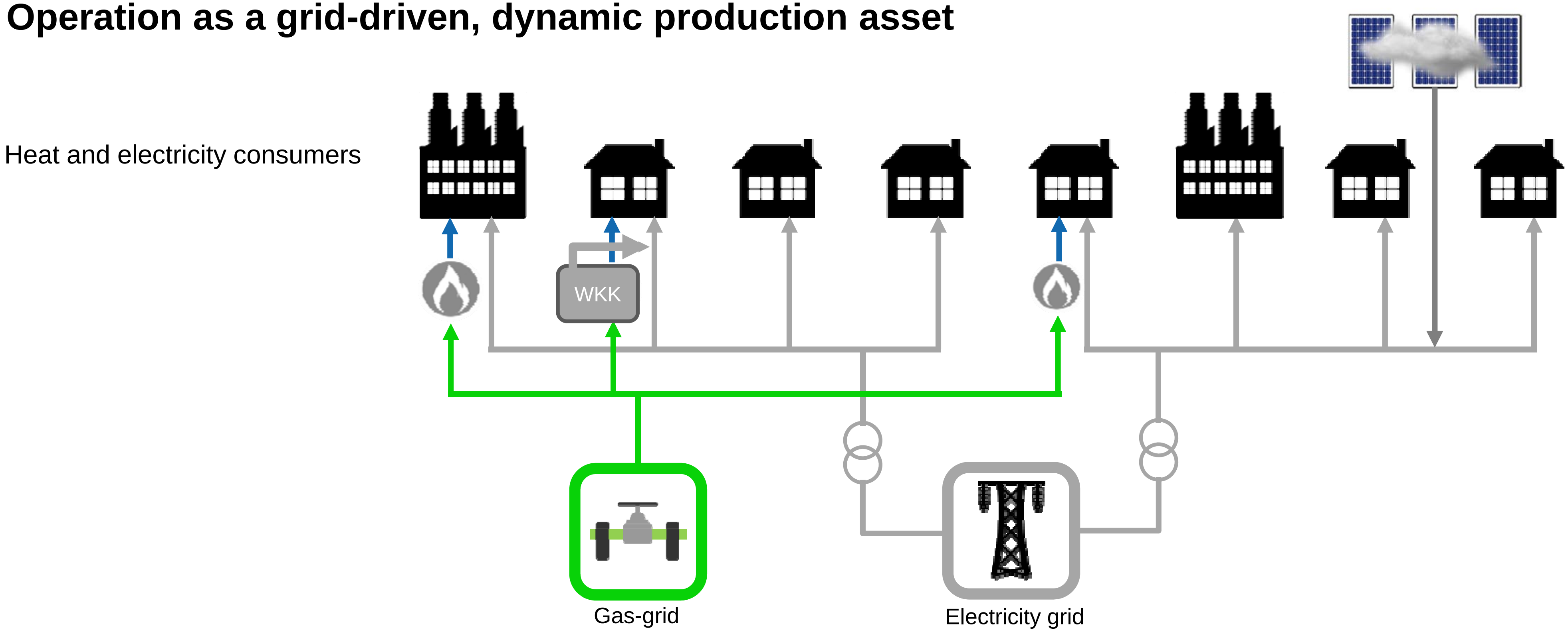
Without storage = «boiler»:
Purely heat-driven pattern
Storage → adds flexibility

Operation pattern of an optimized CHP plant
→ multi-family house during second week of March

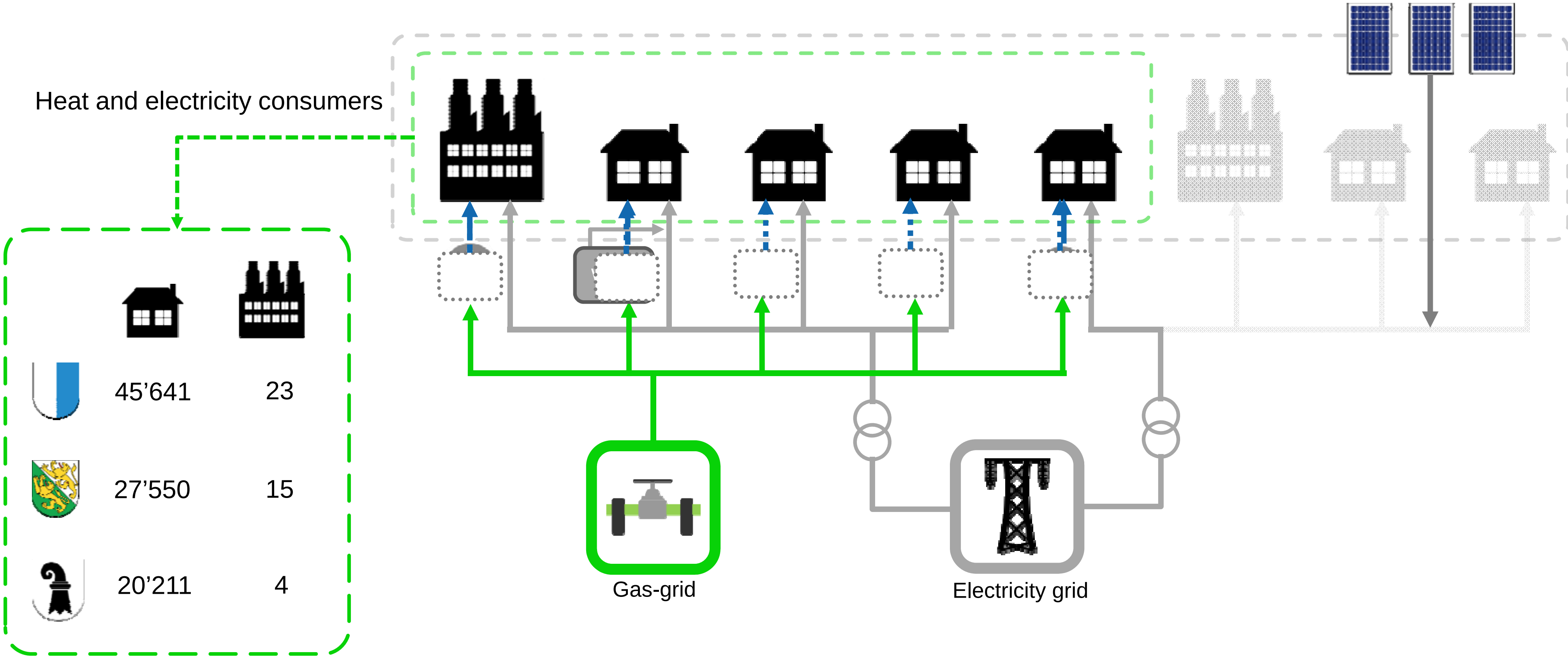


Step 2: compensation of PV-induced fluctuations

Operation as a grid-driven, dynamic production asset

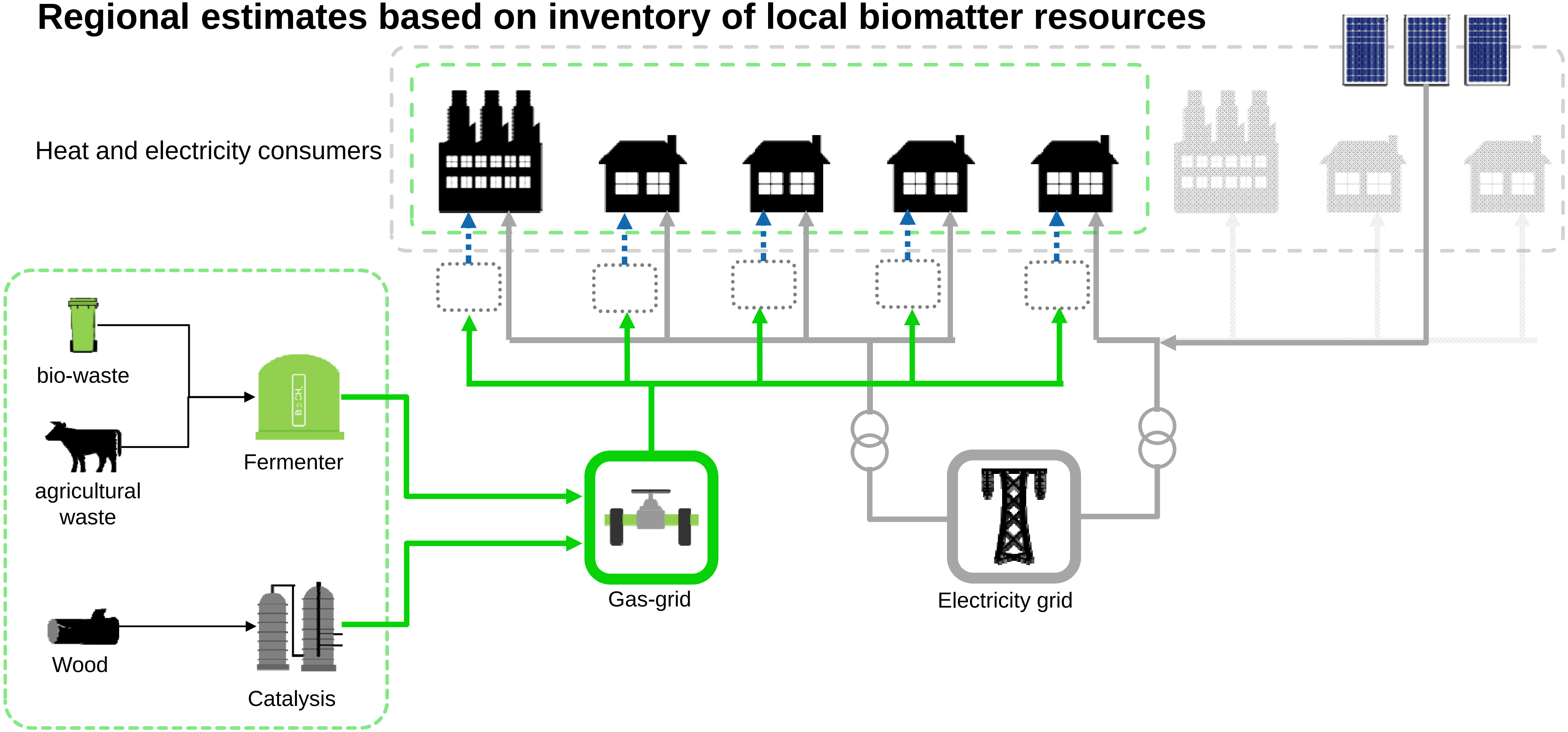


Step 3: Identification of possible installation sites



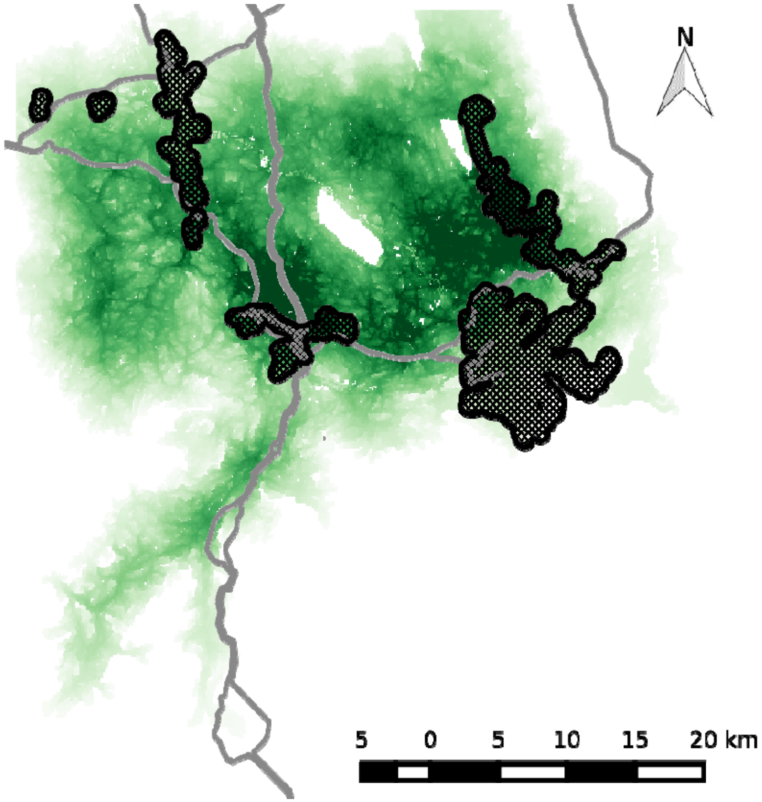
Step 3: Estimation of bio-methane potentials

Regional estimates based on inventory of local biomatter resources

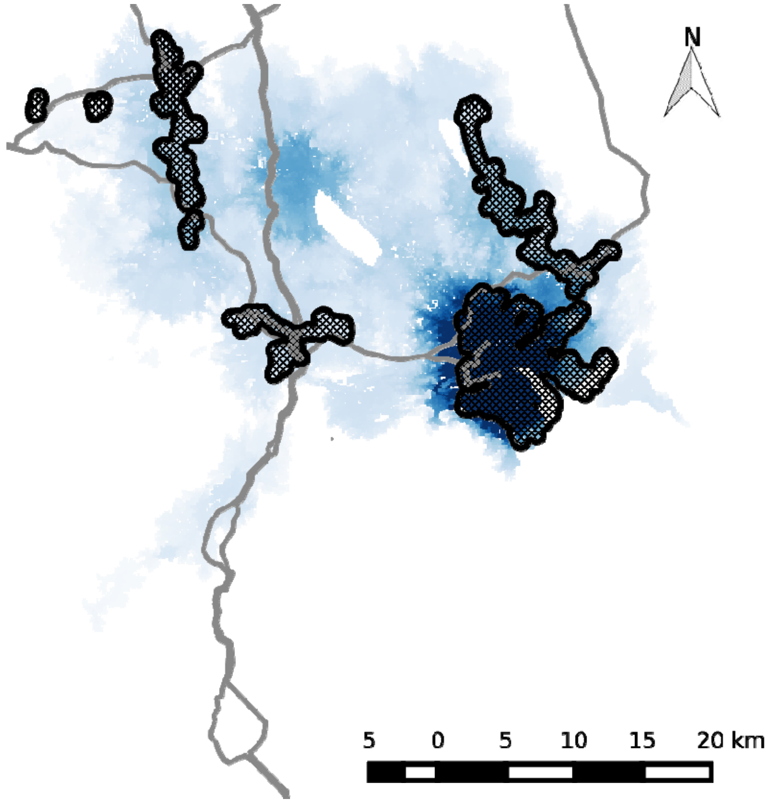


Spatial analysis → example: canton of Lucerne

Agricultural biomatter

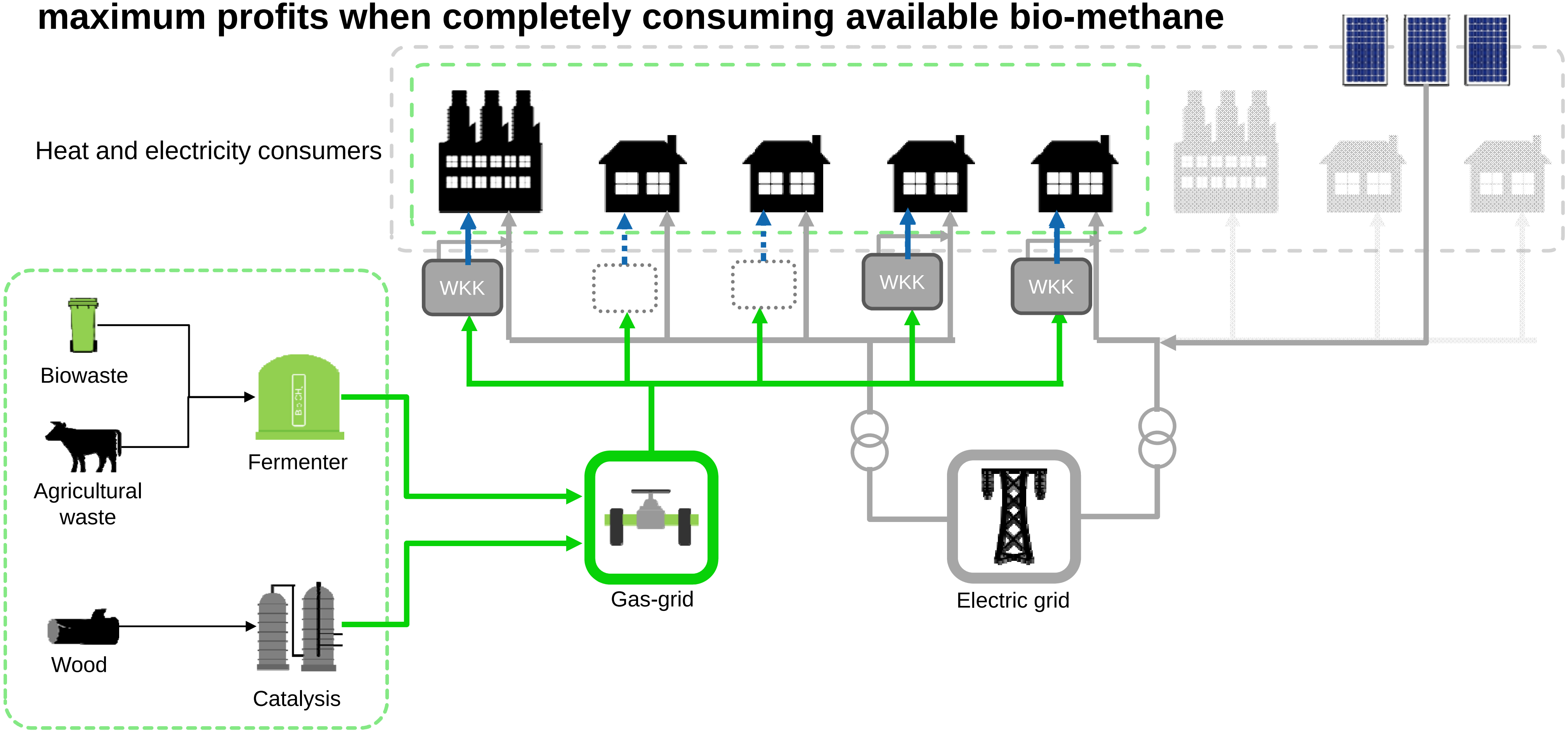


Biowaste from households, services, …



Step 5: Composition of a swarm of individual CHP plants

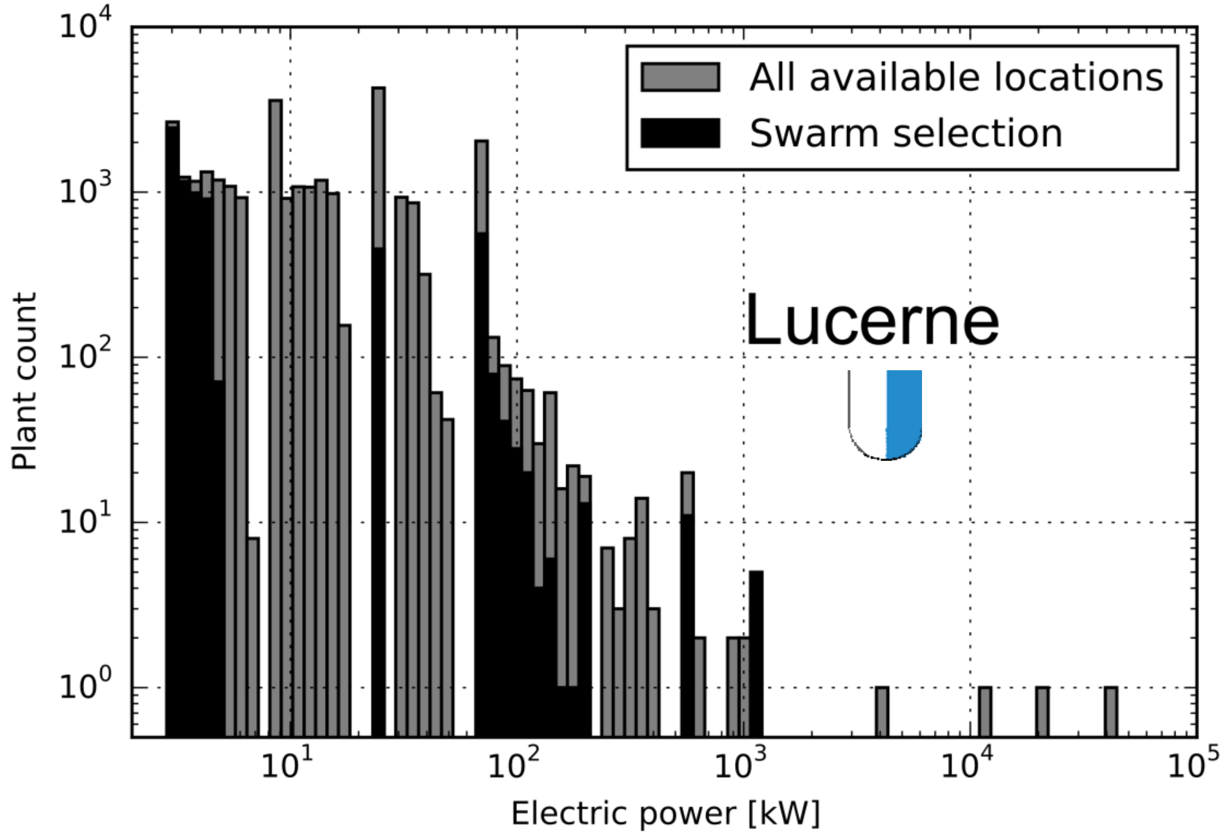
maximum profits when completely consuming available bio-methane

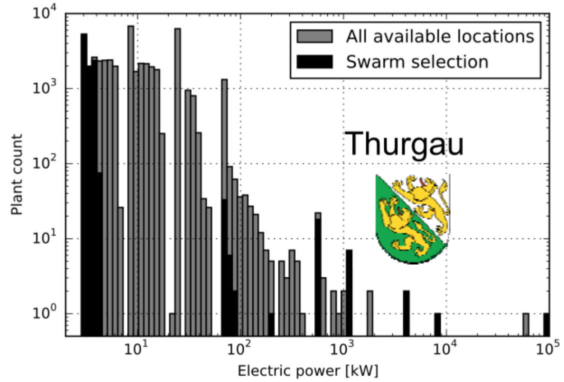


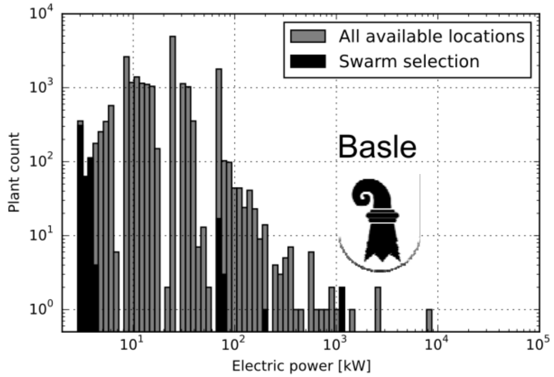
Results

Optimal swarm composition for different region

Maximum profits while fully consuming all available bio-methane

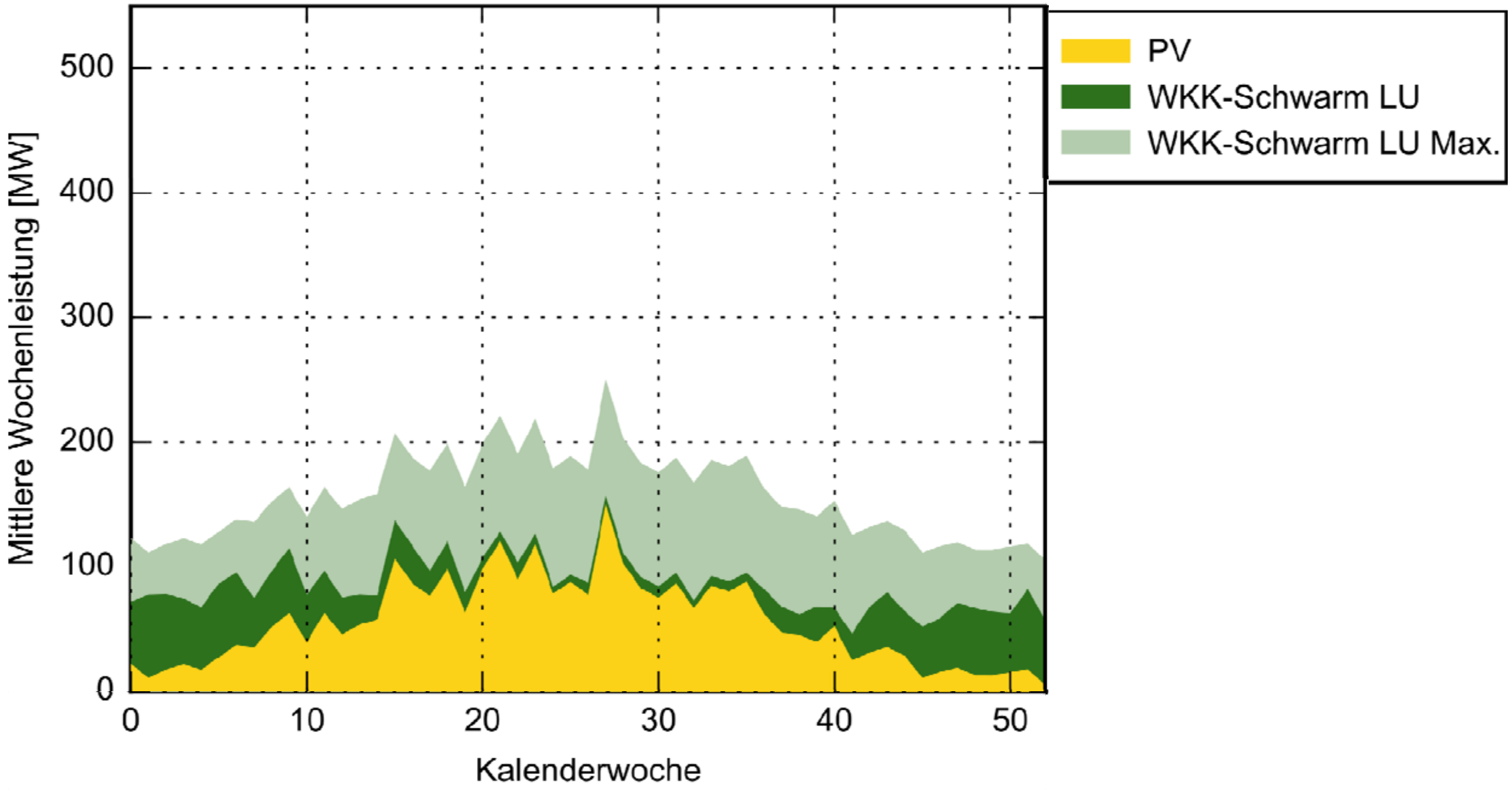






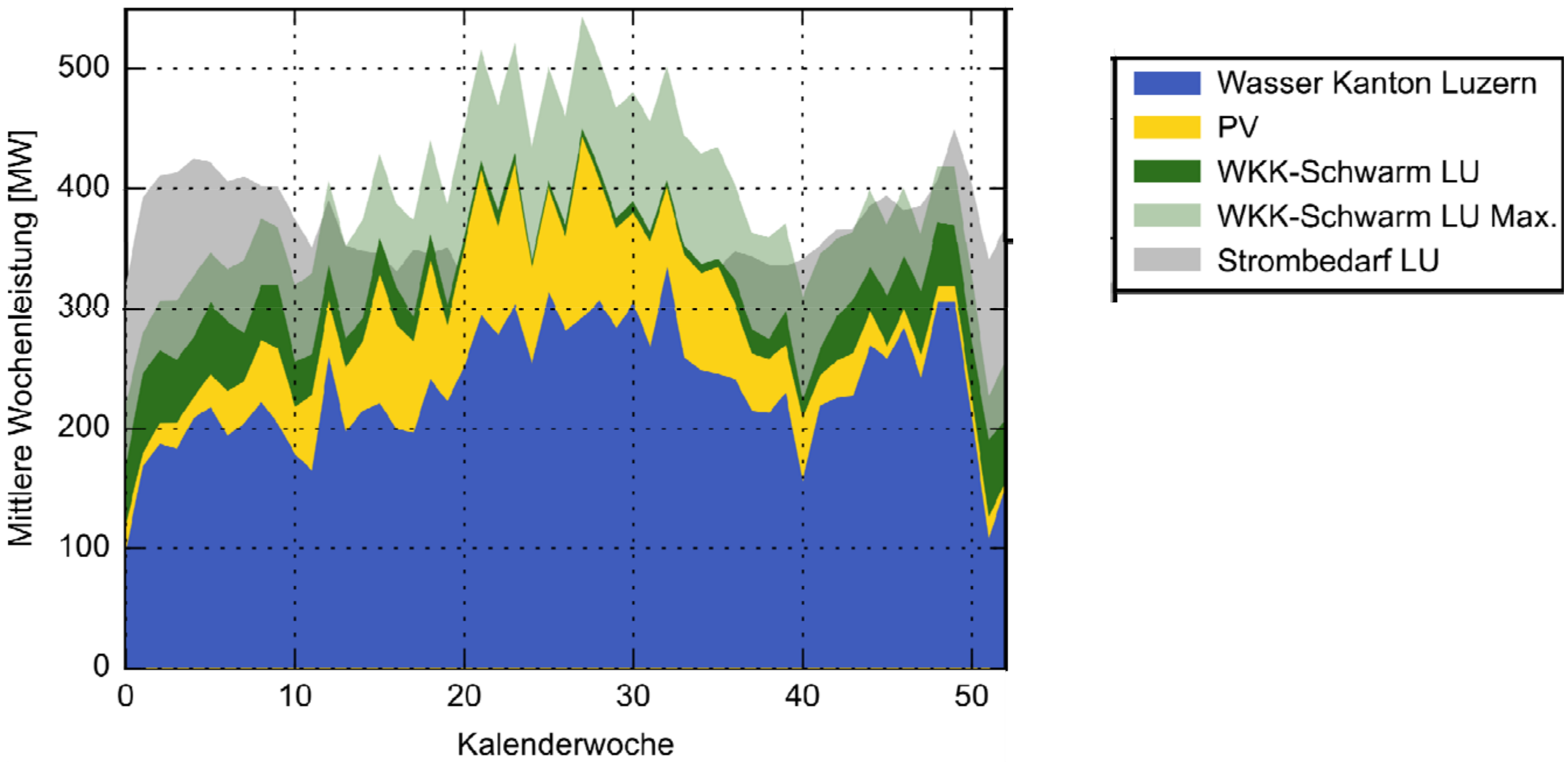
Electricity production → Example: Region of the size of Lucerne

In the background: swarm peak production power

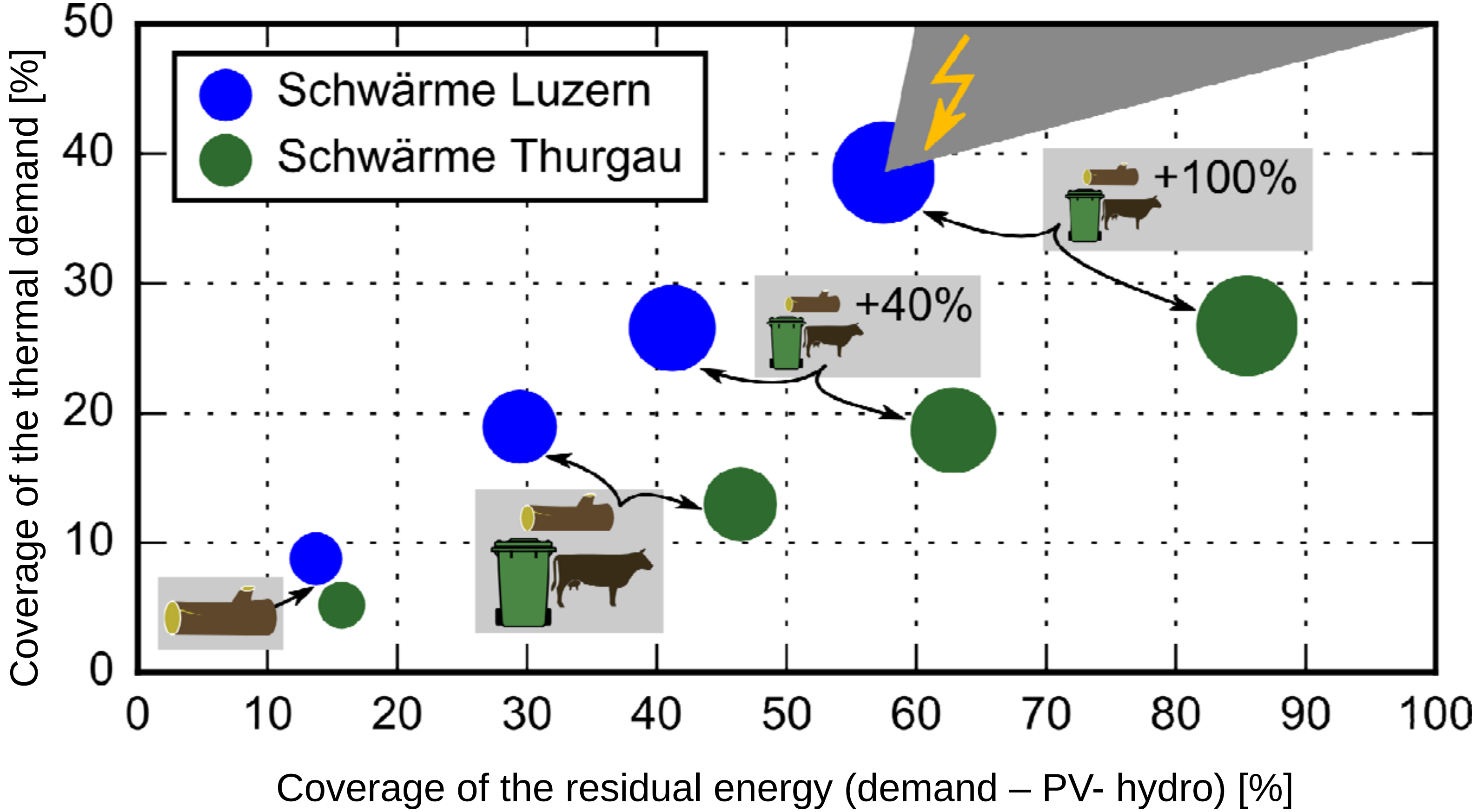


Comparing with the electricity demand and hydro production

Demand and hydro-production scaled by population



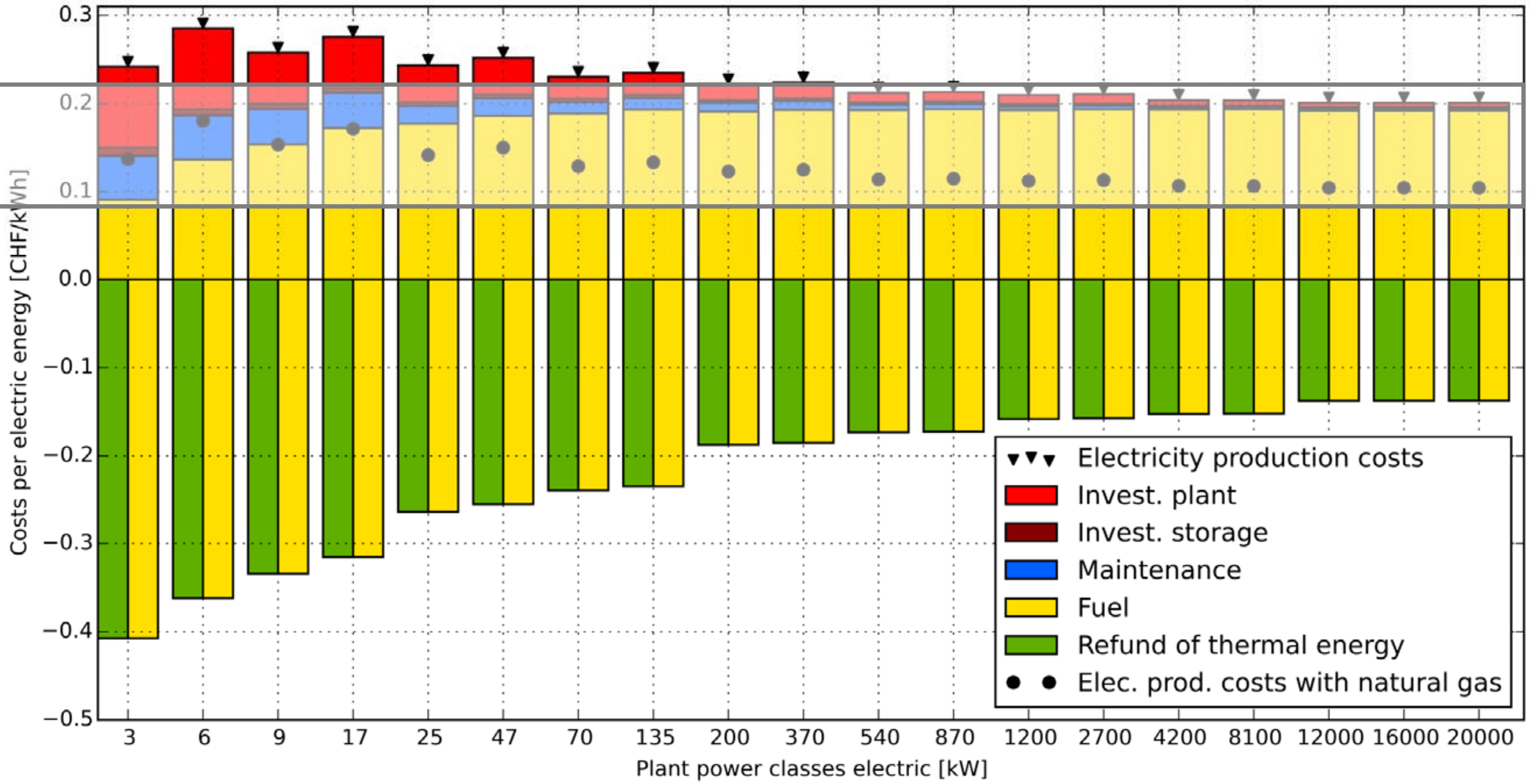
Electricity and heat production potentials of the swarms



Cost break-down → production costs incl. heat sales revenues

static analysis, balanced over one year

Vergütung Hochtarif
(je nach Kanton)



Annahmen

Wärmepreis: äquiv. Gasheizung

Betrieb: 2000h/a

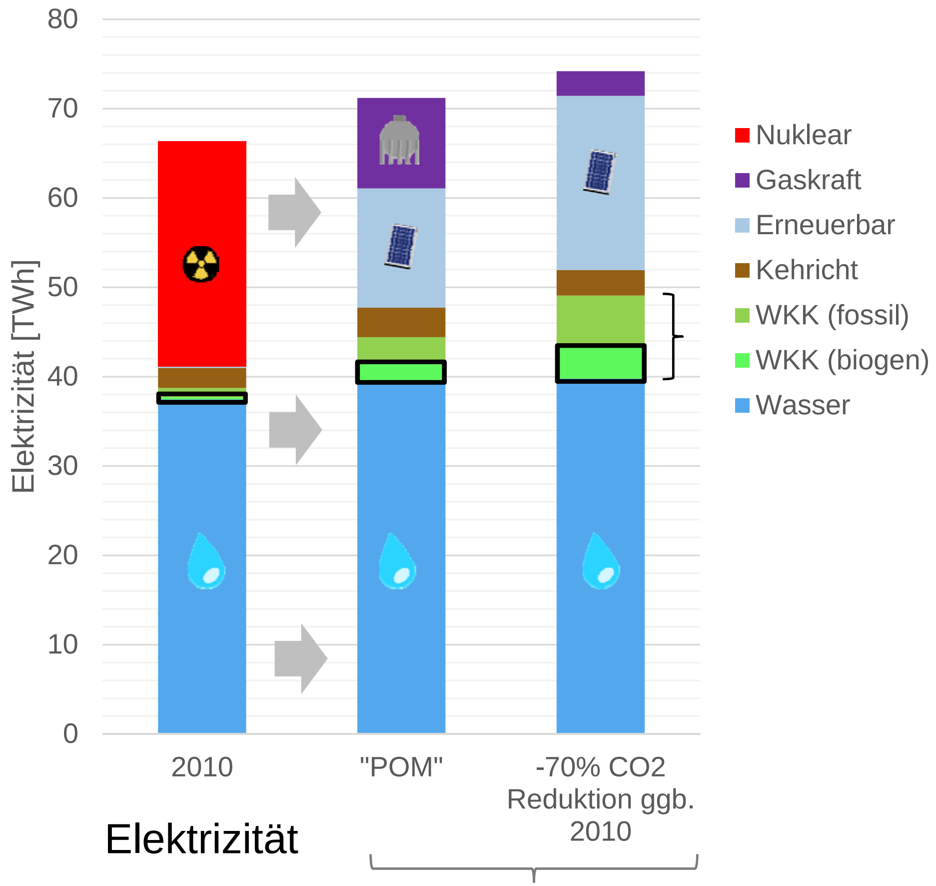
Wärmspeich: 4h·P_{th}

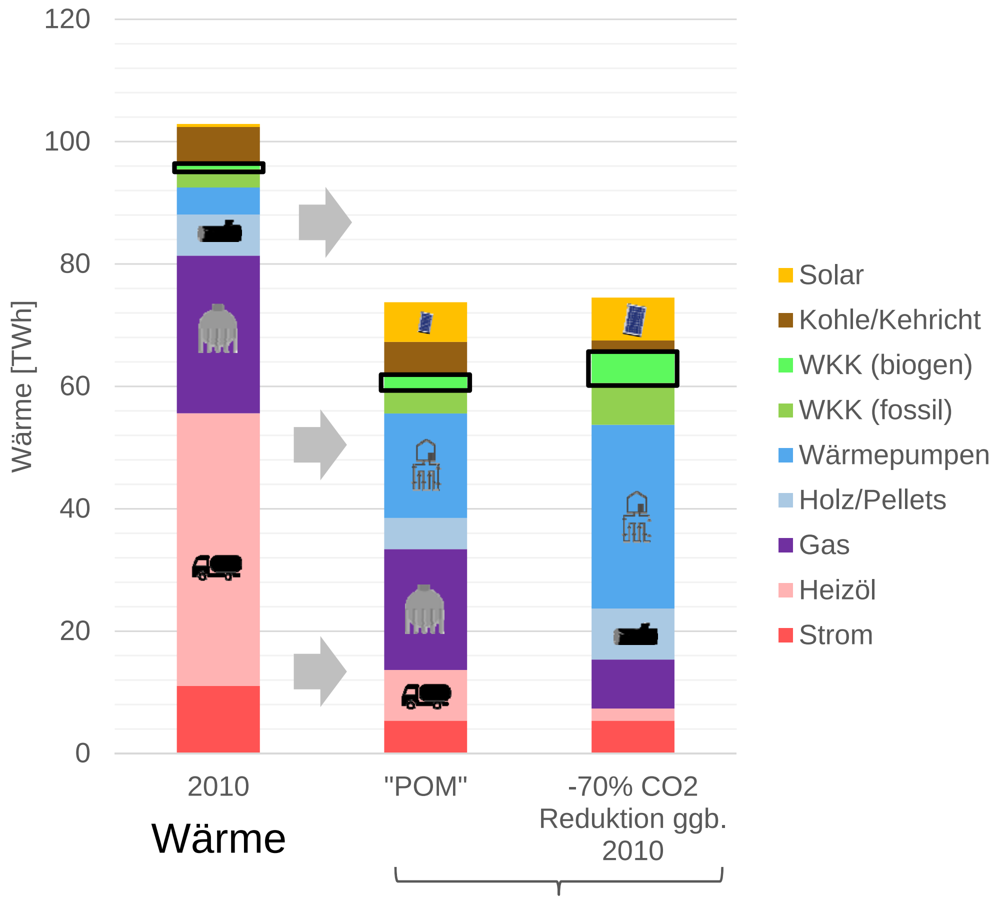
Gaspreise:

Biogas: 0.16CHF/kWh

Erdgas: 0.08CHF/kWh

Energy-economic analysis: perspectives in 2050





Outlook & Conclusions

Conclusions

- In winter, plant can contribute 16 % CH demand
  - Anticyclic correlation with PV hand run-of-the-river hydro production
- High dyamic operation (~Minute)
  - Business case: peaks in electricity prices induced by fluctuating renewables
- Limiting factors to the size of the swarm (and hence its production):
  1. Available bio-methane / bio-mass
  2. Bottlenecks in the electric grid
  3. Heat demand → also decades from now, there should be enough heat sinks
- Depending on economic and political boundary conditions, CHP plants can achieve non-negligible market penetration
  - Depending on the scenario: **30-60%** of the sustainable, Swiss bio-mass potential is allocated to CHPs in an economically optimal manner

Outlook

- Extension of the existing methodology to include (in case-studies):
  - Strategies for swarm-deployment
  - Heat pumps and district heating networks
  - The role of the gas-grid as a seasonal energy storage
  - Local storage: batteries, power to gas
  - Integration of future mobility
- Development of a micro-CHP plant with 2 Swiss industry partners
  - prove feasibility of the concept (high efficiency, minimal emissions)
  - 4 plants undergoing long-term testing, including dynamic operation patterns

The CHPswarm core-team (authors of this presentation)

Philipp **Vögelin**
voegelin@lav.mavt.ethz.ch
Doktorand am ETHZ LAV

WKK-Technologie: Modellierung, Auslegung, Betrieb von Anlagen und Verbünden, Gebäudemodellierung

Gil **Georges**
gil.georges@lav.mavt.ethz.ch
PostDoc am ETHZ LAV

Projektleitung

René **Buffat**
rbuffat@ethz.ch
Doktorand am ETHZ GIE (Prof. M. Raubal)

Räumliche Daten: Biomasseverfügbarkeit, Biogasproduktion, Standortbestimmung, Gebäudespezifikationen

Konstantinos **Boulouchos**
Professor und Leiter des ETHZ LAV

Projektleitung

boulouchos@lav.mavt.ethz.ch

Giovanni **Beccuti**
beccuti@fen.ethz.ch
Oberassistent am ETHZ FEN

Stromnetze: Netzfluss-Simulationen, Netztopologien, WKK im Netzbetrieb, Regelenergie

Evangelos **Panos**
evangelos.panos@psi.ch
PostDoc am PSI EEG

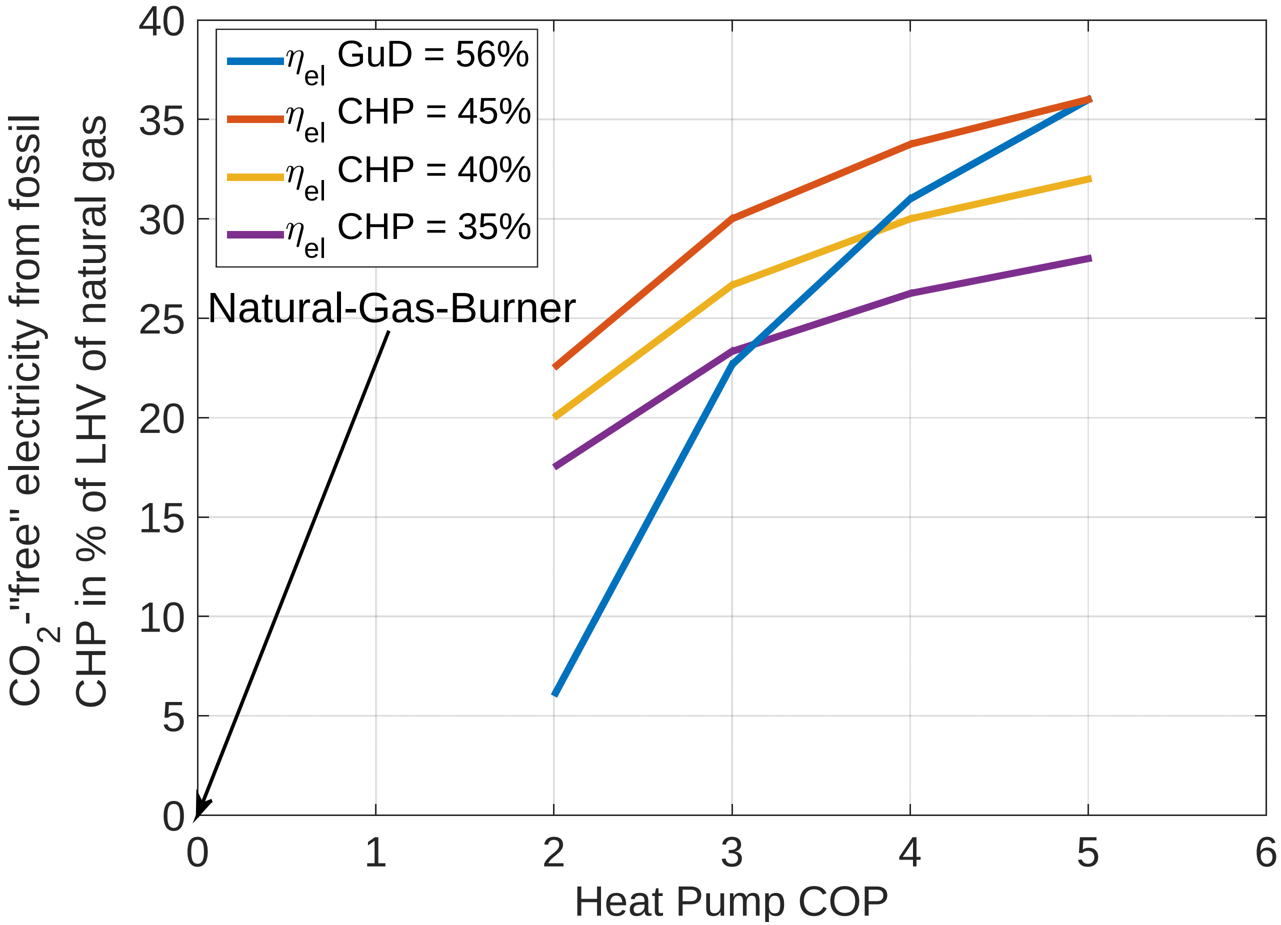
Energieökonomik: Energie-ökonomische Modellierung, Technologiebewertung, Energieszenarien

Final report:
http://bit.ly/1qnnMYB

Wärmeerzeugung mit WKK oder GuD+Wärmepum.

- Gleiche Menge Gas verbrannt
- Gleiche Menge Gebäudewärme erzeugt

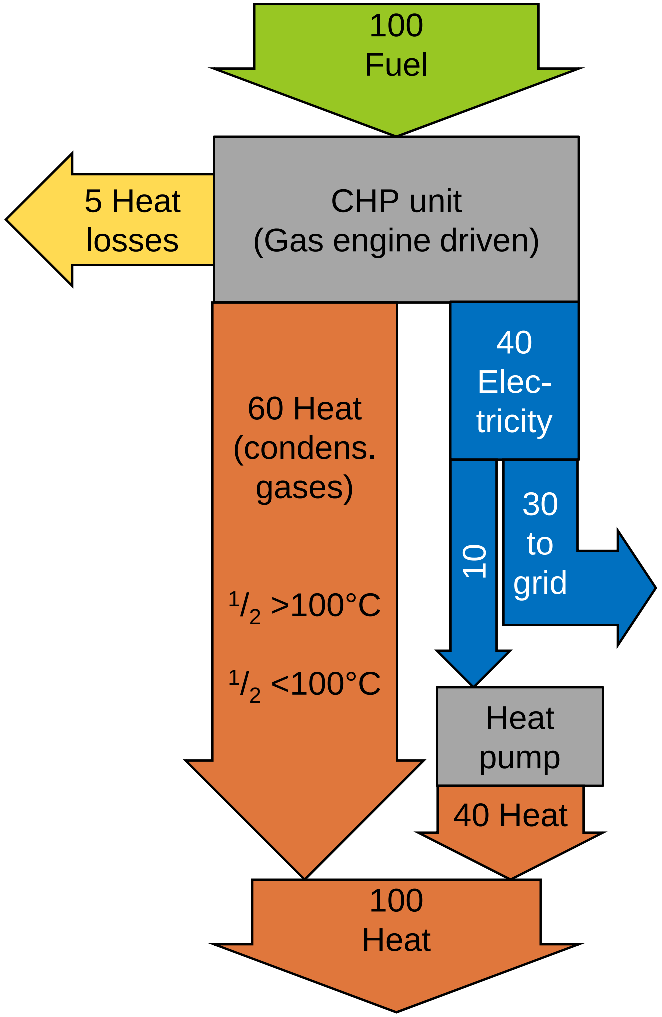
- Fazit:
  - Je kleiner die Leistungsziffer, desto grösser der Vorteil von WKK
  - Kein Strom wird von der Gasheizung erzeugt



Strom aus WKK mit “CO_2-freiem” Potential

- 100 Energieeinheiten zu Wärme
  1. Gasheizung: 100 Wärme, 0 Strom
  2. Gas- und Dampfkraftwerk: 0 Wärme, 55 Strom (netto), 25 el.
     → 100 Wärme (mit Wärmepumpe LZ=4)
     30 el. CO_2-frei
  3. WKK: 60 Wärme, 40 Strom, 10 el.
     → 40 heat (mit Wärmepumpe LZ=4)
     30 el. CO_2-frei

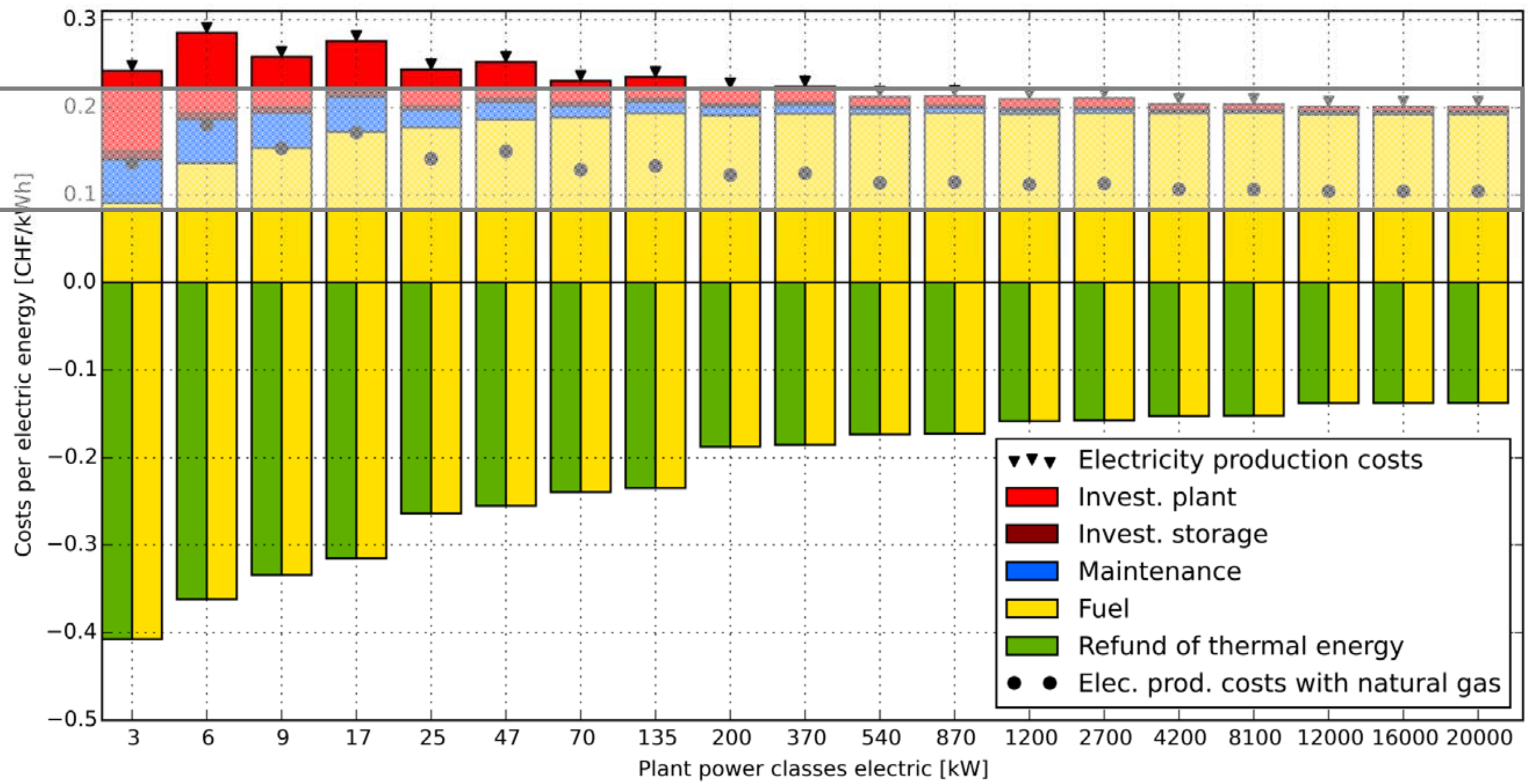
Fossil low temperature domestic heat	"CO2-free electricity generation potential
23TWh/a domestic gas boilers (2010)	**~7TWh/a elec.**
~70TWh/a total fossil domestic heat (2010)	~21TWh/a elec.
~32TWh/a total fossil domestic heat (2050)	~9.5TWh/a elec.



Stromgestehungskosten mit Wärmeverkauf

statische Analyse, Erlös aus Wärmeverkauf abgezogen, jährliche Überschlagsrechnung

Vergütung Hochtarif (je nach Kanton)



Annahmen

Wärmepreis: äquiv. Gasheizung

Betrieb: 2000h/a

Wärmspeich: 4h·P_{th}

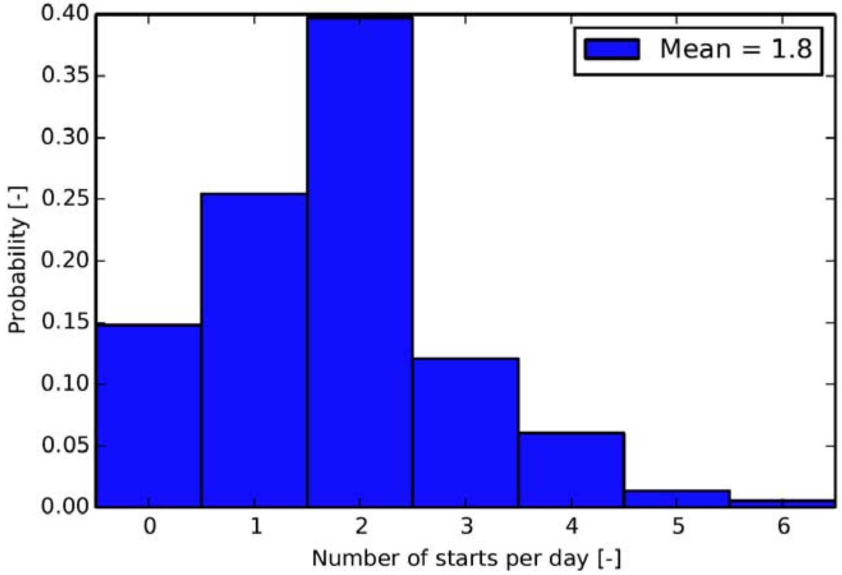
Gaspreise:

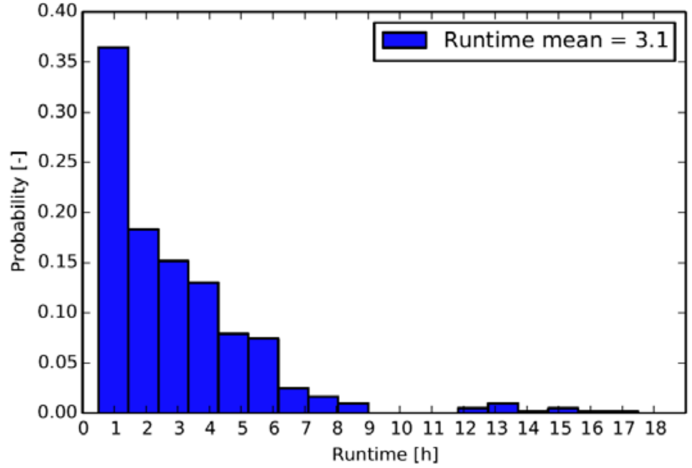
Biogas: 0.16CHF/kWh

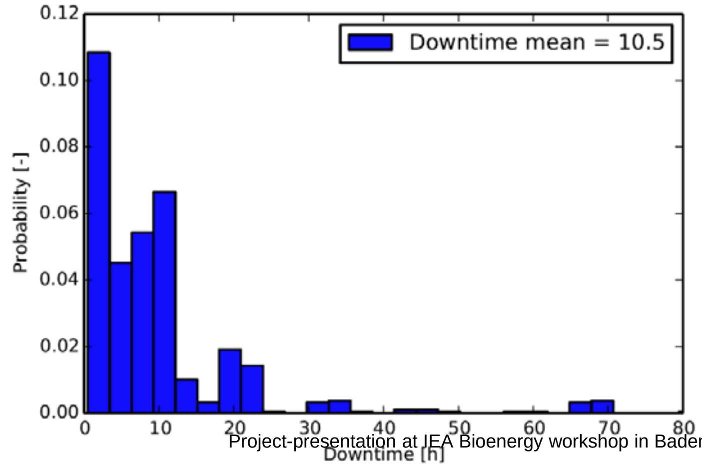
Erdgas: 0.08CHF/kWh

Typische Betriebsstrategie eines WKK im Mehrfamilienhaus

- Wärmebedarf 82’000 kWhtherm/a,
- Strompreise Epex Spot
- Anlagenleistung 23.4 kWel
- 2006 h/a, 400 kWh storage







Impressum

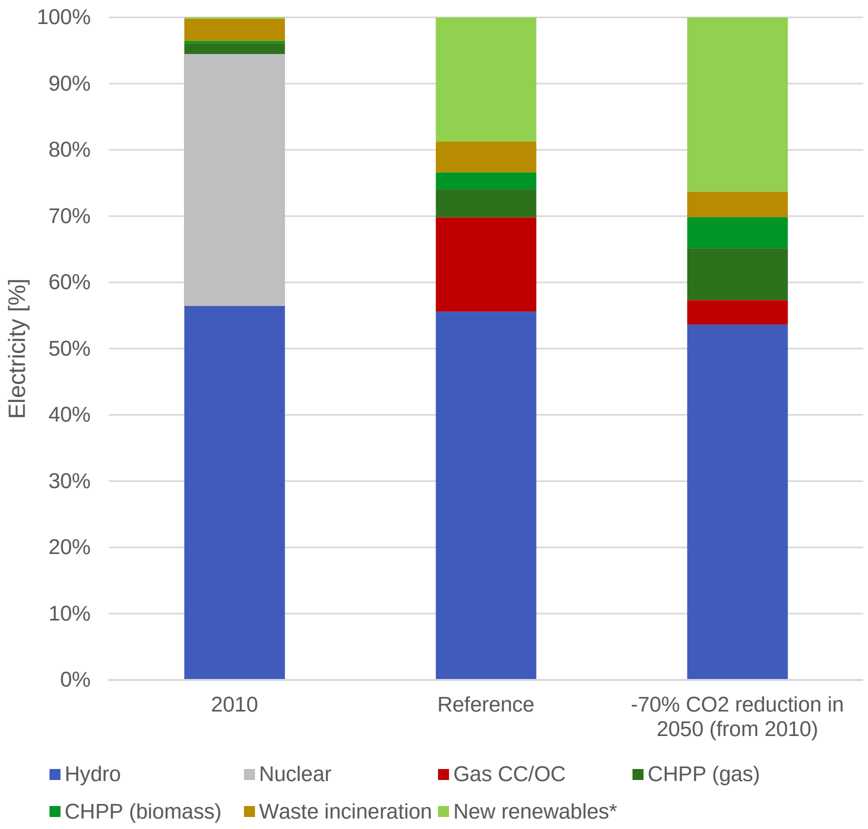
ETH Zürich
Organisationseinheit
Strasse Hausnummer
Postleitzahl Ort

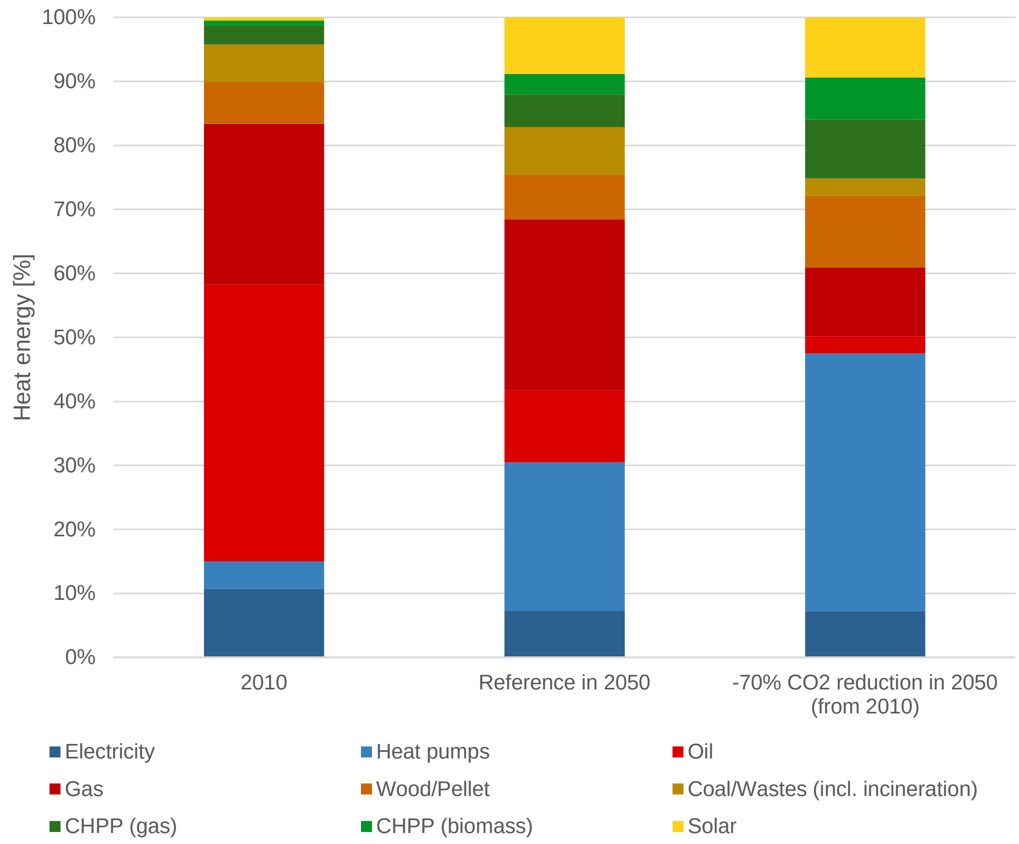
www.ethz.ch

Herausgeber: Organisationseinheit der ETH Zürich
Gestaltung: Name Gestalter
Abbildungen: Bildnachweis (Seite xx), Bildnachweis (Seite xx)

Gebäude, Wetter und PV

Results: Heat production by technology





Stromnetz LU: Transformatorstationen Netzebene 6

- Versorungsgebiet der CKW in Luzern
- Einzugsgebiete der N6 Trafostationen (nearest neighbour Approxmation)

Resultate der Fallstudien

Reference swarm properties	Unit	Thurgau	Lucerne	Basle
Cantonal electricity demand	GWh	1'763	2'713	2'393
Heat demand in gas grid area	GWh	2’588	1’977	1’762
Total bio-methane potential	GWh	684	692	30
Bio-CH_4 from wet biomass	GWh	431	370	30
Bio-CH_4 from woody biomass	GWh	253	322	0
Number of possible CHP sites	-	45'687	27'585	20'216
Sites effectively in swarm	-	9'676	6'806	509
Building CHPs in swarm	-	9648 (of 45'641)	6'785 (of 27'550)	508 (of 20'211)
Industrial CHPs in swarm	-	5 (of 23)	1 (of 15)	0 (of 4)
Biogas plant CHPs in swarm	-	23 (of 23)	20 (of 20)	1 (of 1)
Swarm peak power electric	MW	169	101	5.6
Swarm electricity output	GWh	289	256	11
Swarm covered heat demand	GWh	323	359	15
PV scenario “low”	GWh	176	248 (263)	127
PV scenario “medium”	GWh	352	467 (527)	254
PV scenario “high”	GWh	704	745 (1054)	509