Techno-Economic Evaluation of Combined Micro Power and Heat Generation Assets: Implications for the Multi-Tenant Building Market in Germany

ENERDAY 2019
Dresden, April 12, 2019

Gedeon Zimmermann, Reinhard Madlener

FCN | Future Energy Consumer Needs and Behavior
E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

Presentation Outline

1. The Multi-Family Tenant Housing Prosumer Concept
2. Research Motivation
3. Methodology
4. The Tenement
5. Model Description
6. Results
7. Conclusions & Outlook

1. Multi-Family Tenant Housing Prosumer Concept (MTPC) 1/3

Concept referring to energy being directly produced and consumed within tenements

- Large house with several parties:
  - **Rooftop** → PV or Solar thermal systems
  - **Basement** → Heat pumps (HP), Combined heat and power (CHP), or Storage units

- More consumers than in 1-/2-family houses → higher demands for:
  - **Electricity**
  - **Warm water**
  - **Room heat**

Increased demand → Larger DER units → Reduced specific costs

DER … Distributed Energy Resource

Potential economic gains for:

1. Multi-Tenant Energy Service Provider (MTESP)

Amortizazion of plants + Further realization of profits + Dedicated subsidies for avoiding grid charges

2. Tenement Owner

Compensation for leasing roof / basement space

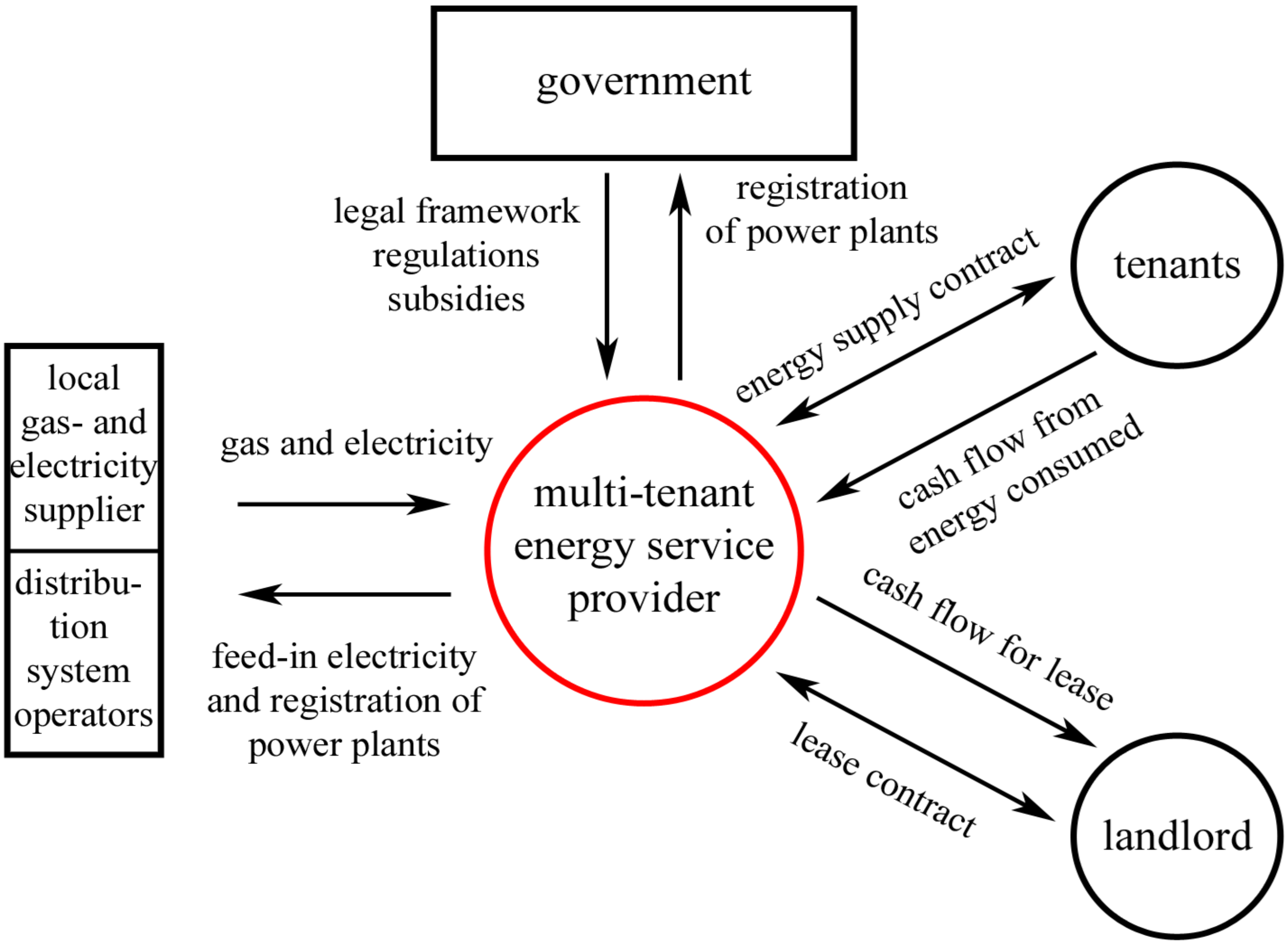
3. Tenants

Lower energy prices, 'Greenness'

Market potential:

- About 3.8 million apartments in 370,000 multi-tenant buildings with potential for MTESPs (BMWi, 2017)
- Less suitable for small tenements or single-family homes due to the lack of economies of scale

1. Multi-Family Tenant Housing Prosumer Concept (MTPC) 3/3



2. Research Motivation

Establishment of a new **regulatory framework** in Germany, the **“Mieterstromgesetz” (2017)**:

→ Statutory privileges for single-family homes transferred to multi-tenant homes (+ expanded)

→ Suitable remuneration scheme for electricity produced with PV and consumed on site

Using **‘big data’** for techno-economic optimization of **distributed energy resources (DER)**:

Numerous technologies & combinations thereof:
PV, HP, CHP, Storage

Predictions for production and demand:
Electricity, Thermal energy, Natural gas

Individual calculations for every project (for different houses, locations, nos. of occupants etc.)

Building properties:
Thermal insulation, Irradiation, Usable roof / basement space etc.

3. Methodology

- Find out whether the investment in new devices is worthwhile for the MTESP
- Determination of potential cost advantages by the use of new technologies in comparison to conventional technologies
- Methods used: Net Present Value (NPV) approach; Annuity method

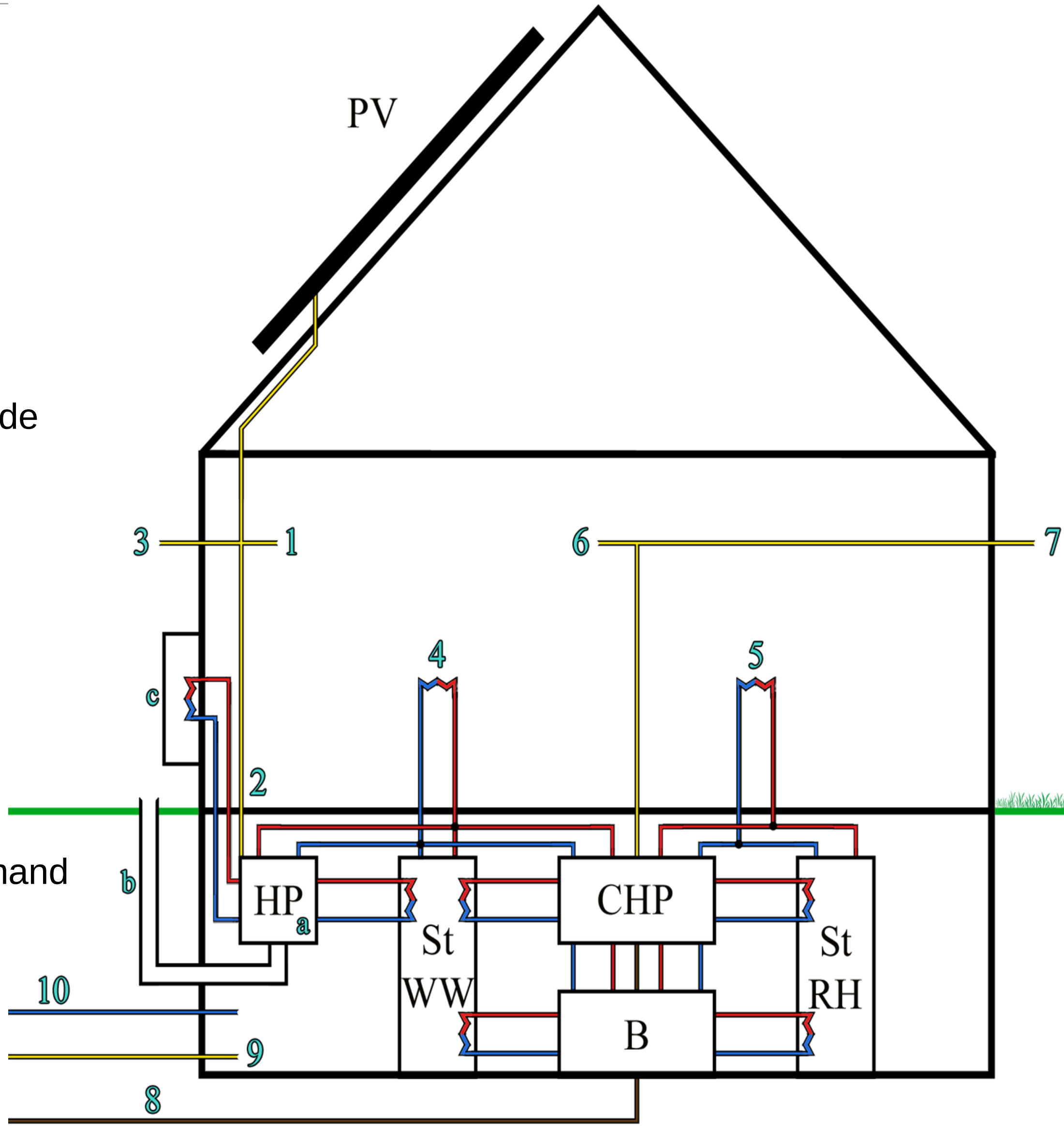
We use **data science methodologies** to create a techno-economic optimization model for combinations of DER in a tenement. On the basis of this model, we explore new possibilities for the still infant **multi-tenant DER market**.

Exemplary Tenement

1. PV generation for self-consumption
2. HP powered by PV:
    a. Small device in the basement
    b. Bigger device requiring air shaft
    c. Bigger device partly constructed outside
3. PV connection to power grid
4. Warm water cycle
5. Room heating

(4 and 5: Direct use or separated storage)

6. CHP for self consumption
7. CHP connection to power grid
8. Connection to gas grid
9. Connection to electricity grid in case of demand
10. Connection to water grid



4. The Tenement 2/2

Design of three types:

- Small-sized tenement (ST)
- Medium-sized tenement (MT)
- Large-sized tenement (LT)

Assumption that the model is at least applicable for tenements with 10–30 apartments / parties

Table 1: Building parameters

Parameter	Unit	ST	MT	LT
Construction year	[-]	1960	1960	1960
Last renovation year	[-]	1990	1990	1990
Apartments	[-]	10	20	30
Total area	[m²]	730	1,460	2,190
Usable area for PV	[m²]	100	150	200
Average storey height	[m]	3	3	3
Amount of floors	[-]	2	2	2
Demand for electricity p.a.	[kWh/a]	28,000	30,000	45,000
Area-specific demand for electricity p.a.	[kWh/a·m²]	38.35	20.55	20.55
Demand for warm water p.a.	[kWh/a]	8,889	20,513	30,770
Area-specific demand for warm water p.a.	[kWh/a·m²]	12.18	14.05	14.05
Demand for room heat p.a.	[kWh/a]	43,993	104,750	154,167
Area-specific demand for room heat p.a.	[kWh/a·m²]	60.26	71.75	70.4

Acknowledgment: Demand data (electricity, warm water and room heat) were kindly provided by the E.ON ERC institute “Energy Efficient Buildings and Indoor Climate (EBC)” (Schiefelbein et al., 2017).

5. Model Description 1/5

Create all possibilities arising from combining each different type of device with one another

Device	No. of types
PV	3*
HP	5
CHP	4
StWW	2
StRH	2

* Scaling factors for the PV array for each tenement type to account for available roof space.

Additionally, a zero column for each type of device (except for storage units)

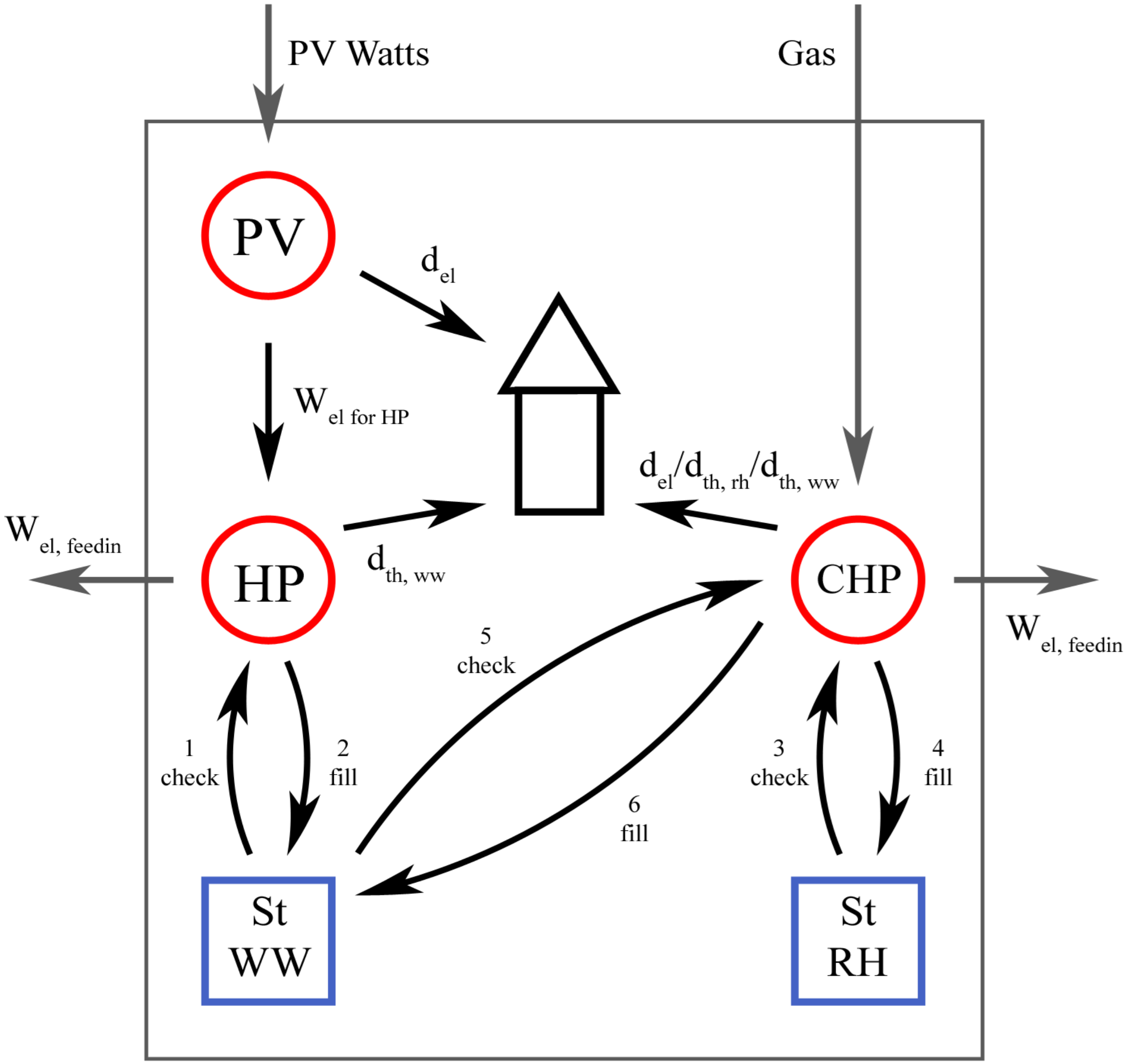
→

240 possible combinations
Because demand datasets of three different tenements types are considered, there are 720 possible sets which have to be processed to answer one research question.

Procedure for finding the optimal combination of devices:

1. 15-minute resolution to dynamically account for the economic gains that can be achieved.
2. For each device, add up the quarter-hour revenues over one year (→ annual revenues).
3. Determination of the best possible device setting by searching for the maximum in the combination of yearly revenues.

5. Model Description 2/5



d_{el} - Demand data for electricity

$d_{th,\ ww}$ - Demand data for warm water

$d_{th,\ rh}$ - Demand data for room heat

PVWatts - Input data for PV

5. Model Description 3/5

(1) $E_{el,house,PV} = W_{el} \cdot \left(p_{el} + \left(p_{feedin,PV} - 8.5\right)\right)$

(2) $E_{th} = W_{th} \cdot p_{th}$

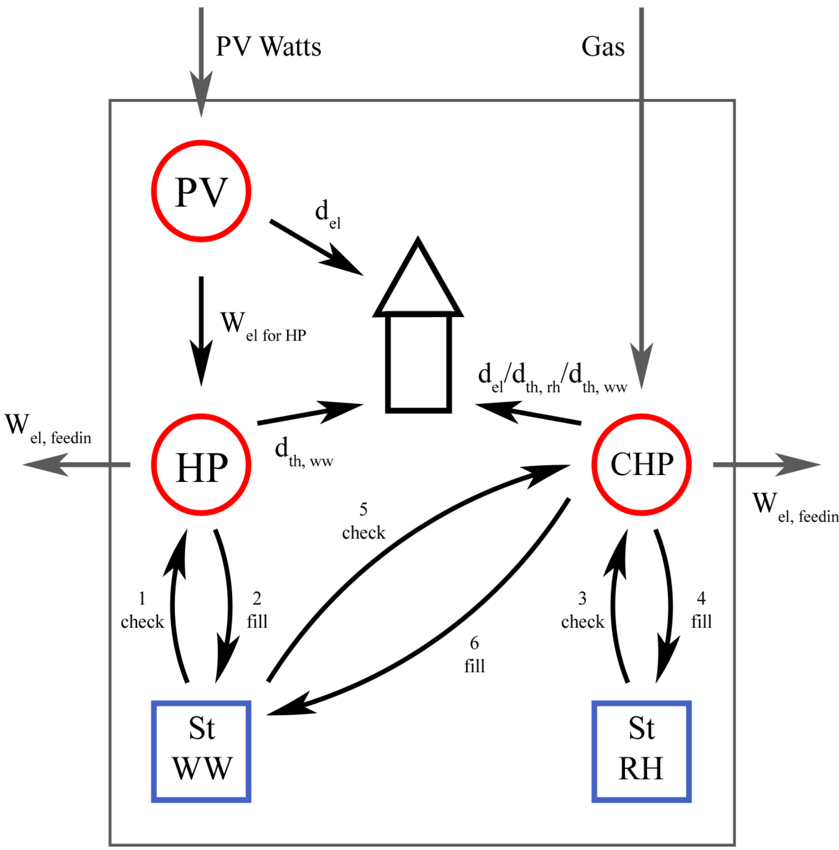
(3) $E_{el,feedin,PV} = W_{el} \cdot p_{feedin,PV}$

(4) $E_{el,house,CHP} = W_{el} \cdot \left(p_{el} + p_{el,house,CHP}\right)$

(5) $E_{el,feedin,CHP} = W_{el} \cdot p_{feedin,CHP}$

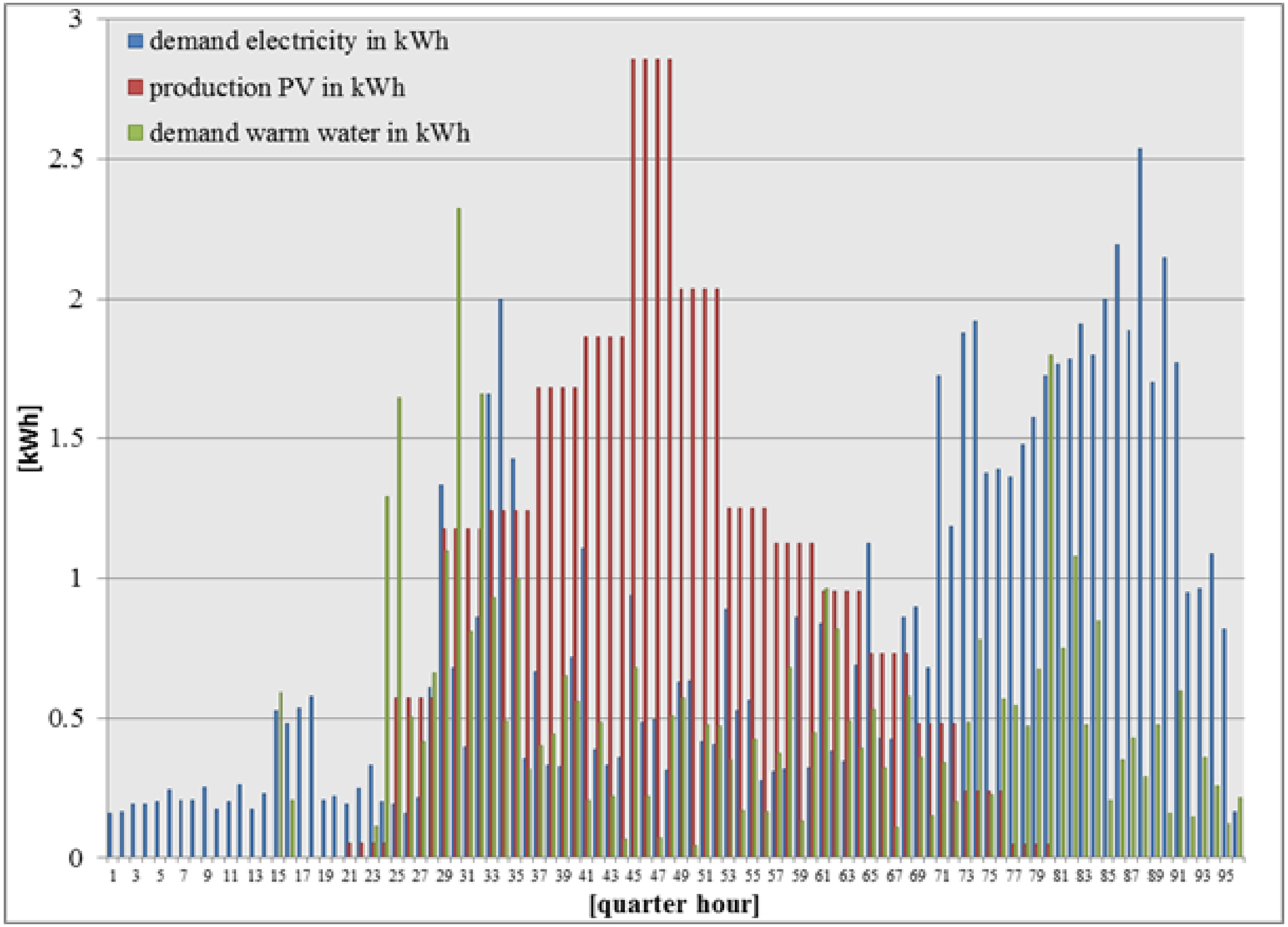
(6) $g = \frac{W_{el}+W_{th}}{H \cdot c \cdot \eta_{CHP}}$

(7) $C_{gas} = g \cdot p_{gas}$



Production & Demand Structures

Demand for **electricity and warm water**, as well as production from PV, in kWh for each quarter hour on July 3, 2017, for the MT.



Calculations of the annualized costs and the net present values:

Annuity and NPV for **PV**:

(8) $a_{PV} = [(C_{inv,PV} + C_{ins,PV}) \cdot f] \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1} + C_{op,PV} \cdot f + p_{leaseroof,PV} \cdot A_{PV} \cdot f + C_{meter}$

(9) $NPV_{PV} = -[(C_{inv,PV} + C_{ins,PV}) \cdot f] + \sum_{n=1}^{N} \frac{(E_{house,PV} + E_{feedin,PV}) - (C_{op,PV} \cdot f + p_{leaseroof,PV} \cdot A_{PV} \cdot f + C_{meter})}{(1+i)^n}$

Annuity and NPV for **HP**:

(10) $a_{HP} = (C_{inv,HP} + C_{ins,HP} - S_{HP}) \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1} + C_{op,HP} + p_{leasecellar,HP} \cdot A_{HP}$

(11) $NPV_{HP} = -(C_{inv,HP} + C_{ins,HP} - S_{HP}) + \sum_{n=1}^{N} \frac{E_{th,HP} - (C_{op,HP} + p_{leasecellar,HP} \cdot A_{HP})}{(1+i)^n}$

Annuity and NPV for **CHP**:

(12) $a_{CHP} = (C_{inv,CHP} + C_{ins,CHP} - S_{CHP}) \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1} + C_{op,CHP} \cdot W_{el,CHP} + p_{leasecellar,CHP} \cdot A_{CHP}$

(13)
$$NPV_{CHP} = -(C_{inv,CHP} + C_{ins,CHP} - S_{CHP}) + \sum_{n=1}^{N} \left(\frac{E_{th,CHP} + E_{el,house,CHP} + E_{el,feedin,CHP}}{(1+i)^n} - \frac{C_{gas} + C_{op,CHP} \cdot W_{el,CHP} + p_{leasecellar,CHP} \cdot A_{CHP}}{(1+i)^n} \right)$$

Determination of best possible device setting by searching for the maximum in the combination of yearly revenues

5. Model Description 5/5

In order to gain further insights on MTCP possibilities, various scenarios were considered for the different tenement types considered (ST / MT / LT):

Scenario 1: Base case

Price of thermal energy is coupled to lower quantity-based gas price

→ Revenues from sales of thermal energy are too low

Scenario 2:

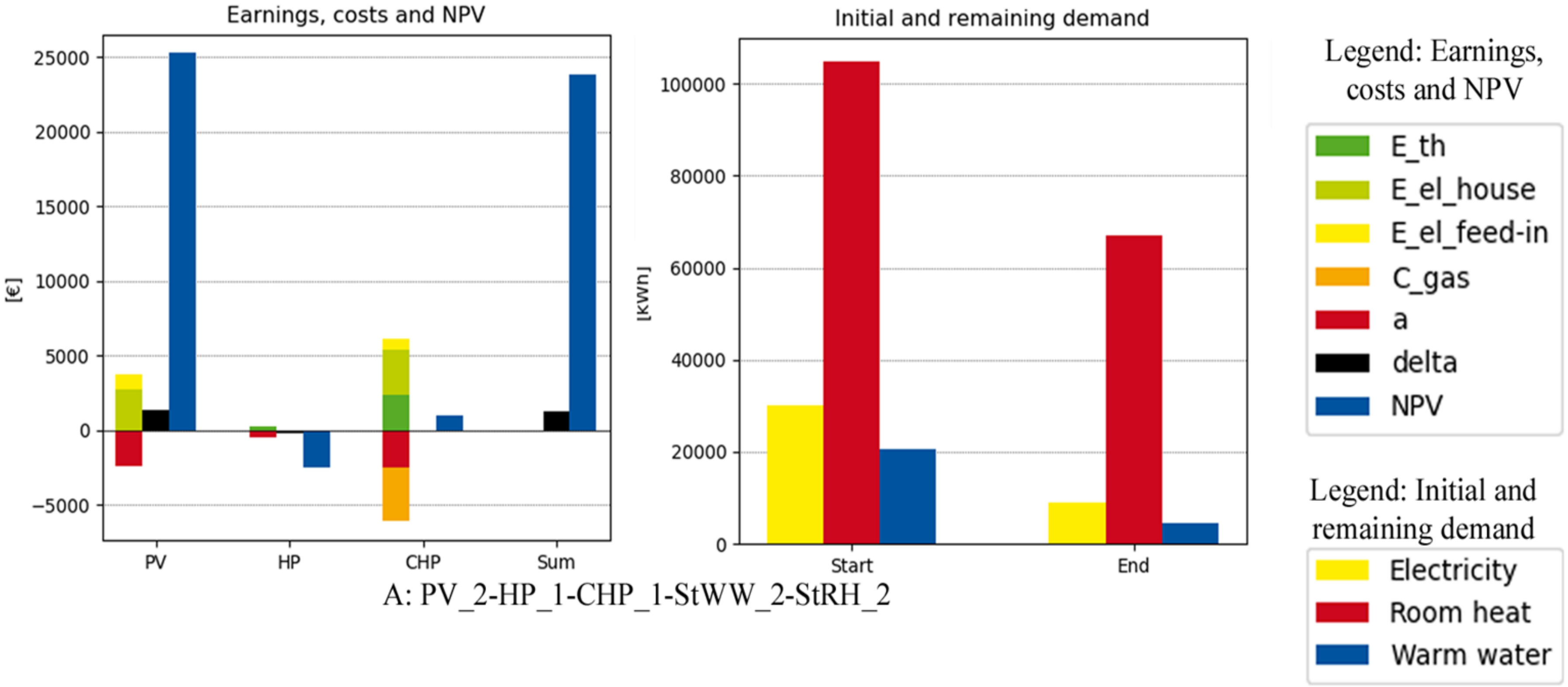
- Price for thermal energy is no longer coupled to lower quantity-based gas price, but equivalent to the gas price of an average German household
- Maintenance costs for HP are lowered

→ Increased revenues for HP

Scenario 3:

- Increased price of thermal energy
- Decreased price of electricity
- Learning effects → reduced initial costs
- Slight increase in interest rate to 1.5 %

Examplary visualization of earnings, costs and NPVs, and initial and remaining demands for a set of devices



A: PV_2-HP_1-CHP_1-StWW_2-StRH_2

6. Results 2/4

Issue	IR	Tenement	PV	CHP	PV+HP	PV+CHP	PV+HP+CHP
Scenario 1	1%	ST	Profitable	No	Average	No	No
		MT	Profitable	Profitable	Average	Average	No
		LT	Profitable	Profitable	Average	Profitable	No

Main findings (Scenario 1):

- **PV** is, generally speaking, the **most profitable** option.
- With the **size** of the tenement, the **profitability of CHP** rises.
- Prices of **thermal energy** are too low to allow the **HP** running cost-efficiently, since low **seasonal revenues** are offset by **high annual maintenance costs** (HP-only is not shown).
- **Device combinations** can result in conflicts / competition for satisfying demands, e.g.:
  - CHP revenues from the sale of electricity to occupants are lowered when combined with PV.
  - PV revenues from feeding in electricity are lowered when combined with HPs.
  - HP revenues from selling thermal energy to occupants are lowered when combined with CHP.

6. Results 3/4

Depending on the parameters determined by the model series, the following evaluations evolve

6. Results 4/4

Table 2: Classification of results

Issue	IR	Tenement	PV	CHP	PV + HP	PV + CHP	PV + HP + CHP
Scenario 1	1%	ST	Profitable	No	Average	No	No
		MT	Profitable	Profitable	Average	Average	No
		LT	Profitable	Profitable	Average	Profitable	No
Scenario 2a	1%	ST	Profitable	Average	Average	Average	No
		MT	Profitable	Profitable	Average	Average	No
		LT	Profitable	Profitable	Average	Profitable	No
Scenario 2b	2%	ST	Profitable	No	No	No	No
		MT	Profitable	Profitable	Average	Average	No
		LT	Profitable	Profitable	Average	Profitable	No
Scenario 2c	3%	ST	Profitable	No	No	No	No
		MT	Profitable	Average	No	No	No
		LT	Profitable	Profitable	Average	Profitable	No
Scenario 3	1.5%	ST	Profitable	Average	Average	No	No
		MT	Profitable	Profitable	Average	Average	No
		LT	Profitable	Profitable	Average	Profitable	Average
Final evaluation		ST	Profitable	No	No	No	No
		MT	Profitable	Profitable	No	No	No
		LT	Profitable	Profitable	No	Average	No

The *Profitable* solution means that the set contains one or more devices with high NPVs which are all feasible, as well as with respect to all other costs.

The *Average* solution says that either the NPV is low, but still considerable even with respect to all other costs, or one device with a large NPV cross-subsidizes another device with marginal or negative NPV.

No solution means that the NPV is either negative or the NPV is too low such that with respect to all other costs (e.g. planning and executing costs) the described combination of devices is economically not feasible.

7. Conclusions & Outlook 1/2

1. We provide a first, model-based tool to assess the economic potential of the multi-family tenements in Germany for specialized energy service providers
2. PV is found to be profitable in all cases, and can be supplemented with a CHP unit as the size increases. A combination between PV, HP and CHP is found to be uneconomical.
3. Less favorable sets, for example, a small CHP unit for the LT, or smaller PV units, may be considered when there is insufficient space available in the basement or on the rooftop, which is the limiting factor for the size of the devices.
4. Proper understanding of the “big data” involved is key for an MTESP because accurate calculations are needed to ensure the profitability of the DER.
5. Furthermore, for a comprehensive technical energetic retrofit of a building, costs for peak-load devices and storage units have to be considered as well.

7. Conclusions & Outlook 2/2

Table 3: Total buildings suitable for multi-tenant prosumer concept (BMWi 2017).

	Total no. of buildings suitable for multi-tenant prosumer concepts
Total	367,594
3 – 6 apartments	71,666
7 – 12 apartments	228,168
13 and more apartments	67,761

LT ≙ 30 Apartments
MT ≙ 20 Apartments
ST ≙ 10 Apartments

Thank you for your kind attention!

Contact:

Institute for Future Energy Consumer Needs and Behavior (FCN), E.ON Energy Research Center
Mathieustraße 10
52074 Aachen
Germany

Prof. Dr. Reinhard Madlener, ERC Director FCN
T +49 241 80 49820
F +49 241 80 49820
RMadlener@eonerc.rwth-aachen.de
http://www.eonerc.rwth-aachen.de/FCN

FCN | Future Energy Consumer Needs and Behavior | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

References

BMWi (2017). *Mieterstrom. Rechtliche Einordnung, Organisationsformen, Potenziale und Wirtschaftlichkeit von Mieterstrommodellen (MSM) (Tenant electricity: Legal situation, organization forms, potentials, and cost effectiveness of tenant electricity models; in German),* Bundesministerium für Wirtschaft und Energie (BMWi), Berlin.

Schiefelbein, J., Javadi, A., Fuchs, M., Müller, D., Monti, A., Diekerhof, M. (2017). *Modellierung und Optimierung von Mischgebieten*, *Bauphysik*, 39: 23–32.

Zimmermann G., Madlener R. (2018). Techno-Economic Evaluation of Combined Micro Power and Heat Generation Assets: Implications for the Multi-Tenant Building Market in Germany, *FCN Working Paper No. 18/2018*, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Backup Slides

- PV input data
- HP input data
- CHP input data
- StRH and StWW input data
- Production and demand structures

PV Input Data

	Parameter	Unit	Abbr.	PV 1, PV 2, PV 3
General data	Manufacturer	[-]	[-]	Hanwha Q CELLS GmbH
	Product name	[-]	[-]	Q.PLUS BFR-G4.1
	Lifespan	[a]	Li_{PV}	20
	Area needs (1 panel)	[m²]	A_{PV}	1.7
	Scaling factor	[-]	f_{PV}	PV 1 (58), PV 2 (88), PV 3 (117)
Economic data	Investment costs (1 panel)	[€]	$C_{inv\ PV}$	342
	Operation & maintenance costs (1 panel)	[€/a]	$C_{Op,\ PV}$	5.7

PV Input Data

Input parameters for PVWatts for the solar cell Q.PLUS BFR-G4.1

	Parameter	Unit	Value
General information	Solar resource rata	[-]	Cologne
System Information	DC system size	[kW_p]	0.275
	Area of one cell	[m²]	1.7
	Array type	[-]	Fixed (roof mount)
	Tilt	[°]	25
	Azimuth	[°]	150
	DC to AC size ratio	[-]	1.1
	Inverter efficiency	[%]	98
System losses	Shading	[%]	5
	Mismatch	[%]	4
	Wiring	[%]	3
	Connections	[%]	0.5
	Light-induced degradation	[%]	1.5
	Nameplate rating	[%]	1
	Age	[%]	0.66

HP Input Data

	Parameter	Unit	Abbr.	HP 1	HP 2	HP 3	HP 4	HP 5
General data	Manufacturer	[-]	[-]	Carrier	Carrier	Carrier	Carrier	Carrier
	Product name	[-]	[-]	30AW H004H	30AW H006H	30AW H008H	30AW H0012 H	30AWH 0015H
	Lifespan	[a]	Li_{HP}	15	15	15	15	15
	Area needs	[m²]	A_{HP}	2	2	2	2	2
Technical data	Thermal power summer	[kW_{th}]	$P_{th, S, HP}$	4.19	6.24	8.03	12.31	15.05
	Electrical power summer	[kW_{el}]	$P_{el, S, HP}$	1.24	1.96	2.33	3.83	4.43
	Thermal power winter	[kW_{th}]	$P_{th, W, HP}$	4.19	6.24	8.03	12.31	15.05
	Electrical power winter	[kW_{el}]	$P_{el, W, HP}$	1.24	1.96	2.33	3.83	4.43
Economic data	Investment costs	[€]	$C_{inv\ HP}$	5358	5883	6290	8110	8878
	Operation & maintenance costs	[€/a]	$C_{Op, HP}$	95	95	95	95	95
	Subsidies	[€]	S_{HP}	1000	1000	1000	1000	1000

CHP Input Data

	Parameter	Unit	Abbr.	CHP 1	CHP 2	CHP 3	CHP 4
General data	Manufacturer	[-]	[-]	Vaillant	Vaillant	Viessmann	EAW
	Product name	[-]	[-]	EcoPower 3.0	EcoPower 4.7	Vitobloc 200 EM-920	EWK 20 S
	Lifespan	[a]	Li_{CHP}	15	15	15	15
	Area needs	[m²]	A_{CHP}	4	4	8	10
Technical data	Thermal power	[kW_{th}]	$P_{th, CHP}$	8	12.5	20.1	45
	Electrical power	[kW_{el}]	$P_{el, CHP}$	3	4.7	8.5	20
	Total efficiency	[-]	η_{CHP}	0.9	0.9	0.926	0.93
Economic data	Investment costs	[€]	$C_{inv\ CHP}$	25,200	29,330	38,550	55,100
	Operation & maintenance costs	[€/kWh_{el}]	$C_{Op, CHP}$	0.0400	0.0435	0.0486	0.0315
	Subsidies	[€]	S_{CHP}	2500	2870	3250	350

StRH & StWW Input Data

	Parameter	Unit	Abbr.	StRH 1	StRH 2	StWW 1	StWW 2
Technical data	Max. capacity	$[kWh_{th}]$	St_{rh} / St_{ww}	16	30	16	30
	Loss factor	[-]	l_{rh} / l_{ww}	0.0011	0.0007	0.0012	0.0008

Production & Demand Structures

Demand for **electricity and solar PV production**, in kWh for each quarter hour on July 3, 2017, for the MT building.