Process system engineering applied to the integration of renewable energy in buildings

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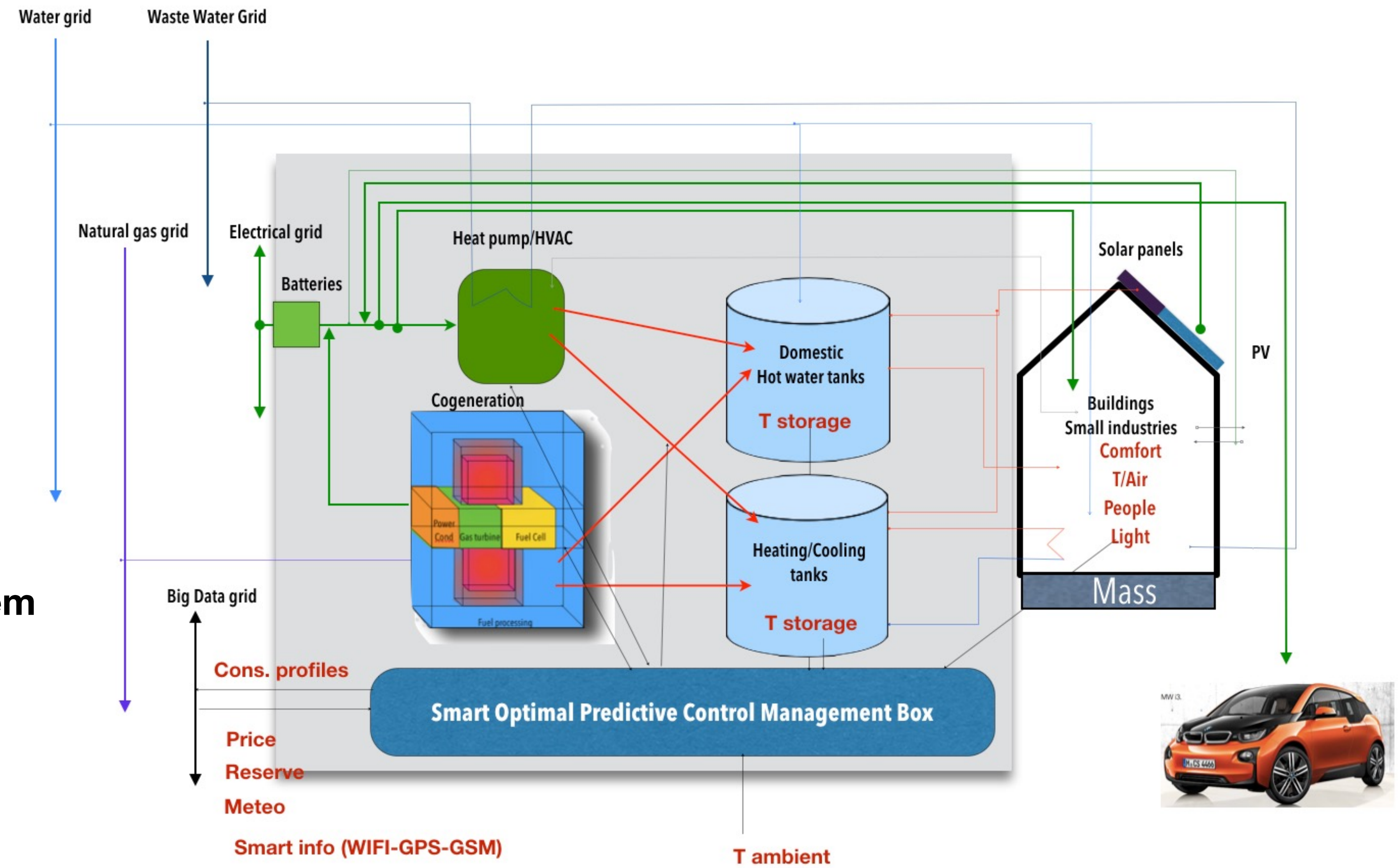
Model predictive control integration in a building

Energy services
- Comfort
  - Hot water
- Electricity
- E-mobility

Energy efficiency
- Building efficiency

Solar integration
- Photovoltaic
- Thermal
- Hybrid

Energy conversion system
- Heat pumps
- Cogeneration
- Heat storage
- Electricity storage



Energy system design problem

- **Energy system = for each building system (n)**
  - Investments (expected life time : 20 Years)
    - Energy Conversion Units $\forall u \in Units; \forall n \in Nodes \Rightarrow Size_{u,n}$
    - Storage $\forall s \in Storage; \forall n \in Nodes \Rightarrow V_{s,n}$

$$\sum_{n=1}^{Nodes} \sum_{u=1}^{Units} \frac{1}{\tau_{y,i}} (I(Size_{u,n}) + I(V_{s,n}))$$

  - Operating costs (expected operation time = 25x8760h)
    - Management strategy $\forall s \in Storage; \forall n \in Nodes; \forall t \in time \Rightarrow \dot{m}_{u,n}(t), V_{s,n}(t), \dot{E}(t)$

$$\int_{t=1}^{Time} (\sum_{u=1}^{units} (c_r^+(t)\dot{m}_{r(u),n}(t)) + c_e^+(t)\dot{E}^+(t))dt$$

  - Constraints
    - Energy services $\forall n \in Nodes; \forall t \in Time; \forall c \in Cons. \Rightarrow \dot{Q}_{n,c}(t), \dot{E}_{n,c}(t)$
    - Grid capacities $\forall t \in Time : \sum_{n=1}^{Nodes} \dot{E}(t) \leq \dot{E}_{max}(t)$
    - Grid constraints $\forall q \in quarter(Time) : \sum_{n=1}^{Nodes} \int_{t=q}^{q+15} \left|\dot{E}_n(t) - \dot{E}_n(t-1)\right| dt \leq \Delta\dot{E}_{max}(t)$

IPESE INDUSTRIAL PROCESS AND

EPFL

Constraints

Electricity production

$$(el_{SOFC}(t) + el_{grid}(t)) - (el_{RC}(t) + el_{PAC}(t) + cons\_el(t)) \geq 0 (kW) \quad (2)$$

Heat production

$$el_{SOFC}(t)/\eta_{el} * \eta_{th} - ((AC2(t)/AC2_{COP}) + HEX\_heat(t) + unusable\_heat(t)) \geq 0 (kW) \quad (3)$$

Storage balance

$$stored\_energy(t) = stored\_energy(t-1) - storage\_losses(t) - storage_{out}(t) + storage_{in}(t) (kJ) \quad (4)$$

$$T_{stock}(t=1) = T_{stock}(t=24) (C) \quad (5)$$

cyclic constraint

$$losses\_param = 10\% * stock\_size * \rho_{water} * Cp_{water} * (T_{max} - T_{room}) (kJ) \quad (6)$$

Storage losses

$$storage\_losses(t) = losses\_param * \frac{1 hour}{24 * 3600} * (T_{stock}(t) - T_{room})/(T_{max} - T_{room}) (kW) \quad (7)$$

Heat/cool cons

$$cons\_heat(t) = HEX\_heat(t) - heat\_stock_{in}(t) + heat\_stock_{out}(t) + el_{PAC}(t) * COP_{PAC} (kW) \quad (8)$$

$$cons\_cool(t) = AC2(t) - cool\_stock_{in}(t) + cool\_stock_{out}(t) + el_{RC}(t) * RC_{COP} (kW) \quad (9)$$

t=1…24

Multi-objective optimization (ϵ-moo) to study different system configurations

Objectives

Operation expenses

$$\min_{\boldsymbol{\Sigma}} \sum_{p=1}^{\boldsymbol{P}} \sum_{t=1}^{\boldsymbol{T}} (\mathrm{op}_{p,t}^{el,+} \cdot \dot{E}_{\mathrm{grid},p,t}^{+} - \mathrm{op}_{p,t}^{el,-} \cdot \dot{E}_{\mathrm{grid},p,t}^{-} + \mathrm{op}_{p,t}^{ng,+} \cdot \dot{H}_{\mathrm{grid},p,t}^{+}) \cdot \mathrm{d}_p \cdot \mathrm{d}_t \tag{1}$$

Capital expenses

$$\frac{1}{\tau} \sum_{u=1}^{\boldsymbol{U}} \mathrm{inv}_{1,u} \cdot y_u + \mathrm{inv}_{2,u} \cdot F_u \leq \epsilon_{inv} \tag{2}$$

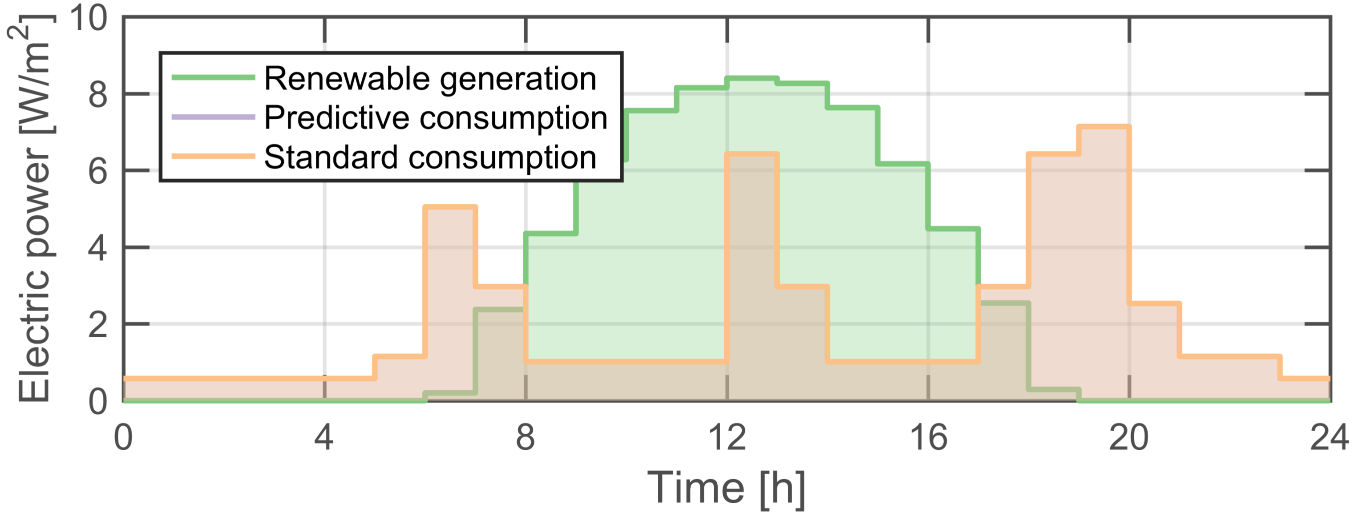
Grid multiple

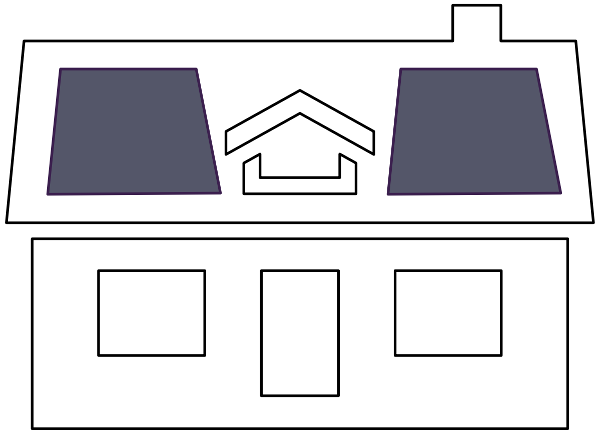
$$\frac{(\dot{E}_{\mathrm{grid},p,t}^{+} - \dot{E}_{\mathrm{grid},p,t}^{-})}{\frac{1}{n_t} \sum_{t=1}^{\boldsymbol{T}} (\dot{E}_{\mathrm{grid},p,t}^{+} - \dot{E}_{\mathrm{grid},p,t}^{-})} \leq \epsilon_{gm} \tag{3}$$

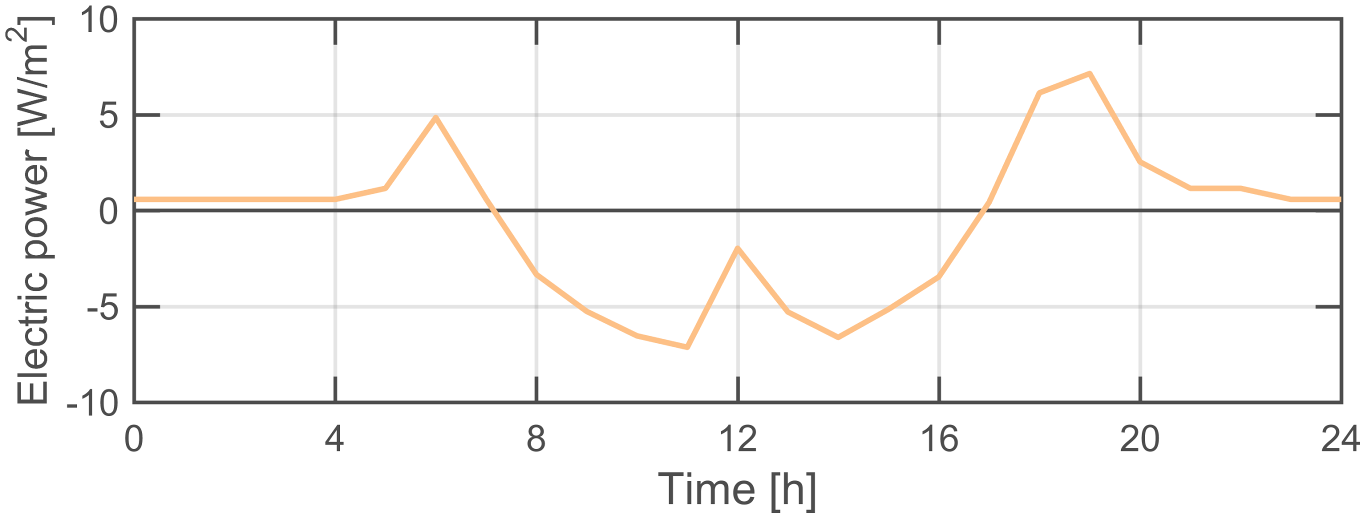
subject to:

- Energy & Mass balances, Heat cascade & Modelling constraints

Self consumption in a building







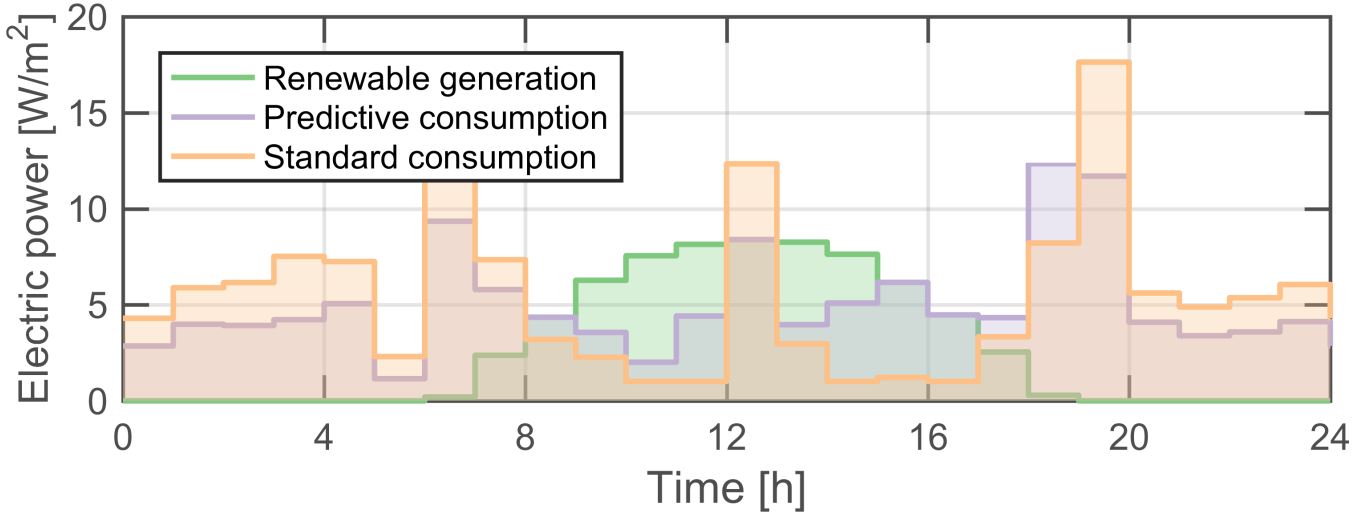
$$SelfSufficiency = \frac{kWh_{PVused}}{kWh_{cons}}$$

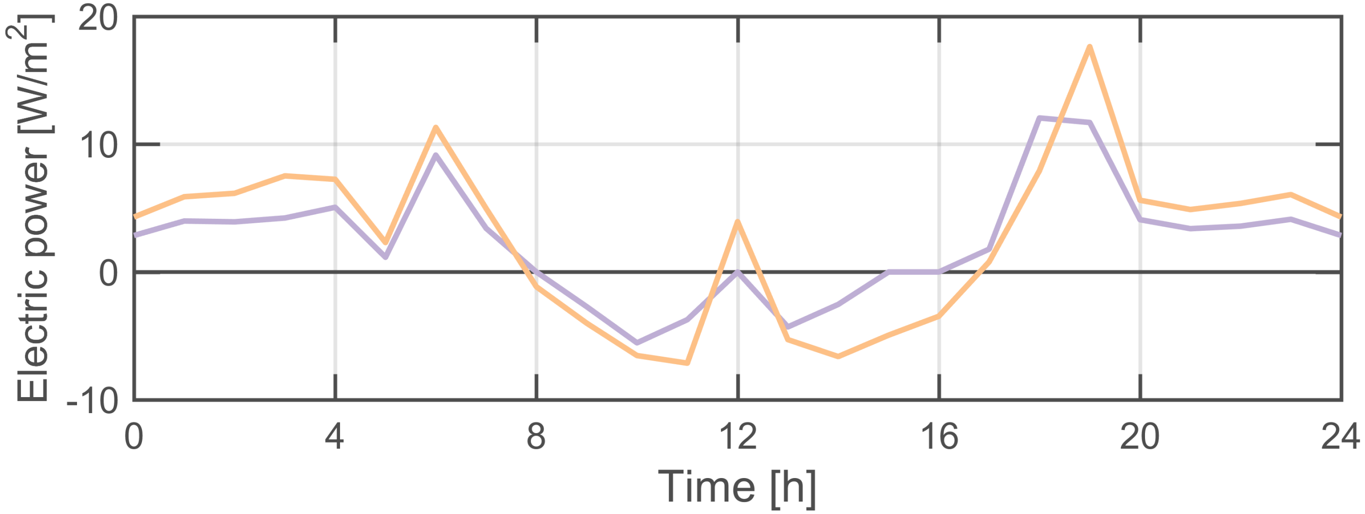
$$SelfConsumption = \frac{kWh_{PVused}}{kWh_{PV}}$$

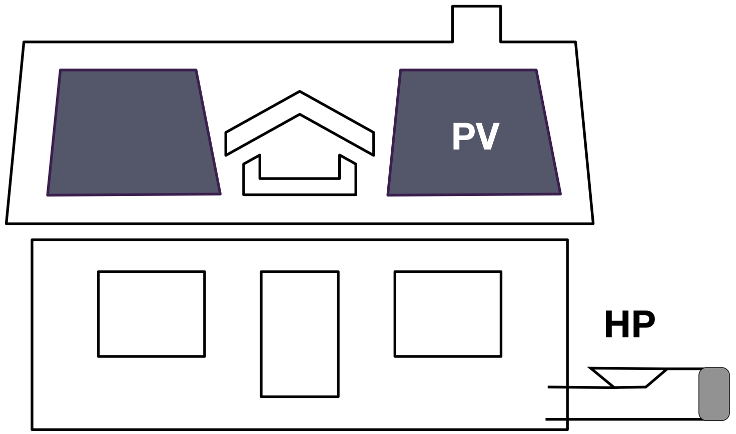
Self Sufficiency = 36 %

Self Consumption = 42 %

Heating with heat pump (shiftable load)







Without MPC

Self Sufficiency = 12 %

Self Consumption = 52 %

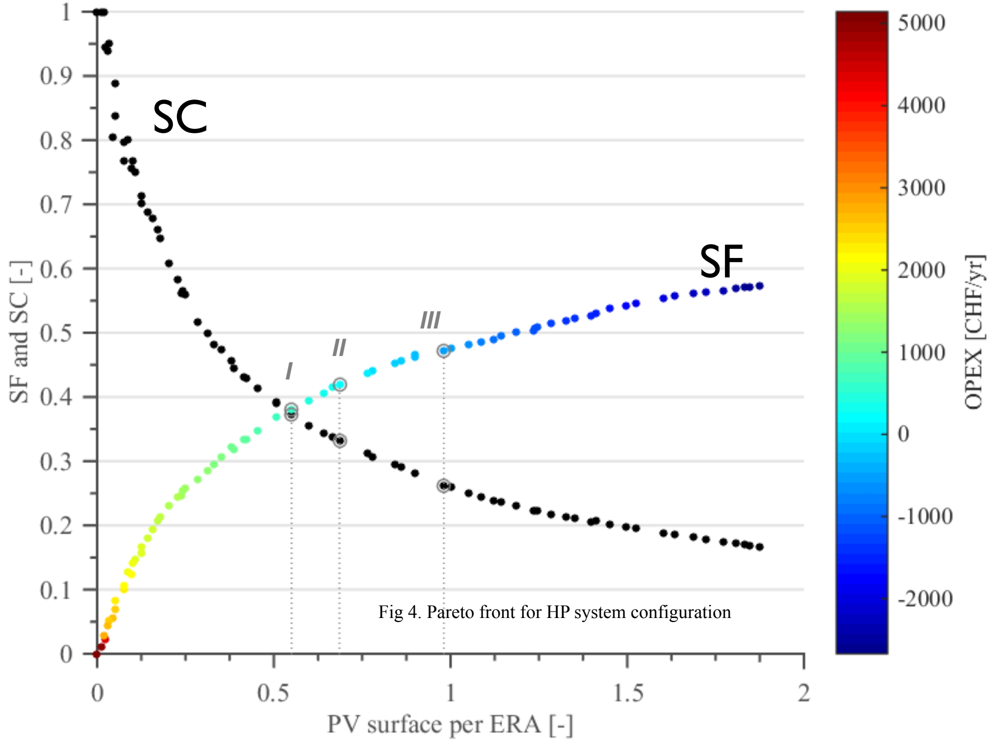
With MPC

Self Sufficiency = 18 %

Self Consumption = 70 %

Optimal design of solar integrated systems

Single family house : 4 pers 160 m2 : with heat pump



SF and SC as a function of the PV area

The grid is a seasonal battery

Case I

Energy system			Off-site storage	
PV array	**88**	*m²*	Redox Battery	
Battery	**4.95**	*kWh*	**8.14** *MWh*	
HW tank	**2.43**	*m³*	**406.9** *m³*	(20 Wh/l)
Heat Pump	**3.59**	*kW*	**4'070'000 €**	(500 €/kWh)

Annual energy balance

Case II

Energy system			Off-site storage
PV array	**109.7**	*m²*	Redox Battery
Battery	**7**	*kWh*	**10.8** *MWh*
HW tank	**2.46**	*m³*	**540.2** *m³*
Heat Pump	**3.5**	*kW*	**5'400'000 €**

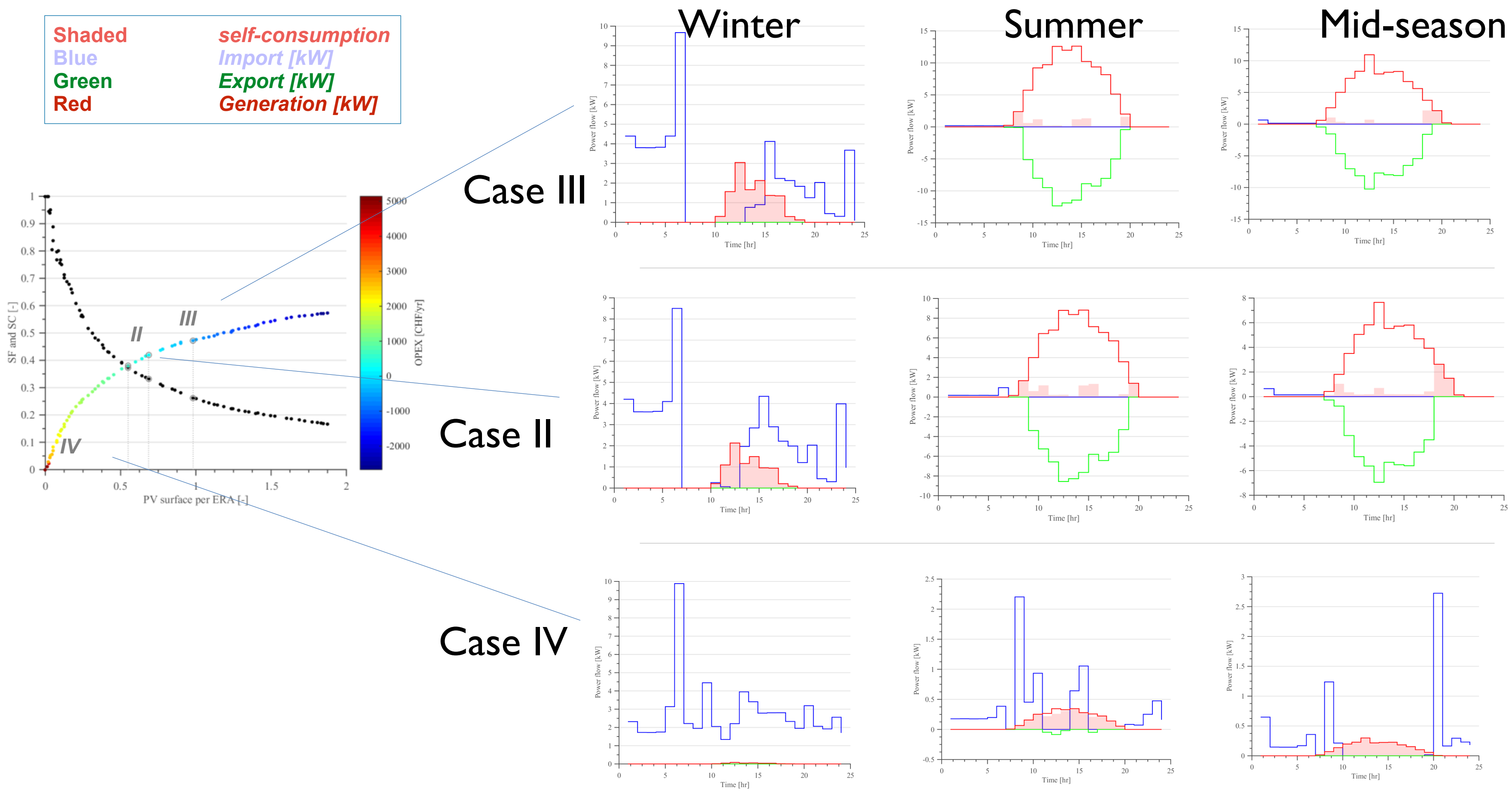
Long term storage : 85%

Case III

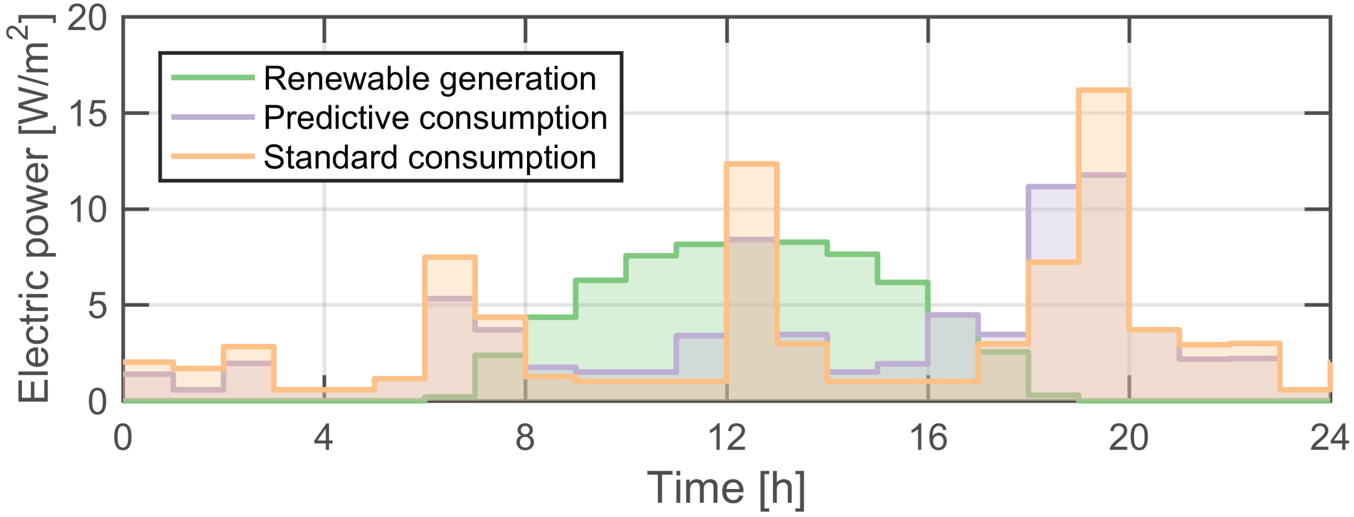
Energy system			Off-site storage
PV array	**156.9**	*m²*	Redox Battery
Battery	**8.63**	*kWh*	**17.1** *MWh*
HW tank	**2.39**	*m³*	**854.6** *m³*
Heat Pump	**3.7**	*kW*	**8'550'000 €**

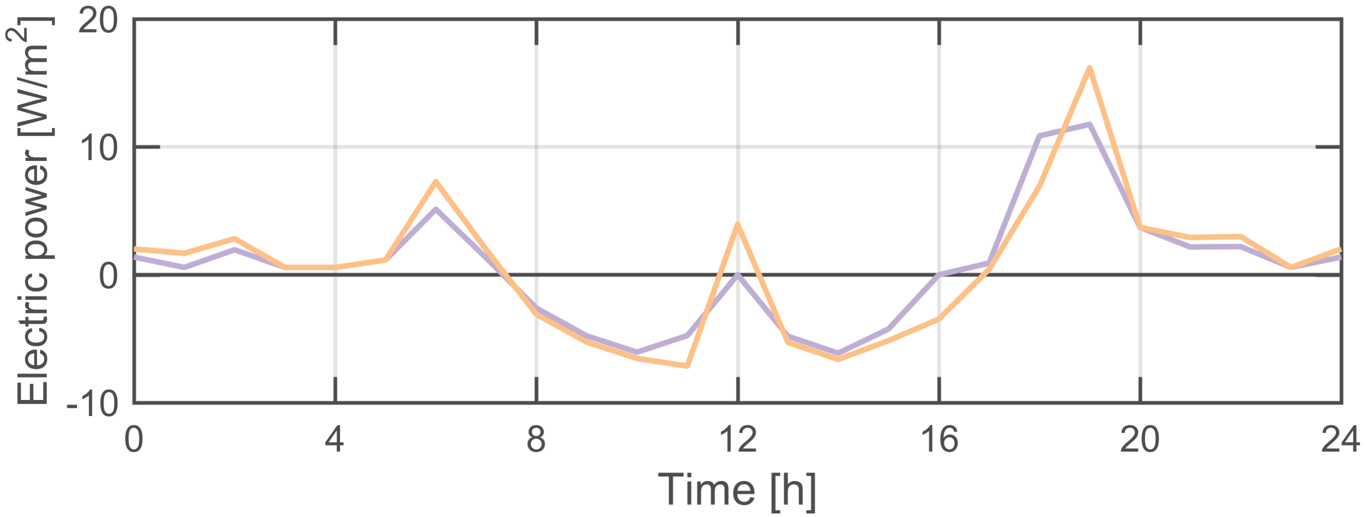
Long term storage : 55%

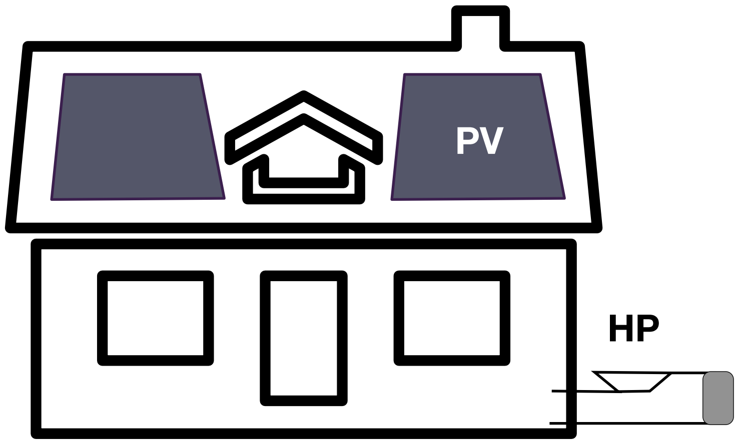
E-technology : model predictive control



Renovating the building

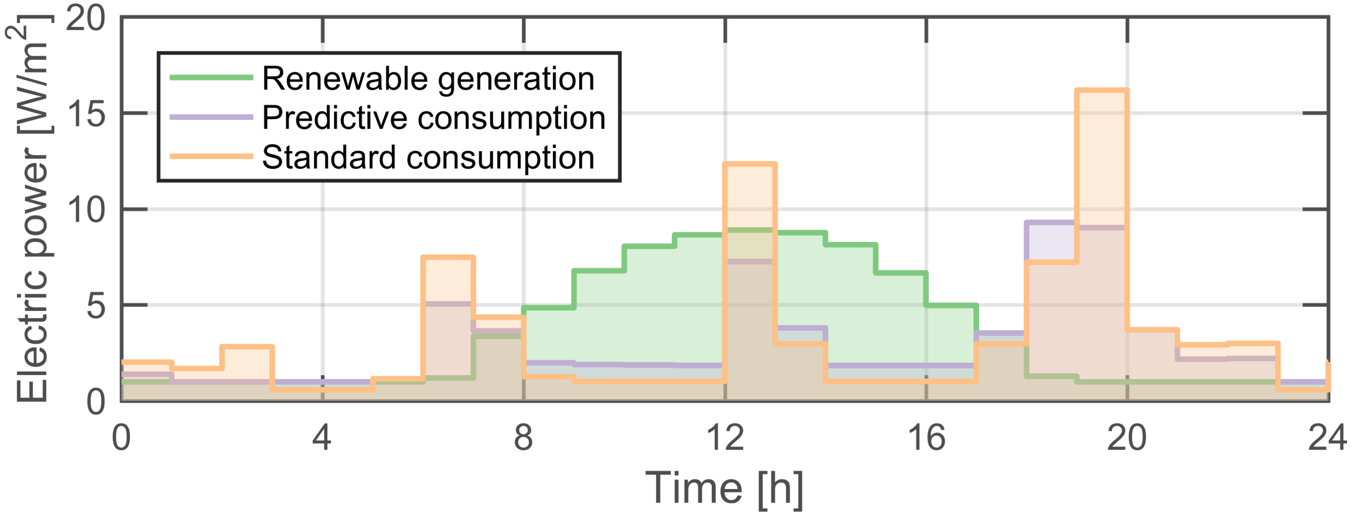


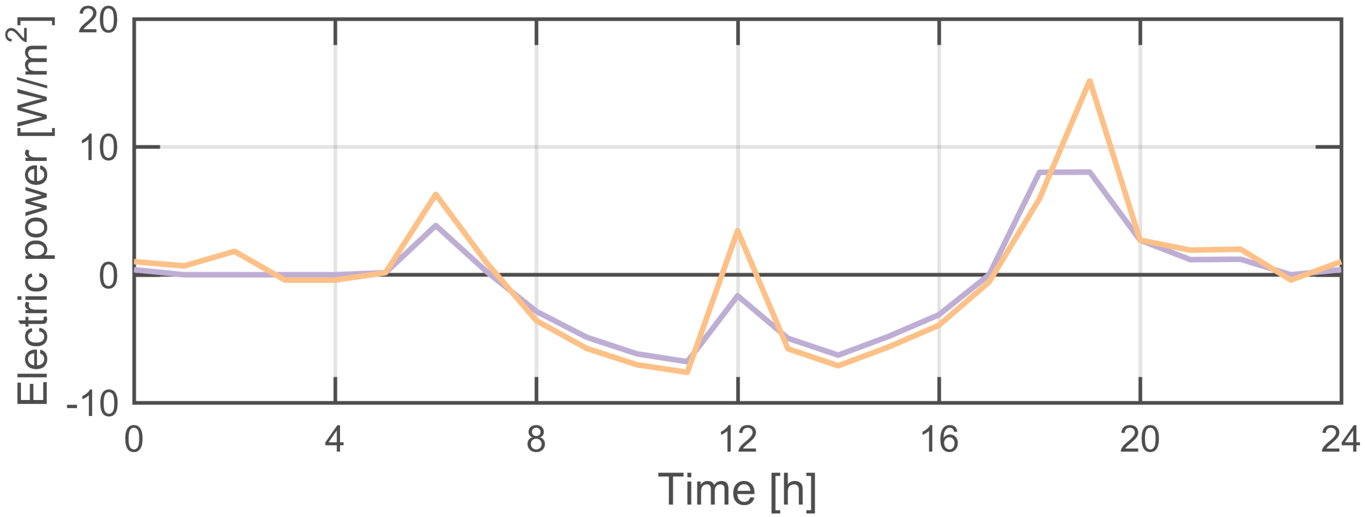


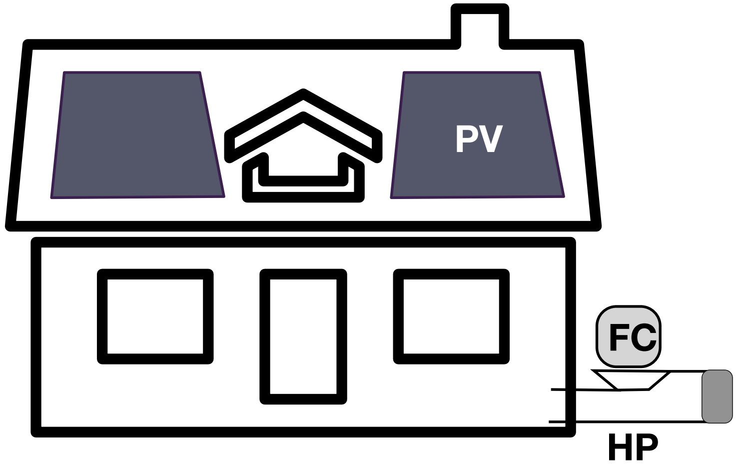


	before	after
Self consumption	18%	29%
Self sufficiency	70%	68%

Heat pump and cogeneration





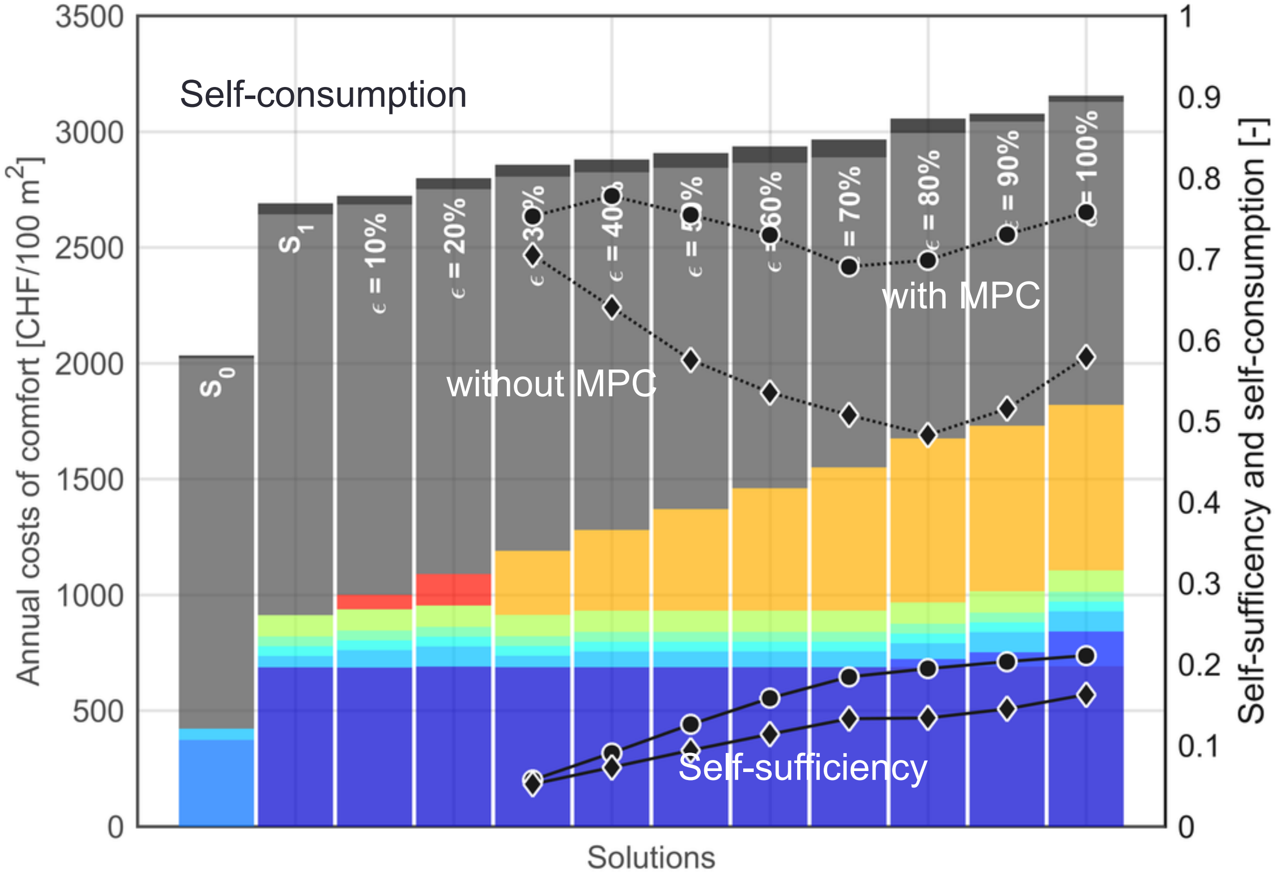


	HP	FC/HP
Self consumption	29%	48%
Self sufficiency	68%	69%

Investment strategies for PV penetration : at building level

- ***Cost of Comfort***
  - ***2000 - 3000 CHF/year/100 m2***
  - ***66 CHF/month/hab***
  - ***60 % investment***
  - ***up to 80% CO2 emission reduction***

- **AHP** Air-source heat pump,
- **BAT** Battery,
- **BOI** Boiler,
- **HWT** Hot water tank,
- **ELH** Electrical heater - space heating
- **ELH** Electrical heater – hot water production
- **HST** Heat storage tank
- **PVA** Photovoltaic array,
- **STP** Solar thermal panel
- **OPEX** Operating expenditure



Single family house 1970-1980 – without grid peak constraint

MPC increases by 40% the self consumption

Stadler P, Girardin L, Ashouri A and Maréchal F (2018) Contribution of Model Predictive Control in the Integration of Renewable Energy Sources within the Built Environment. Front. Energy Res. 6:22. doi: 10.3389/fenrg.2018.00022

Imposing a constraints on the maximum variation

No constraint

Max : 50% of the mean power

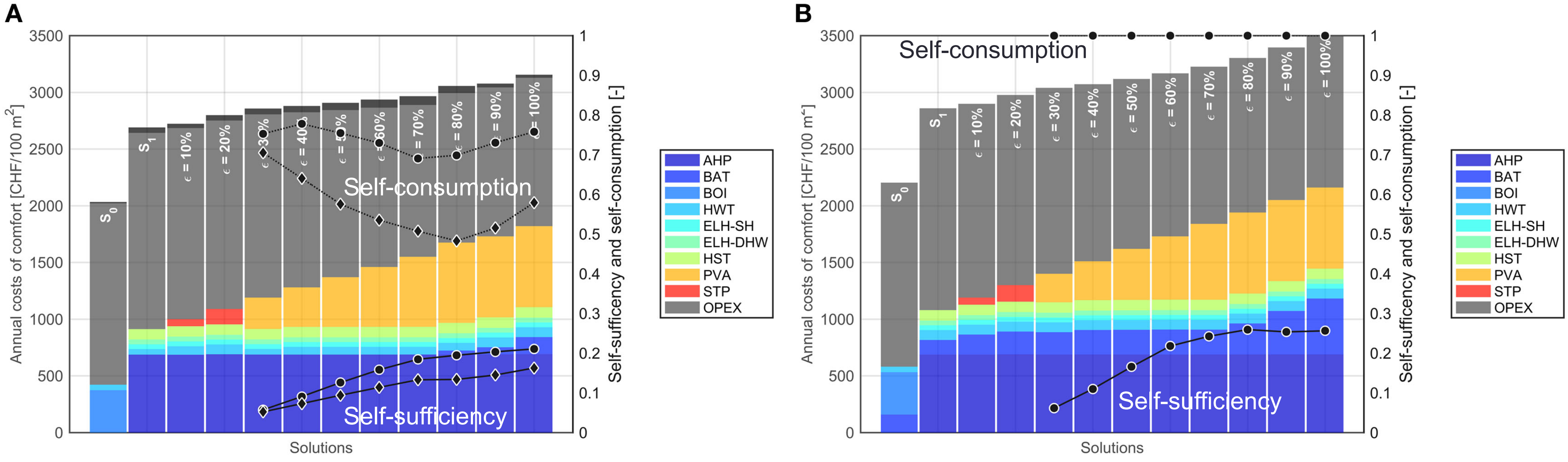


FIGURE 9 | Multi-objective optimization results for a single-family house (Geneva, 1970–1980). Differences in operating costs between both control methods are represented by the dark gray stacked boxes. The self-consumption and self-sufficiency are represented through dotted and solid lines, respectively (MPC circles and RBC diamonds). **(A)** No ϵ_{gm} (i)–(ii). **(B)** $\epsilon_{gm} = 1.5$ (iii).

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Extrapolation at national level

Considering the complete building stock

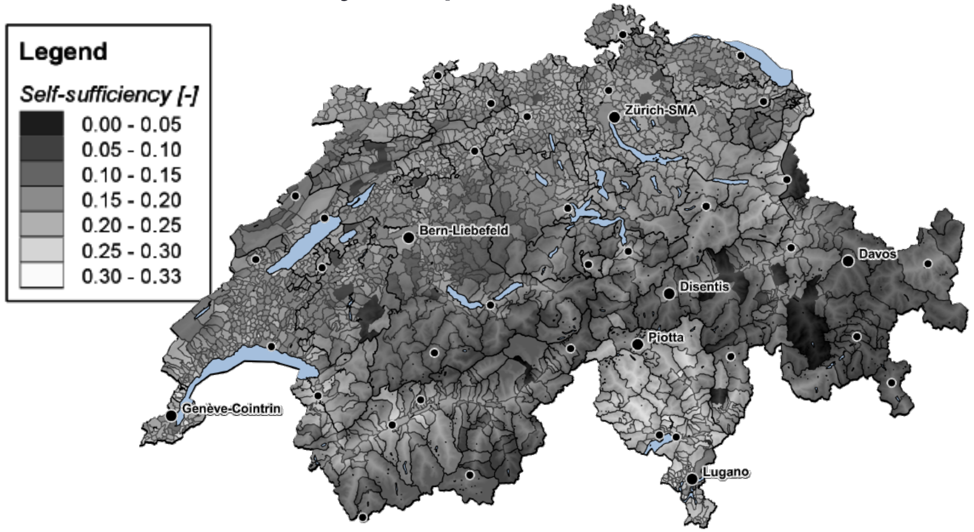
(a) 19 billion CHF/yr for factor 5 CO2 emissions reduction.

(b) Boiler phase out before renovation

(c) PV and renovation

further reduction needs seasonal storage

Self-sufficiency maps



CH-Map of solution nº 50 (upper investment bound)

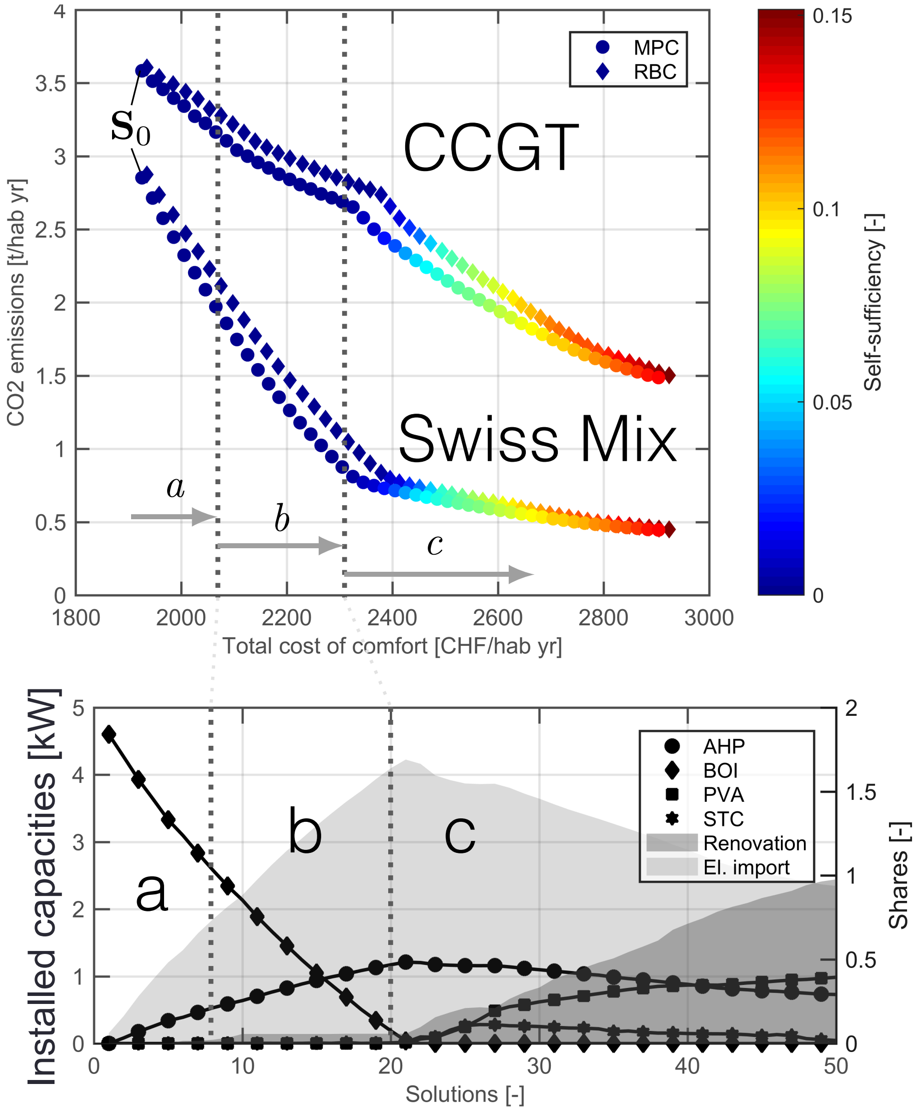


FIGURE 12 | Pareto fronts for Switzerland when applying MPC (circles) and RBC (diamonds). The marker size reflects the renovation share of the current built environment.

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System Flexibility

PHASE A
Input data
Historic day-ahead market price[2]
Normal. w.r.t. daily mean $\Delta_{s,p,t}$

PHASE B
Partitioning around medoids
A-priori classification w.r.t. periods
Iterative process ($\forall k$)

PHASE C
Number selection k
Silhouette index

PHASE D
Cost definition $op^{el}_{s,p,t}$
$op^{el}_{s,p,t} = (1 + \Delta_{s,p,t}) \cdot op^{el}$
Equivalent aggregated daily cost

Fig 1: Variation profiles [-] and associated cluster centre (Zone Geneva-Cointrin)

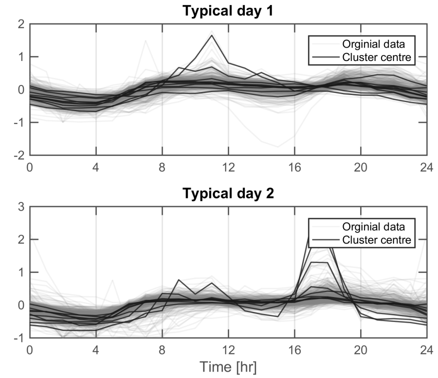
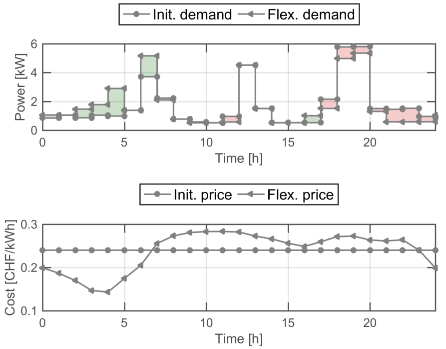


Fig 1: Flexible price profile for scenario s and day p



What are the most likely price variations that the system will see ?

- Define a flexible price of electricity profile
- Apply to the system operation when it has advertised a given profile

3. Performance : capacity (F^{cap} [kWh]), power (F^{pow} [kW]) and round-trip eff. (η^{eff} [-])

$$F^{pow}_{s,p} = \frac{1}{n_t} \sum_{t=1}^{Time} | \dot{E}'_{grid,s,p,t} - \dot{E}_{grid,p,t} | \quad \forall p \in Period, s \in Scenario \quad (9)$$

$$F^{cap}_{s,p} = \max_t SOC_{s,p,t} \quad \forall p \in Period, s \in Scenario \quad (10)$$

$$\eta^{eff}_{s,p} = \frac{(SOC_{s,p,1} - SOC_{s,p,n_t})}{\sum_{t=1}^{Time} (\Delta \dot{E}^{+}_{s,p,t} \cdot d_t)} \quad \forall p \in Period, s \in Scenario \quad (11)$$

System flexibility

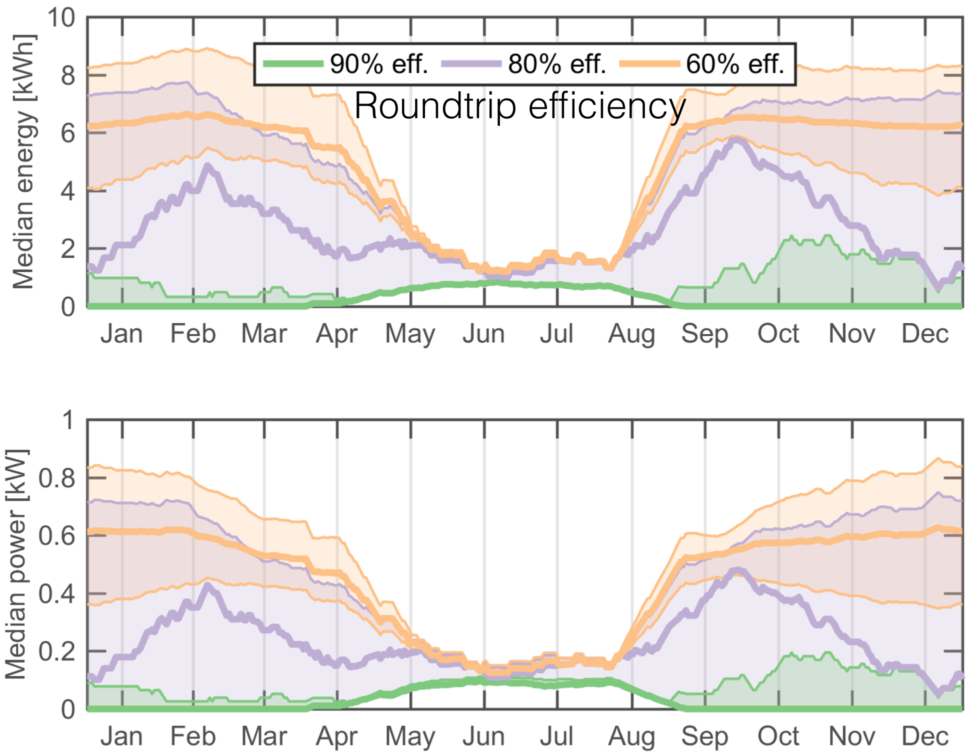
Building performance (solution I)

Ind.	Value (imp/exp/gen)
E [MWh]	34.8 / 00.0 / 00.0
H [MWh]	00.0 / 00.0 / 00.0
COP [-]	3.00

Building energy system design (solution I)

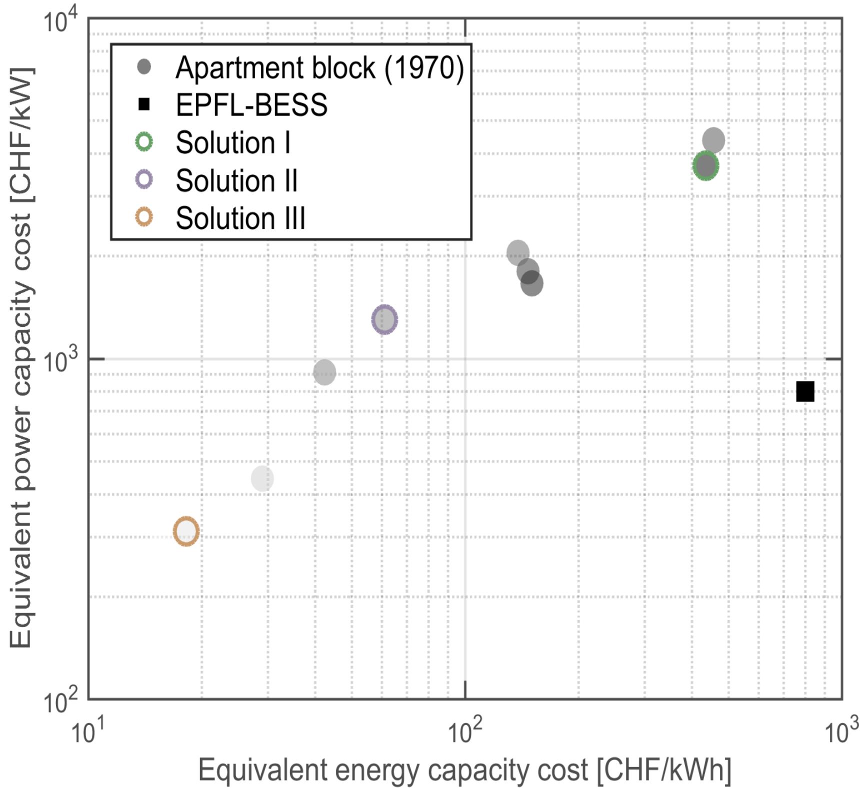
Unit	Size	
Heat pump	**7.0**	kW_e
Battery	0	kWh_e
Boiler	0	kW_{th}
Water tank	**0.22**	m^3
Electric heater	**14**	kW_e
Heat tank	**1.0**	m^3
Photovoltaics	0	kW_p
Solar thermal	0	m^2
SOFC-CHP	0	kW_e

Offered stored energy and power by the system

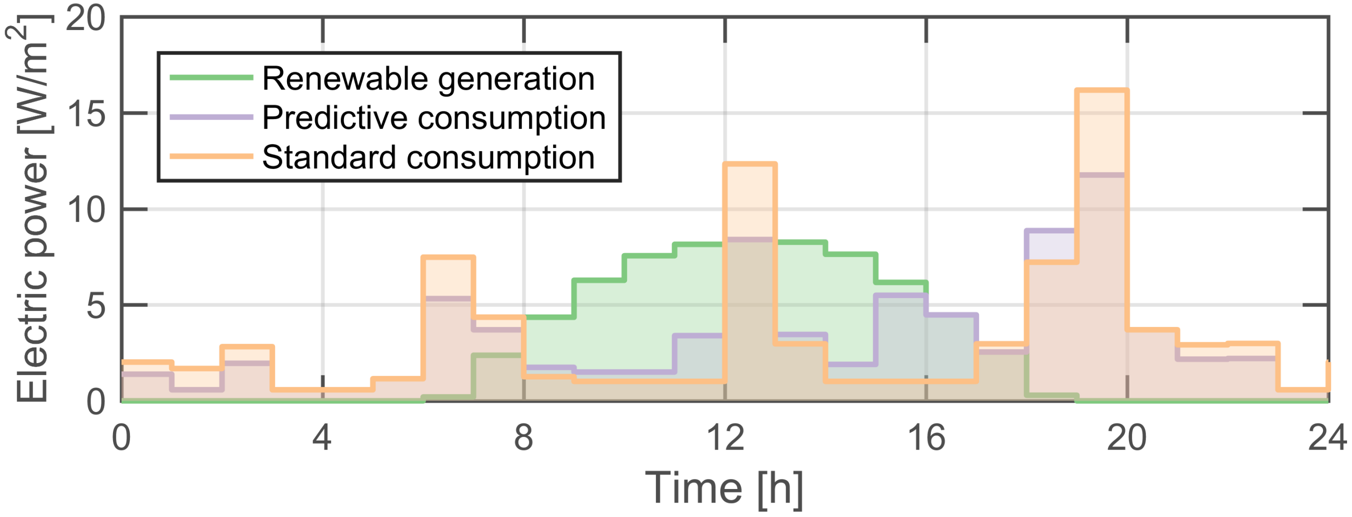


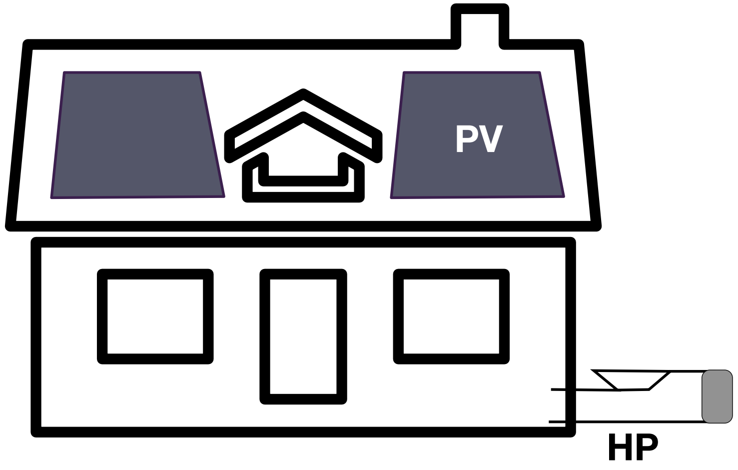
Annual equivalent battery performance

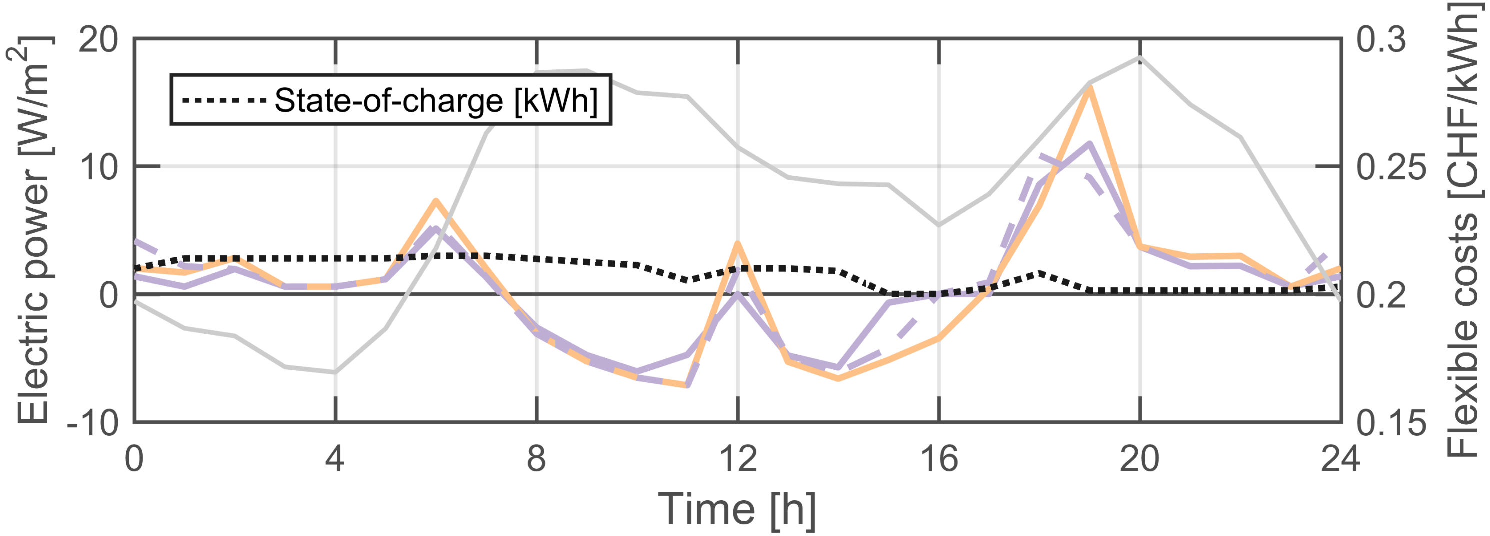
Equivalent Battery



The building is also a “free” battery







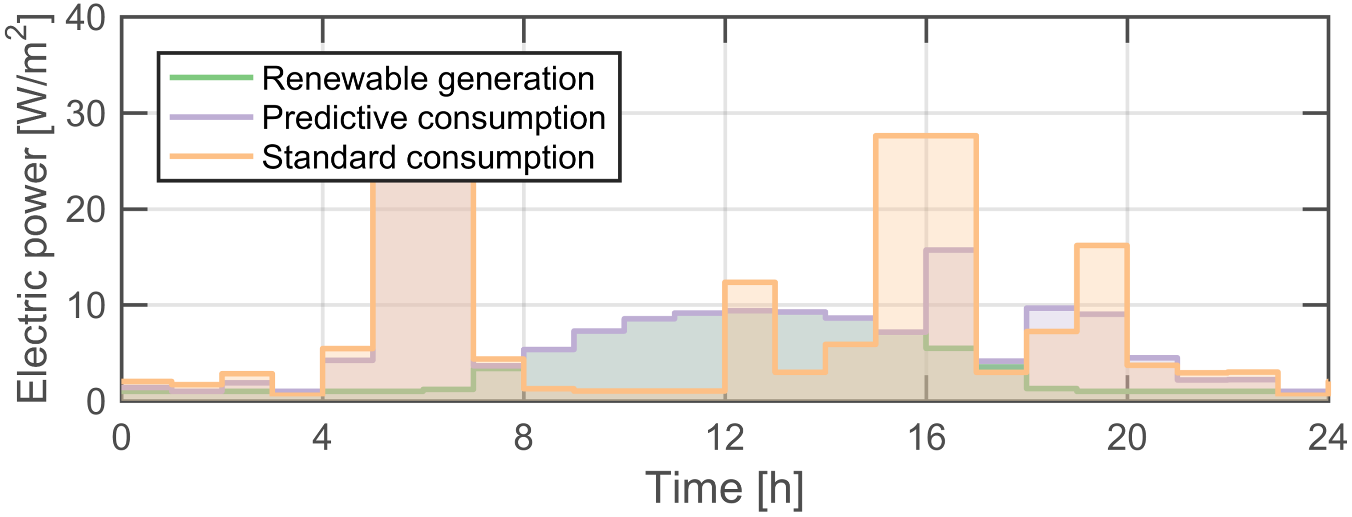
Equiv. Battery : cost 0

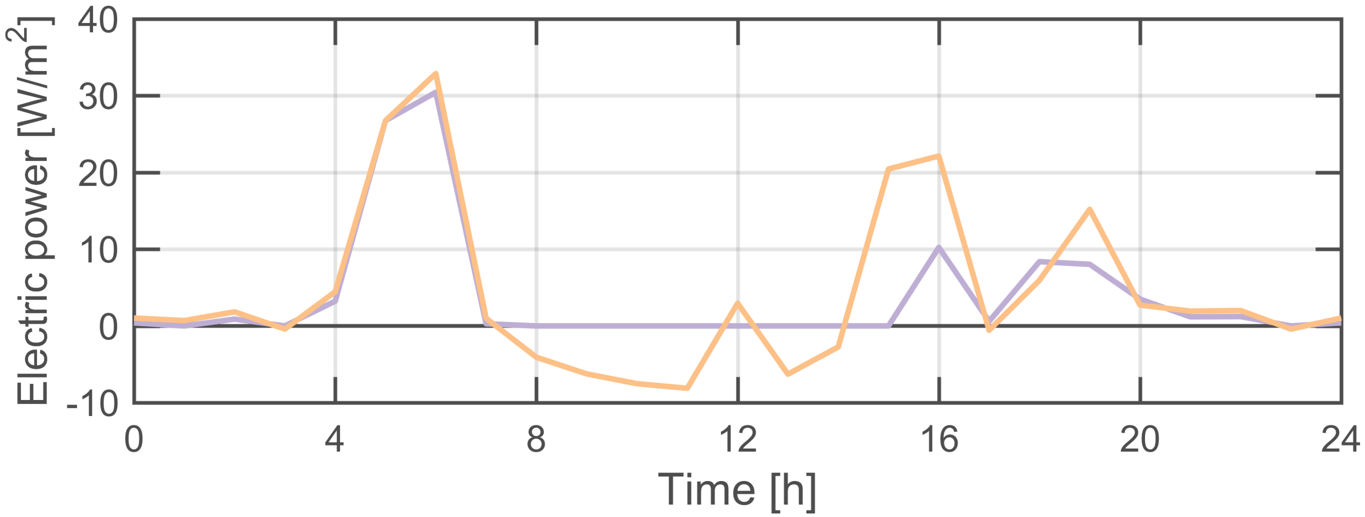
Power max = 1 hour

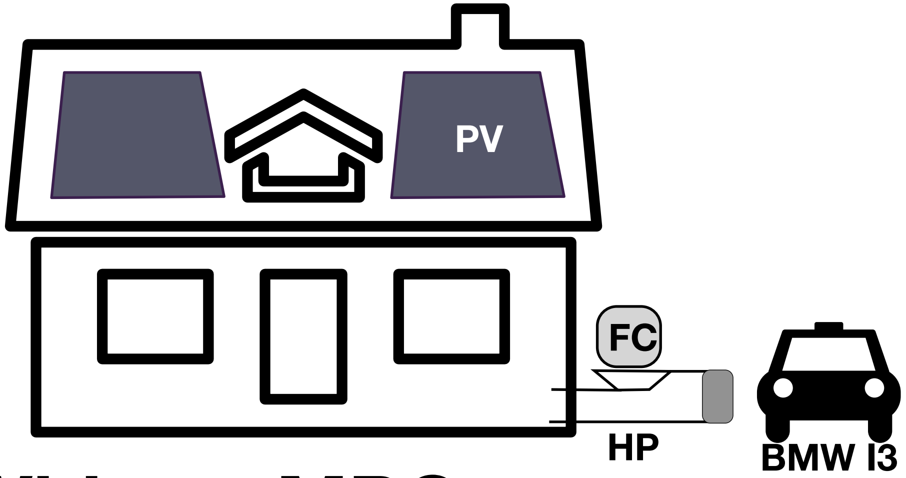
Energy = 30% Mean cons

Roundtrip = 1.0 - 0.95

Including electrical mobility







Without MPC

Self Sufficiency = 21 %

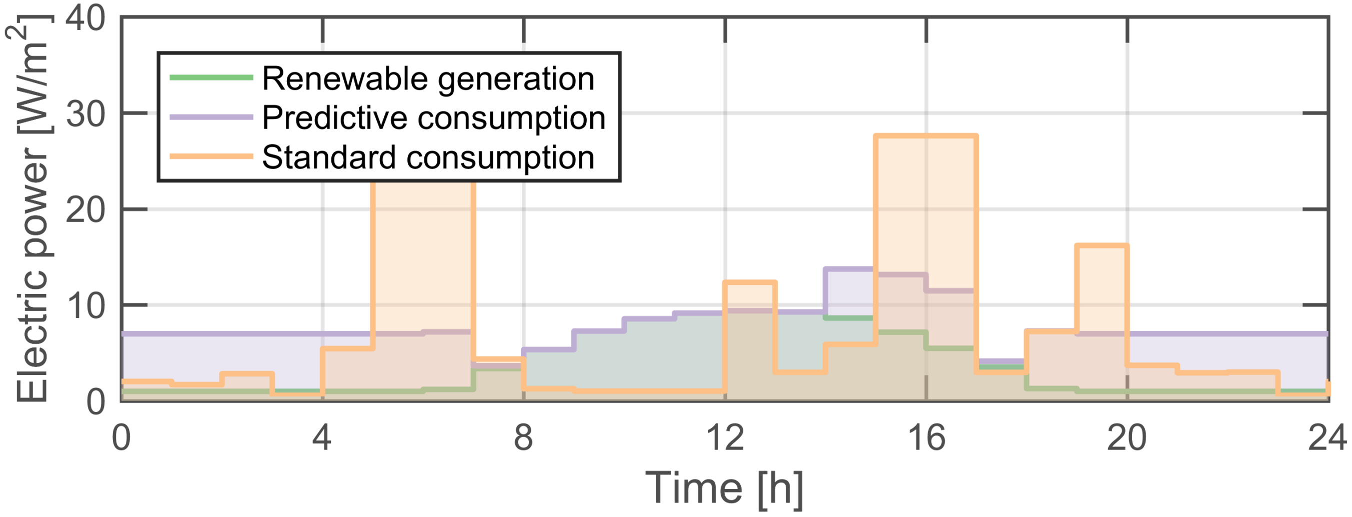
Self Consumption = 69 %

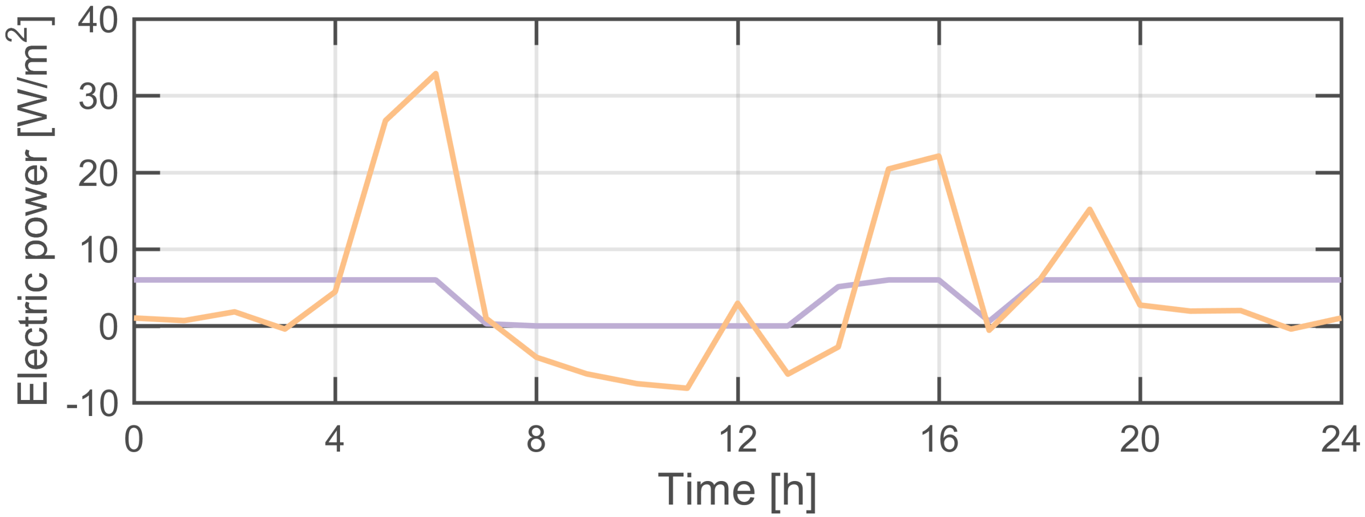
With MPC

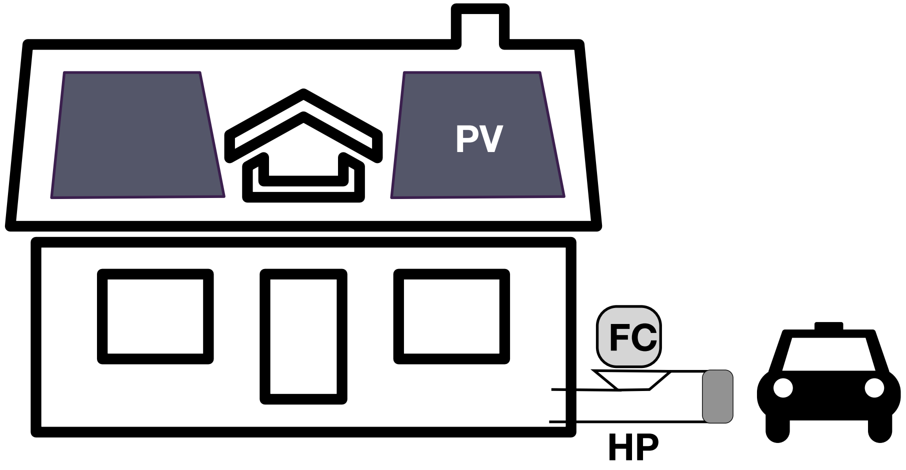
Self Sufficiency = 32 %

Self Consumption = 100 %

Max power variation







Without MPC

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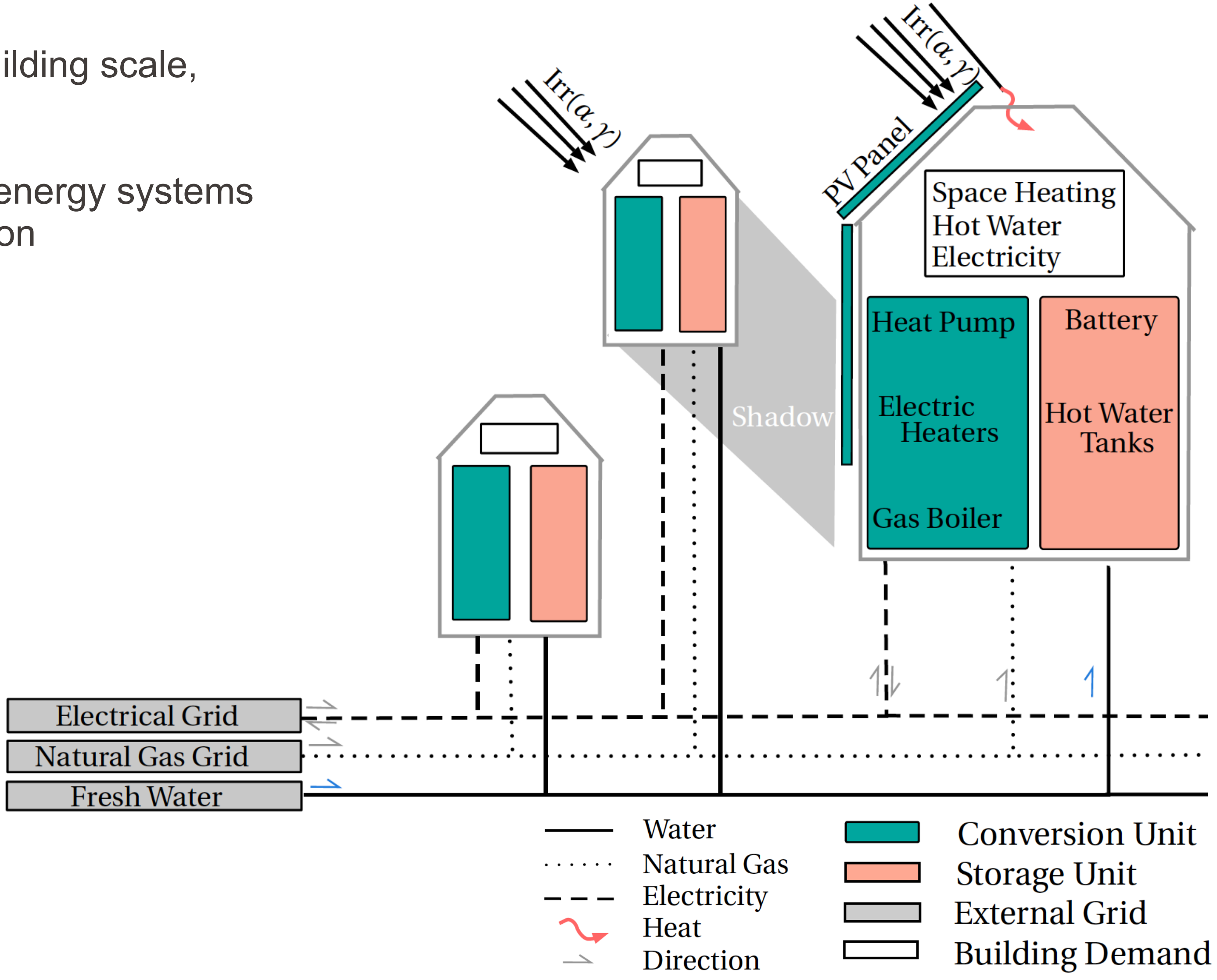
Modelling adaptation for decentralized building energy systems in districts

- Collection of renewable energy hubs at the building scale, balanced at the low-voltage transformer
- Inclusion of facades in <u>optimization</u> of district energy systems
  - Piece-wise discretization of PV cost function
  - Improvement solar heat gain model



3

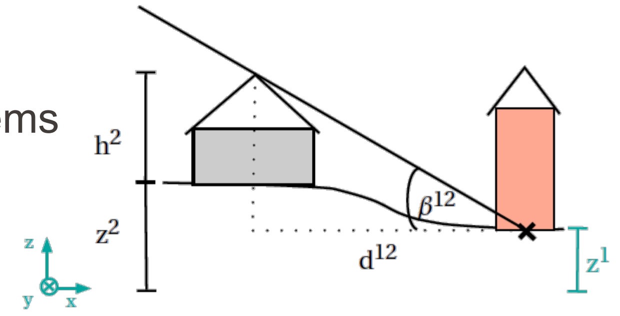
Method

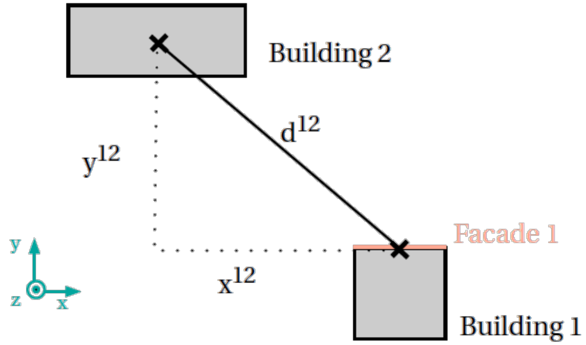
Modelling adaptation for decentralized building energy systems in districts

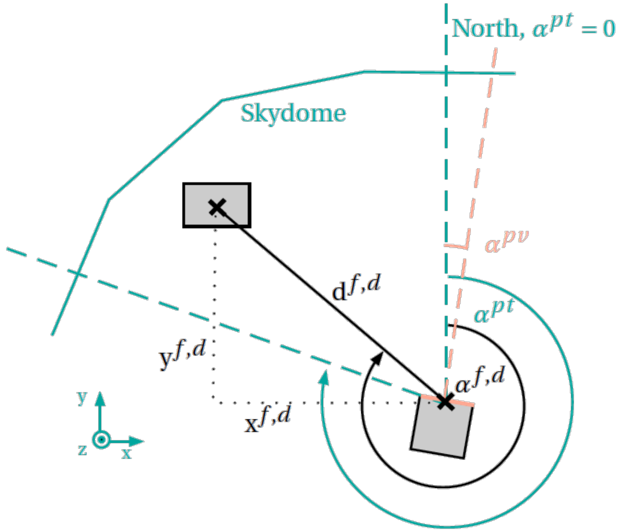
- Collection of renewable energy hubs at the building scale, balanced at the low-voltage transformer

- Inclusion of facades in optimization of district energy systems
  - Piece-wise discretization of PV cost function
  - Improvement solar heat gain model

- Shadowing cannot be neglected
  - 3D modelling of buildings in district
  - Shadows from vegetation neglected

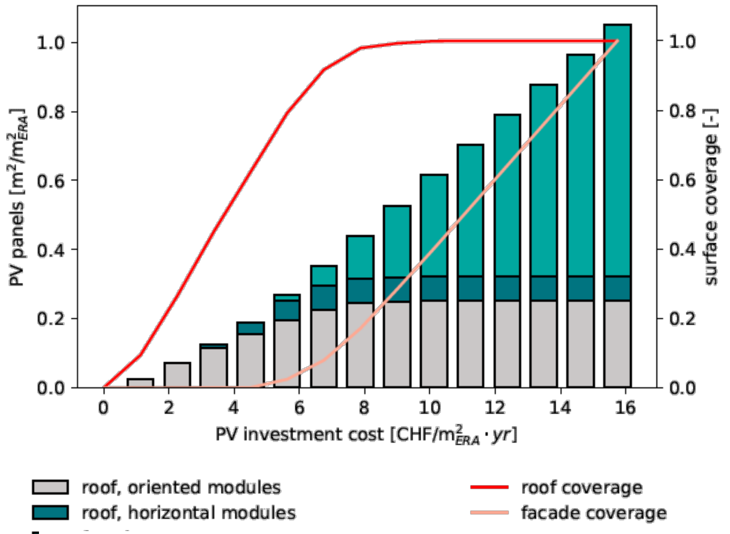




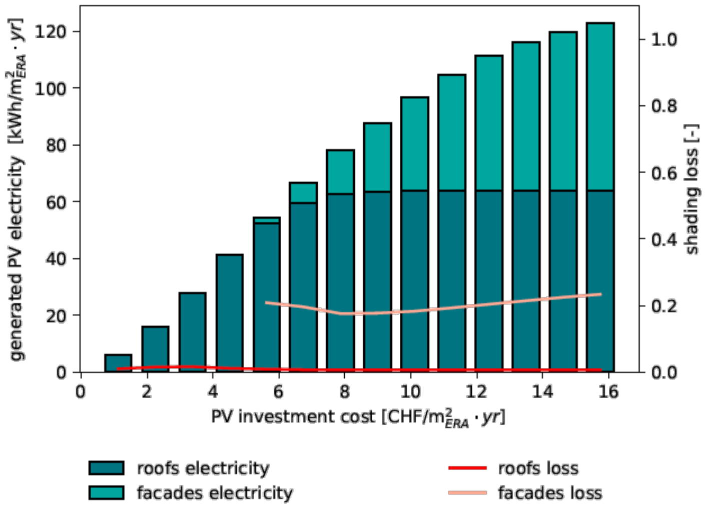


Role of facades

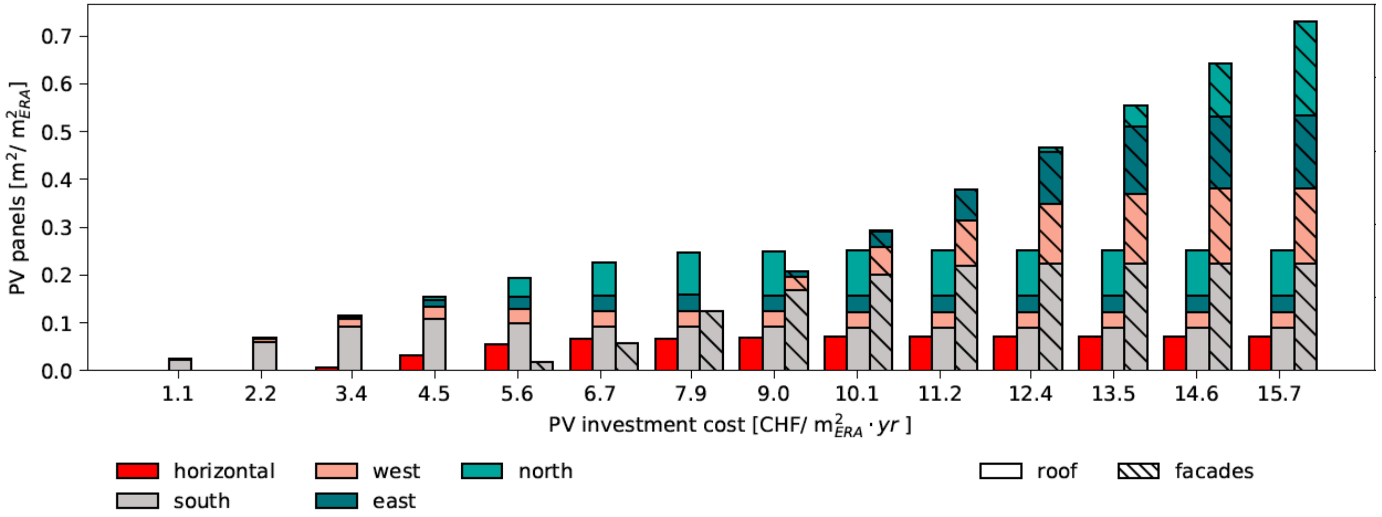
What is the potential of energy generation from PV in the district?



Facades account for:
- 70% of potential surface



- 40% of potential electricity generation
- shading losses 5% - 25%



Optimal placement order:

- south → west → east → north
- south facades before north roofs

Modelling Swiss building stock

- Geometry
  - x,y,z, coordinates, height
  - roof and facades area & orientation
- Classification
  - type, renovation status
- Thermodynamic properties
  - supply/return temperature
  - heat transfer/capacity factor
- Grid
  - allocated transformer, load measurements

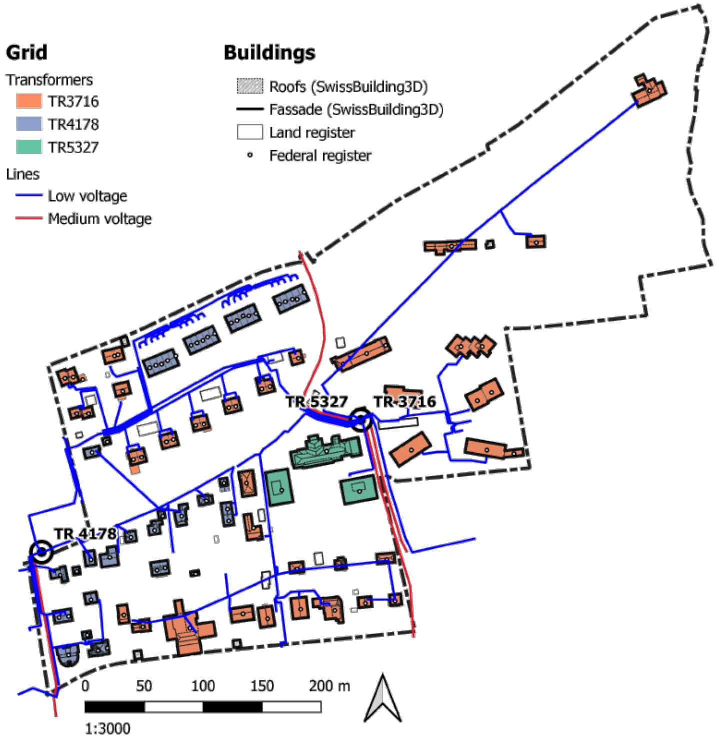
Renewable energy hub

Electricity demand
Space heating demand
Hot water demand
Heat gains

Type	Data	Description
Environment	Weather data	Temperature and solar irradiation [48, 132]
Land registery	Cadastre	Footprint area [44, 133]
Buildings	Official Buildings Registry	Usage, construction/renovation date, heating system, height, number of floors, reference energy area [44, 45]
	3D model	3D surface [12[illegible]]
	Solar roof and facade	2D surface area and orientation [130, 134]
	Energy statistics and standards	Overall heat transfer coefficient, heat capacity, people presence, electrical loads, internal and external gain [31, 131]
Grid	Grid topology	Location and parameters of transformer, lines and injection points [135]
	Load measurements	Hourly load aggregated at the transformer [87, 135]

Open government databases

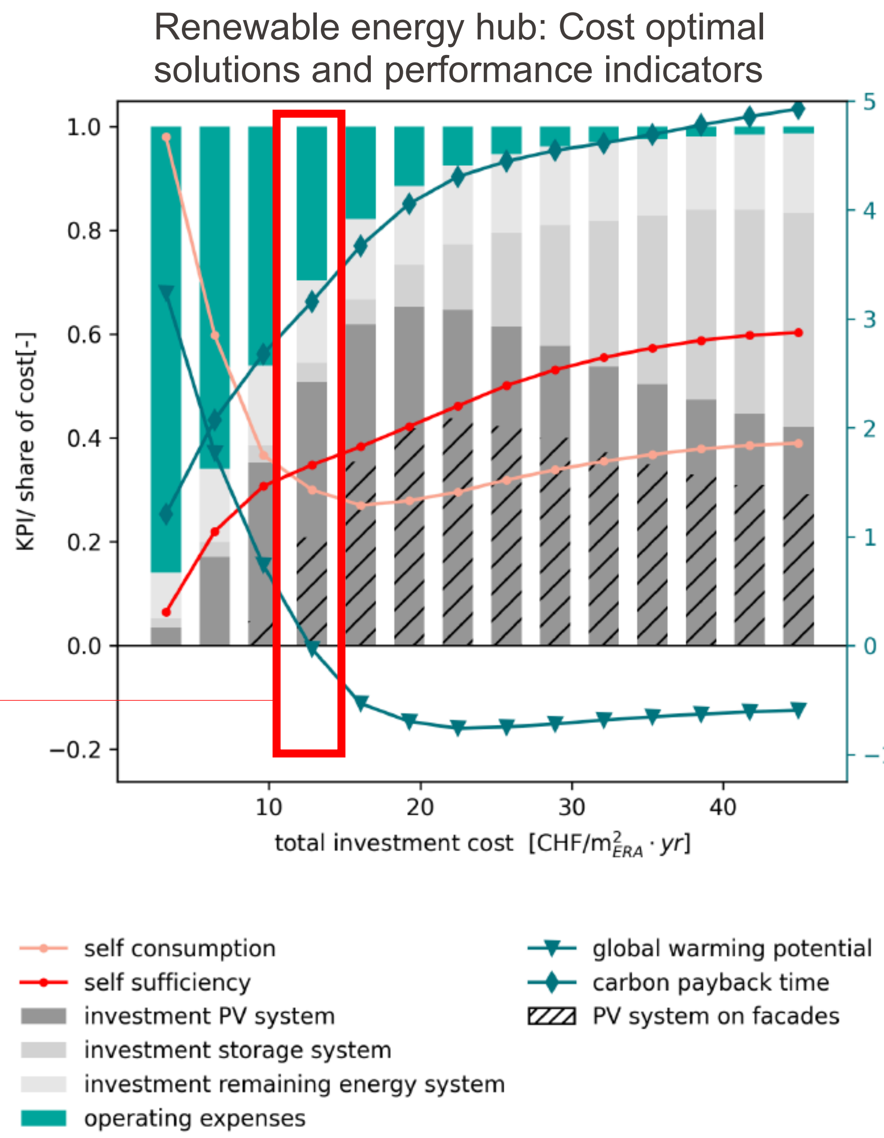
Case Study
- 1 transformer
- 31 residential buildings
- outskirts of Geneva, CH



3
Method

Role of facades

Are PV installations on facades needed to become carbon neutral?



Yes. 41% of available facades

Assumptions:
- based on PV electricity only
- no renovation
- hourly CH electricity grid mix 2019
- exports are accounted

3

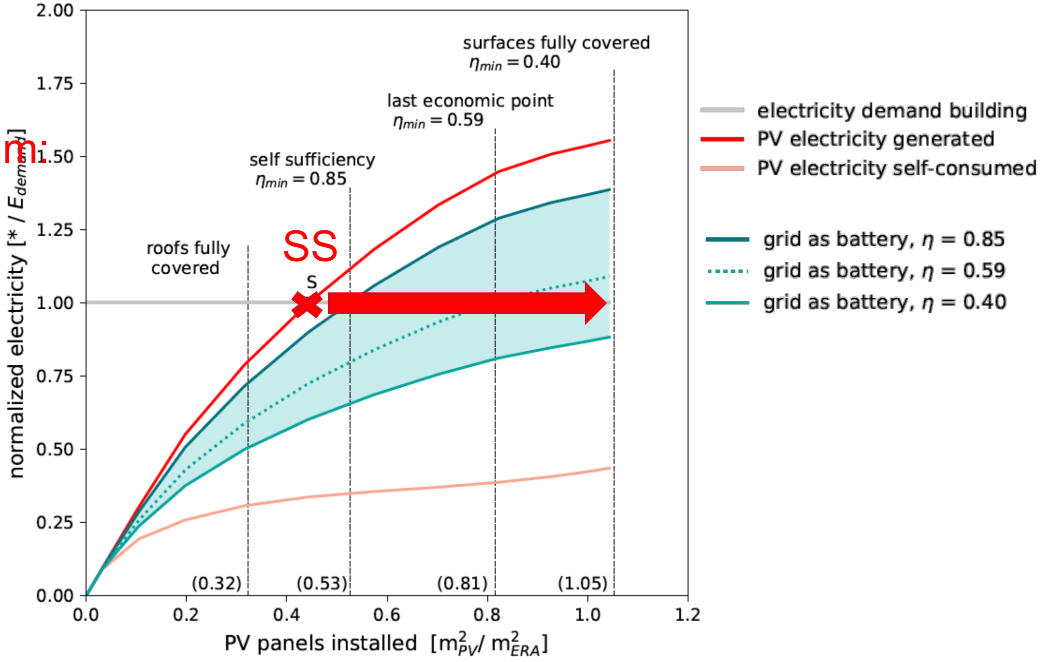
Results

Facades and self-sufficiency

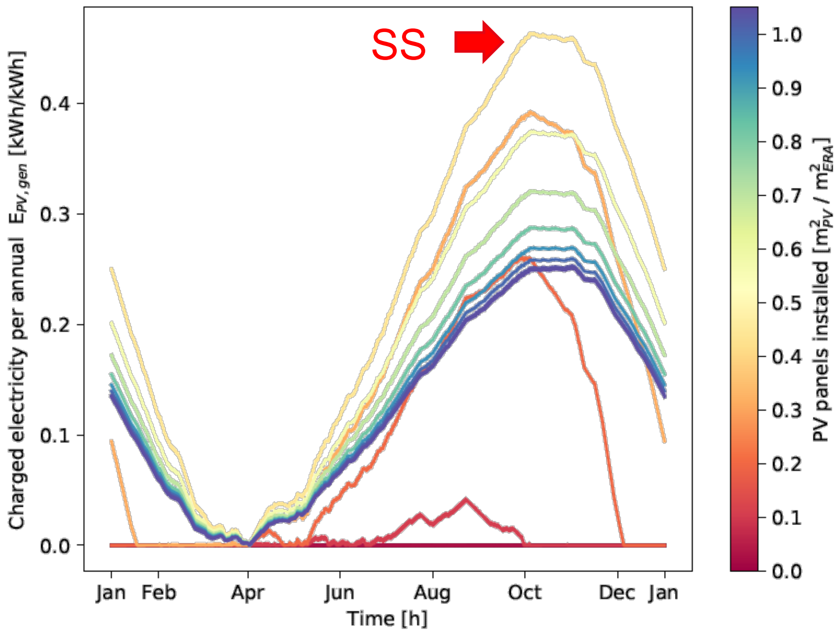
Are PV installations on facades needed to become self-sufficient?

Renewable energy hub: Electricity balance

Yes. Minimum: 16% of available facades



Required grid storage size



- Self- sufficiency with more than 42% PV coverage
- Renovation can reduce PV and storage by 50%

- Threshold for seasonal storage: 20% PV coverage
- SS: 50% of generated PV electricity needs to be stored

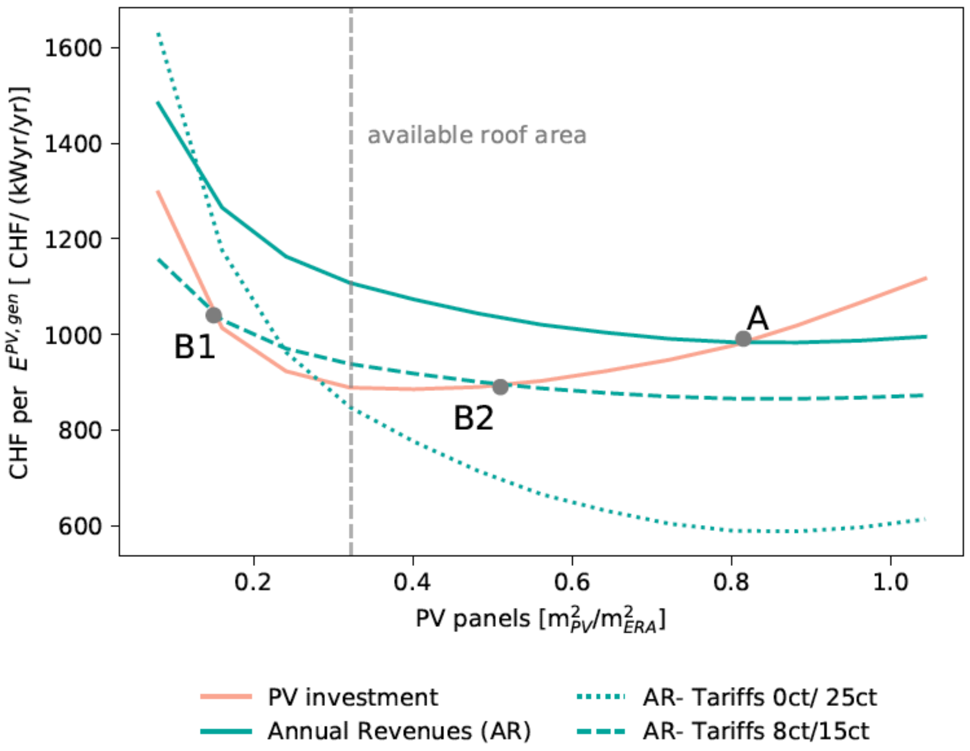
full SS solutions with $\eta = 100\%$	storage capacity		PV coverage	
Air HP	**35.0** kWh/m^2_{ERA}		**41.9%**	
CO_2 HP	29.0 kWh/m^2_{ERA}	(-17.1%)	36.2%	(-13.6%)
Building envelope renovation	18.8 kWh/m^2_{ERA}	(-46.3%)	23.8%	(-43.2%)

3

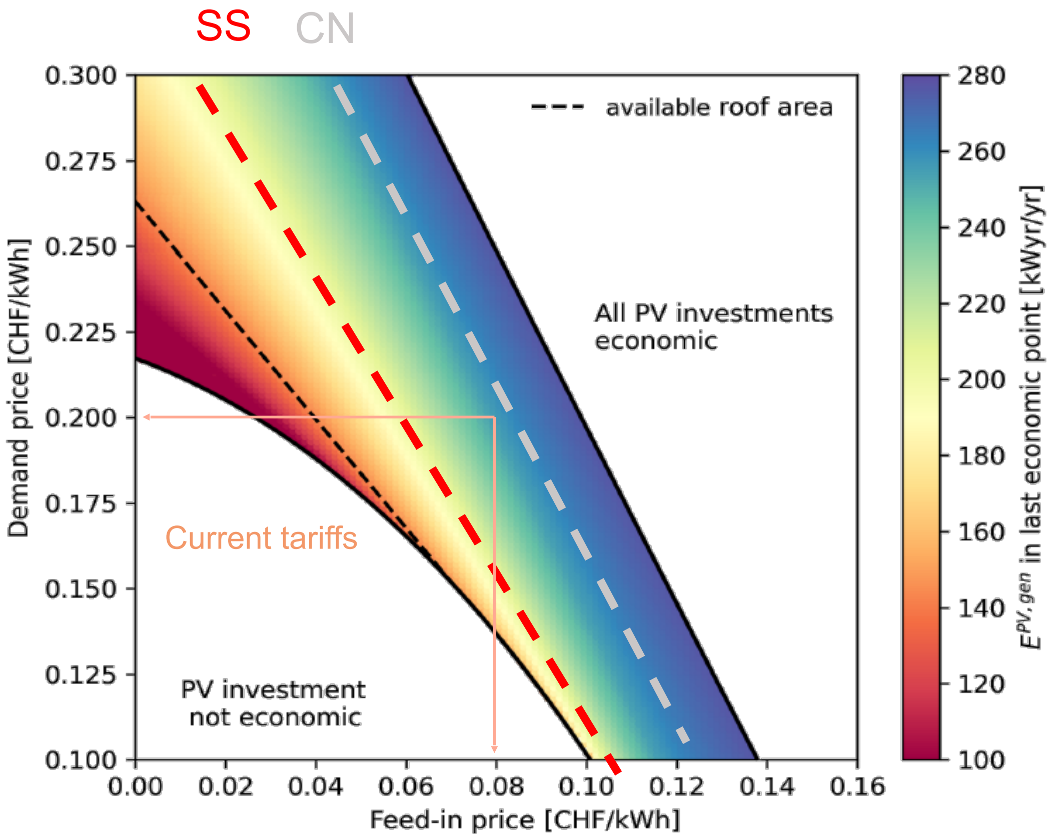
Results

Solar integration

How much electricity can be generated locally and cost-efficiently?



Economic analysis PV integration

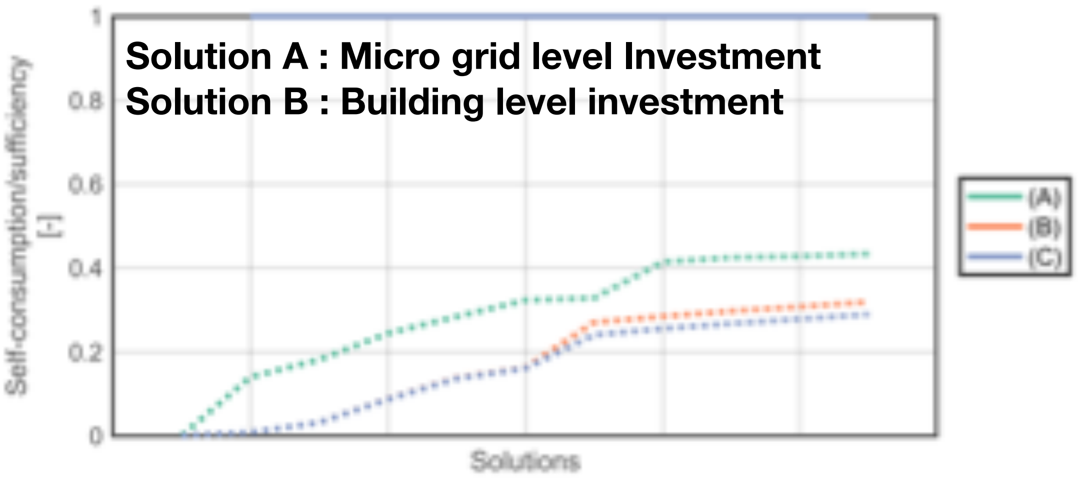


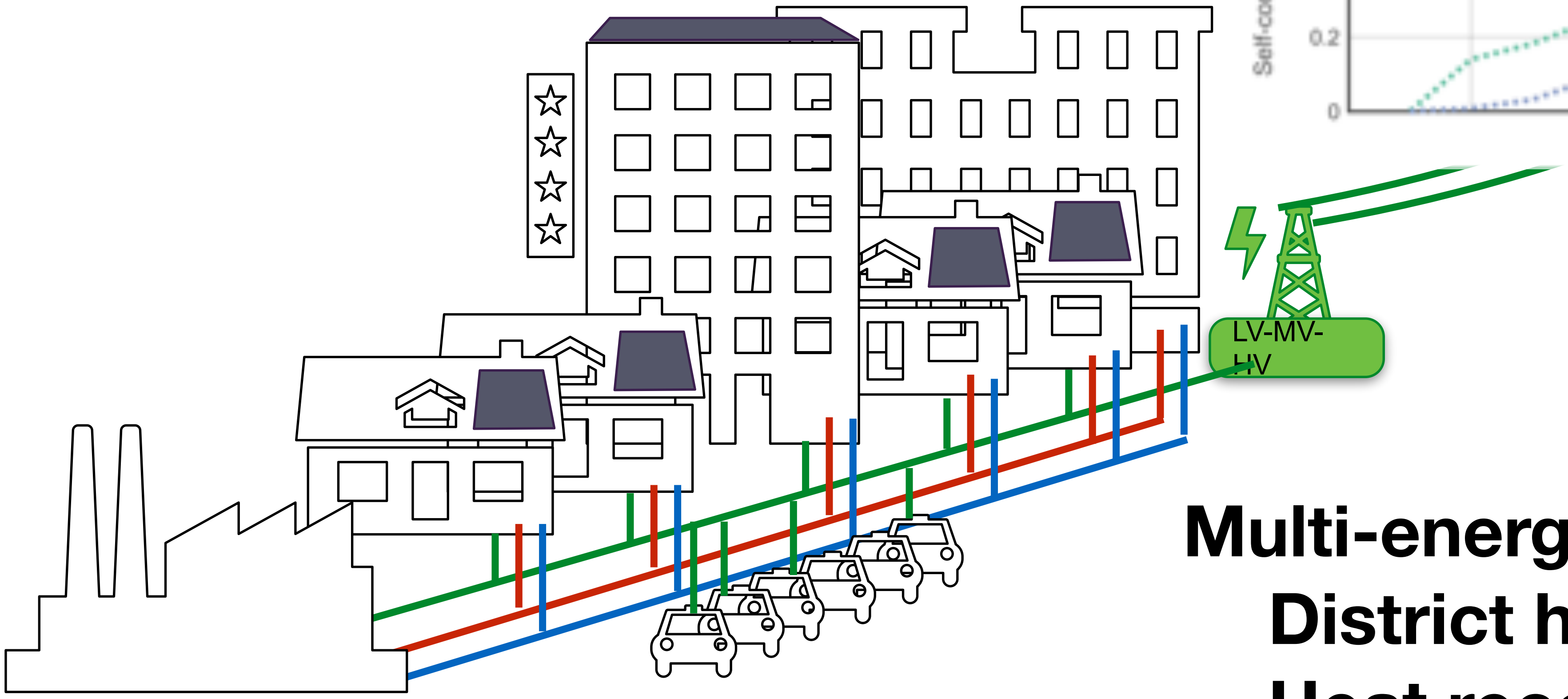
Result economic analysis ("Point A")

→ PV installation economically feasible for wide range of tariffs
→ SS economically feasible at current tariffs
→ PV investment not coordinated in the district

3
Results

AR – annual revenues
SS – self-sufficiency
CN – carbon neutrality



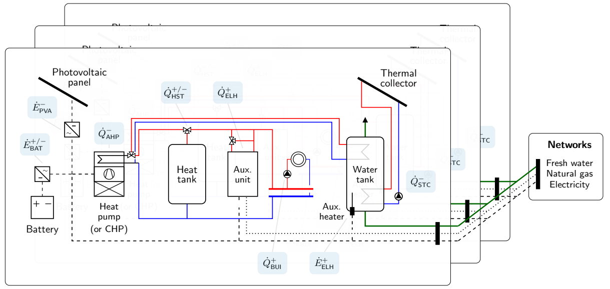


Multi-energy system

- **District heating and cooling**
- **Heat recovery from industry**
- **Centralised cogeneration**

Mixed uses

The benefit of operating at the district level

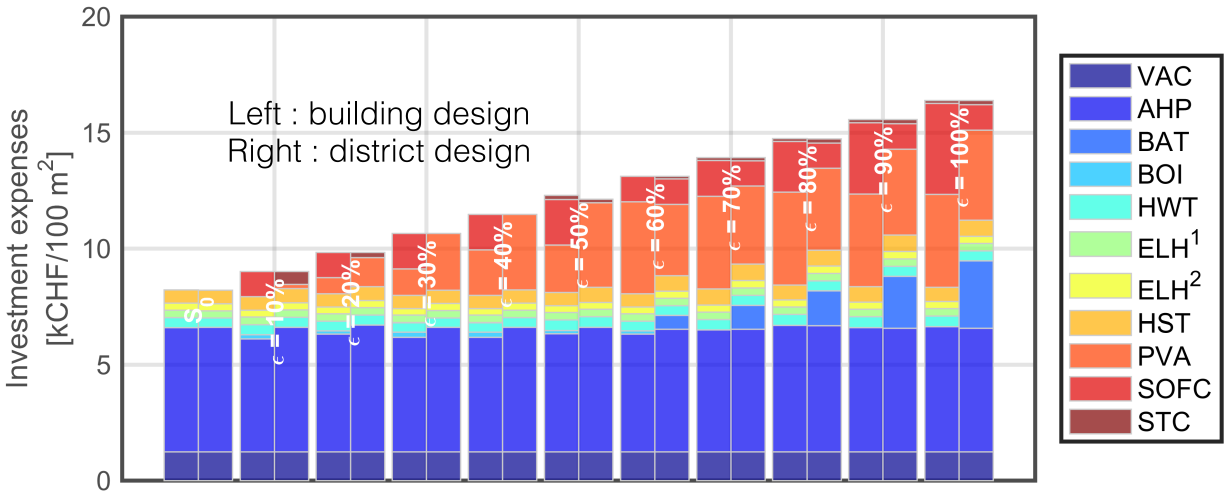


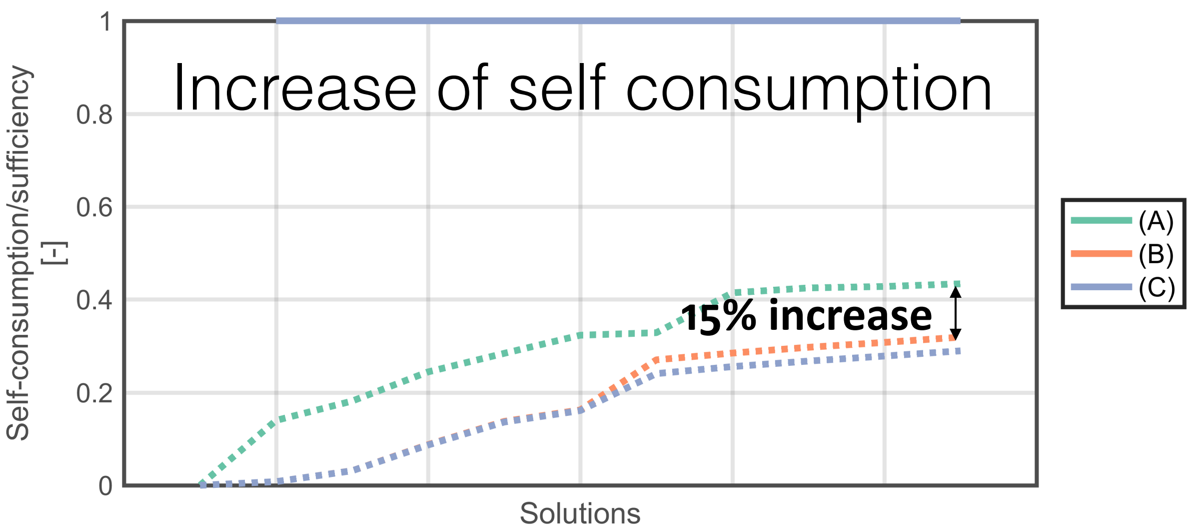
Operating cost MILP Coordinated

$$\min_{\Sigma} \sum_{p=1}^{P}\sum_{t=1}^{T}(\mathrm{op}_{p,t}^{el,+}\cdot \dot{E}_{\mathrm{grid},p,t}^{+} - \mathrm{op}_{p,t}^{el,-}\cdot \dot{E}_{\mathrm{grid},p,t}^{-} + \mathrm{op}_{p,t}^{ng,+}\cdot \dot{H}_{\mathrm{grid},p,t}^{+})\cdot \mathrm{d}_p \cdot \mathrm{d}_t$$

Investissement

$$\underbrace{\sum_{u=1}^{U}(\mathrm{F}_{\mathrm{BM},u}\cdot(\mathrm{inv}_{1,u}\cdot y_u + \mathrm{inv}_{2,u}\cdot F_u))}_{C_{\mathrm{inv}}} + \underbrace{\sum_{u=1}^{U}\sum_{n=1}^{rep_u}\frac{1}{(1+\mathrm{r})^{n\cdot \mathrm{L}_u}}\cdot(\mathrm{inv}_{1,u}\cdot y_u + \mathrm{inv}_{2,u}\cdot F_u)}_{C_{\mathrm{rep}}} \leq \epsilon_{\mathrm{inv}}$$



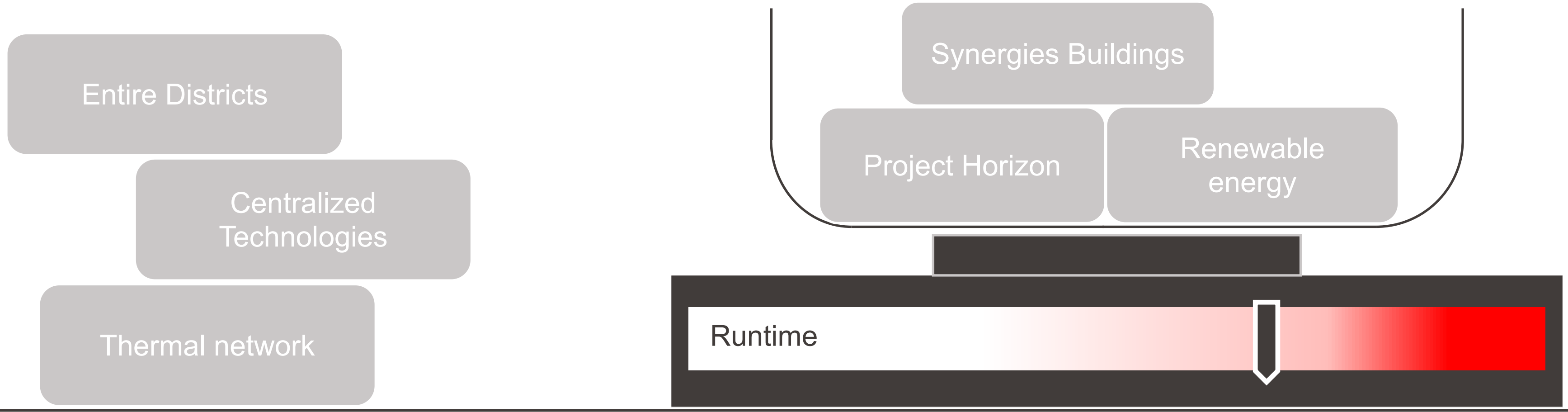


Solution A : Micro grid level Investment
Solution B : Building level investment + District operation
Solution C : Building level investment + Building operation

The Challenge : the size

780.000 variables
9000 binaries

4 million variables
44000 binaries



Chapter 4

What is the best method to overcome runtime issues when generating centralized energy hub designs?

4[1]

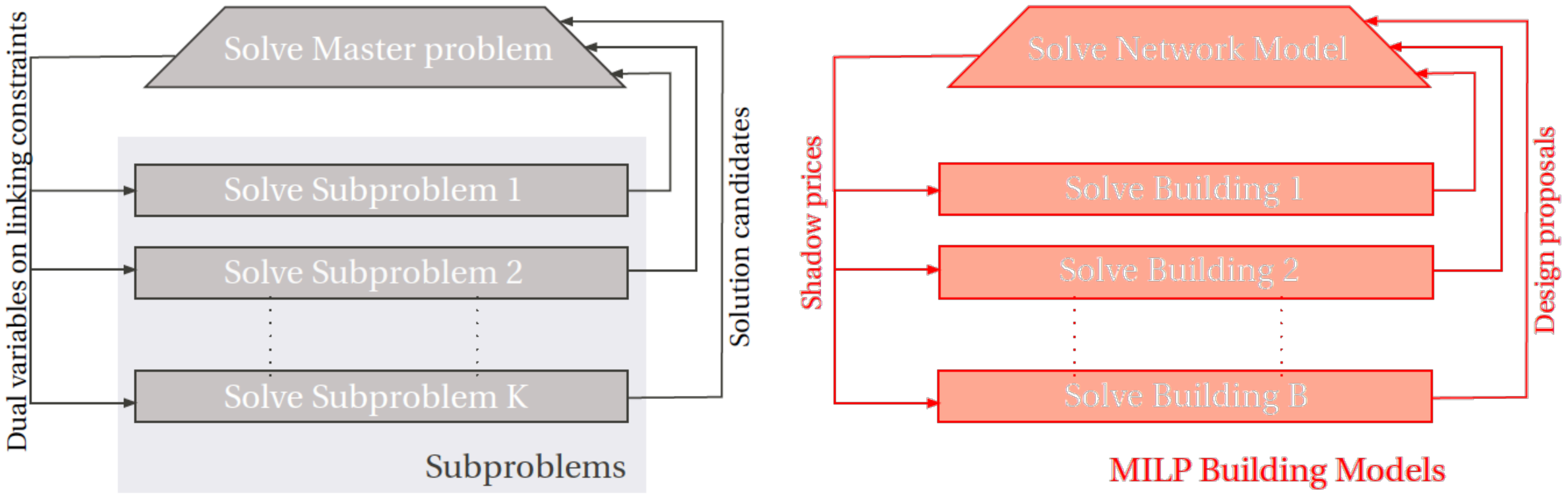
Reduction of input data
→ time-series aggregation

4[2]

Reduction of complexity
→ decomposition

Solving the size problem

Dantzig-Wolfe Decomposition



(a) Dantzig–Wolfe decomposition algorithm [169].

(b) Application to centralized energy systems.

42

Method

MILP – mixed integer linear programming

Dantzig-Wolfe Decomposition

$$0 \le \lambda_{i,b} \le 1 \quad \forall i \in \mathrm{I}, \quad \forall b \in \mathrm{B}$$

$$\sum_{i\in \mathrm{I}} \lambda_{i,b} = 1 \quad \forall b \in \mathrm{B} \quad \backsim [\mu_b]$$

Convexity constraints

$$\sum_{i\in \mathrm{I}}\sum_{b\in \mathrm{B}} \lambda_{i,b}\cdot\left(\dot{E}^{gr,+}_{i,b,p,t} - \dot{E}^{gr,-}_{i,b,p,t}\right)\cdot d_p \cdot d_t = E^{TR,+}_{p,t} - E^{TR,-}_{p,t} \quad \forall p\in \mathrm{P}, \quad \forall t \in \mathrm{T} \quad \backsim [\pi_{p,t}]$$

Electricity balance

$$C^{op} = C^{el} + \sum_{i\in \mathrm{I}}\sum_{b\in \mathrm{B}} \lambda_{i,b}\cdot C^{gas}_{i,b}$$

Overall objectives

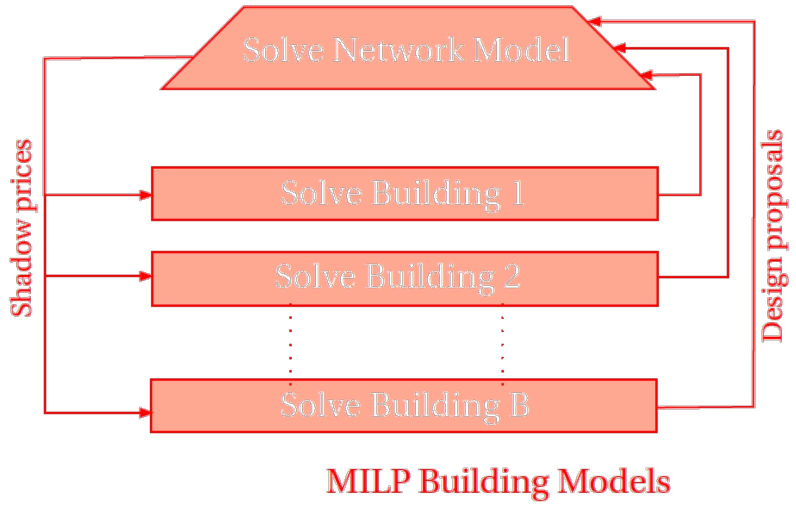
Master problem

Main decision variable:
λ: design proposal

$$[\mu_b] = \frac{\Delta \mathrm{obj}}{\Delta\left(\sum_{i\in \mathrm{I}}\lambda_{i,b}\right)} \quad \forall b\in \mathrm{B}$$

$$[\pi_{p,t}] = \frac{\Delta \mathrm{obj}}{\Delta\left(E^{TR,+}_{p,t} - E^{TR,-}_{p,t}\right)} \quad \forall p\in \mathrm{P}, \quad \forall t \in \mathrm{T}$$

Electricity prices



(b) Application to centralized energy systems.

Design proposals

$$\mathrm{obj}_b = \min(C^{op}_b - \mu_b) \quad \forall b\in \mathrm{B}$$

Modified objectives

$$C^{op}_b = \sum_{p\in \mathrm{P}}\sum_{t\in \mathrm{T}} \left(\pi_{p,t}\cdot \dot{E}^{gr,+}_{b,p,t} - \pi_{p,t}\cdot \dot{E}^{gr,-}_{b,p,t} + c^{ng,+}_{p,t}\cdot \dot{H}^{gr,+}_{b,p,t}\right)\cdot d_t\cdot d_p \quad \forall b\in \mathrm{B}$$

Sub problems

Main decision variable:
Unit installation & scheduling

42
Method

CAPEX – capital expenses
MILP – mixed integer linear programming

Districts as renewable energy hubs

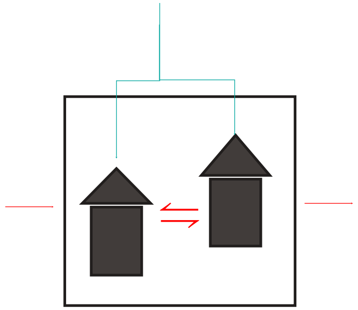
Centralized design strategy	Decentralized design strategy
At the district scale	At the building scale + post computation
Central objective Coordinated decisions	Decentralized objective Independent decisions
Method of Chapter 4 (Dantzig Wolfe decomposition)	Method of Chapter 3
Central units and constraints ✓	✗Central units and constraints

2 Perspectives for both strategies:

building □ community

Difference: exchanges within community

$$\psi = \frac{\sum_{p\epsilon P}\sum_{t\epsilon T}\left(\left(\sum_{b\epsilon B}\dot{E}^{gr,-}_{b,p,t}\right) - \dot{E}^{TR,-}_{p,t}\right)\cdot d_p \cdot d_t}{\sum_{b\epsilon B}\sum_{p\epsilon P}\sum_{t\epsilon T}\dot{E}^{gr,-}_{b,p,t}\cdot d_p \cdot d_t}$$



5

Method

Modelling Swiss building stock

- Geometry
  - x,y,z, coordinates, height
  - roof and facades area & orientation
- Classification
  - type, renovation status
- Thermodynamic properties
  - supply/return temperature
  - heat transfer/capacity factor
- Grid
  - allocated transformer, load measurements

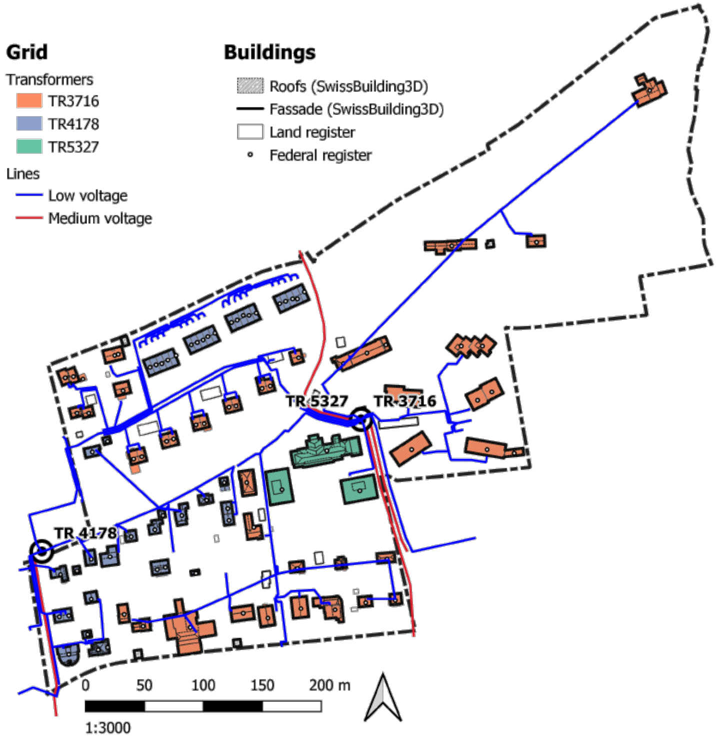
Renewable energy hub

Electricity demand
Space heating demand
Hot water demand
Heat gains

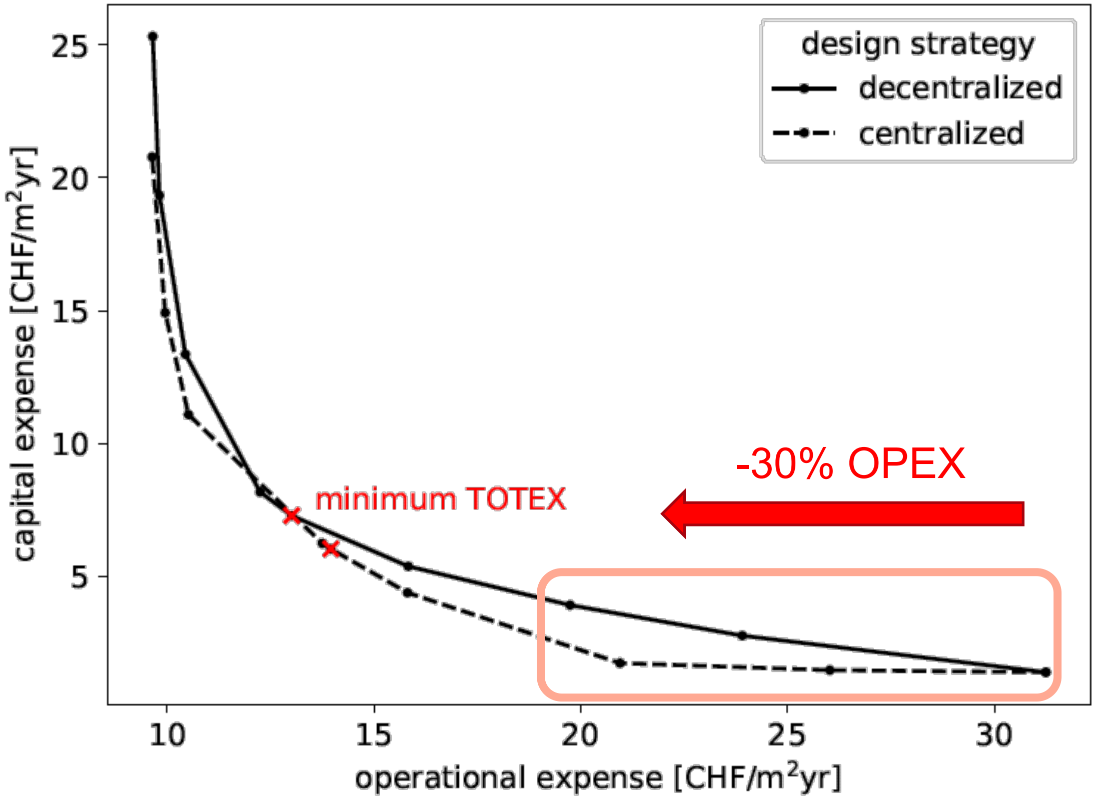
Type	Data	Description
Environment	Weather data	Temperature and solar irradiation [48, 132]
Land registery	Cadastre	Footprint area [44, 133]
Buildings	Official Buildings Registry	Usage, construction/renovation date, heating system, height, number of floors, reference energy area [44, 45]
	3D model	3D surface [illegible]
	Solar roof and facade	2D surface area and orientation [130, 134]
	Energy statistics and standards	Overall heat transfer coefficient, heat capacity, people presence, electrical loads, internal and external gain [31, 131]
Grid	Grid topology	Location and parameters of transformer, lines and injection points [135]
	Load measurements	Hourly load aggregated at the transformer [87, 135]

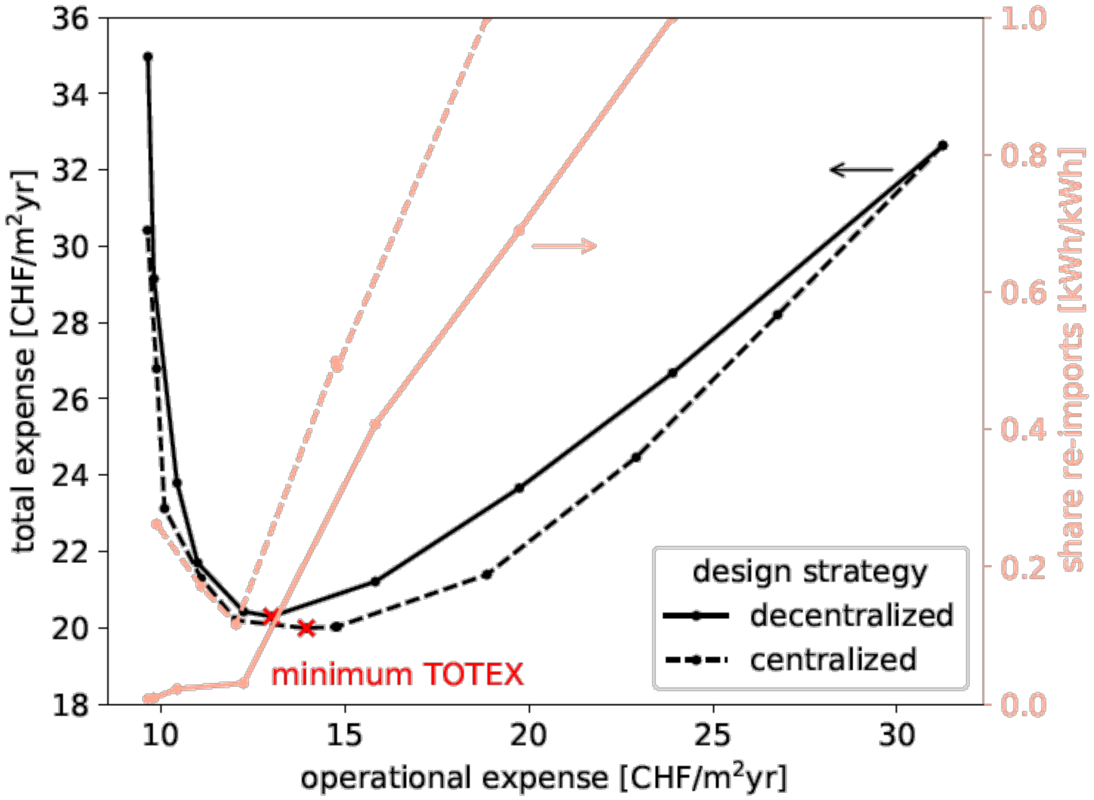
Open government databases

Case Study
- 1 transformer
- 31 residential buildings
- outskirts of Geneva, CH



Benefits centralized approach





-30% OPEX:
Centralized: +5% CAPEX
Decentralized: +180% CAPEX

→ Investment better used

Increased re-imports, better usage of storage

→ Improved operation strategy

5

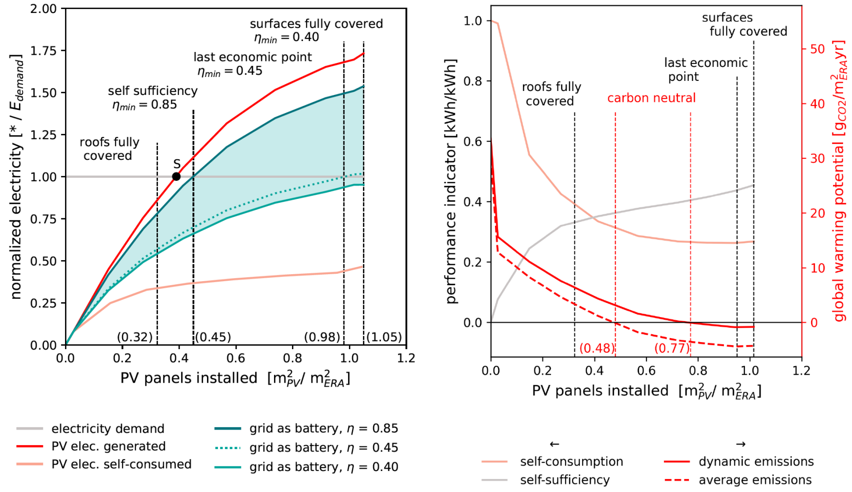
Results

OPEX – operational expenses
CAPEX – capital expenses

Centralized investment strategy

How much PV is needed to achieve self-sufficiency or carbon neutrality?

KPIs for increasing PV penetration

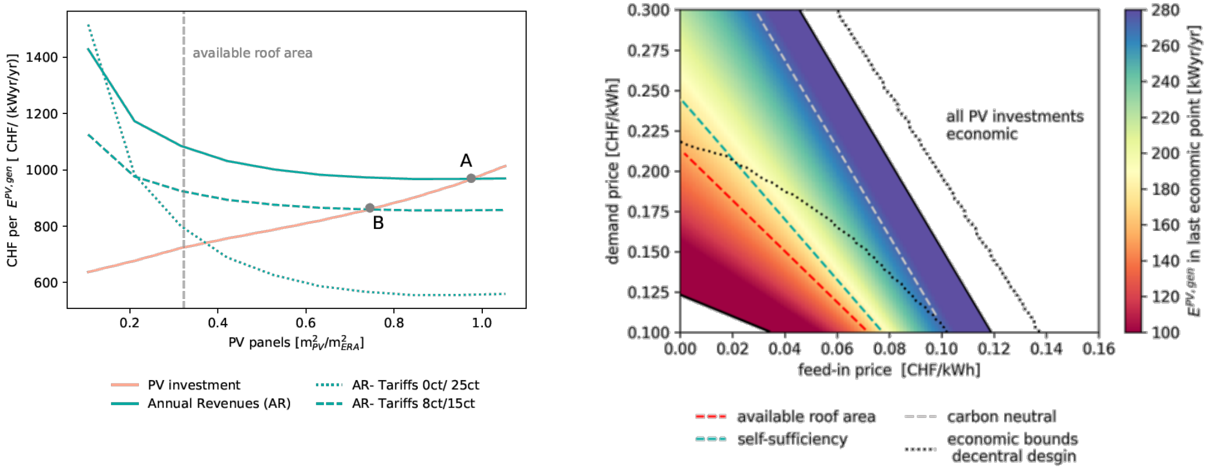


With grid as storage
→ Self-sufficient at $0.40\ m^2_{PV}/m^2_{ERA}$

Without storage
→ SS increases to 45%
→ Carbon neutral at $0.77\ m^2_{PV}/m^2_{ERA}$

How much PV solar energy can be generated locally and cost-efficiently?

Economic analysis for increasing PV penetration



- Central investment strategy linear trend
- Economic feasibility to a wide range of tariffs
- SS and carbon neutrality economic feasible

→ Large PV capacities required
→ They are economical feasible
→ Role of the grid?

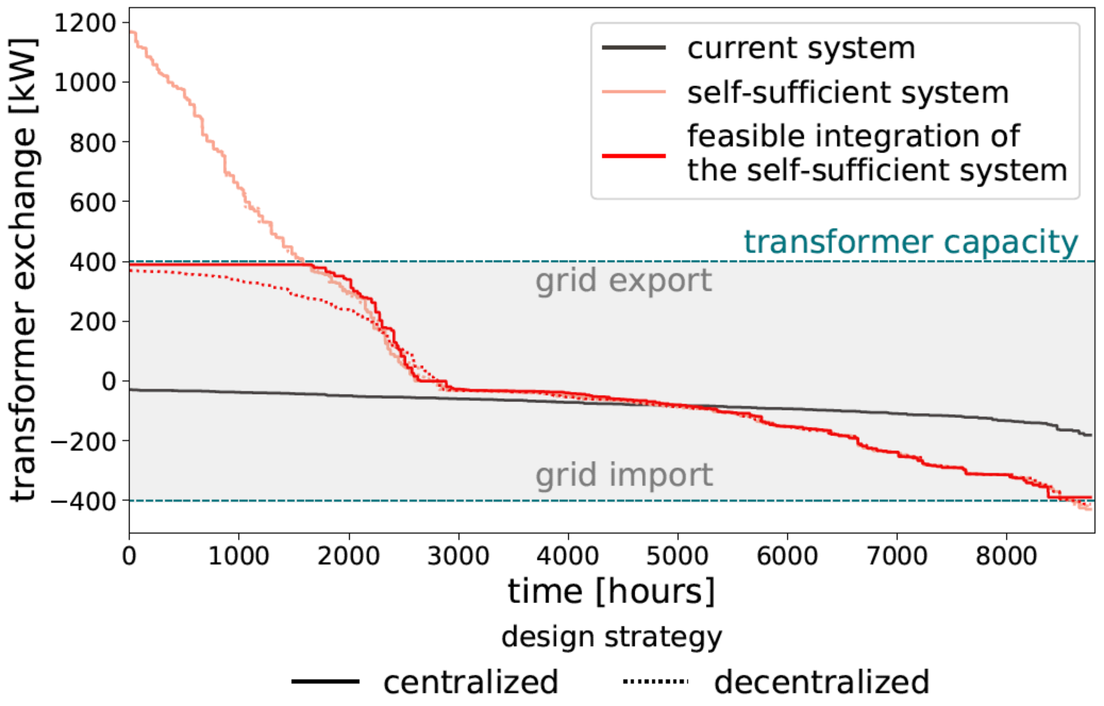
GWP – global warming potential
SS – self-sufficiency
SC – self-consumption

5

Results

Grid–aware integration of renewable energy hubs

What is the influence of capacity constraints imposed from the electrical grid?



Load duration curves on transformer for 0% and 66% peak reduction.

Scenario SS (η =0.7) → 0.58 m^2_{PV}/m^2_{ERA}

→ Infeasible at LV transformer

→ Feasible for 66% peak reduction.

Cheapest solution

- Centralized method:
  - 20% PVC + 50kWh BAT
  - + 60% OPEX, + <1% CAPEX
- Decentralized method:
  - 30% PVC
  - +75% OPEX

OPEX – operational expenses
CAPEX – capital expenses

PVC – PV curtailment
SS – self-sufficiency

Conclusions

Buildings

- MPC to promote self-consumption
- MPC defines buildings as free batteries that can advertise their offered capacities
- Grids constraints impose different investment in buildings

Districts

- District (micro-grid) levels change self consumption levels

Regions

- Region integration allow biogas and power to gas options