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FLEXBUILD

Flexibility KPIs

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Workshop 23.09.2021

ZEN

Research Centre on

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Flexibility KPIs workshop

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- Introduction: Need for flexibility KPIs in Flexbuild and ZEN

- Part 1: Flexibility KPIs *per se*
  - Flexibility definition
  - Flexibility sources, drivers, goals and proposed KPIs
  - Examples of results: two case studies
  - Q/A
  - Breakout group work 1

- Part 2: Flexibility KPIs *links* with
  - Further examples of results
  - End-user and energy system perspectives
  - GHG emissions and Economy KPIs
  - Q/A
  - Breakout group work 2

You will be assigned randomly into the breakout groups
Please agree immediately who takes notes in each group!
Expected notes: keep it short and simple, thanks ☺

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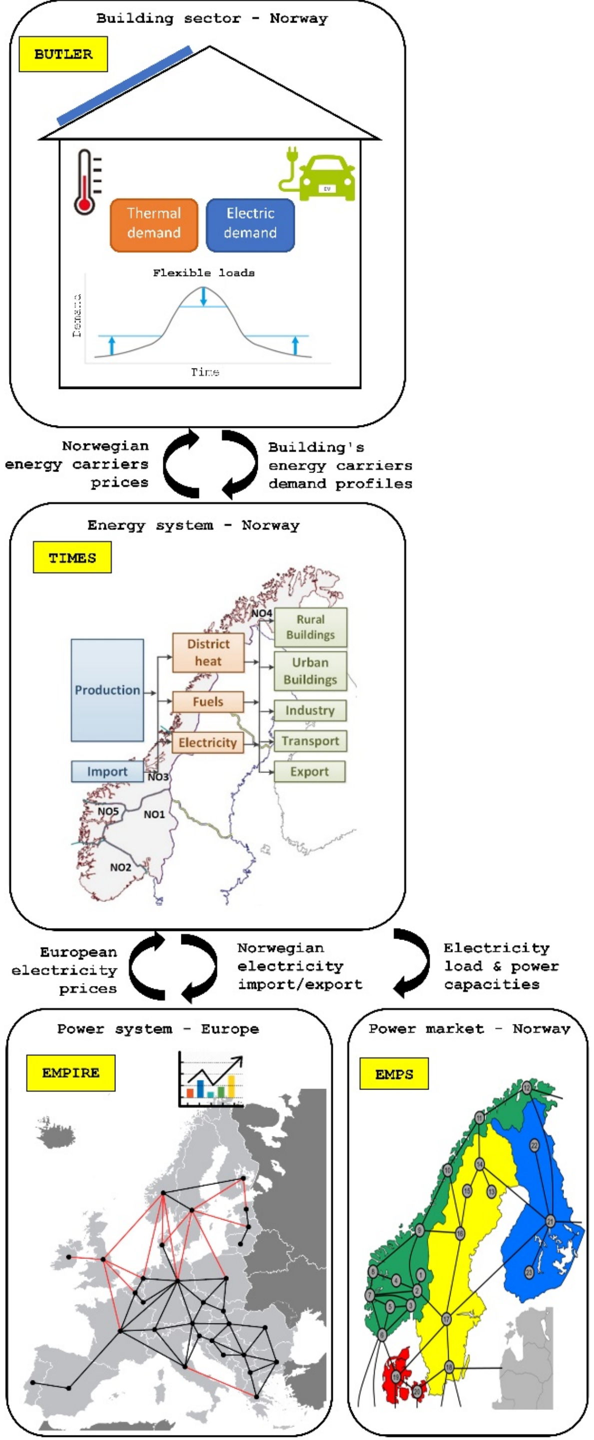
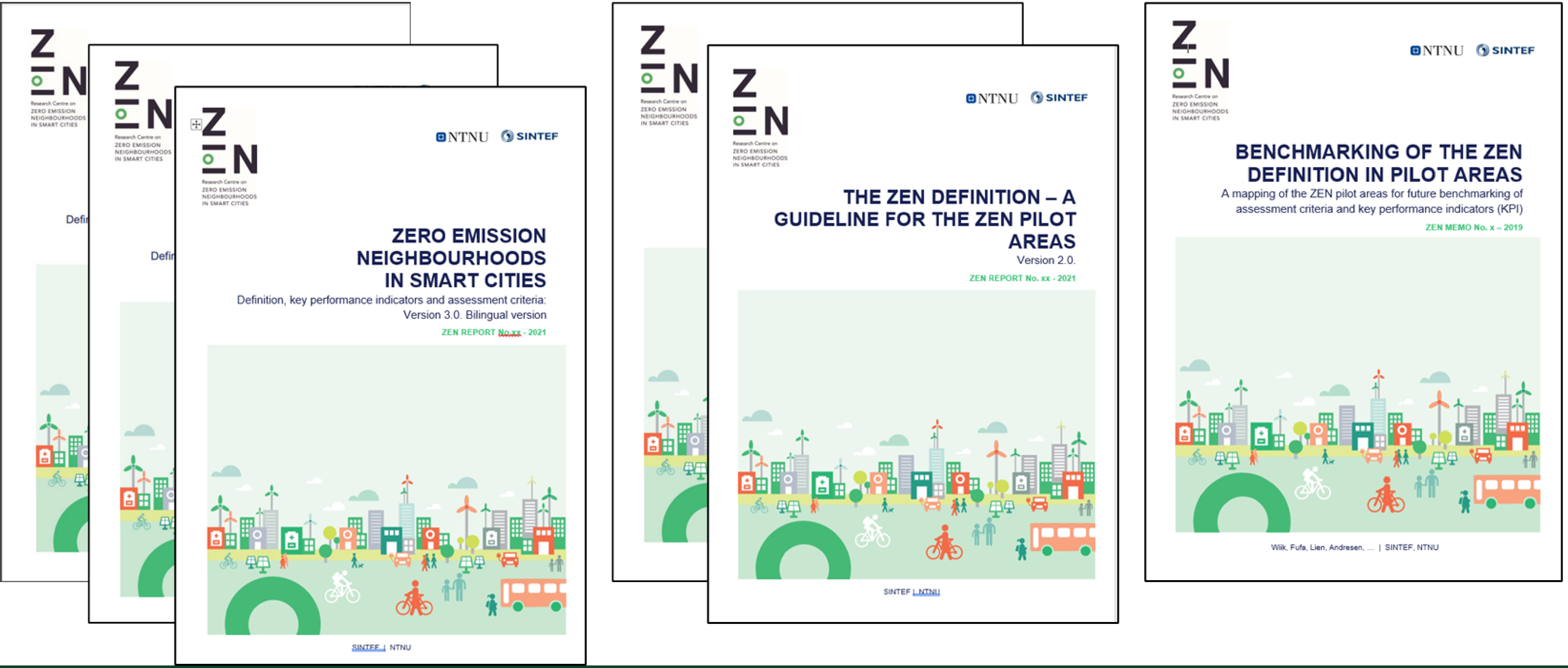
FLEXBUILD
The value of end-use flexibility in the future Norwegian energy system

- Primary objective: to provide knowledge on how end-use flexibility available in the building stock will impact the development of the overall energy system.

- Objective O2: Assess cost-optimal investment and operation of the energy system vs. the financial optimal operation of the private building owner, and address possible mismatch between the two



FME Zero Emission Neighborhoods in Smart Cities
ZEN definition



ZEN KPIs categories

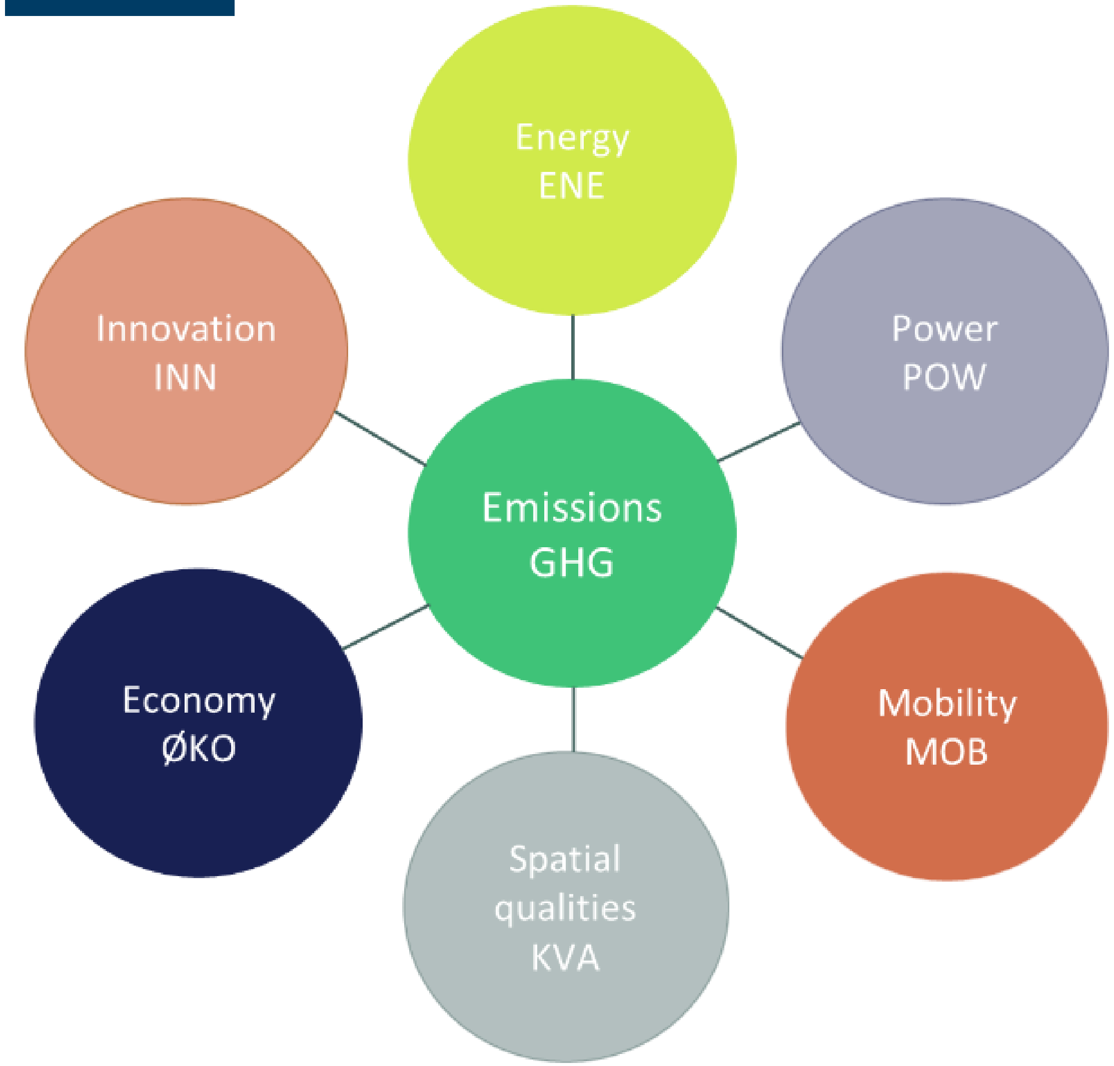


Table 2. ZEN assessment criteria and Key Performance Indicators (KPIs)

Category	Assessment criteria	KPI	Unit	Building (B), neighbourhood (N) or both (BN)	Standards & References	Strategic planning phase	Implementation phase	Operational phase
GHG	Emission reduction	GHG1.1 Materials (A1-A3, B4)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN	NS-EN 15978 (25), NS 3720 (26), NS 3457-3 (29), NS 3451 (27)	x	x	x
		GHG1.2 Clean construction (A4-A5)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
		GHG1.3 Environmental management plan (B1-B3, B5)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
		GHG1.4 Operational energy use (B6)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
		GHG1.5 Operational transport (B8)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
		GHG1.6 Circular neighborhoods (C1-C4)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
	Compensation	GHG1.7 Benefit and loads (D)	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	BN		x	x	x
ENE	Energy efficiency in buildings	ENE2.1 Energy need	kWh/m^2 heated floor area (BRA)/yr	B	SN/TS 3031 (30), ISO 52000 (31)	x	x	x
	Energy carrier	ENE2.2 Delivered and exported energy	kWh/yr	BN	SN/TS 3031 (30), ISO 52000 (31), IEA EBC Annex 52 (32), ZEN research centre (2)	x	x	x
		ENE2.3 Self-consumption and self-generation	%	BN		x	x	x
POW	Power performance	POW3.1 Peak load	kW	BN	Engineering praxis, ZEN research centre (2) IEA EBC Annex 67 (33)	x	x	x
		POW3.2Peak export	kW	BN		x	x	x
		POW3.3 Utilisation factor	%	BN		x	x	x
		POW3.4 Load flexibility				x	x	x
MOB*	Mode of transport	MOB4.1 Green mobility	% share	N	NS-EN 16258 (34), NS 3720 (26), CityKEYS 3.2.3 (9) BREEAM Communities TM01, TM04, TM06 (8)	x	x	x
	Access	MOB4.2 Access to public transport and city centre	Meters	N		x	x	x
		MOB4.3 Car ownership		N		x	x	x
		MOB4.4 Off-street parking		N		x	x	x
ECO*	Life cycle cost (LCC)	ECO6.1 Life cycle cost (LCC)	NOK NOK/m^2 heated floor area (BRA)/yr NOK/m^2 outdoor space (BAU)/yr NOK/capita	BN B N BN	NS 3451 (27), NS 3454 (35), NS-EN 16627 (36), ISO 15686-5 (37), Norsk prisbok (38)		x	x
QUA*	Process	QUA5.1 Demographic analysis	qualitative	BN	BREEAM Communities GO01, SE02 (8)	x	x	x
		QUA5.2 Stakeholder analysis		N		x	x	x
		QUA5.3 Needs assessment		N		x	x	x
		QUA5.4 Consultation plan		N		x	x	x
	Urban form	QUA5.5. Urban accessibility	No. of categories	N		x	x	x
		QUA5.6 Street connectivity	Distance	N		x	x	x
		QUA5.7 Land use mix	Share of residents	N		x	x	x
		QUA5.8 Centrality	Distance	N		x	x	x
INN**								

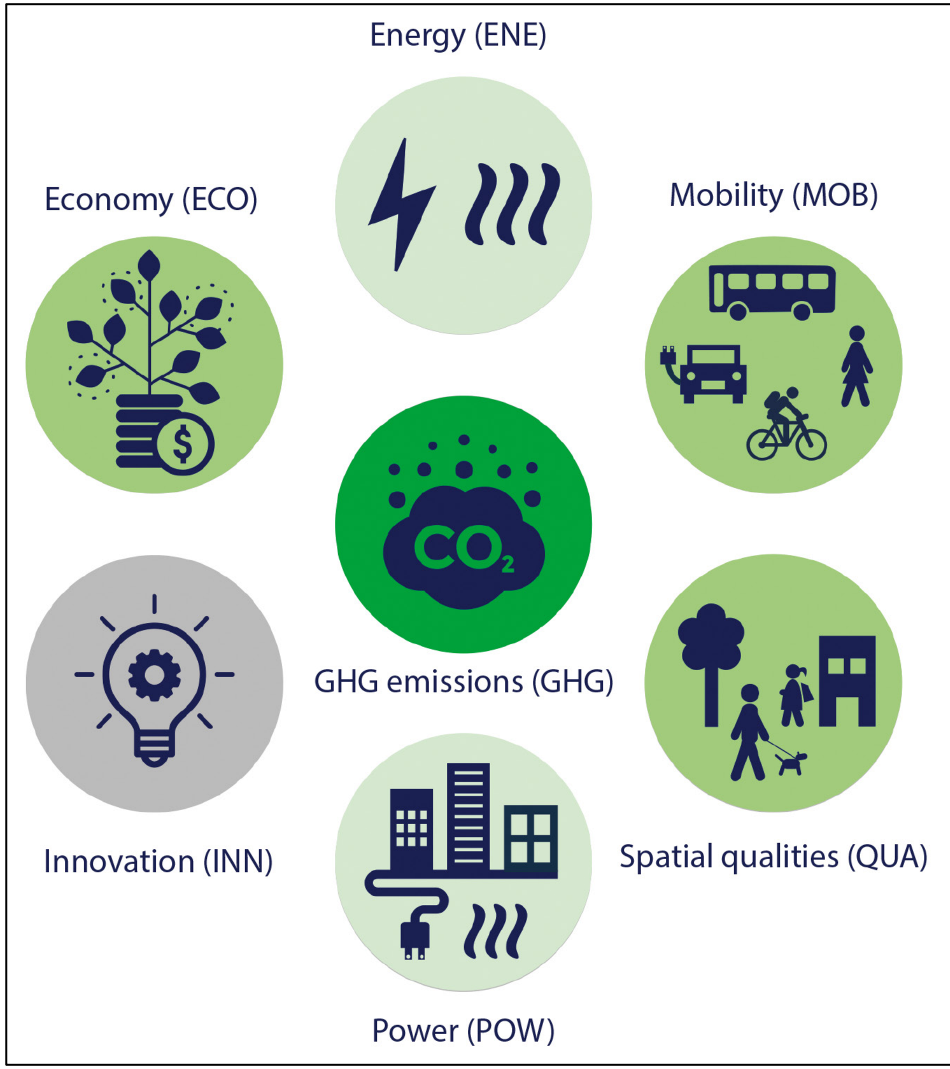
*These KPI's will be further developed in 2021

**Assessment criteria and KPI's for the innovation category can be measured both quantitative and qualitative. The metodh and KPI's will be further developed in 2021.

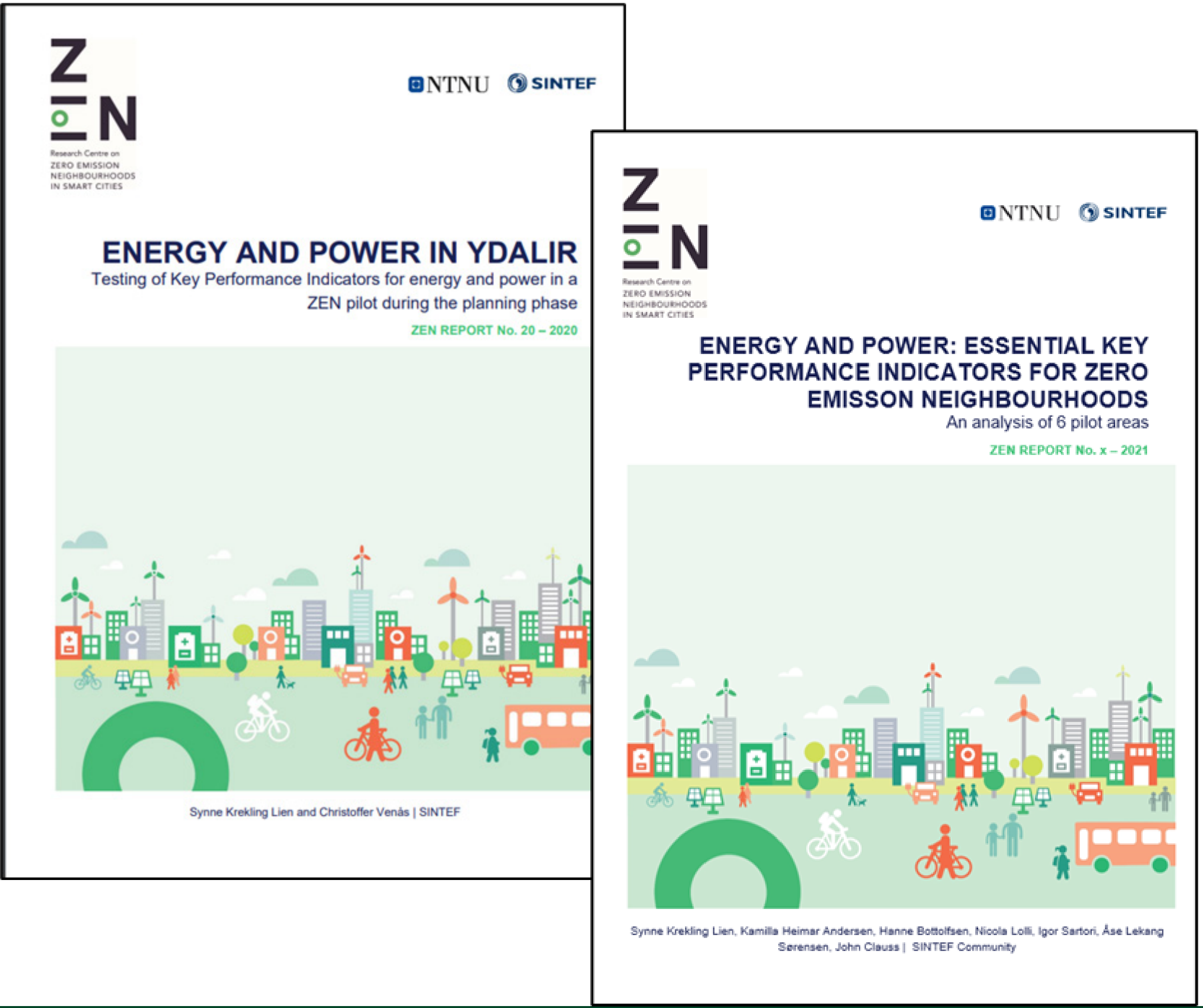
ZEN weighting system

- Evaluate the KPIs comparing two scenarios:
  - ➢ ZEN vs. Reference
- Assign dimensionless 'points' to each KPI
- Sum up according to a weighting system
  - ➢ Obtain an overall rating

ZEN category ratings	
Dark green	80-100%
Green	60-80%
Light green	40-60%
Grey	< 40%
Not assessed	-



ZEN KPIs for Energy and Power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ENERGY AND POWER IN YDALIR
Testing of Key Performance Indicators for energy and power in a ZEN pilot during the planning phase
ZEN REPORT No. 20 – 2020

Synne Krekling Lien and Christoffer Venås | SINTEF

ZEN
Research Centre on ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES
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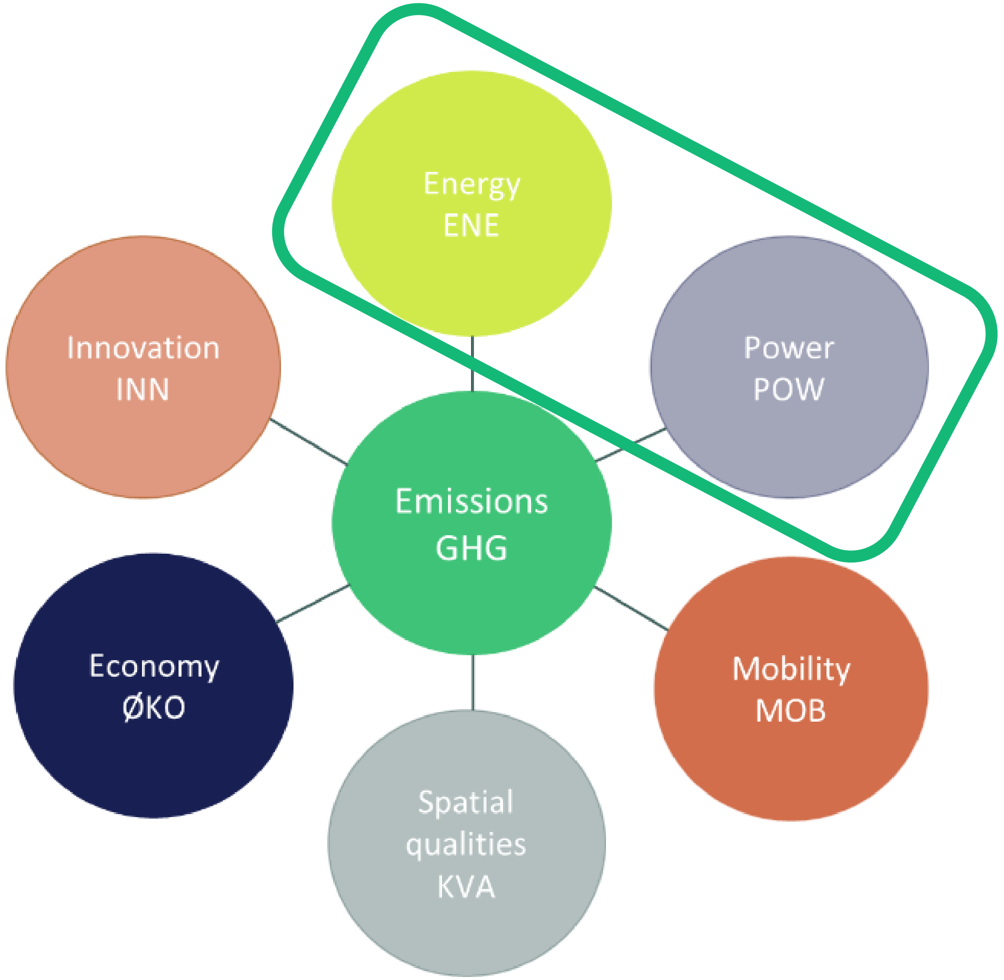
ENERGY AND POWER: ESSENTIAL KEY PERFORMANCE INDICATORS FOR ZERO EMISSON NEIGHBOURHOODS
An analysis of 6 pilot areas
ZEN REPORT No. x – 2021

Synne Krekling Lien, Kamilla Heimar Andersen, Hanne Bottolfsen, Nicola Lolli, Igor Sartori, Åse Lekang Sørensen, John Clauss | SINTEF Community



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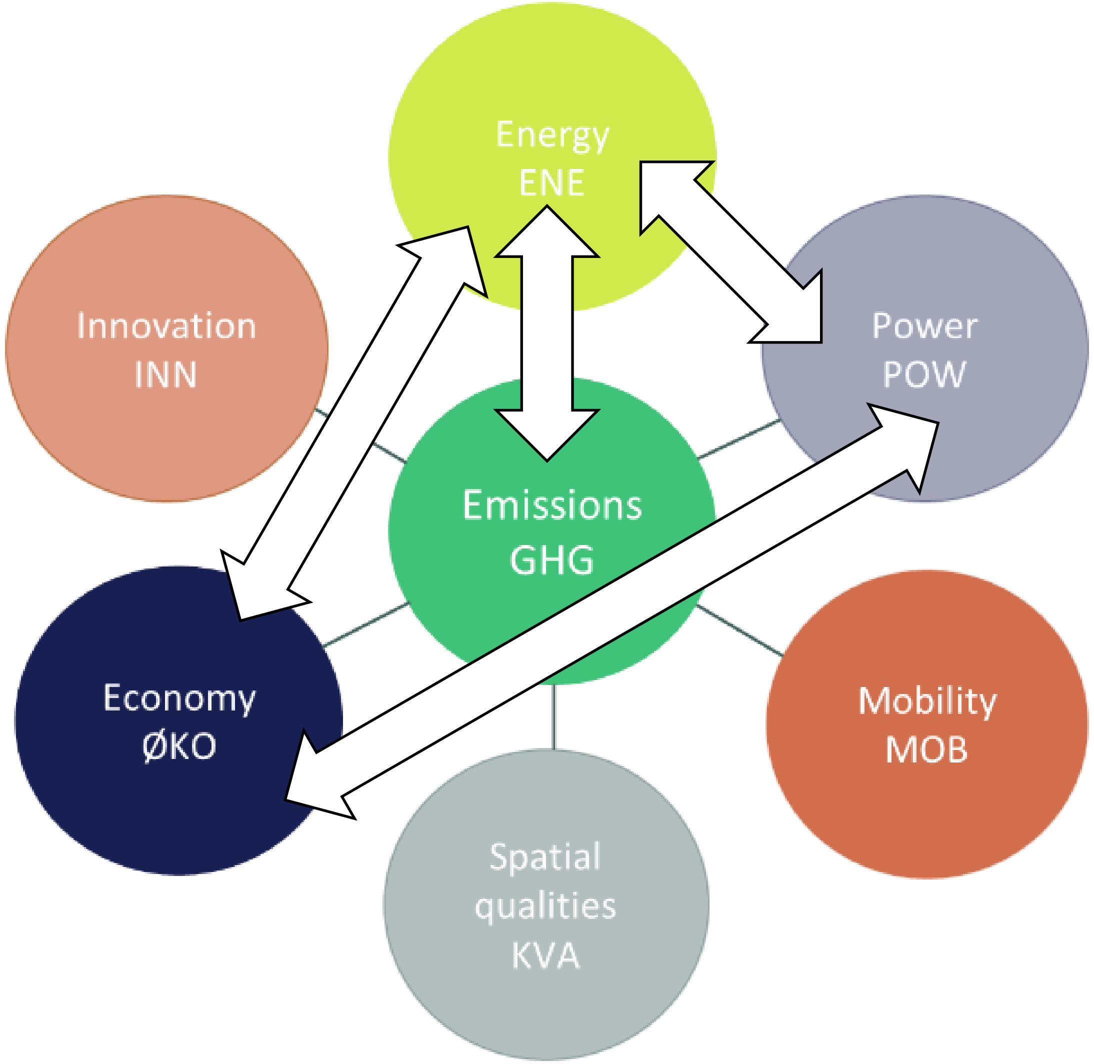
KPIs links

Some KPIs are linked and affect each other. Examples:

- Total electricity / district heating use (ENE) is input to calculation of both emissions (GHG) and operatinal cost (ØKO)
- Dimensioning peak load (POW) influences both energy use (ENE) – and thus GHG, indirectly – and capital/operational costs (ØKO)



Flexibility KPIs still missing
…and so the link to GHG emissions

	KPI	Unit		
ENE	ENE2.1 Energy need in buildings	kWh/m² heated floor area (BRA)/yr		
	ENE2.2 Delivered energy	kWh/yr for each energy carrier and total.		
	ENE2.3 Self-consumption and self-generation of electricity	%		
POW	POW3.1 Peak load	kW	BN	Engineering practices, ZEN research centre [1], IEA EBC Annex [5]
	POW3.2 Peak export	kW	BN	
	POW3.3 Utilisation factor	%	BN	
	POW3.4 Load flexibility	Currently not developed.		

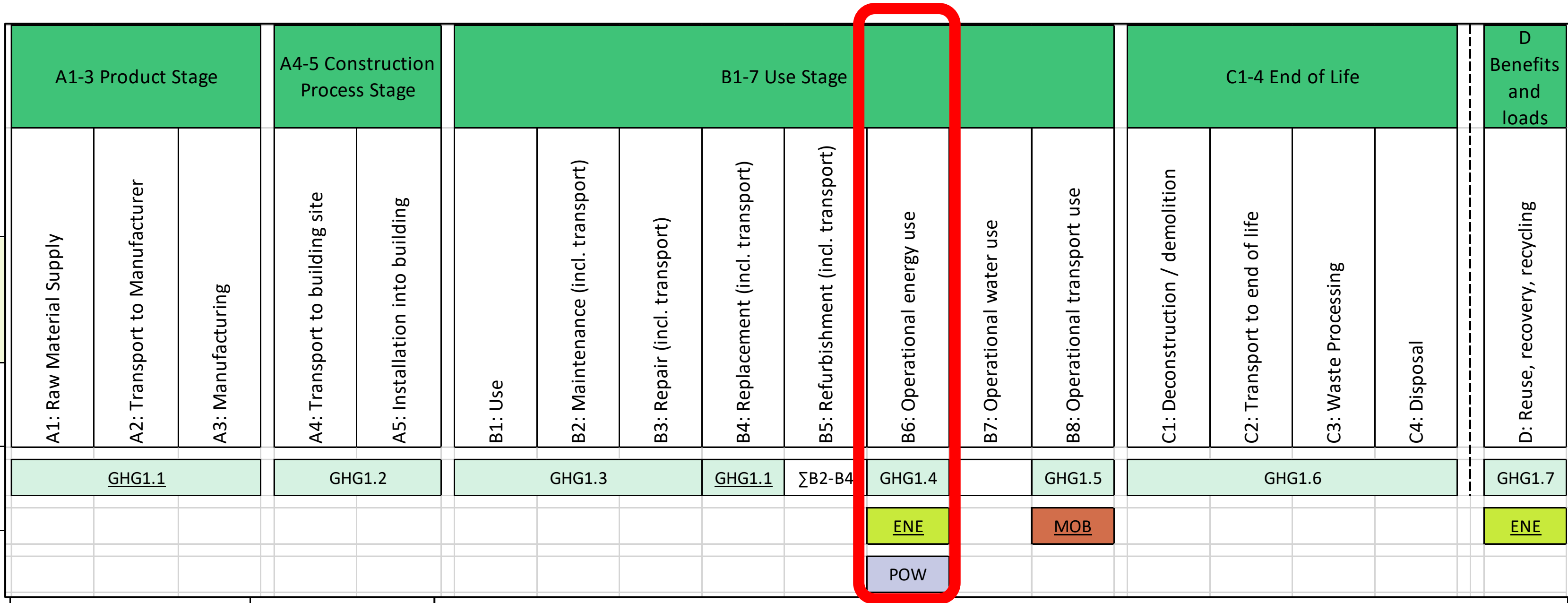


Figure 3. An overview of GHG KPIs per life cycle of buildings and infrastructure. Results from the Energy, Power and Mobility categories will feed into KPIs GHG1.4, GHG1.5 and GHG1.7, respectively

ZEN Report No. xx - 2021
ENERGY AND POWER: ESSENTIAL KEY PERFORMANCE INDICATORS FOR ZERO EMISSON NEIGHBOURHOODS -An analysis of 6 pilot areas

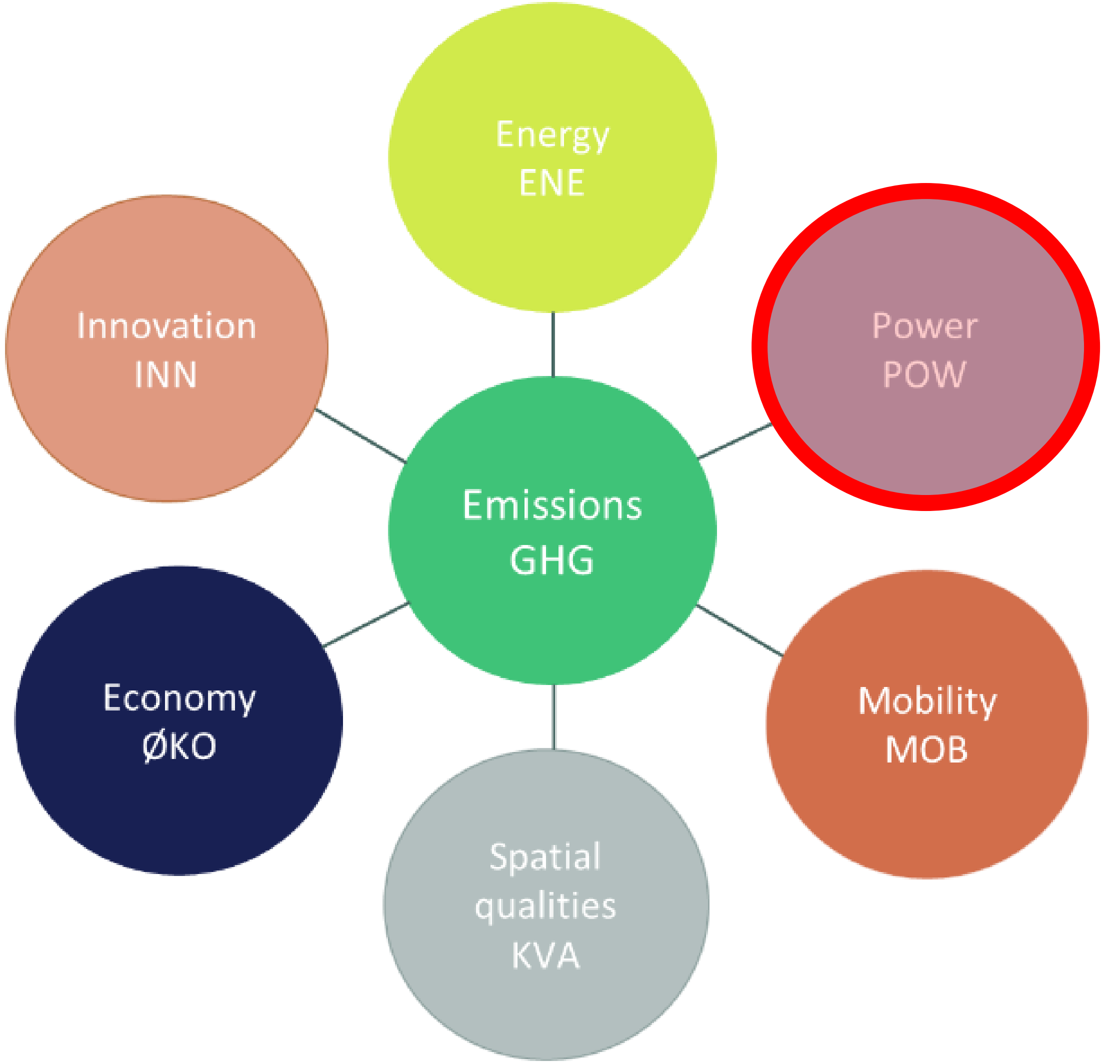
ZEN Report No. 32 - 2021
ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES
Definition, key performance indicators and assessment criteria: Version 2.0

The Workshop today

- PART 1: **Flexibility KPIs** *per se*
- PART 2: Flexibility KPIs ***links*** with
  - end-user and energy system perspectives (Flexbuild goal)
  - GHG emissions/Economy KPIs (ZEN definition)
    - Which is the hardest to tackle

PART 1

Flexibility KPIs *per se*



Flexibility KPIs workshop

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(a) Definition of Energy Flexibility of buildings

- S.Ø. Jensen *et al.*, IEA EBC Annex 67 Energy Flexible Buildings, Energy and Buildings 155 (2017) 25–34 (http://dx.doi.org/10.1016/j.enbuild.2017.08.044):

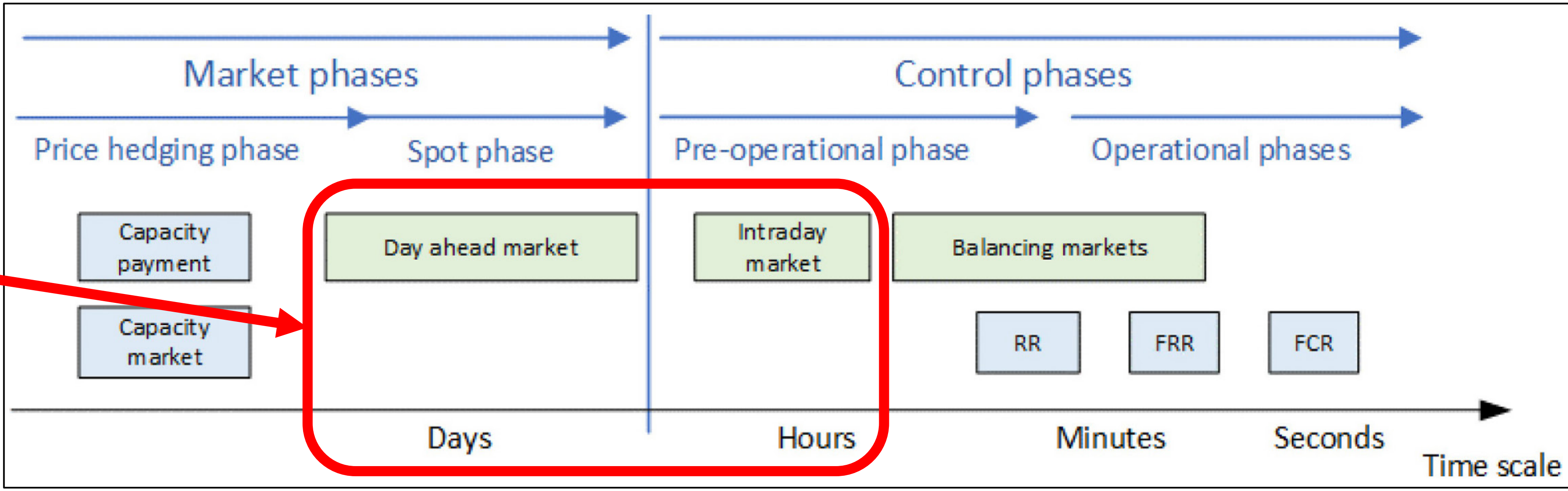
The Energy Flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs, and energy network requirements.

Timing for Energy Flexibility of buildings

- M.Z. Degefa, I.B. Sperstad and H. Sæle, Comprehensive classifications and characterizations of power system flexibility resources, Electric Power Systems Research, 194 (2021) 107022 (https://doi.org/10.1016/j.epsr.2021.107022):

Table 1
Necessary criteria for definition of flexibility.

Scope	Criteria	Description
#1	Type of flexibility resource	The definition enough to enc flexibility, bot generation, sto (transmission,
#2	Duration of activation of flexibility	Activation for one second up need in the po include more efficiency (for measures).
#3	Incentive for activation of flexibility	Flexibility is a signal. This is some resource sake but not re An example is self-consumpti offering servic



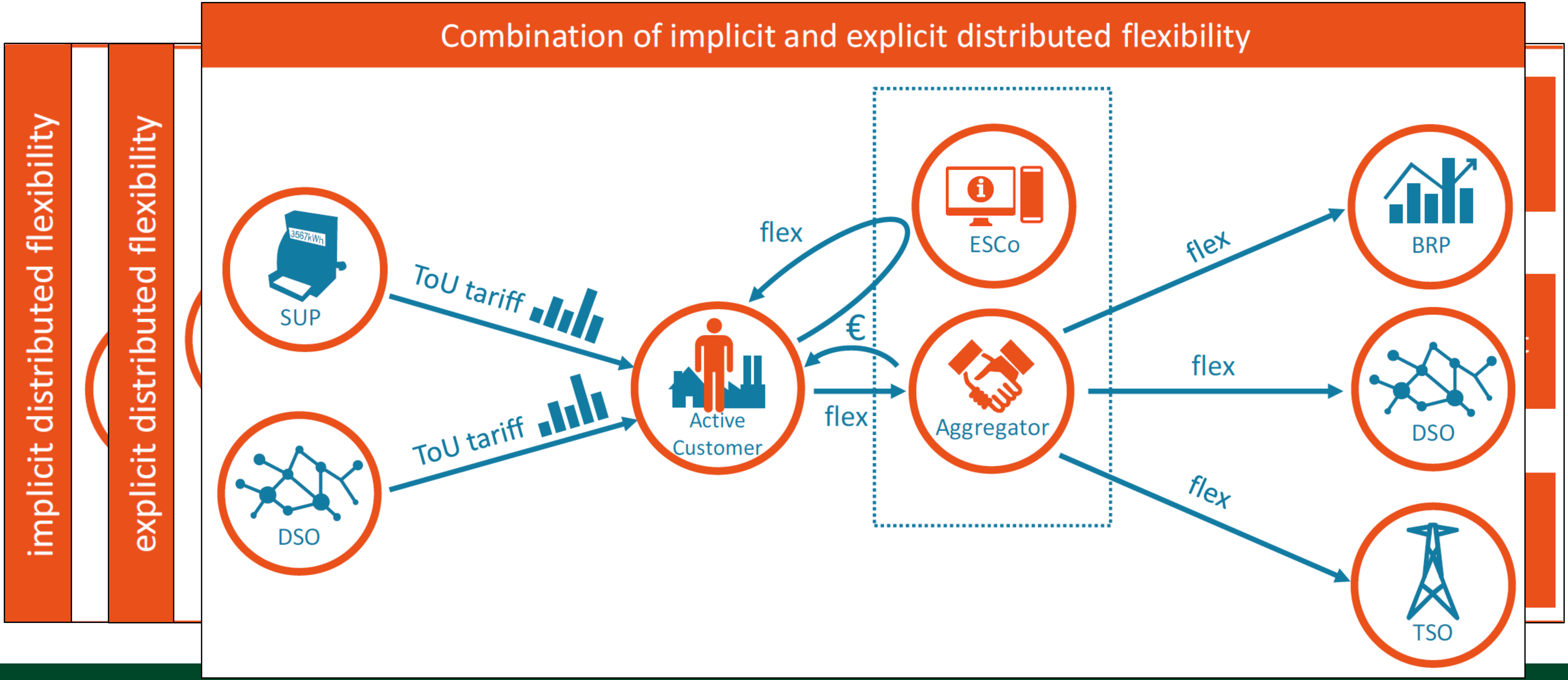
Energy flexibility in FME-ZEN and Flexbuild

- Energy flexibility is the ability of a building/neighborhood to manage its demand, storage and local generation to respond to external signals, while safeguarding user needs and comfort
- It results in load profiles on the grid that deviate from typical ones
- A large amount of flexibility is intrinsically available in the buildings' thermal mass and existing equipment, such as heat storage and the charging of EV (that mostly happens in buildings)
- Lacking automated control applications that exploit these flexibility sources

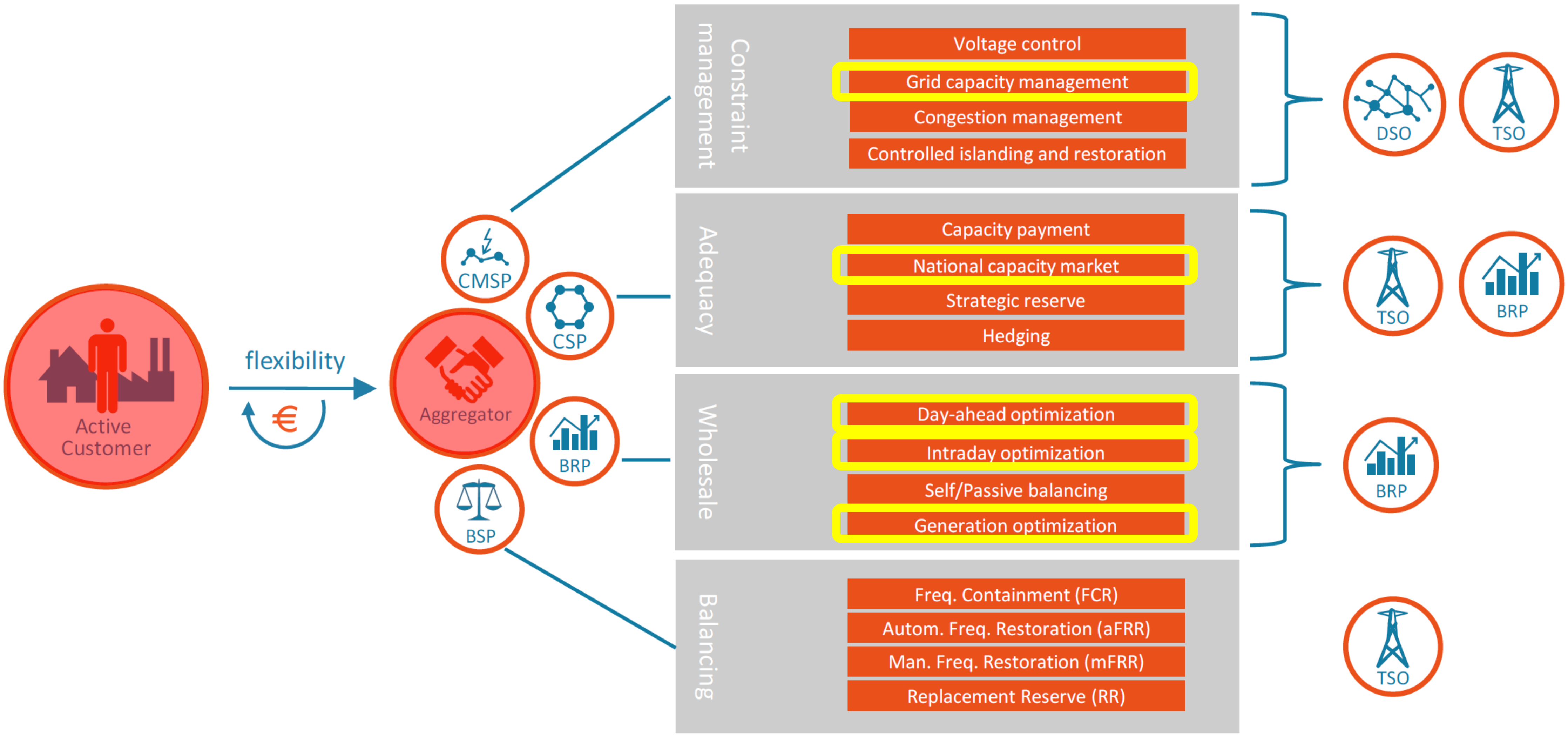
Flexibility value chain

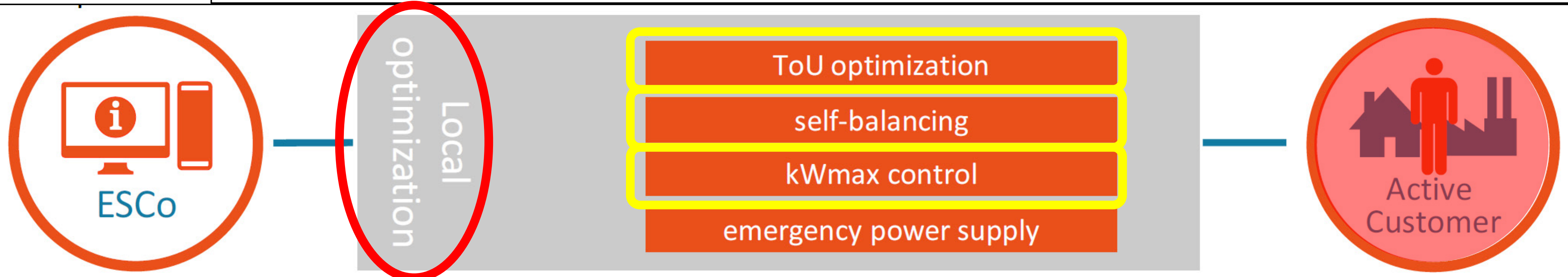
- Some examples to get the context…

Flexibility value chain



[USEF: The Framework Explained]





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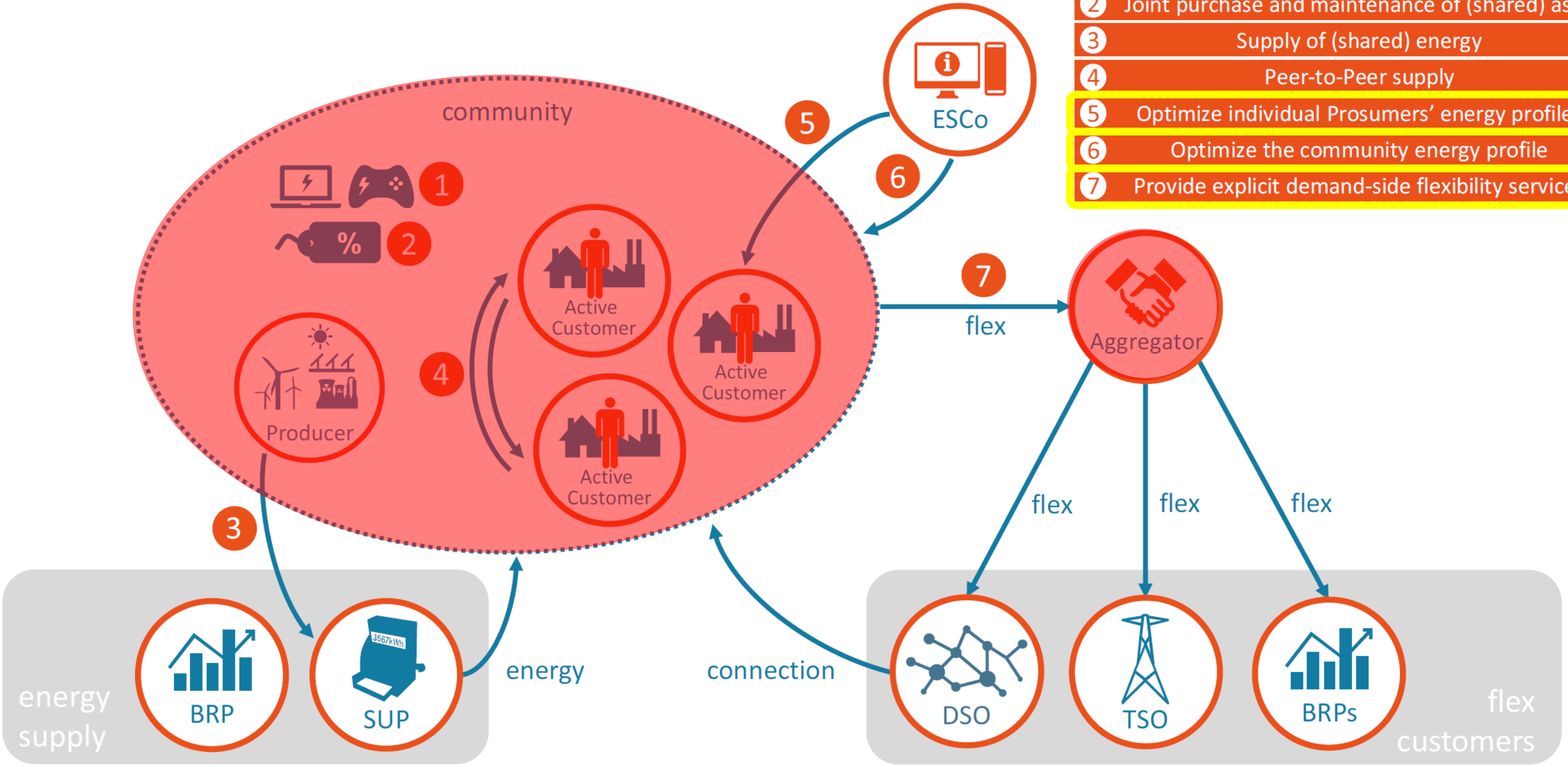
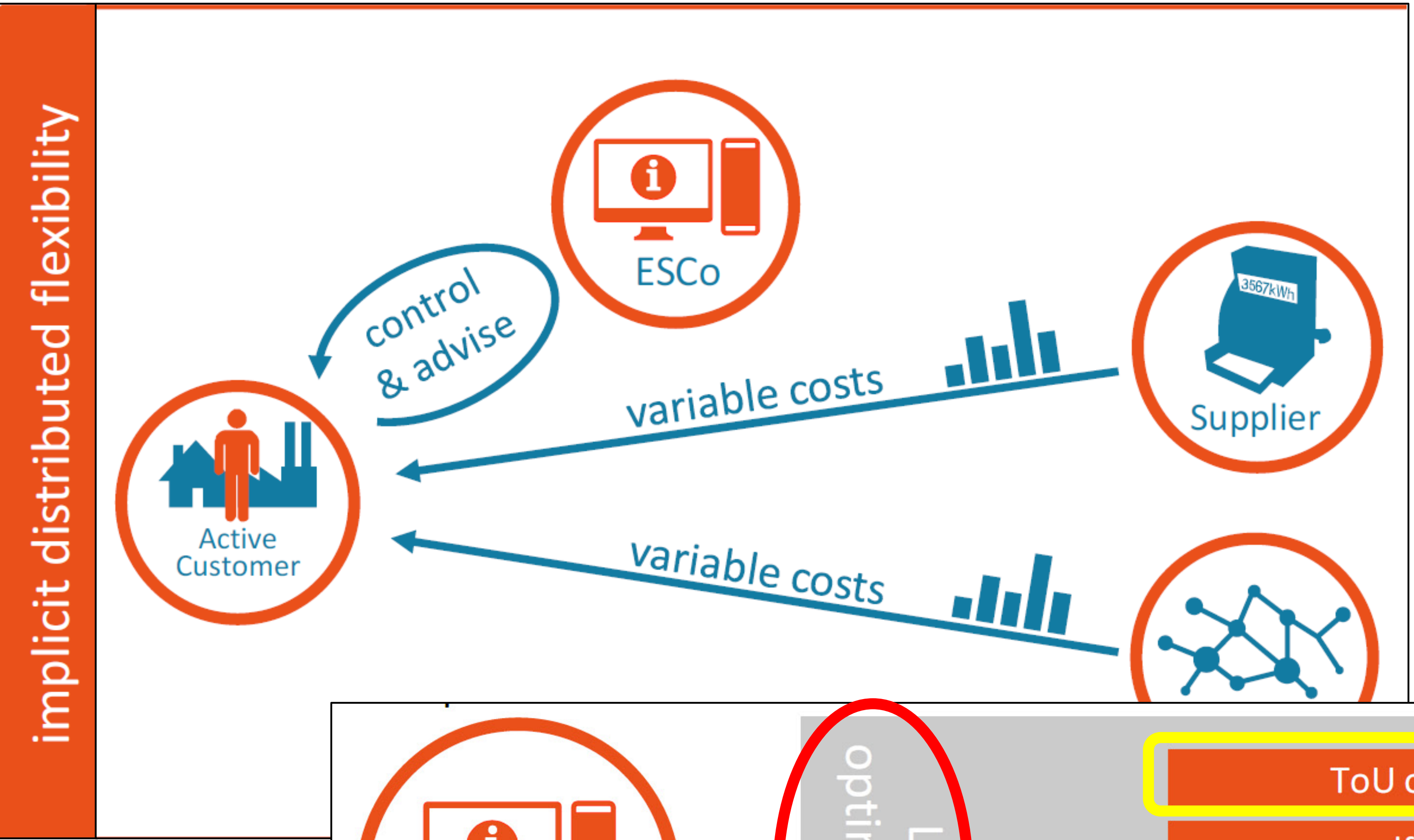
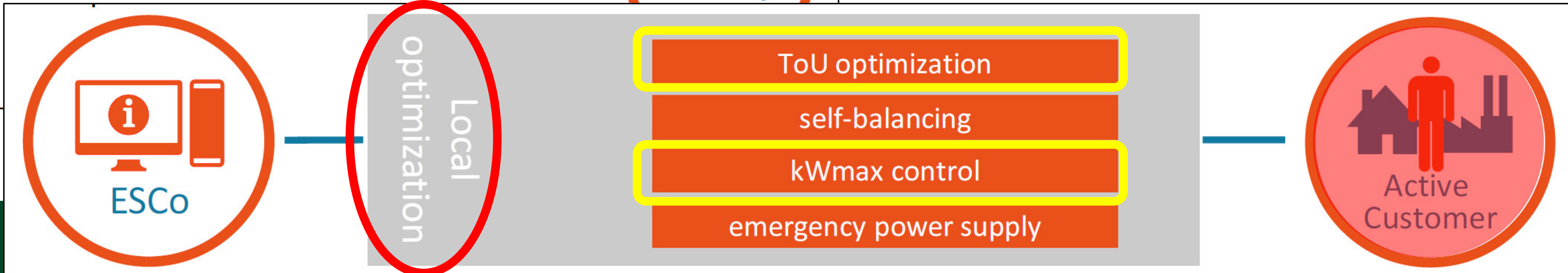
etter society

1. Services to increase energy awareness
2. Joint purchase and maintenance of (shared) assets
3. Supply of (shared) energy
4. Peer-to-Peer supply
5. Optimize individual Prosumers' energy profiles
6. Optimize the community energy profile
7. Provide explicit demand-side flexibility services



Examples we will see today





Energy flexibility of buildings (and neighborhoods)
Characteristics of interest for us

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- Focus on the on the effects of flexibility, not on the characteristics of flexibility itself

- Flexibility is:
  - activated in response to external signals in a predictive way (not reactive)
  - used to schedule optimal operation in pursue of different goals
  - suitable for aggregators operating in day-ahead/intraday market

- …could also be called dispatchable demand

Flexibility KPIs workshop

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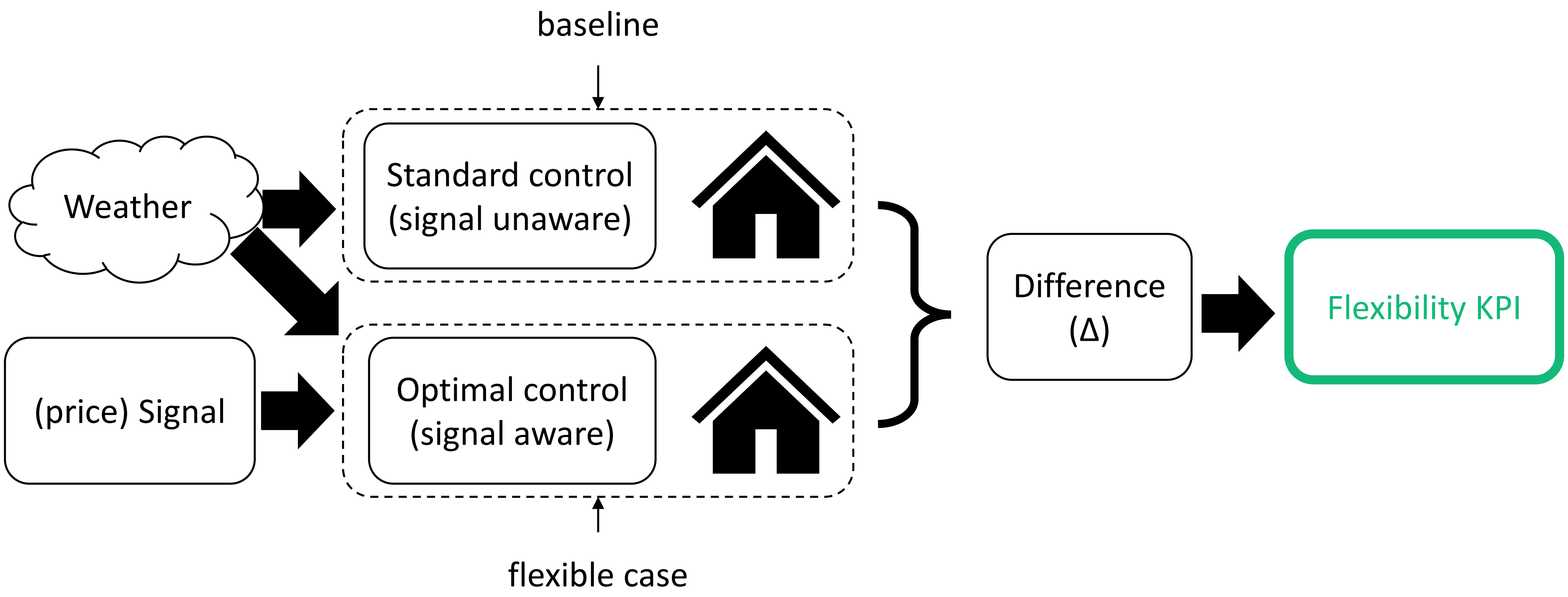
Flexibility KPIs
Methodology sketch

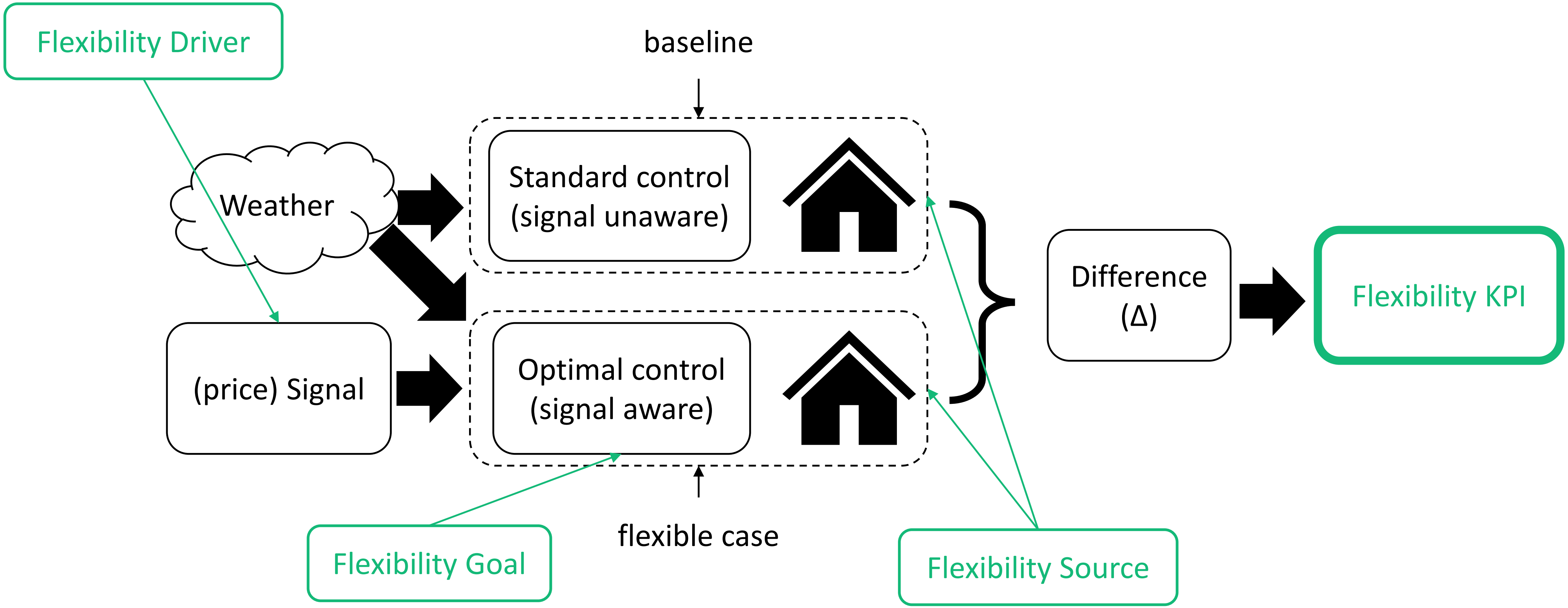


Proposed Flexibility KPIs

- Δ Energy
- Δ Cost
- Δ Energy Stress hours (Energy shifted)
- Δ Peak

- All given in % variation from the baseline

Flexibility KPIs
Methodology sketch



Flexibility sources, drivers, goals

Flexibility Source	Domestic Hot Water (DHW)	Space Heating (SH)	Electric Vehicle (EV)	All together

Flexibility Driver	Energy price		+ Grid tariff	
	Spot Price	Time of Use	Energy Pricing (EP) - *energiledd*	Peak Power Monthly (PPM) - *effektledd*

Flexibility Goal	(operational) Cost minimization (for the user)	Flat profile (as possible, containing losses)

Optimization based only on physical values of Energy and Power, completely independent from energy price and grid tariff

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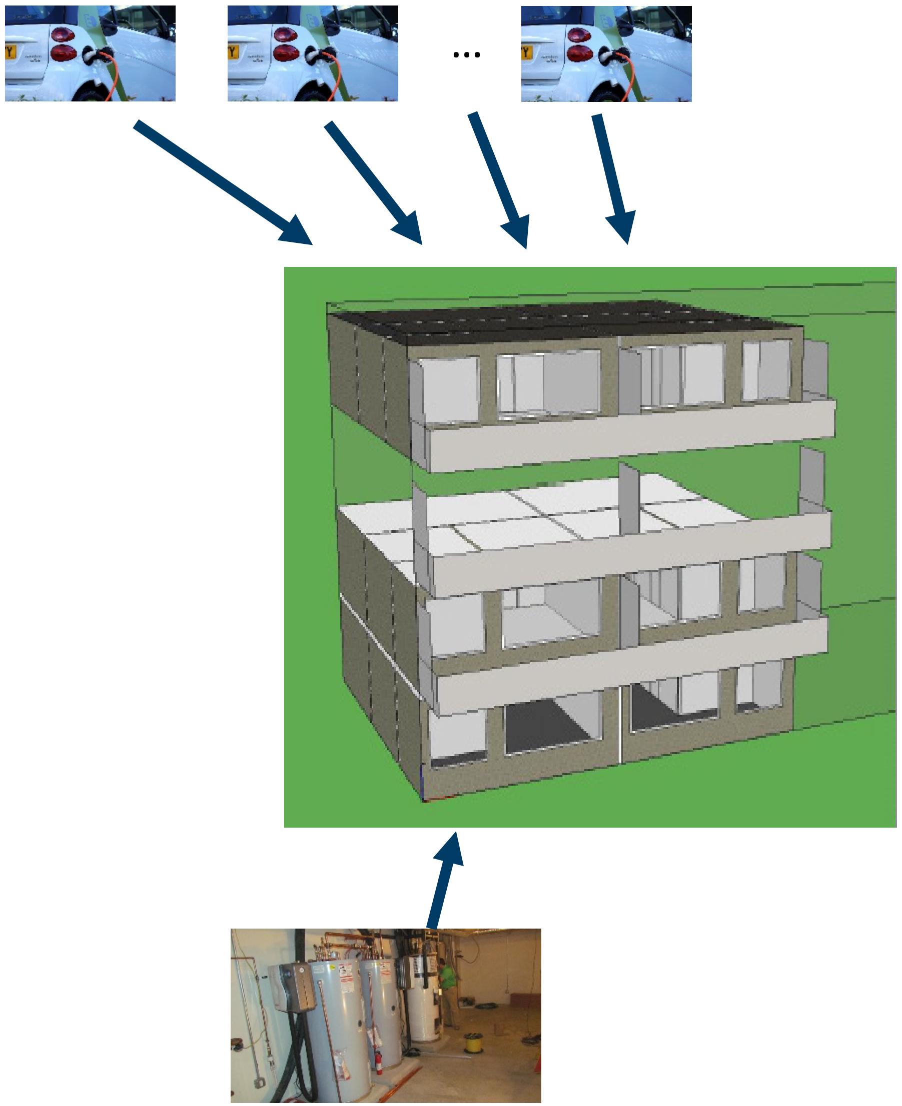
Case 1: Apartments block

- 24 apartments, 1672 m^2
- Regular, as in the stock
- Heating: Electric panels
- **Flexibility sources**:
  - DHW tank
  - Space Heating
  - EV (10 EVs → 0.4 EV per household)

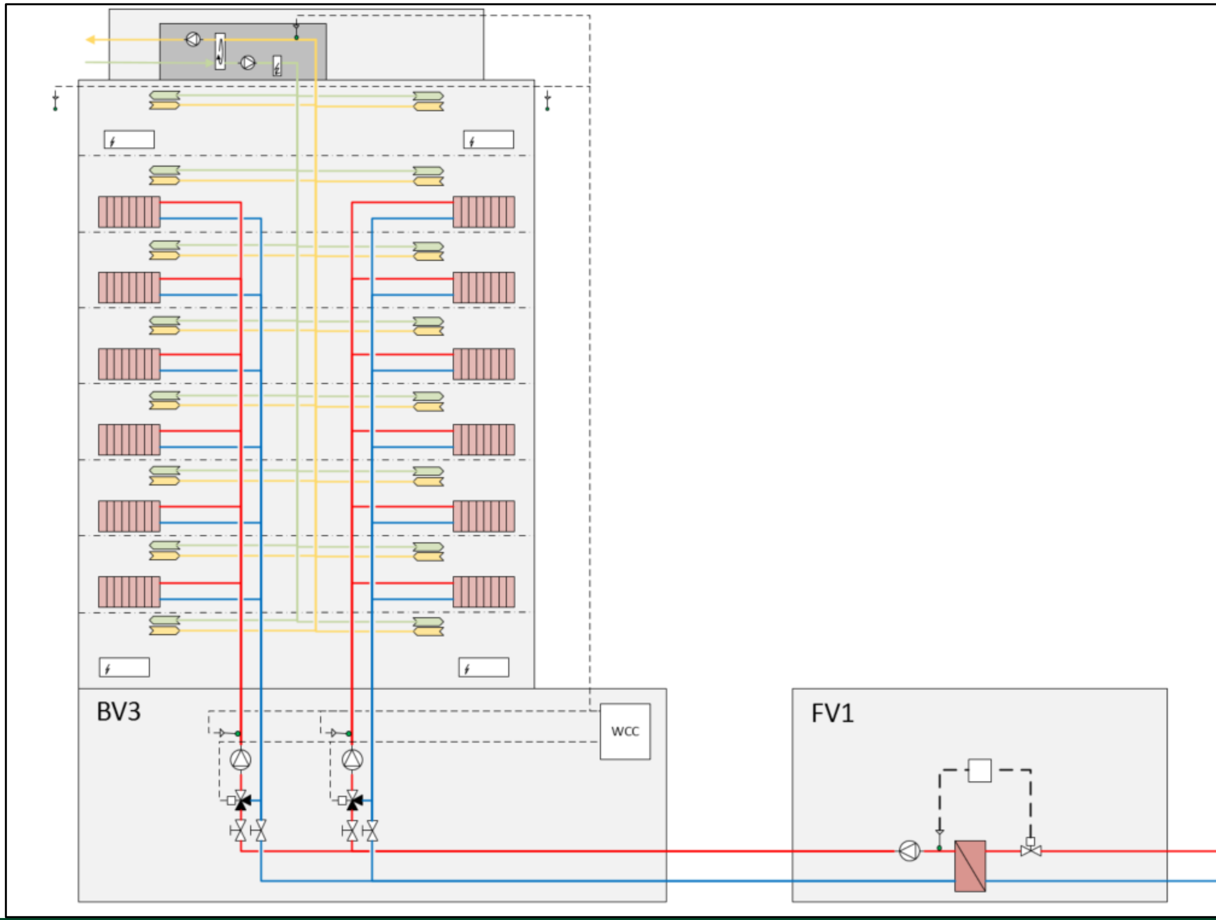


Case 2: Office building

- Efficient, ca. TEK10
- Electric heater in ventilation, CAV
- Waterborne heating

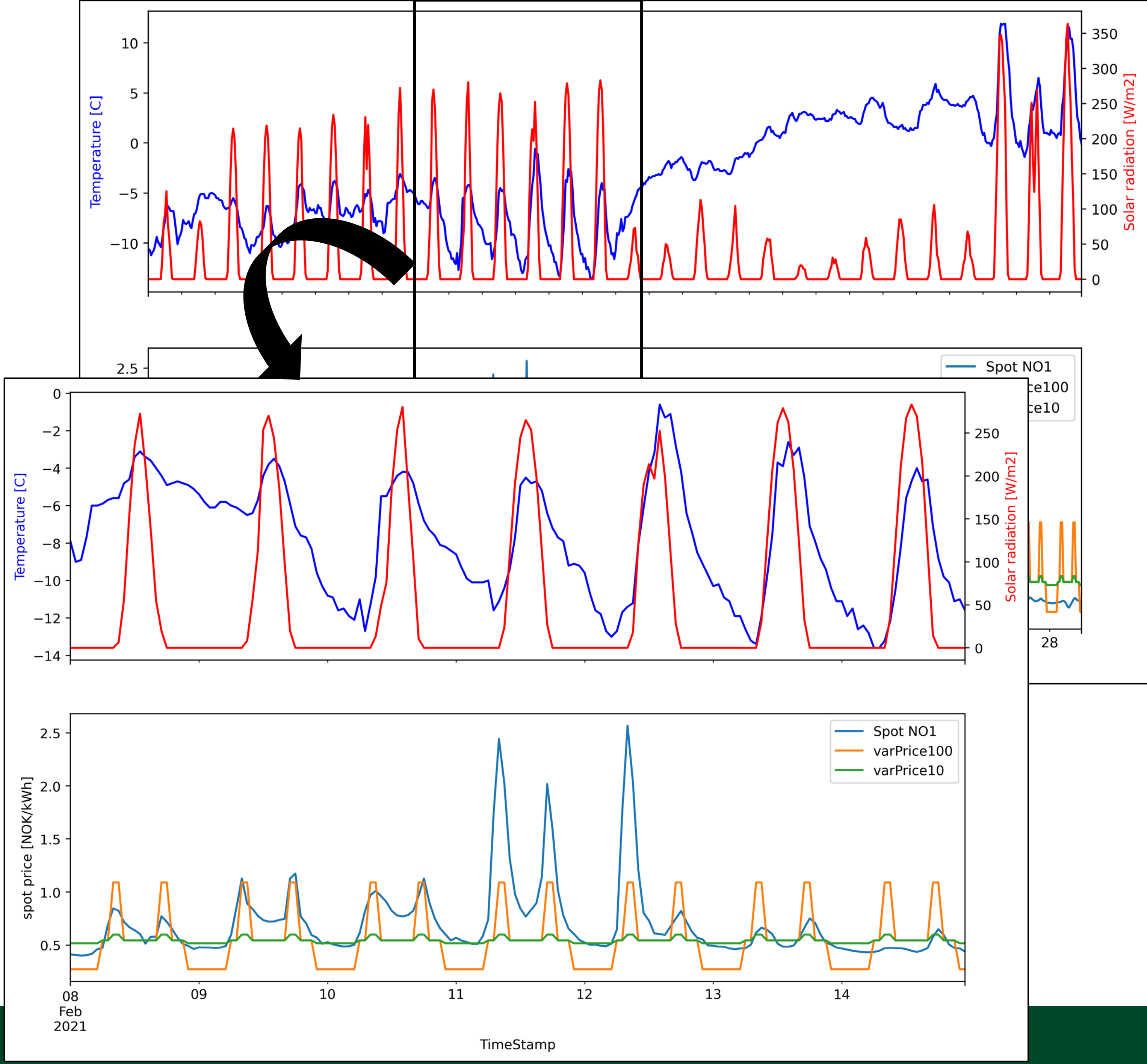
- Heating: Ground Source Heat Pump + Electric Boiler

- **Flexibility sources**:
  - Space Heating



Inputs

- February 2021
- Weather from Oslo/Blinders
- Spot price for NO1
- Time of Use price
  - Three levels: High, medium, low
  - High = Medium + 50%
  - Same shape every day
  - Daily average = spot monthly average



Baseline

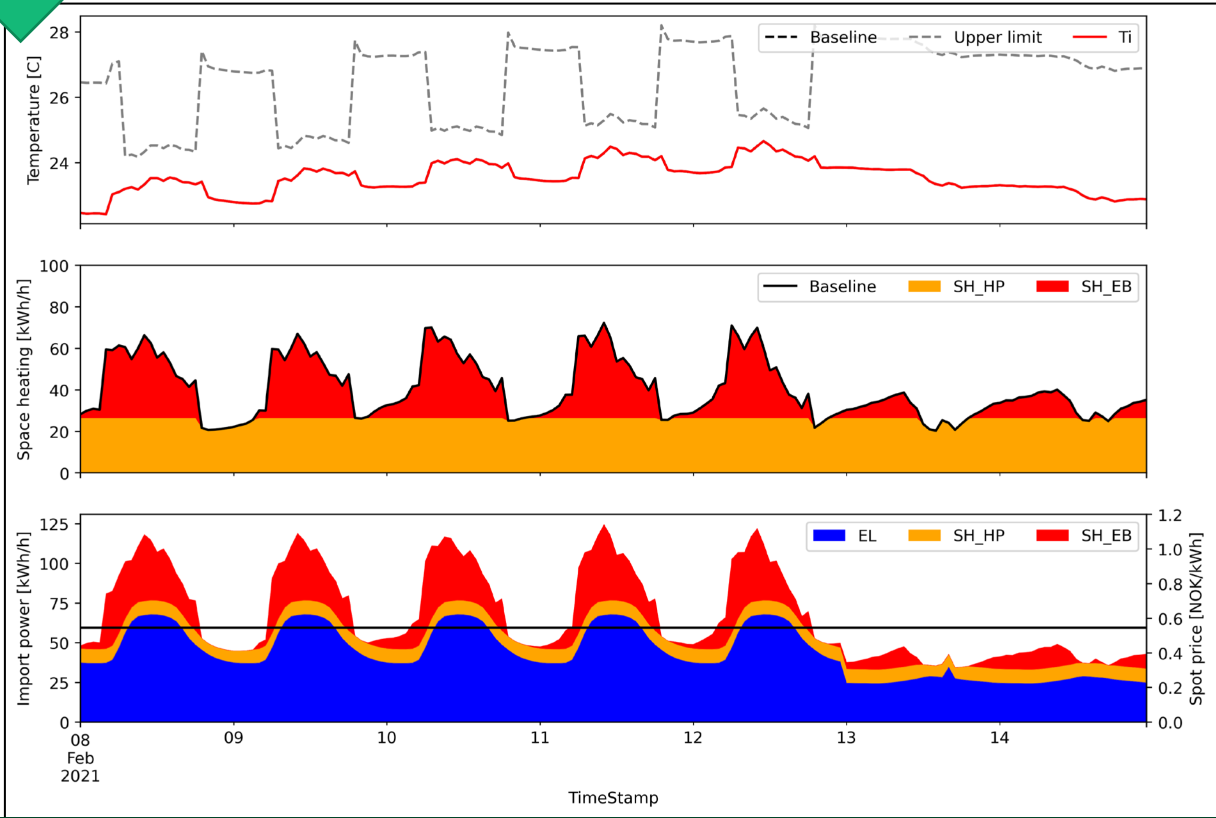
N.B. this is a 'proxy' indoor temperature in the model; it is NOT the same as the real indoor temperature in the building.
The important is to look at its variations!

Apartment block:

- Typical load profiles from PROFet tool (energy demand load profile estimator)

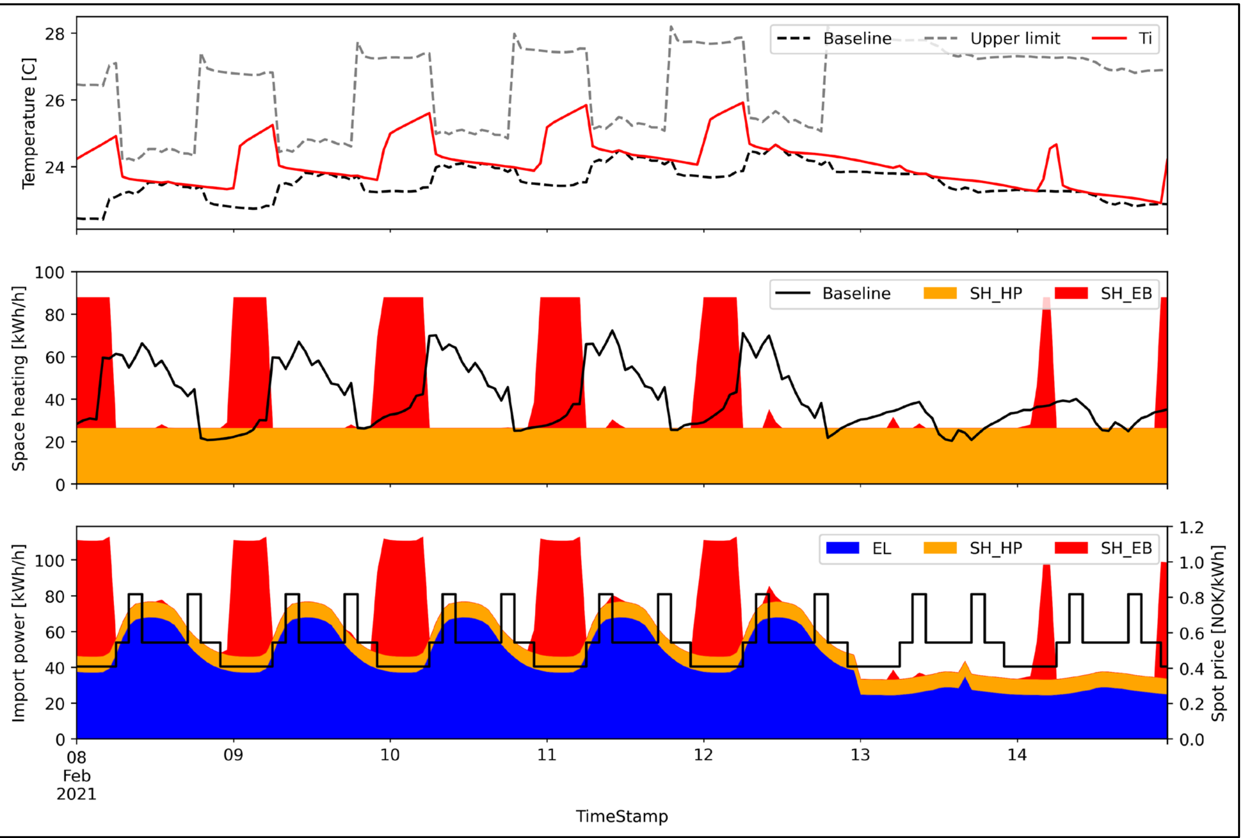
Office Building:

- Building model with WCC (Weather Compensation Curve): when it is colder the water to the radiators gets warmer → as real building

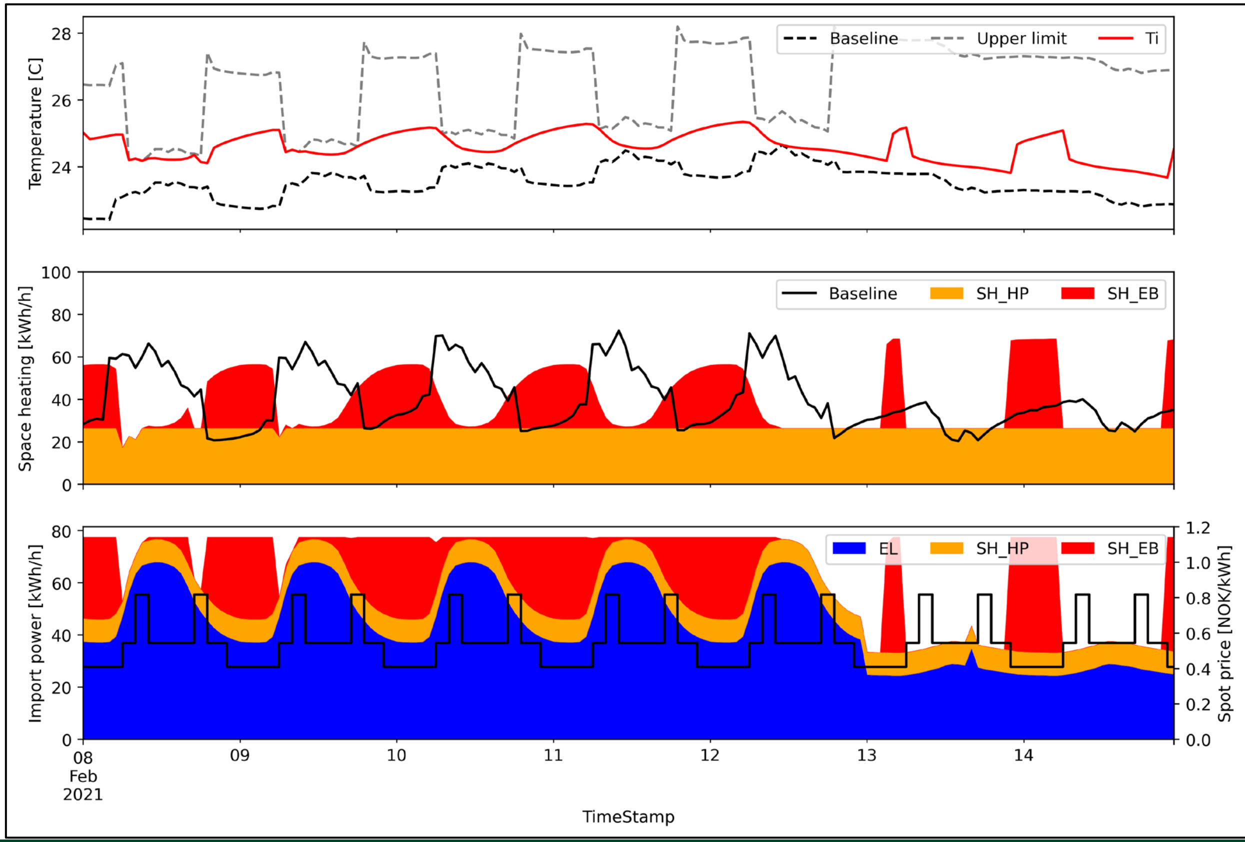


Flexibility activation
Office building – Space Heating – Cost minimization

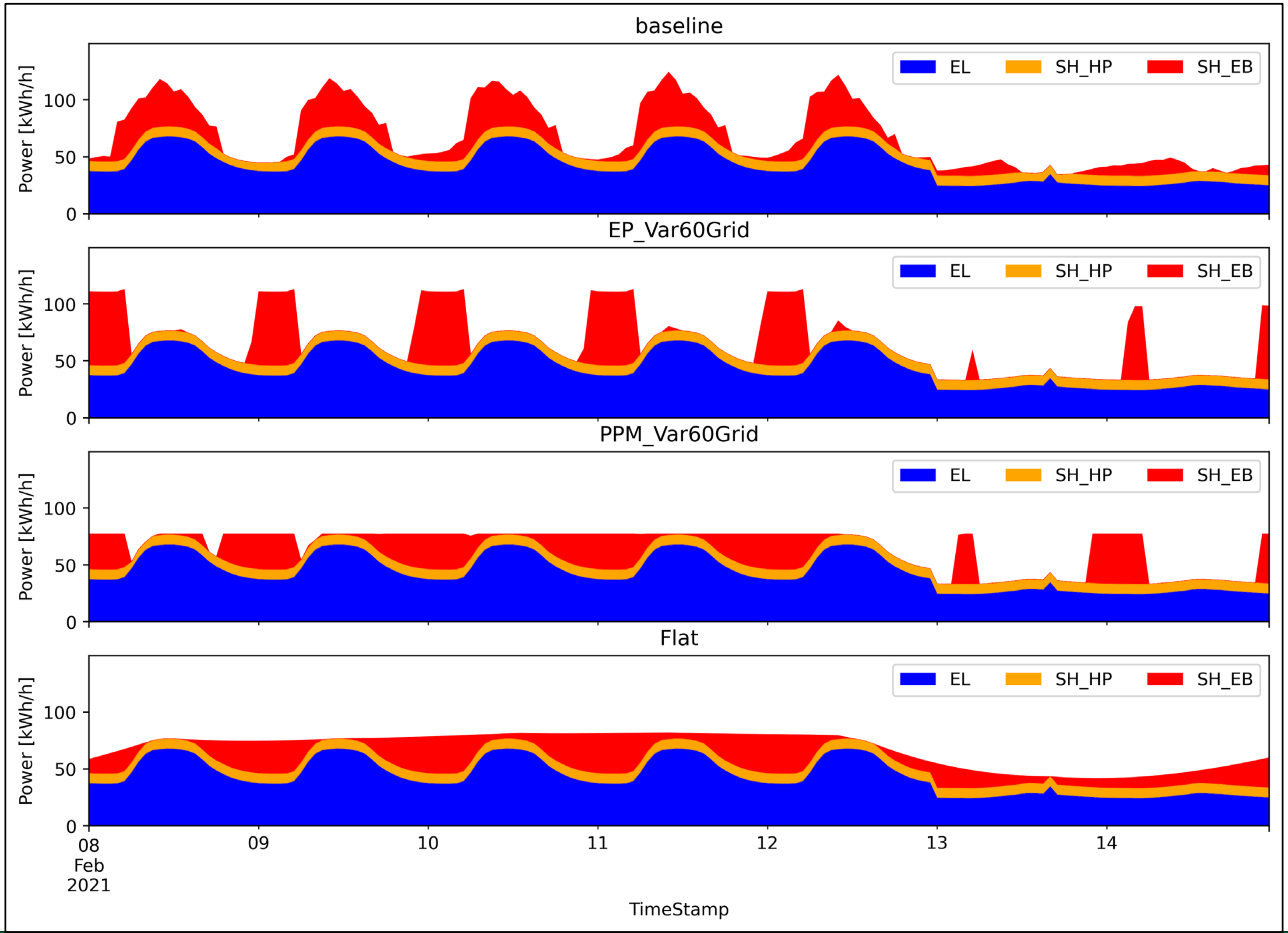
Energy Pricing (EP)



Peak Power Monthly (PPM)

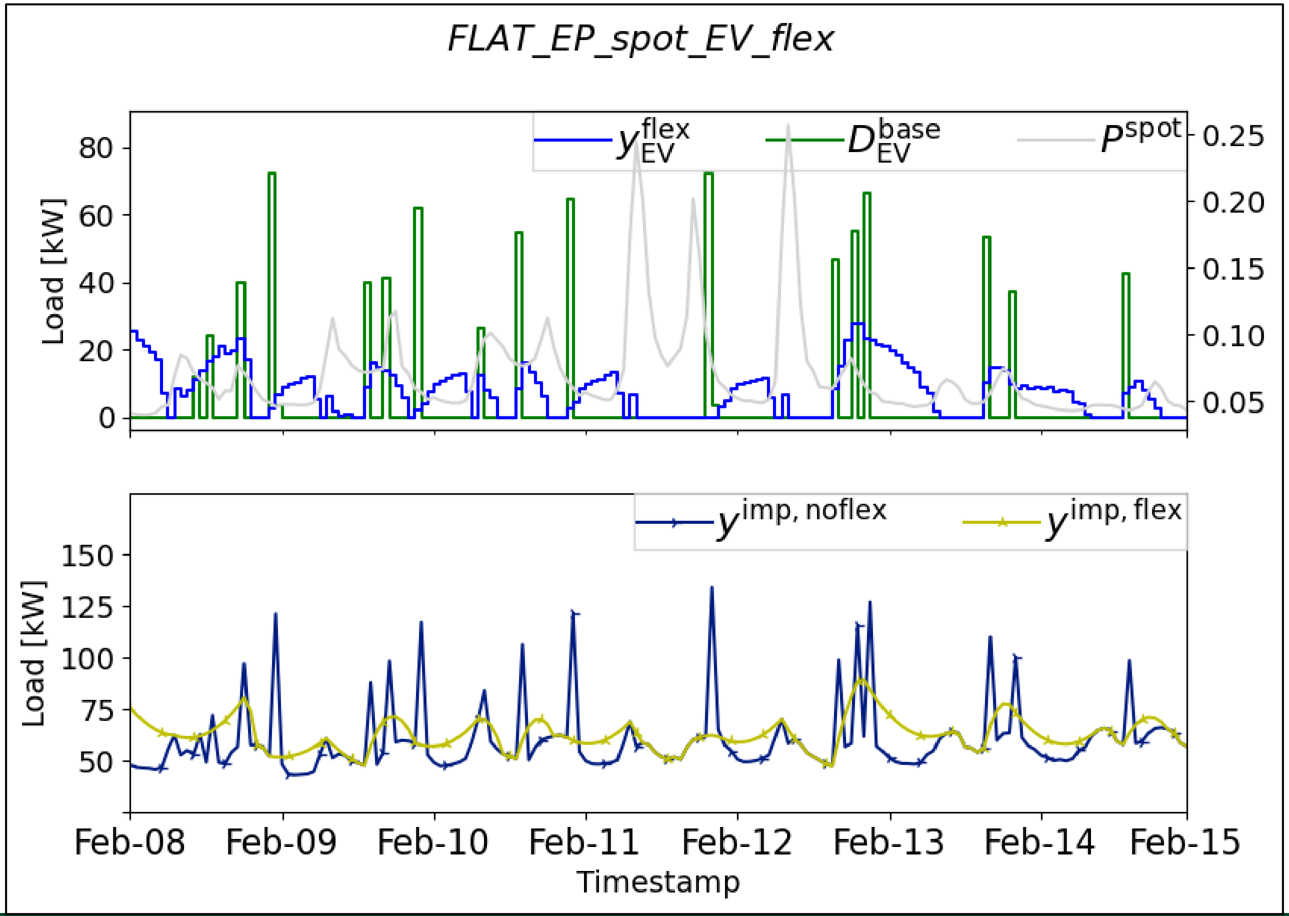


Different ways of activating Space Heating flexibility Office building

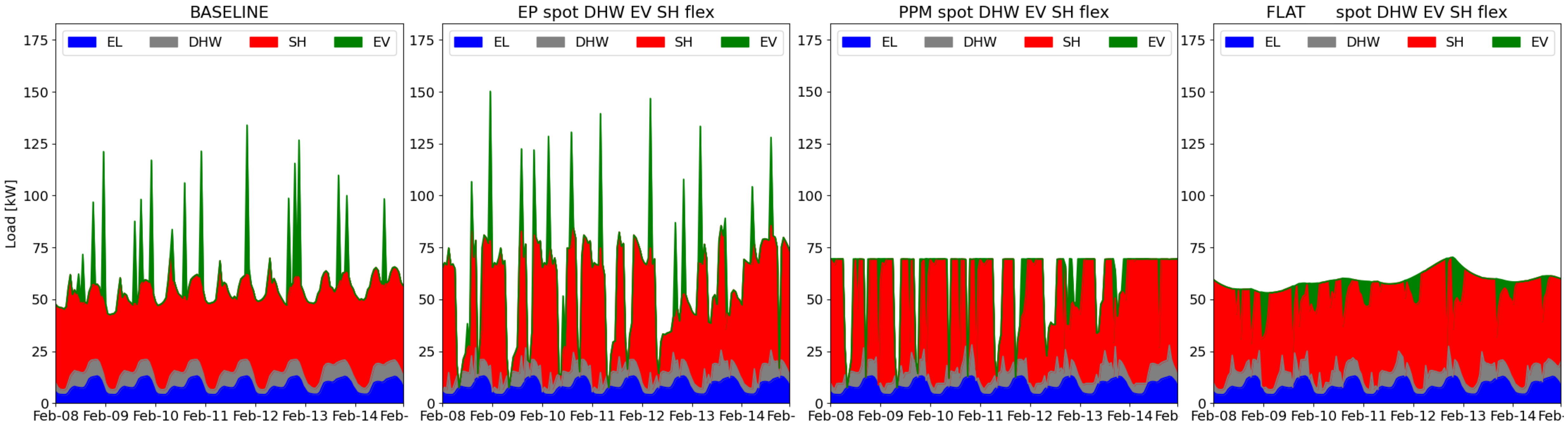


Flexibility activation
Apartment block – Electric Vehicle – Flat profile

EV optimization, when other loads are non-flexible



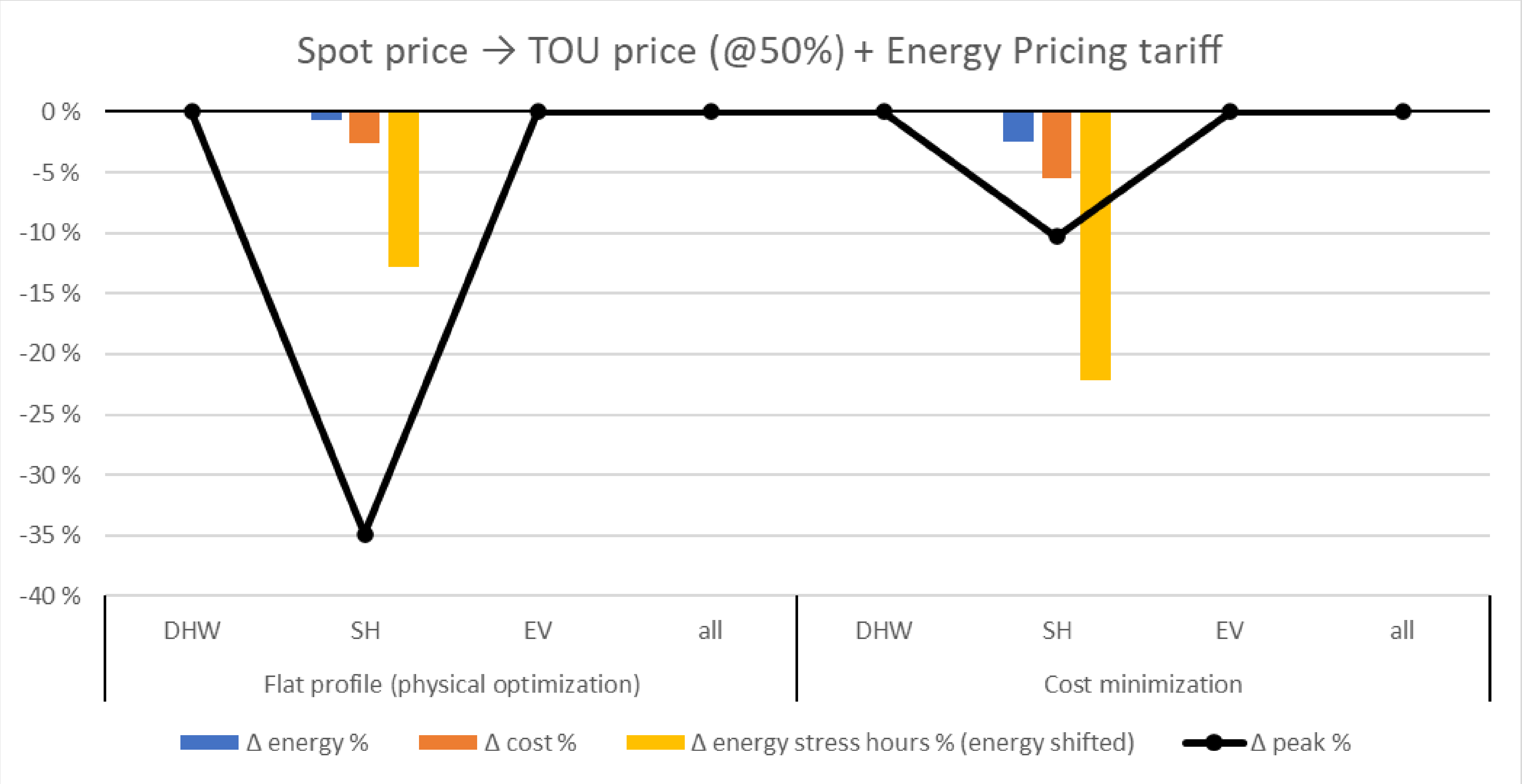
Different ways of activating flexibility
Apartment block



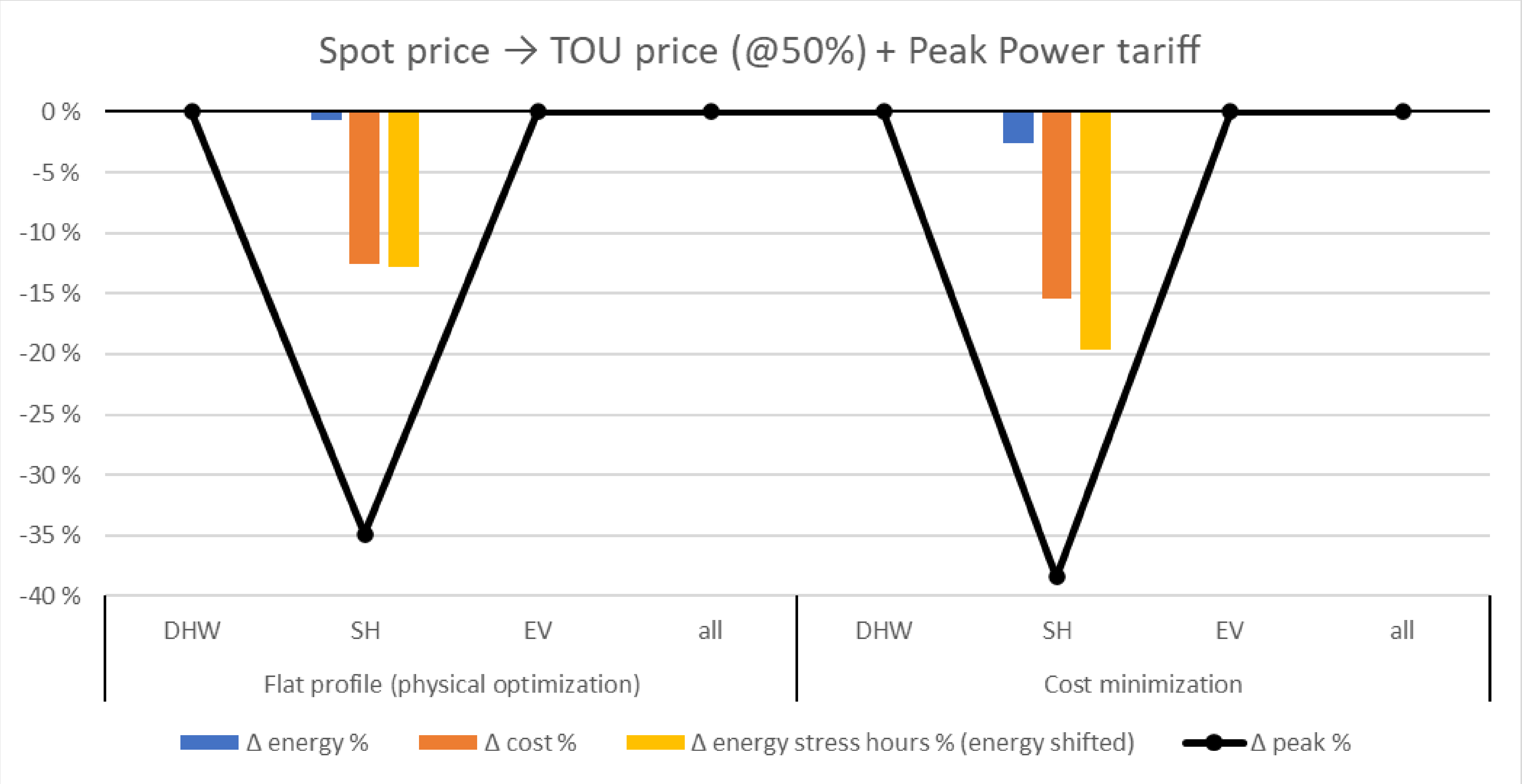
KPI results

- (some)

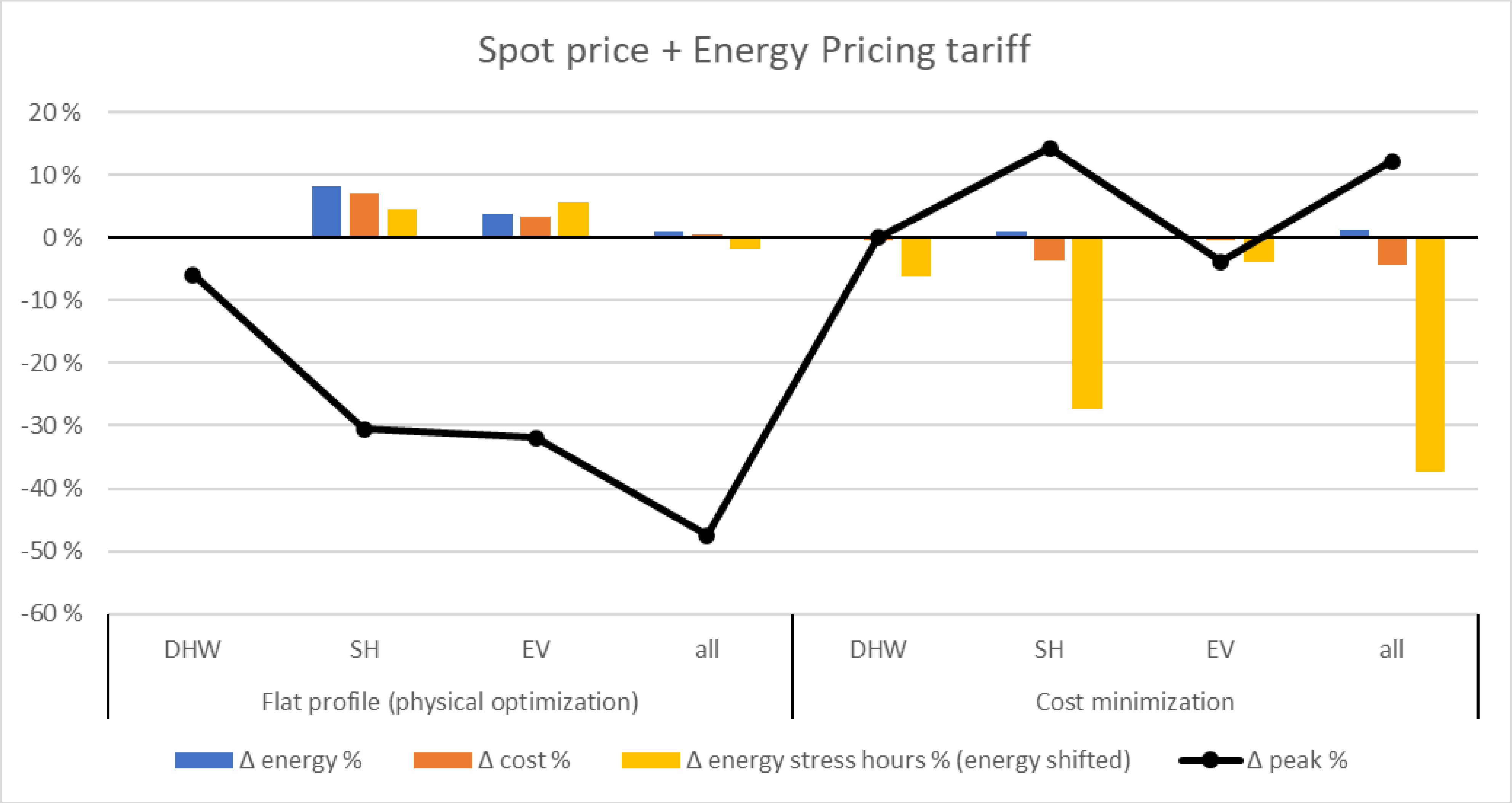
Proposed KPIs – Office
Energy Pricing grid tariff



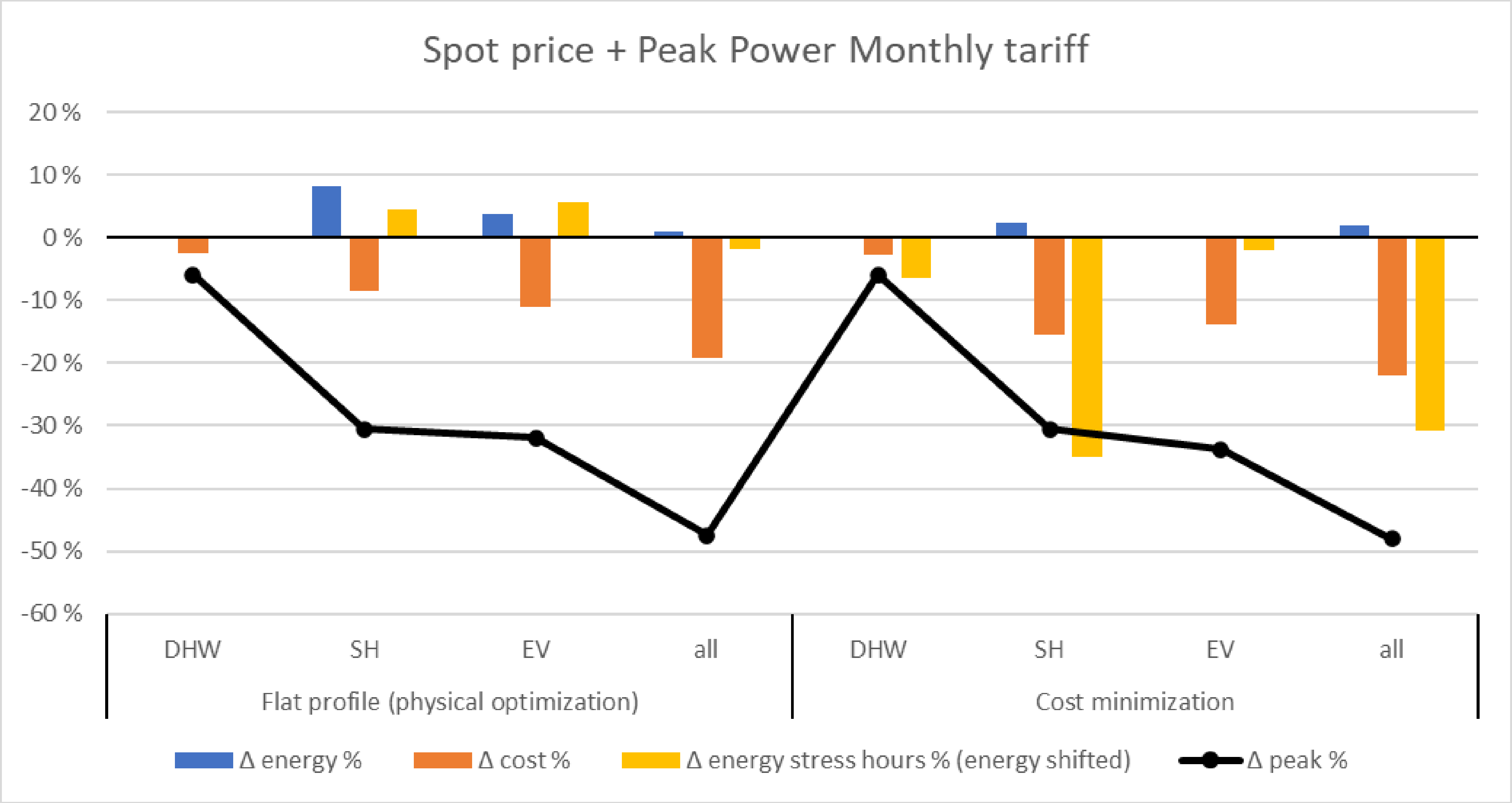
Proposed KPIs – Office
Peak Power Monthly grid tariff



Proposed KPIs – Apartment
Energy Pricing grid tariff



Proposed KPIs – Apartment
Peak Power Monthly grid tariff



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KPI results
Summary – depending on flexibility source

	Δ Energy	Δ Cost	Δ Energy Stress	Δ Peak
Space Heating **Office (GSHP)**	-1% / -3%	- 3% / -15%	-13% / -22%	-10% / -38%
Apartment (PO)	+1% / +8%	+7% / -15%	+4% / -35%	+14% / -31%
Domestic Hot Water	0%	0% / -3%	0% / -6%	0% / -6%
Electric Vehicle	+4% / 0%	+3% / -14%	+6% / -4%	-4% / -34%
All together	**+2% / +1%**	**0% / -22%**	**-2% / -37%**	**+12 / -48%**

KPI results
Summary – depending on flexibility driver & goal

Goal: Cost minimizaion (for the user)

	Δ Energy	Δ Cost	Δ Energy Stress	Δ Peak
Energy price Spot price	no substantial difference except ToU performing somewhat better on Δ Energy Stress			
Time of Use				
Grid tariff Energy pricing	+1% / -3%	-4% / -6%	-4% / -37%	+14% / -10%
Peak Power Monthly	+2% / -3%	-3% / -22%	-2% / -31%	-6% / -48%

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KPI results
Summary – depending on flexibility driver & goal

Goal: Flat profile (as possible, containing losses)

	Δ Energy	Δ Cost	Δ Energy Stress	Δ Peak
Energy price Spot price	no substantial difference except ToU performing somewhat better on Δ Energy Stress			
Time of Use				
Grid tariff Energy pricing	+8% / -1%	+7% - 6%	+4% / -13%	-31% / -35%
Peak Power Monthly		-9% / -15%		

Flexibility KPIs Conclusions

- Space Heating and Electric Vehicles* have large and similar potential
  - Domestic Hot Water has a much smaller potential

- Activating the flexibility can bring reductions in Δ Cost, Δ Energy Stress, Δ Peak
  - Even if there is an increase in Δ Energy

- Cost minimization with PPM (*effektledd tariff*) seems to harvest the best results in all KPIs
  - While EP (*energiledd*) may even increase Δ Peak, though shifting it to cheap hours

- Flat profile as a goal harvest good results too, especially on Δ Peak, while also reducing "deep valleys"
  - Could it be a better target for the energy system? (dispatchable demand for a smooth operation)
  - Could it be easier to implement in buildings since it does not require external signals?**

*with a penetration rate of 0.4 EV per household

**in contraddiction to the definition of Flexibility

Flexibility KPIs workshop

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You will be assigned randomly into the breakout groups
Please agree immediately who takes notes in each group!
Expected notes: keep it short and simple, thanks ☺

Questions for breakout 1

- *Q1: **We focus on flexibility as "dispatchable demand"**, which means optimal scheduling of a building's operation (planned one day or few hours ahead). **Do you think this is a proper focus?** And/or what are we missing that buildings could deliver?*

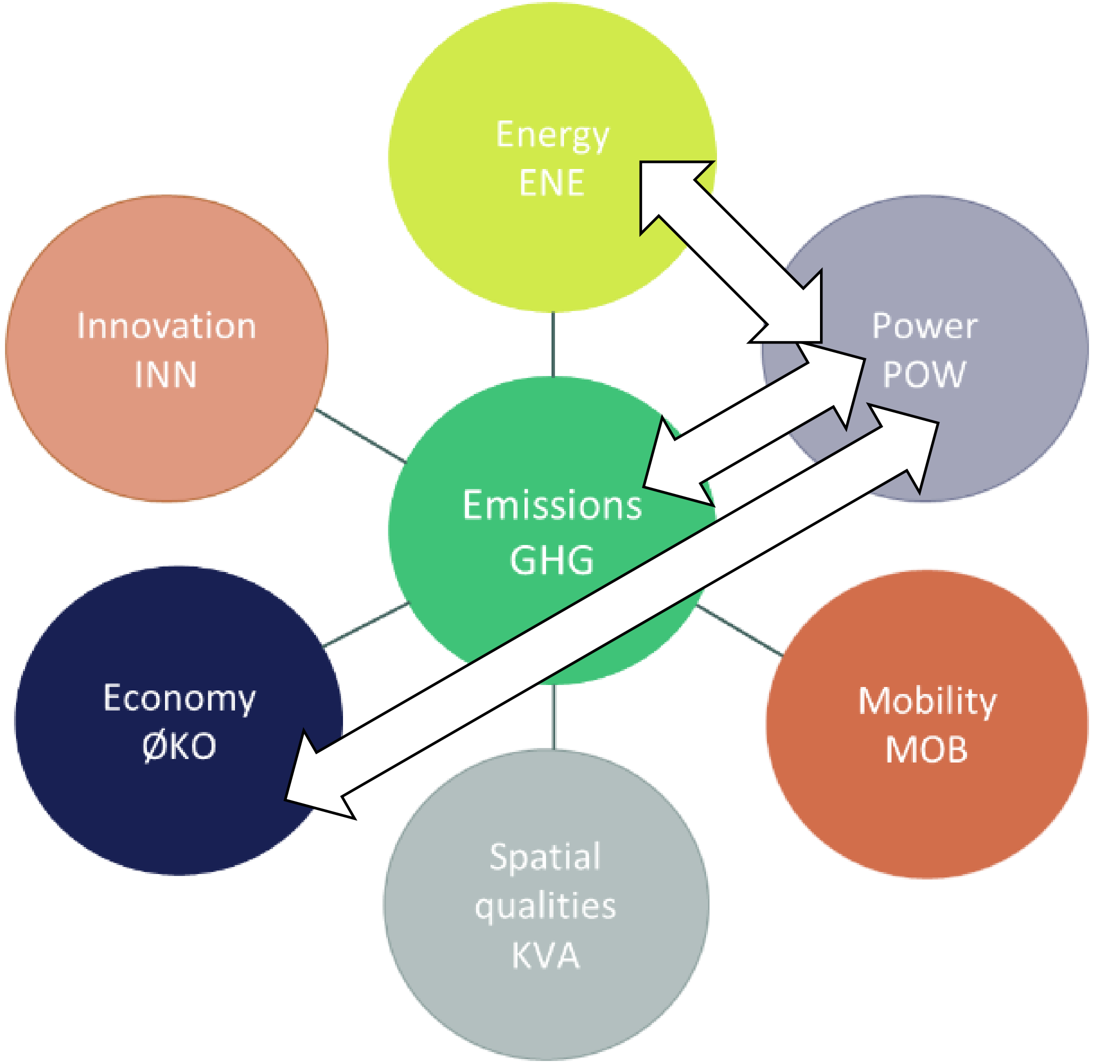
- *Q2: Do you think we have considered the most relevant **drivers and goals for different stakeholders** (building owner, grid/energy company)? And/or what are we evt. missing?*

- *Q3: Do you think the **proposed KPIs** are useful to capture the most important effects of energy flexibility and **to compare different flexibility options**? And/or what are we evt. missing?*

- *…any other feedback is welcome!*

PART 2

Flexibility KPIs *links*



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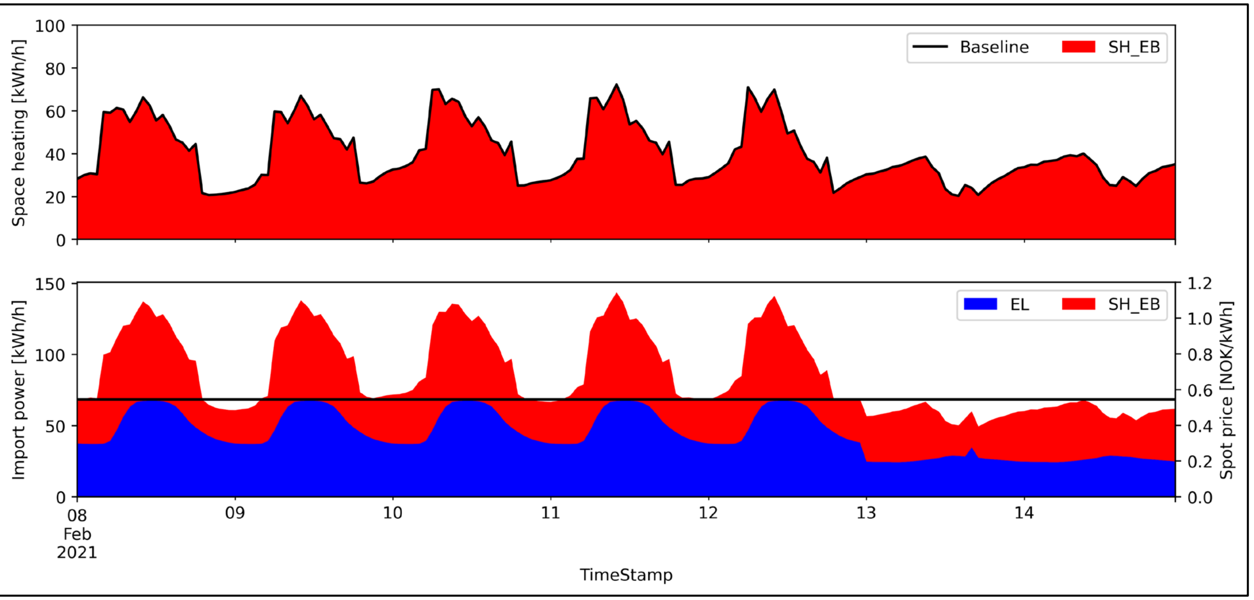
    - GHG emissions and Economy KPIs
    - Q/A
    - ➢ Breakout group work 2

What else can we use the KPIs for? Examples

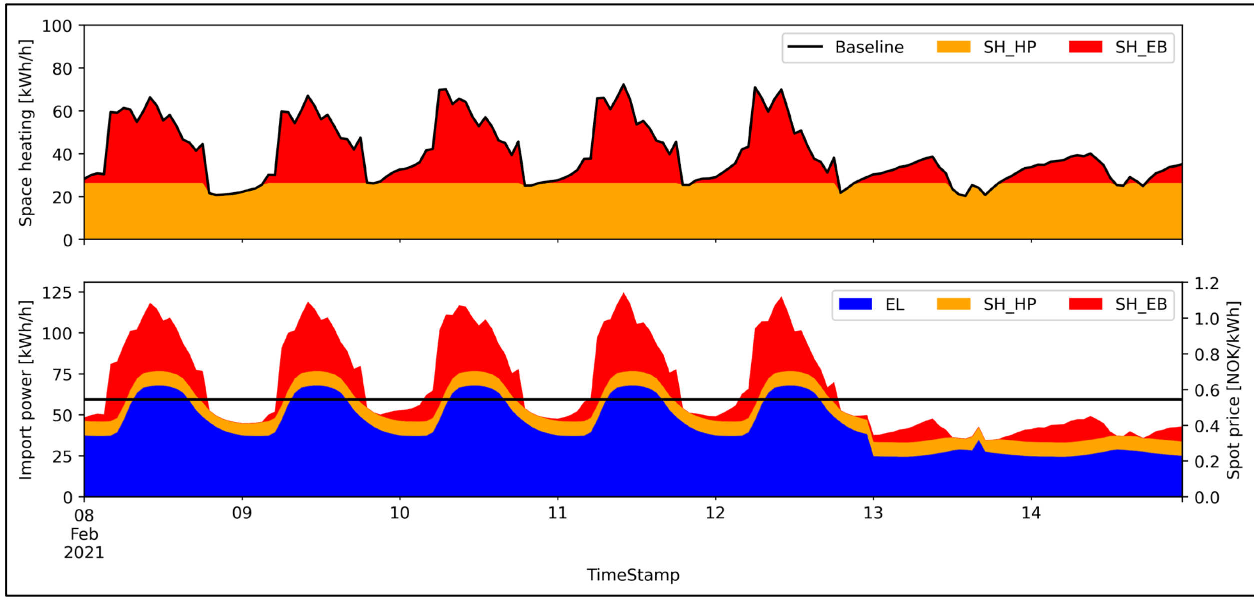
- Compare Flexibility vs. Efficiency
- Compare Flexibility + Efficiency
- Compare Optimal vs. (realistic) MPC control

Proposed KPIs – Office Flexibility vs. Efficiency

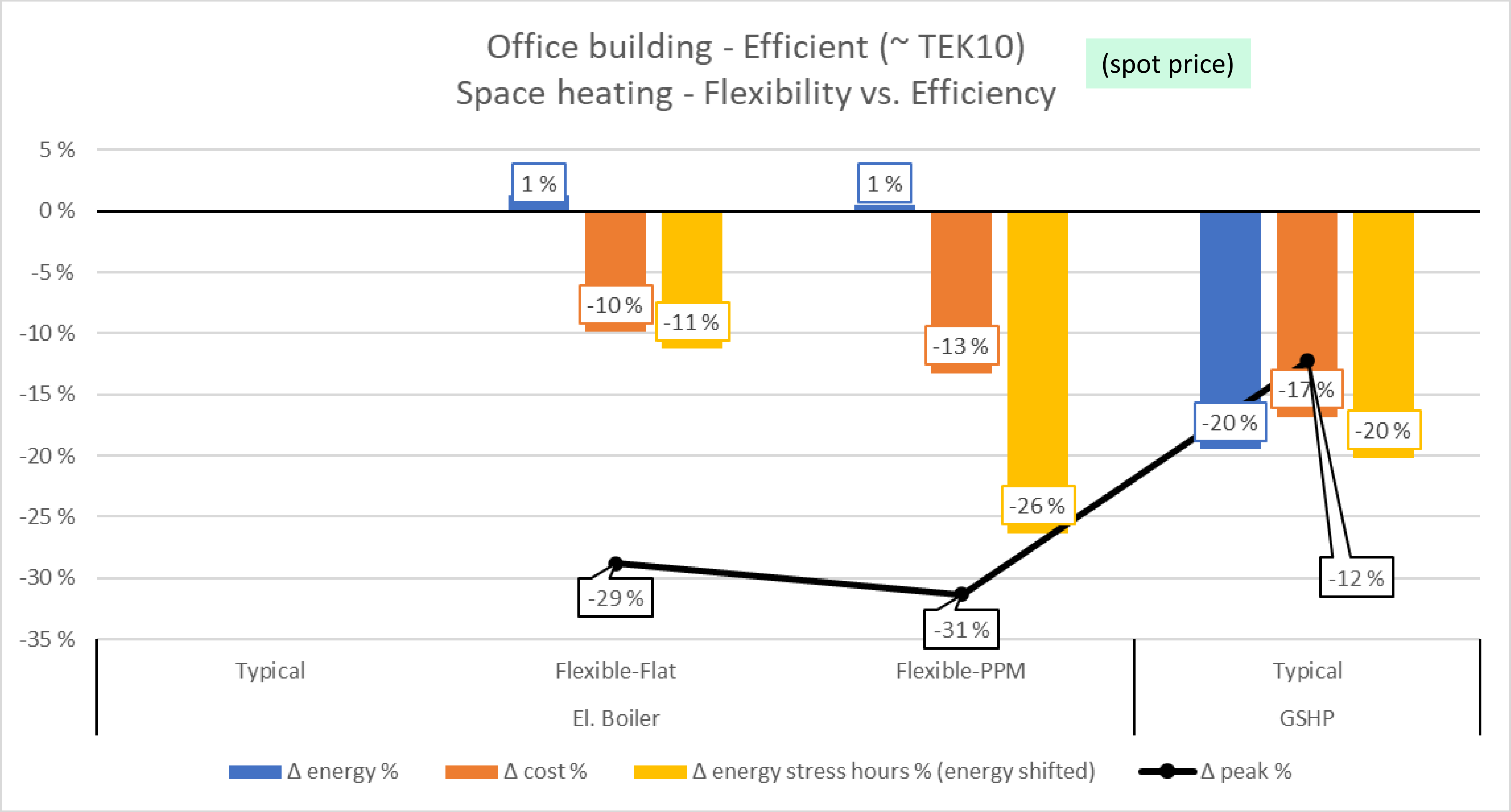
Efficient Office (ca. TEK10) with Electric Boiler



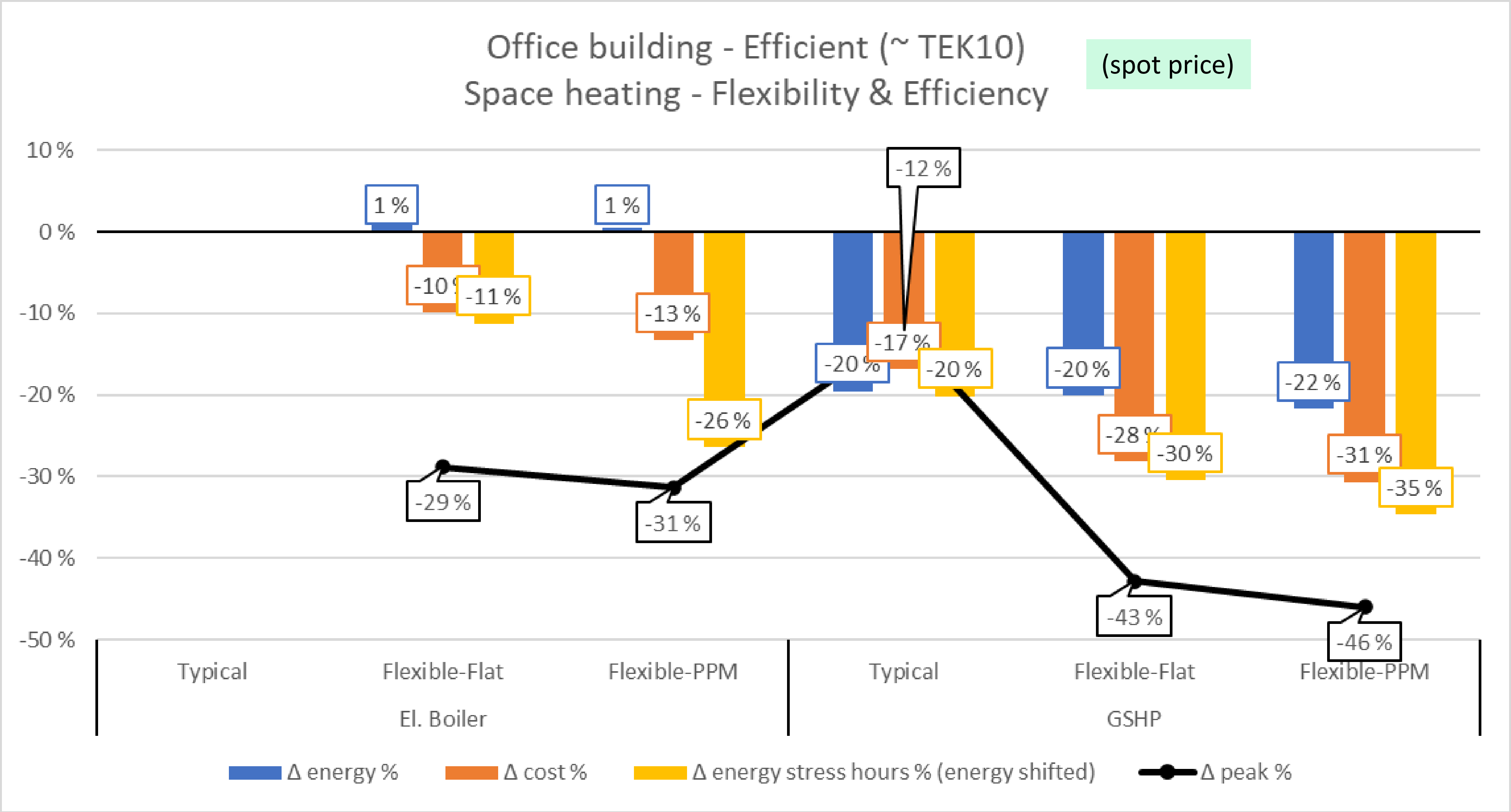
Efficient Office (ca. TEK10) with GSHP + Electric Boiler



Proposed KPIs – Office Flexibility vs. Efficiency

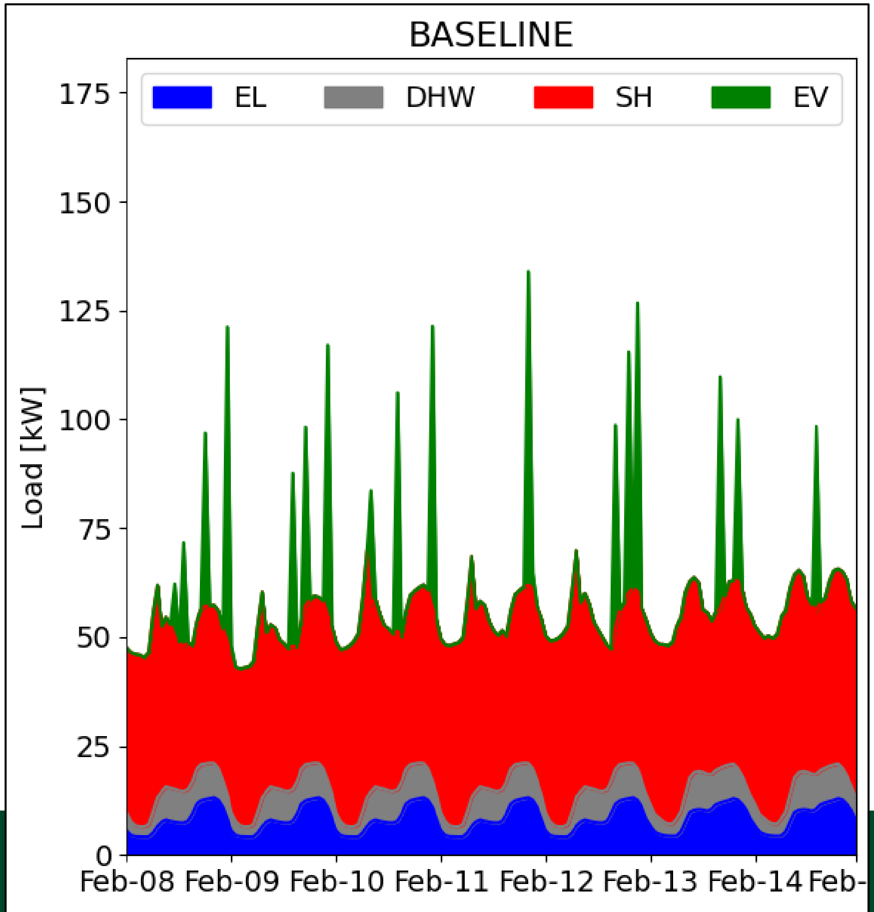


Proposed KPIs – Office Flexibility + Efficiency

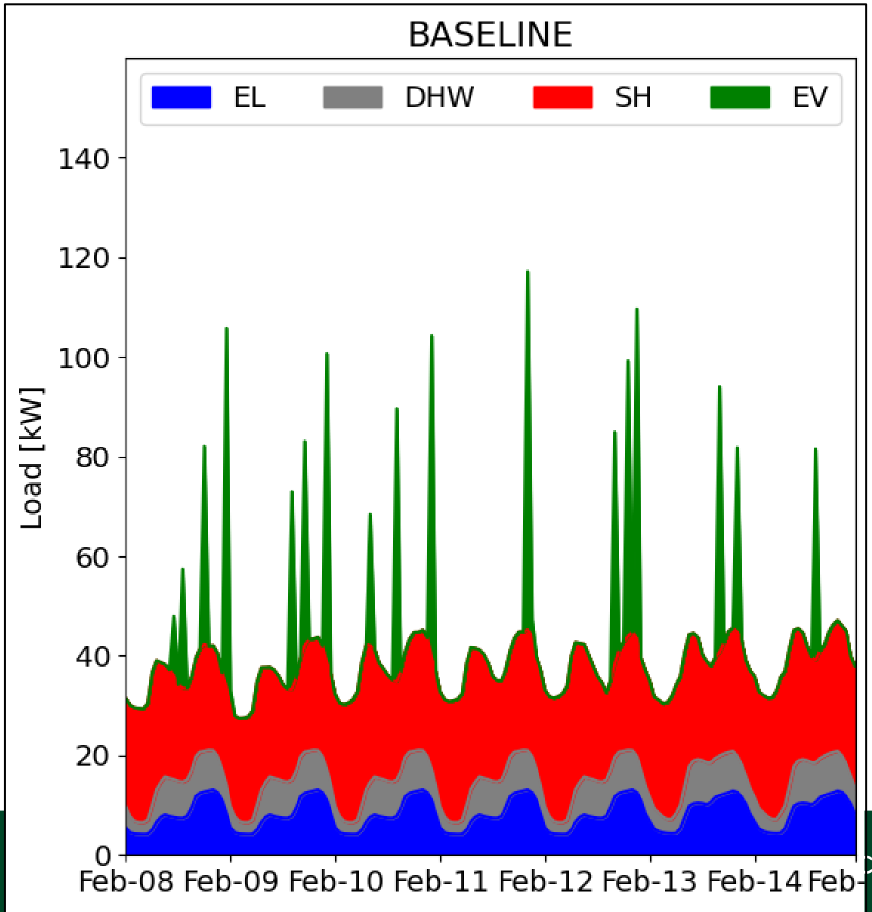


Proposed KPIs – Apartment Flexibility vs. Efficiency

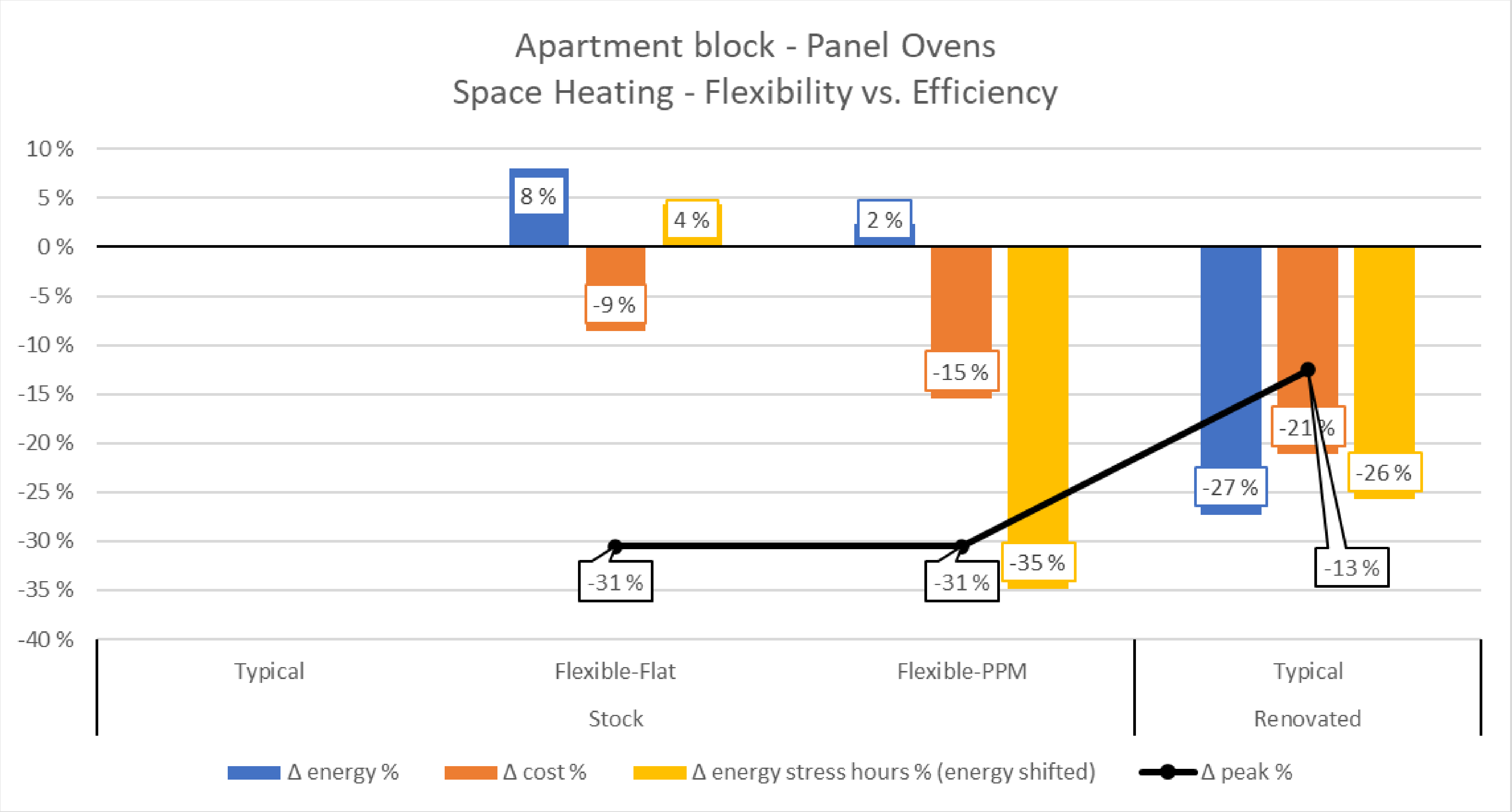
Regular Apartment block in the stock



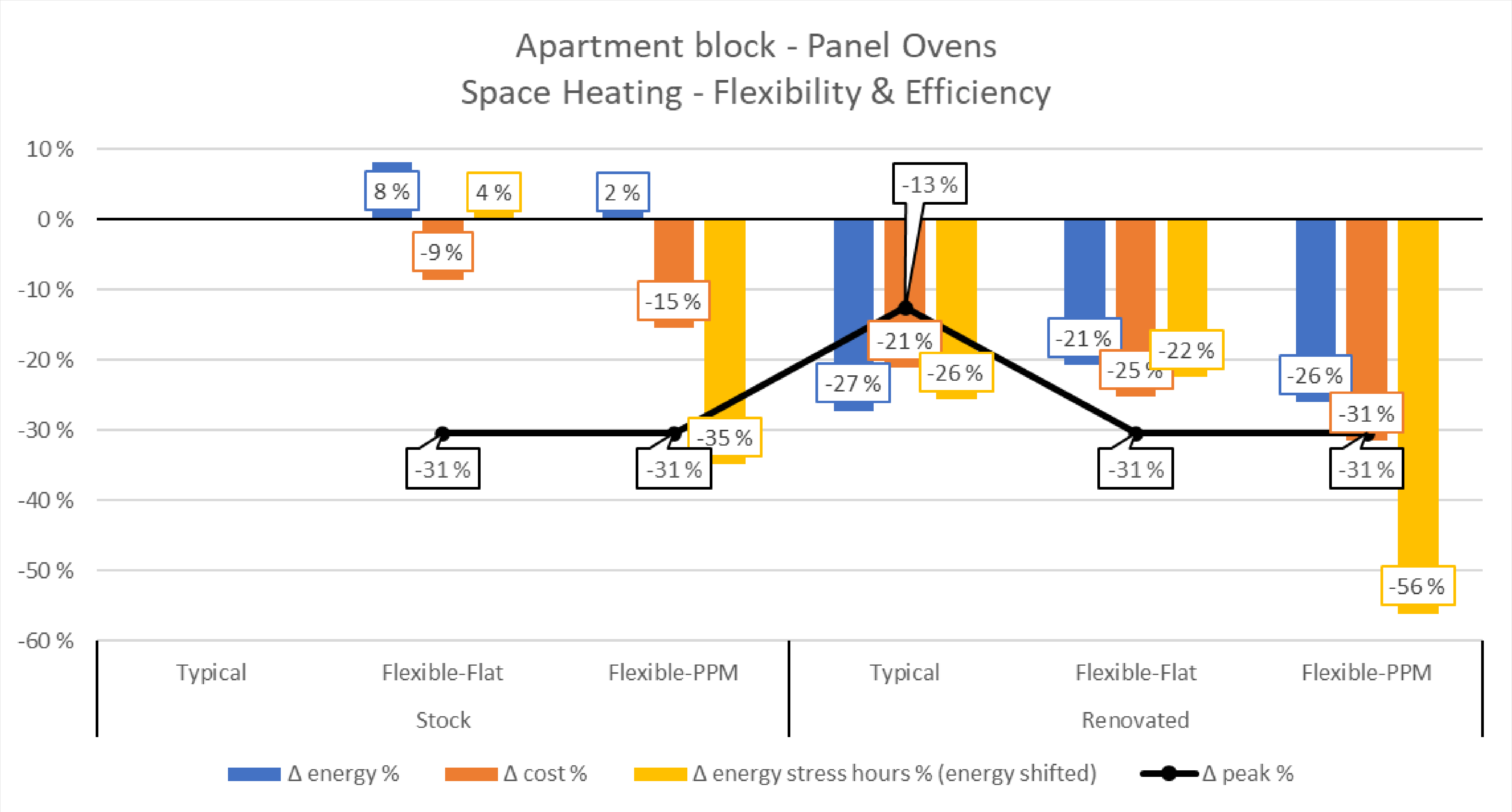
Renovated to an efficient level (ca. TEK10)



Proposed KPIs – Apartment Flexibility vs. Efficiency



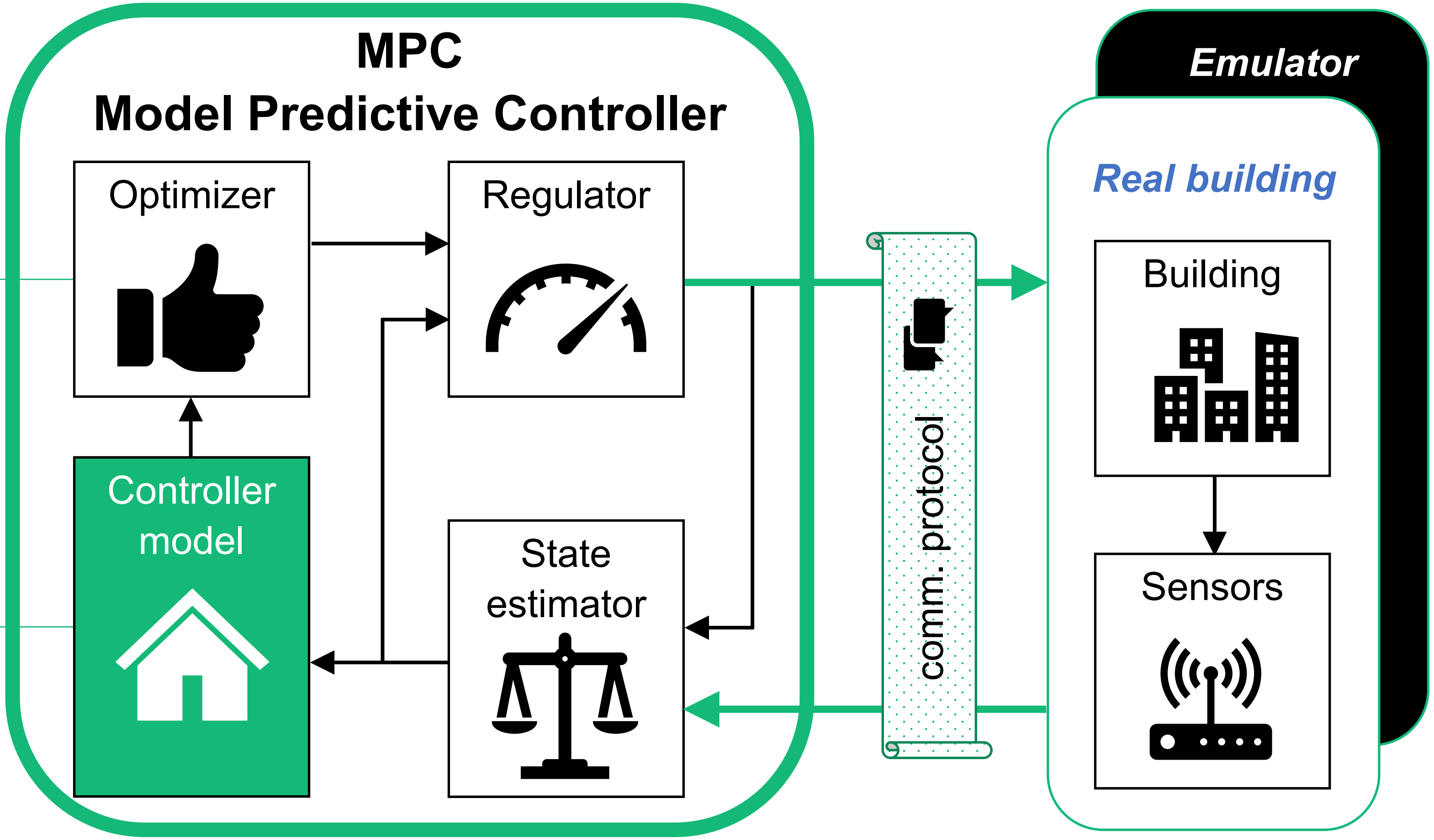
Proposed KPIs – Apartment Flexibility + Efficiency



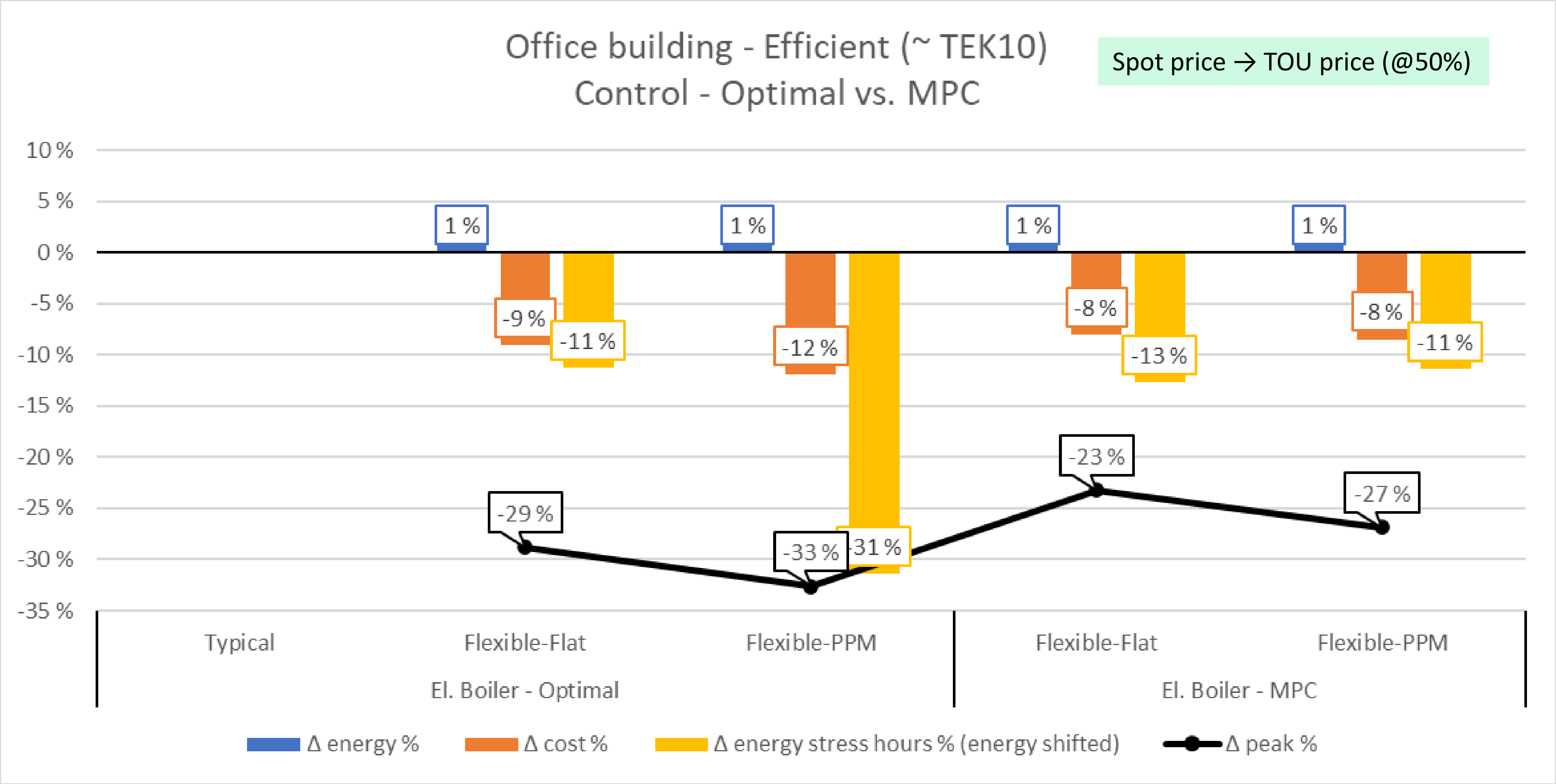
KPI results
Optimal vs. MPC control

KPI results
Optimal vs. MPC control

Optimal
Assumes controller model is perfect



Proposed KPIs – Office
Optimal vs. MPC control



What else can we use the KPIs for? Summary

- Compare Flexibility vs. Efficiency
  - Flexibility could deliver cheaper and faster benefits than Efficiency, when we are not interested in saving energy per se, but in other KPIs such as Cost and Peak load

- Compare Flexibility + Efficiency
  - Nevertheless, Flexibility works equally well on-top of Efficiency, when both are feasible/desirable

- Compare Optimal vs. (realistic) MPC control
  - Real-life control applications will perform worse than the optimal cases shown here. But there is reason to hope

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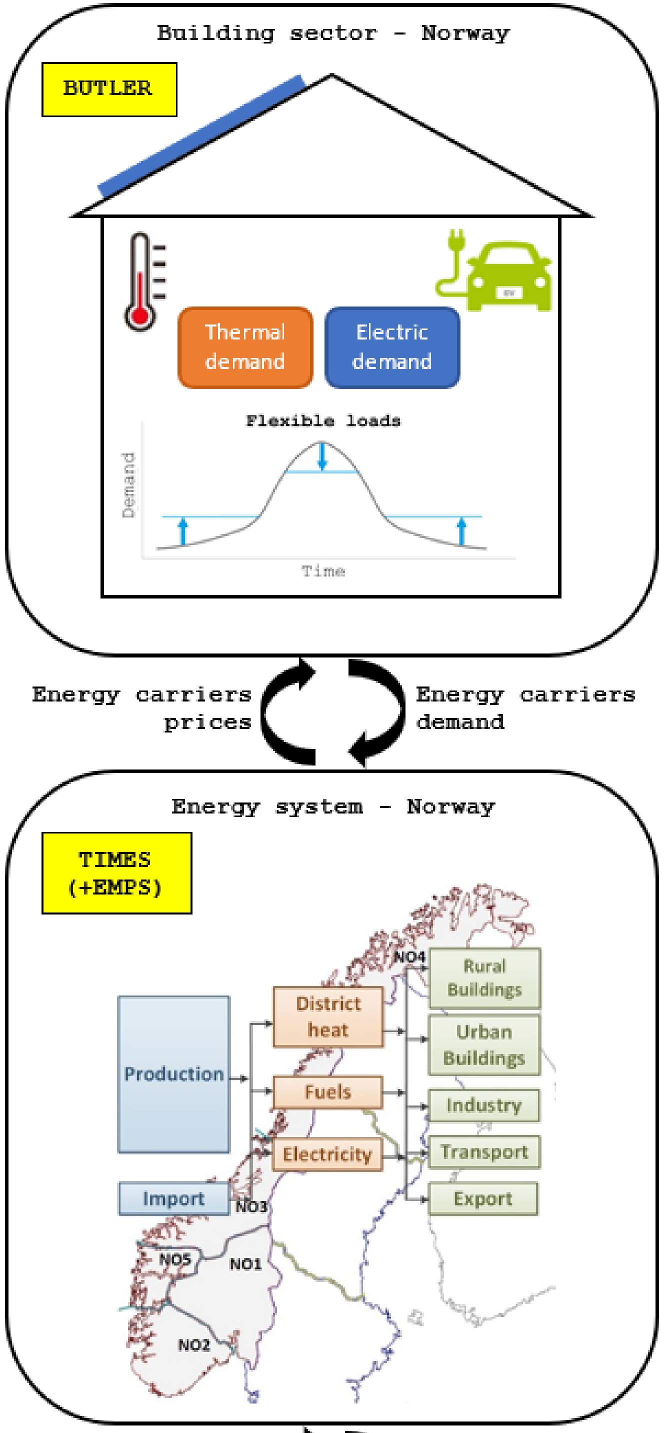
  - Breakout group work 2

End-user and energy system perspectives

- The KPIs are valid for single buildings/neighborhoods, assuming that the energy prices are given
- But if a large share of the building stock begins to activate its flexibility – especially via aggregators – this will in turn affect how energy prices are determined (e.g. in the day-ahead spot market)
- To know the potential benefits for the entire energy system (/Norway) one needs an iterative simulation between demand side and supply side
  - ➢ Which is exactly what the Flexbuild project does



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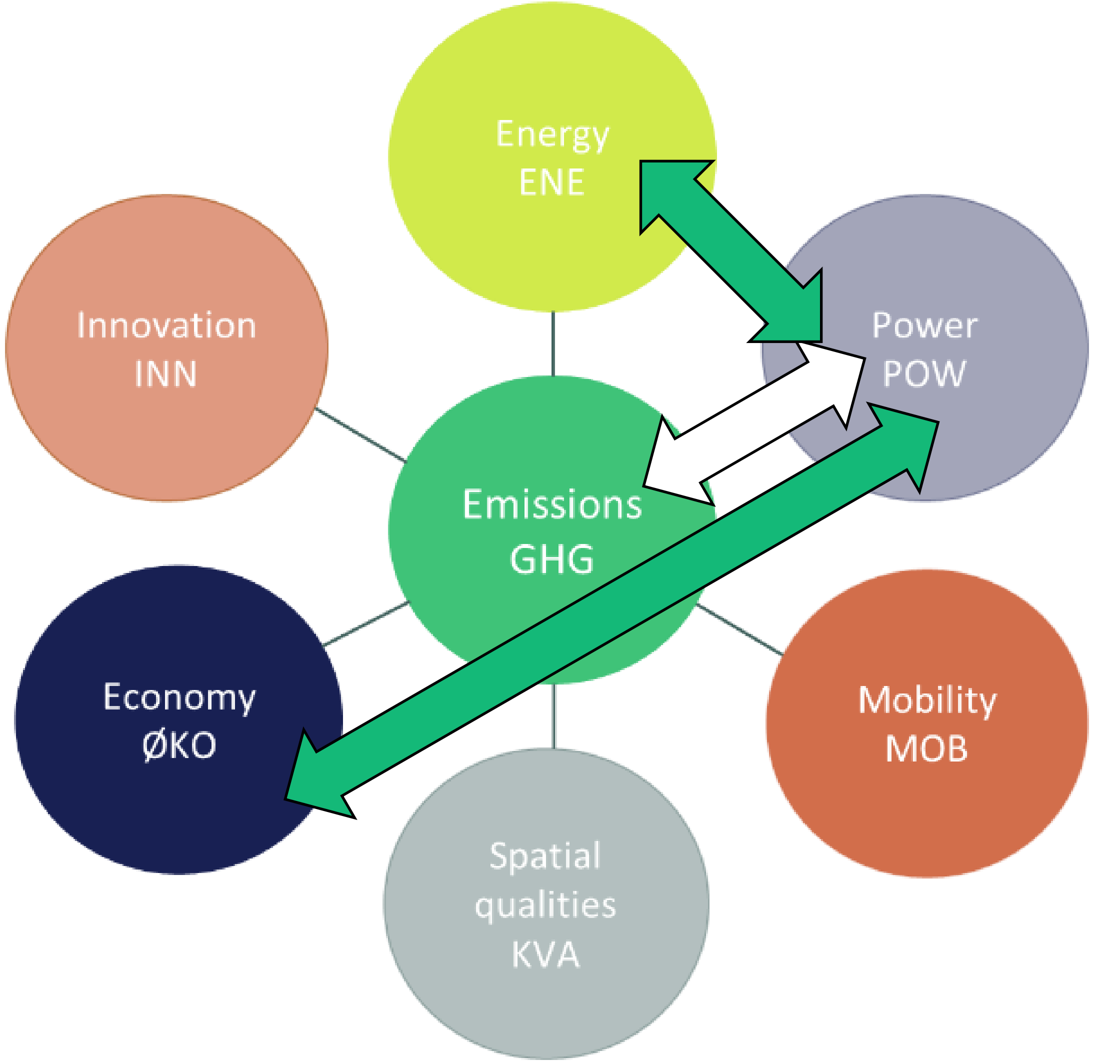
ZEN KPIs

- Activating the Flexibility (and measuring its effects with the proposed KPIs) provide quantitative information on the categories:
  - Energy, Power, Economy

- Just like it happens with energy efficiency measures or the choice of different materials



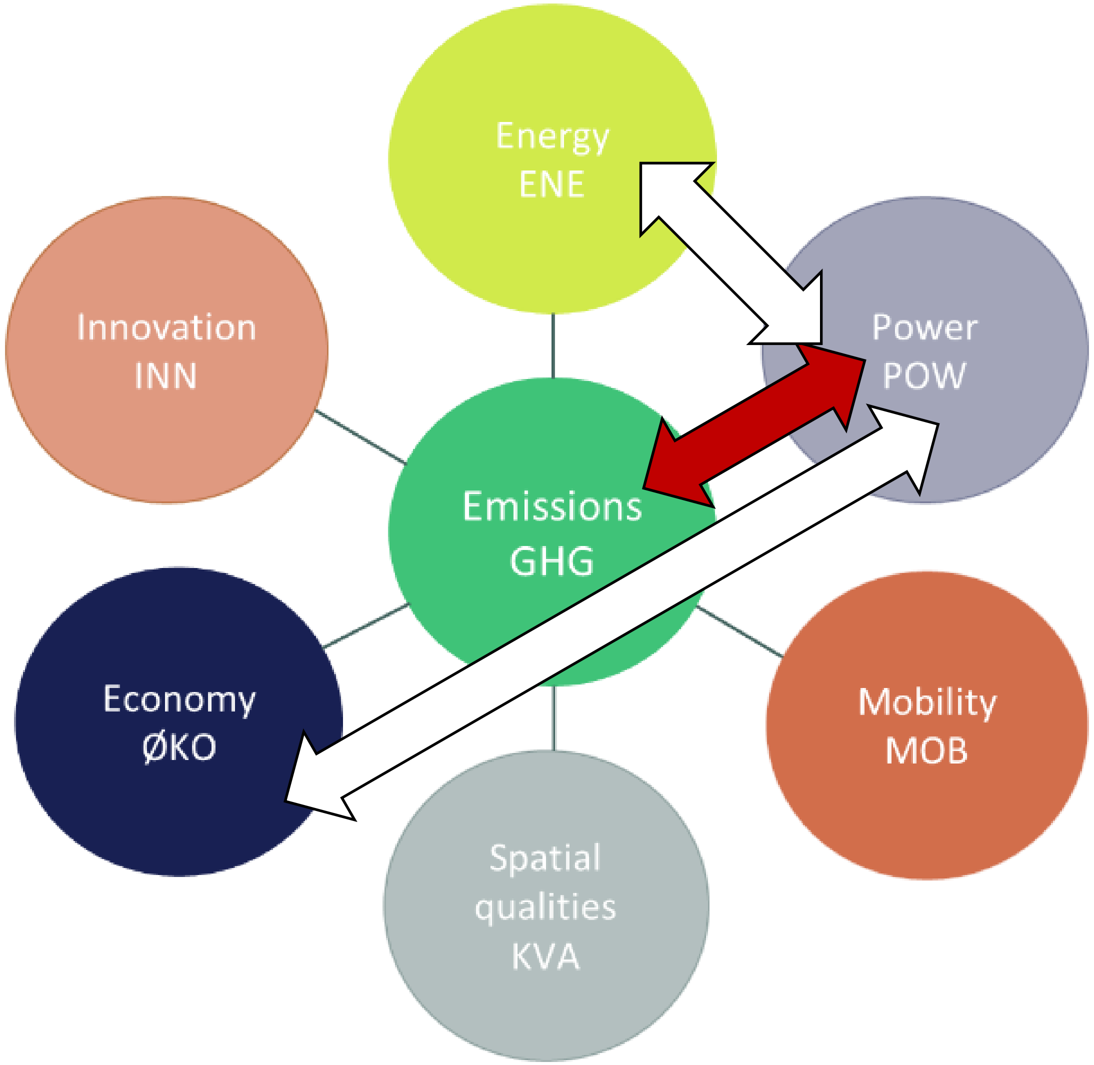
ZEN KPIs

- But energy efficiency measures and choice of different materials also give quantitative information on GHG emissions reduction

- The same does not happen for Flexibility
  - ➢ This is a missing link in the ZEN definition

  (and a major methodological challenge)

- We know that flexible demand is a "key enabling technology" for a decarbonised energy system, but we do not know how to measure its effect
  - ➢ ...at least in Norway



Why it is not a good idea to simply use hourly CO2 factors in Norway

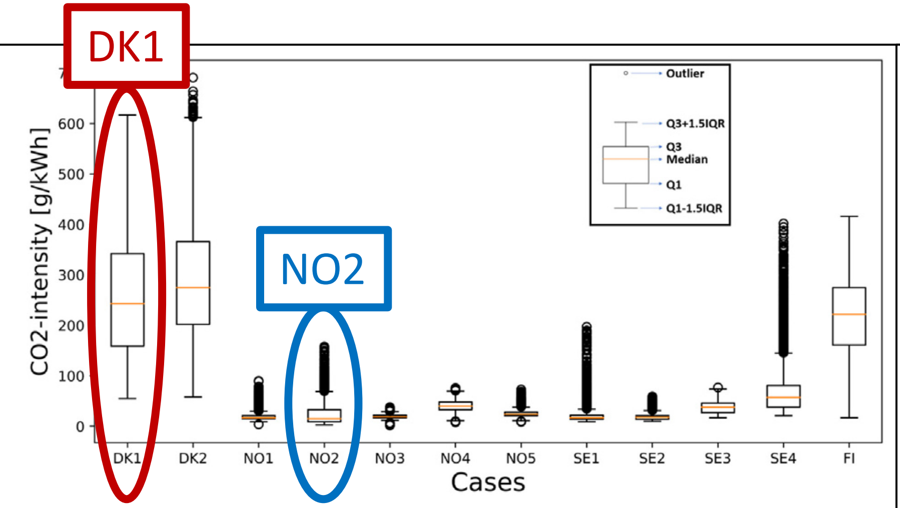
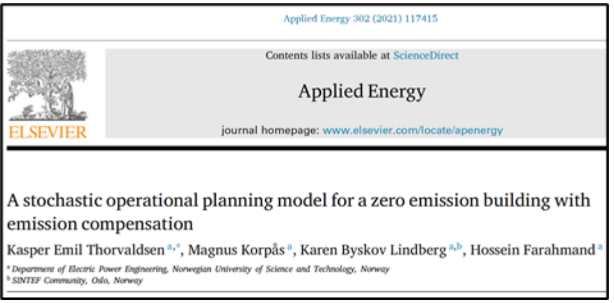


Fig. 6. Overview of hourly CO_{2eq}-intensities for the Nordic bidding zones in 2017



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A stochastic operational planning model for a zero emission building with emission compensation

Kasper Emil Thorvaldsen [a,*], Magnus Korpås [a], Karen Byskov Lindberg [a,b], Hossein Farahmand [a]

[a] Department of Electric Power Engineering, Norwegian University of Science and Technology, Norway
[b] SINTEF Community, Oslo, Norway

https://doi.org/10.1016/j.apenergy.2021.117415

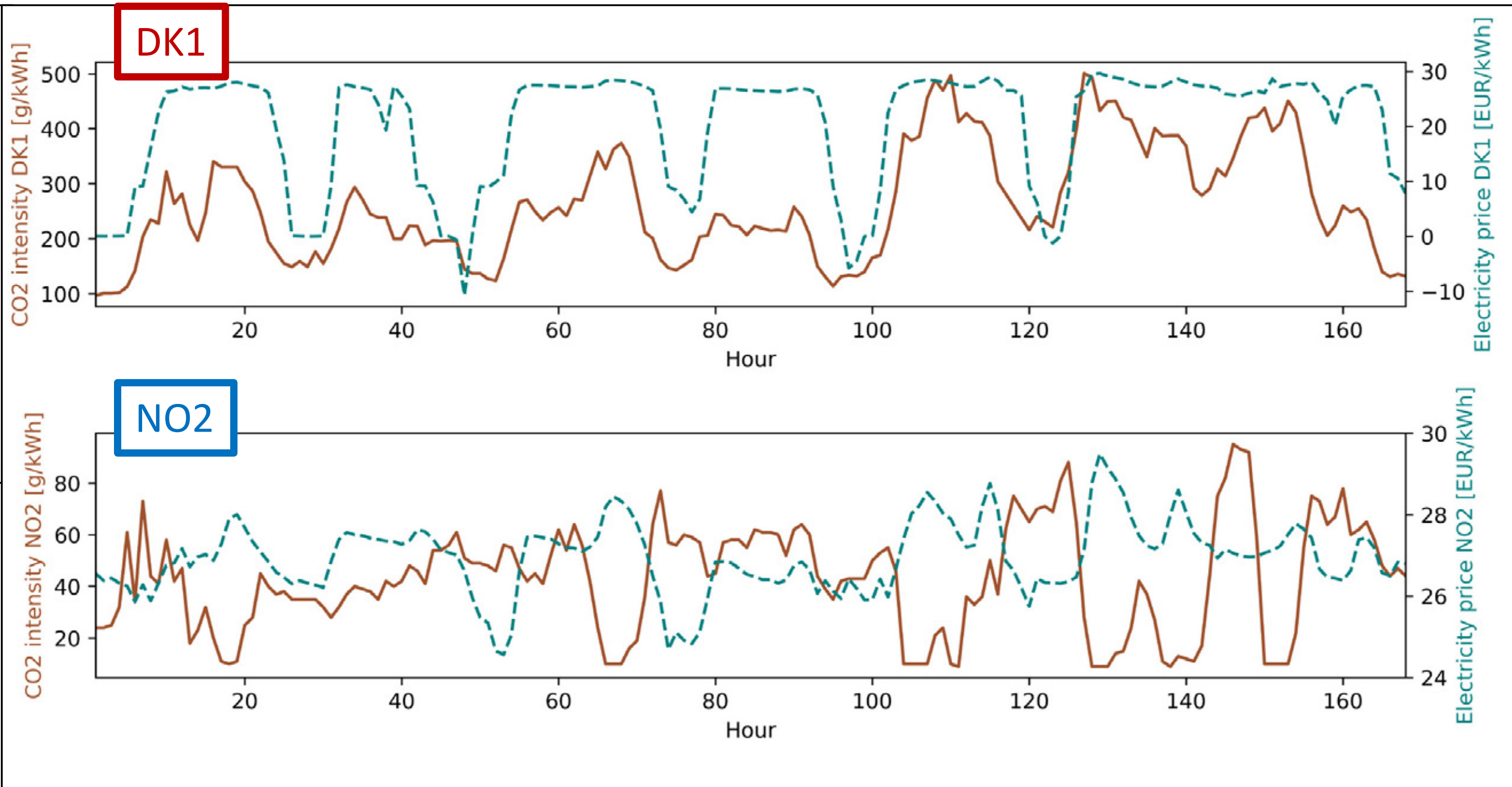


Fig. 9. Correlation between electricity prices and CO_{2eq}-intensities in NO2 and DK1 for week 7.

Why it is not a good idea to simply use hourly CO2 factors in Norway

SINTEF

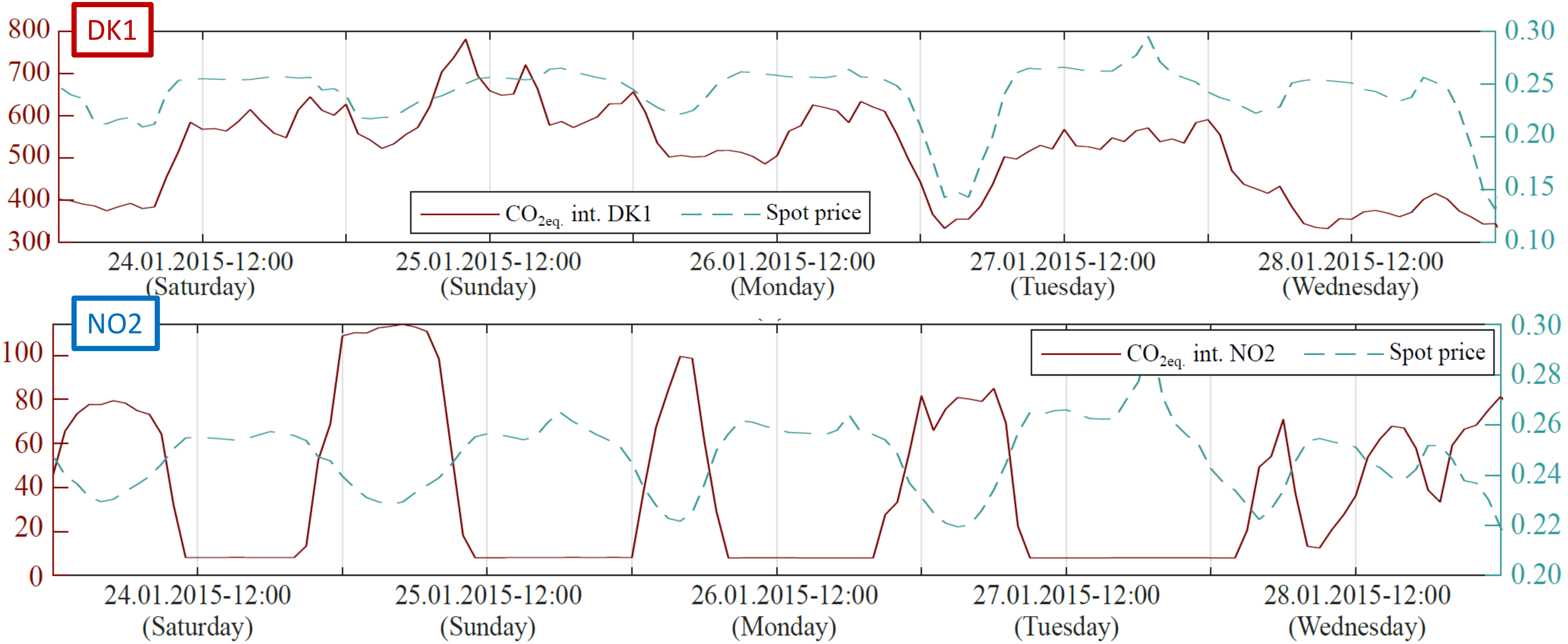
energies

Article

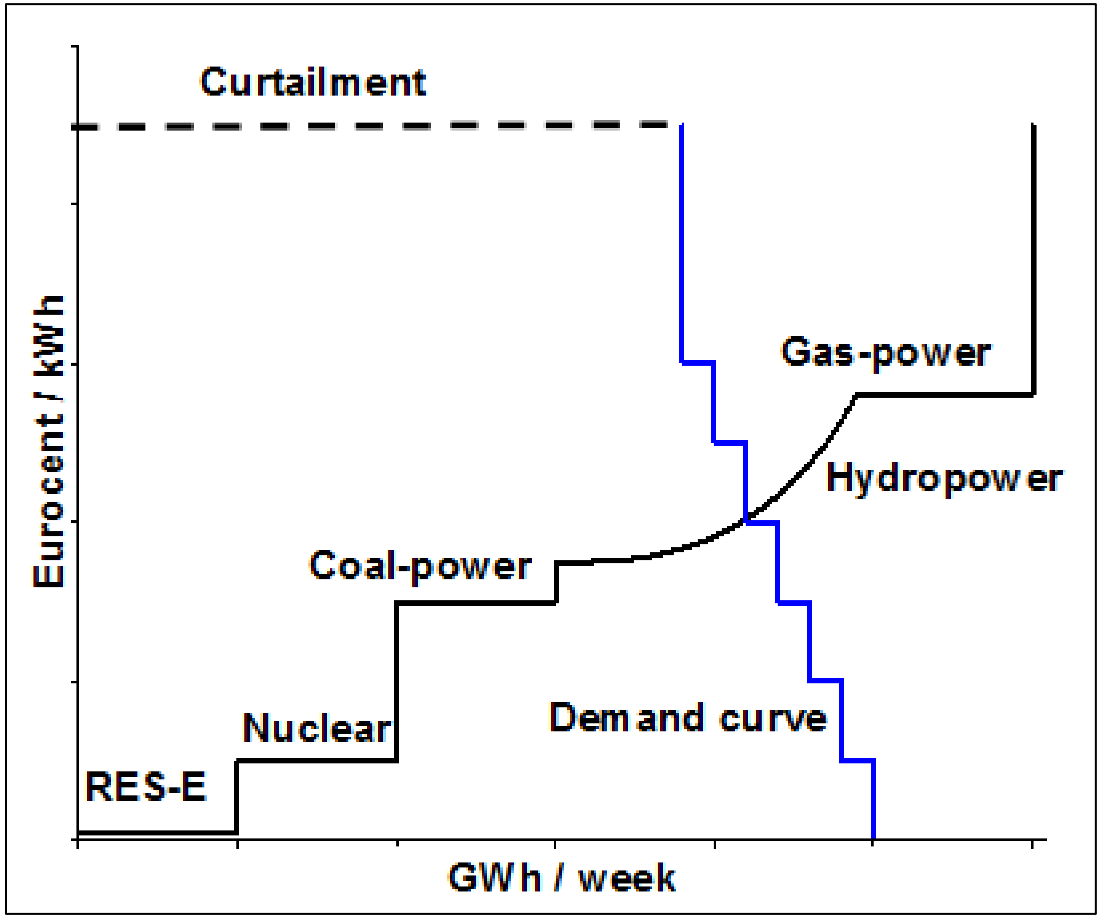
Evaluation Method for the Hourly Average $CO_{2eq.}$ Intensity of the Electricity Mix and Its Application to the Demand Response of Residential Heating

John Clauß [1,*], Sebastian Stinner [1], Christian Solli [2], Karen Byskov Lindberg [3,4], Henrik Madsen [5,6] and Laurent Georges [1,6]

https://www.mdpi.com/1996-1073/12/7/1345#



Why it is not a good idea to simply use hourly CO2 factors in Norway



- Hydropower is dispatchable renewable energy supply
- Does dispatchable (flexible) energy demand have to be a 'competitor'?
- Or can we find ways to make the best use of both, in a win-win situation?

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The missing link

- It should be possible – though not easy – to run a "Flexbuild-like" simulation of the energy system with two scenarios for the energy demand from the building stock:
  - Baseline vs. Flexible

- Then we can know the difference in total CO_2 emissions from the energy system in Norway (and/or EU) in the two scenarios
  - this can then be converted in CO_2 savings / m^2 of floor area and become the "missing link" between flexible operation and emission reduction in the ZEN definition

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Questions for breakout 2

- *Q4: Do you think the* ***proposed KPIs*** *are useful* ***to compare*** *the effects of* ***Flexibility with*** *those of other* ***energy efficiency measures****? And useful* ***to establish*** *Flexibility* ***performance benchmarks****?*
- *Q5: What do you think of the proposed method to* ***link Flexibility KPIs to the CO2 savings*** *it enables in the enrgy system? Or what else could be done?*
- *...any other feedback is welcome!*

Technology for a better society