Opportunity for HVAC in the Building Sector

Prof. Lieve Helsen, KU Leuven – EnergyVille

ESIG - 2023 FALL TECHNICAL WORKSHOP
Session 3: Building Sector Decarbonization in Energy Systems Modeling
San Diego, October 24, 2023

IMPORTANCE AND CHALLENGE

SOLUTION

What?
How?

SCENARIO MODELING

Electrification
District heating

IMPACT ON GRIDS

need for demand FLEX
need for system integrator

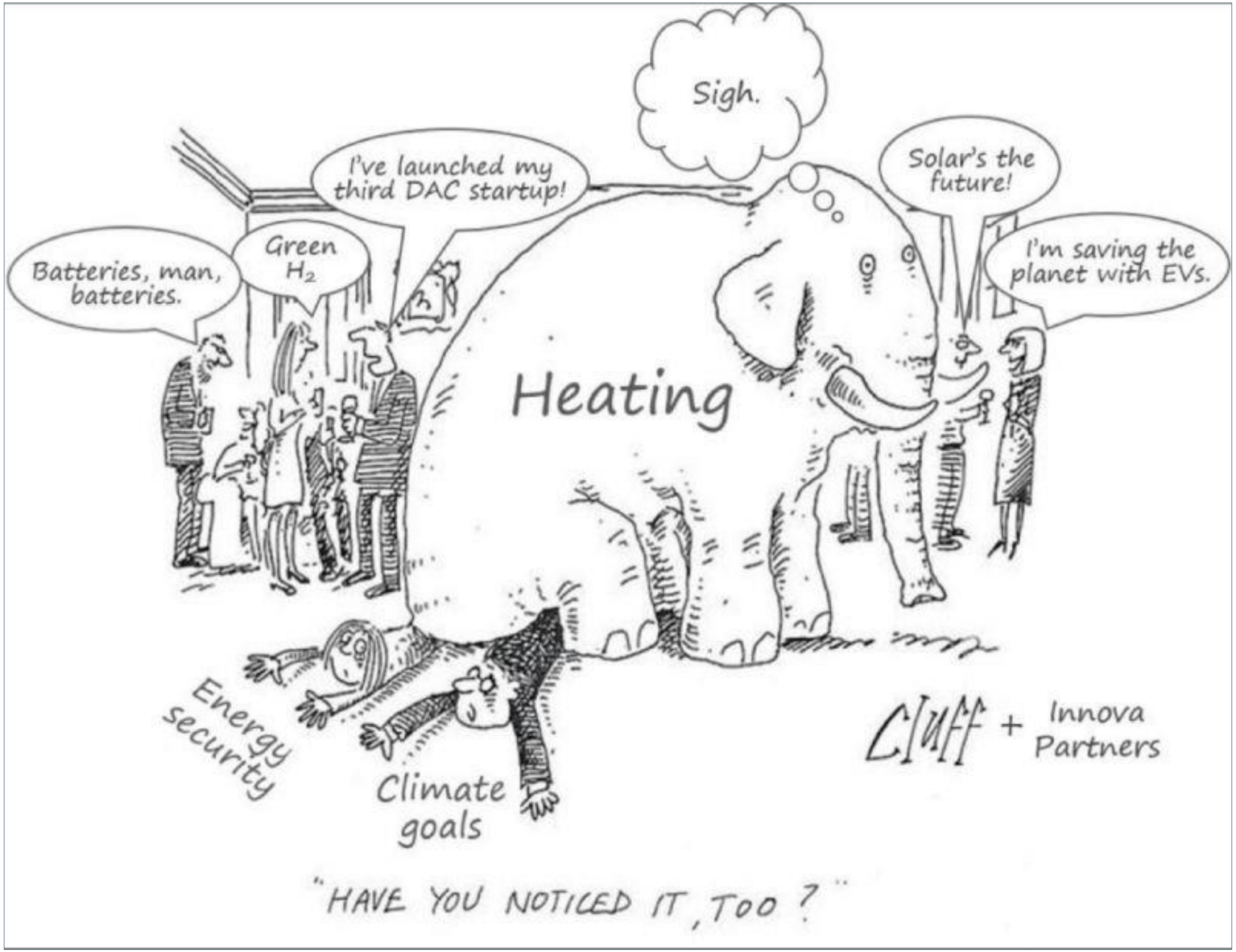
SECTOR COUPLING

as the integrated solution

HVAC

EU - HEATING
the elephant in the room

EU - COOLING
the elephant in the
waiting room



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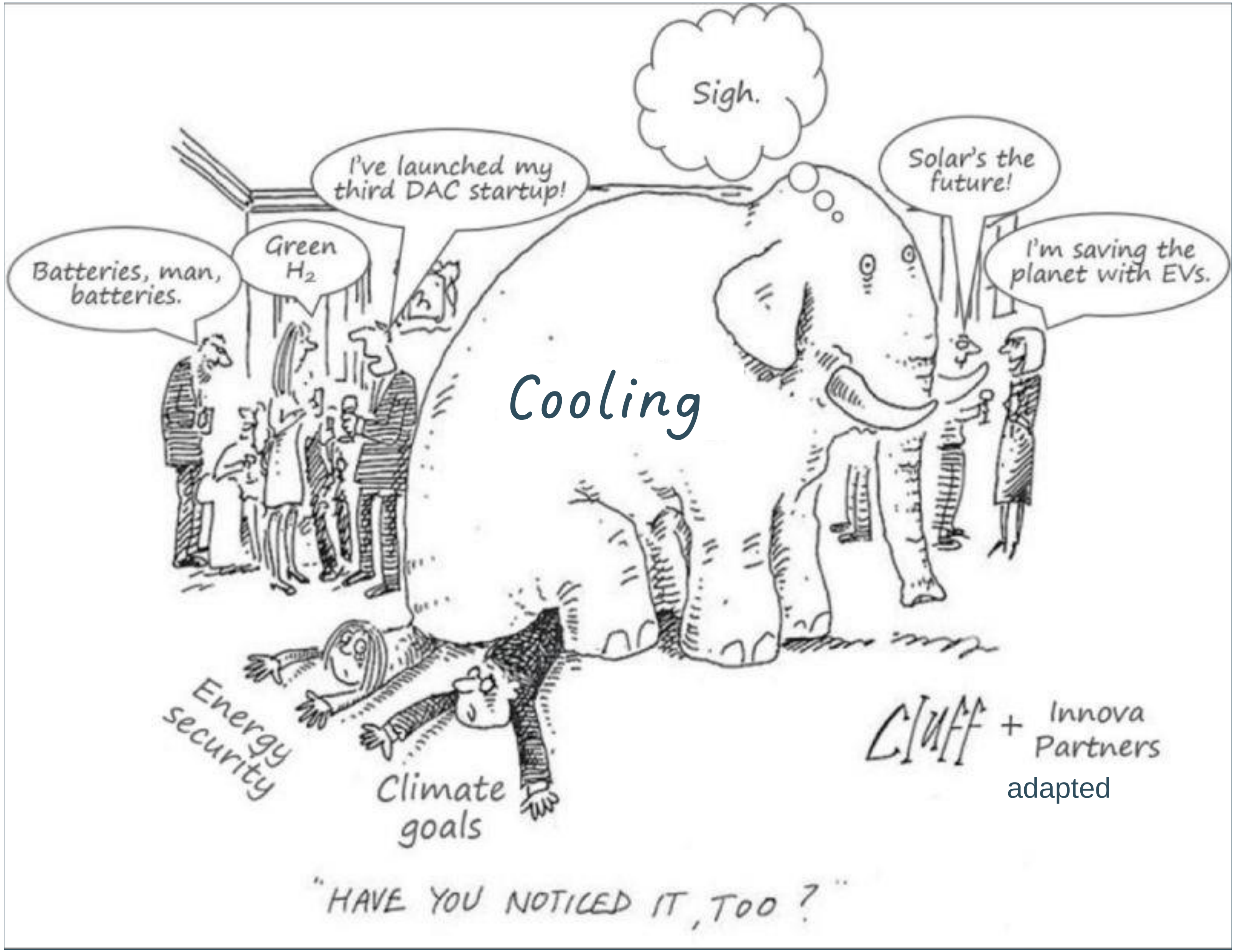
HVAC

US - COOLING
the elephant in the room

World-wide airco

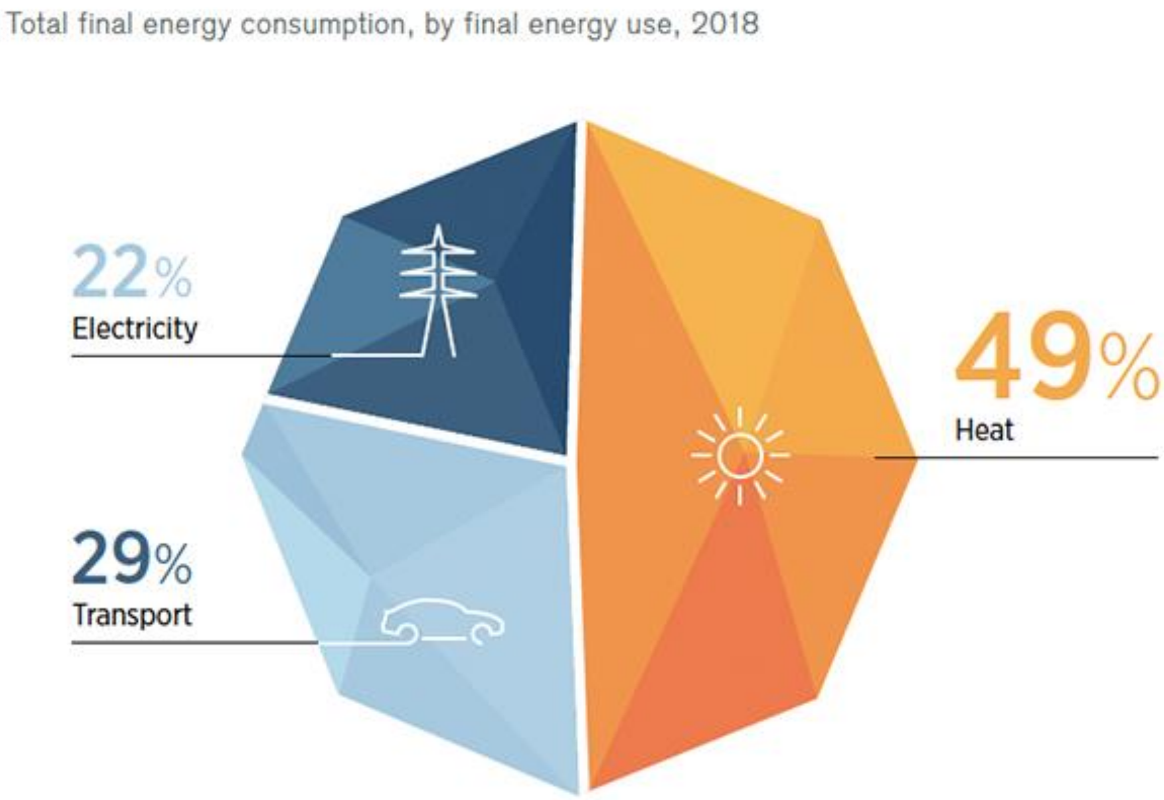
- 1990-2023
  more than tripled
- 2021-2022
  + 5%
- 2022
  2 billion airco's

Impact of smartness - AI



Source: IEA 2023

KEY NUMBERS – FINAL ENERGY USE



Source: IEA, 2020a; IEA, 2020b.

Note: Consistent with statistical conventions and current data availability, the category "heat" includes electricity used for heating. The category "electricity" includes electricity used for cooling.

KEY NUMBERS – CO_2 EMISSIONS

BUILDINGS

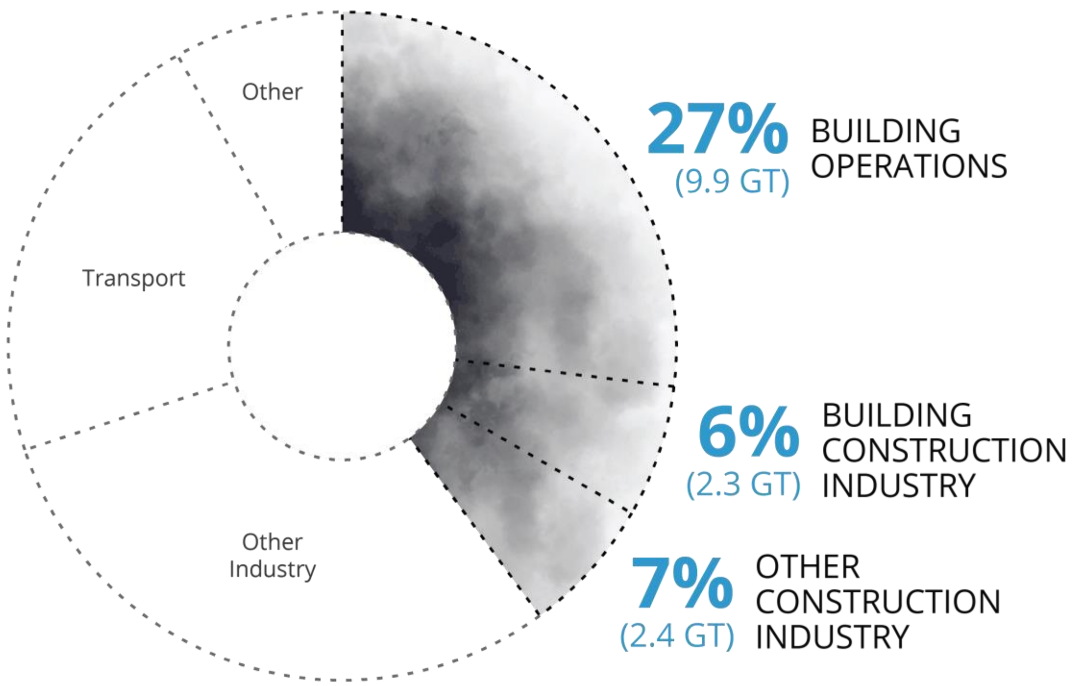
40% of annual global CO_2 emissions

- 27% operation
- 13% embodied

DECARBONIZATION challenge:

Create a comfortable and healthy indoor climate in a carbon-neutral society

Annual Global CO_2 Emissions



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Building Construction Industry and Other Construction Industry represent emissions from concrete, steel, and aluminum for buildings and infrastructure respectively.

SOLUTION FOR THE BUILT ENVIRONMENT?

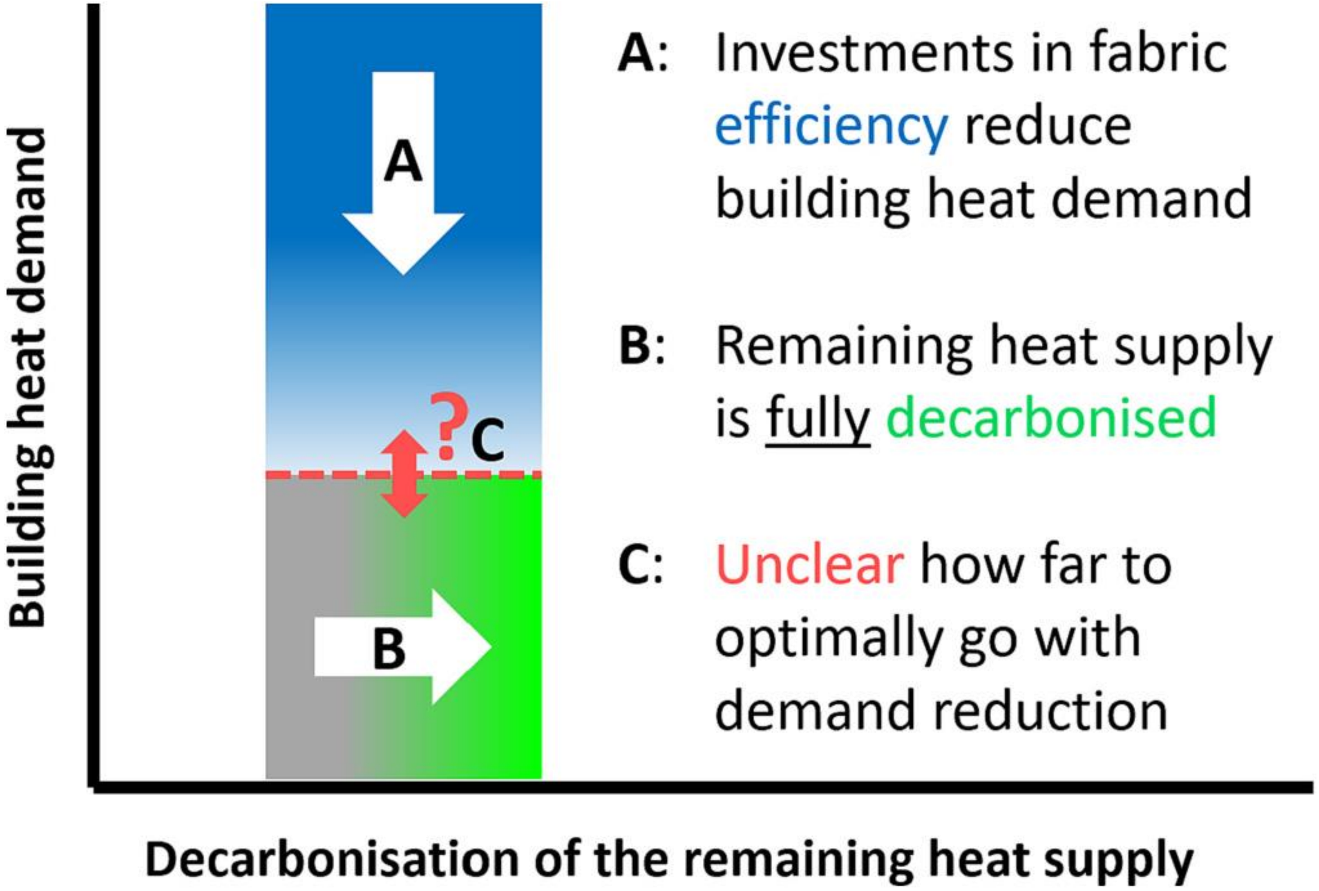
- H/C supply decarbonization (demand equal or growing?)
- H/C demand reduction (efficiency)

BALANCED APPROACH

Optimal balance?

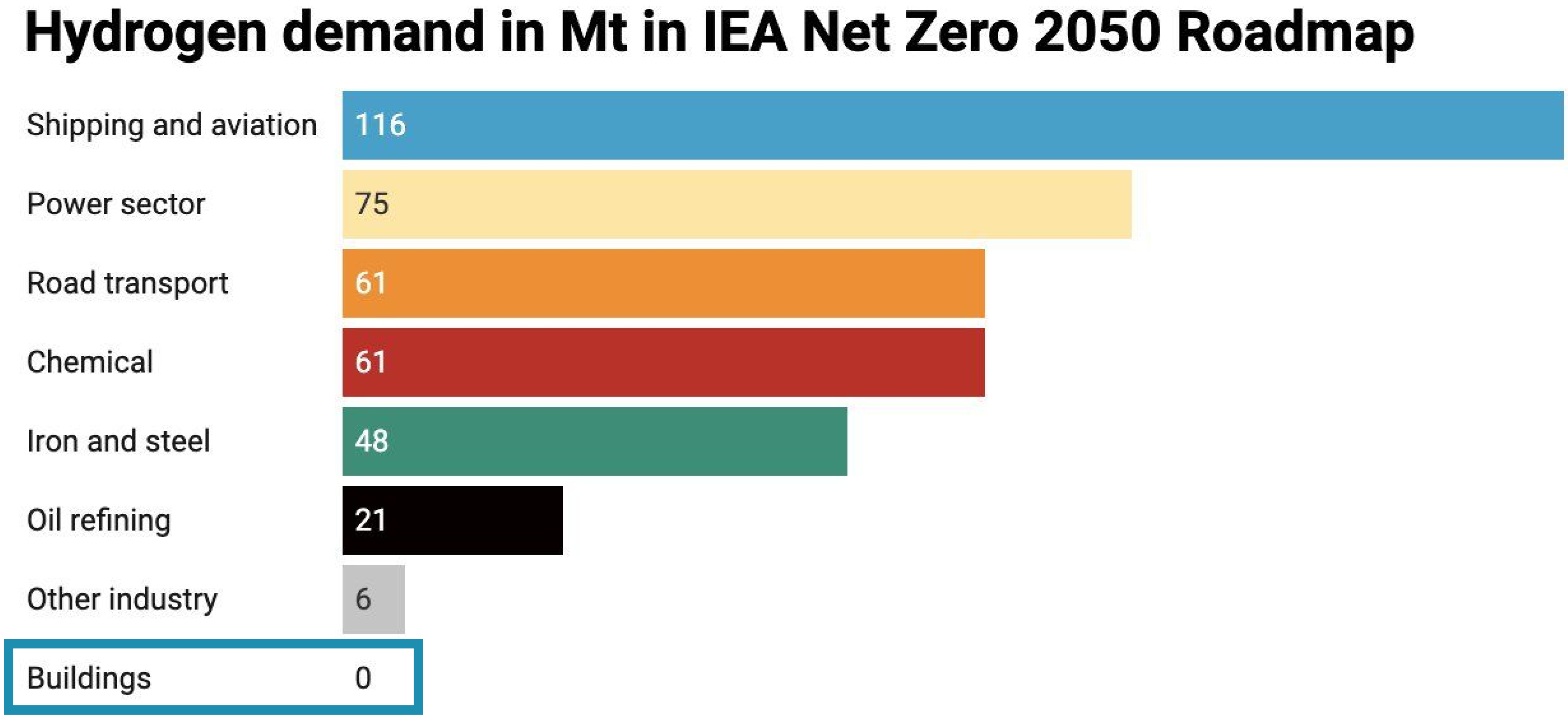
Do not go *too far* with any specific measure

Cost-effective decarbonization



Source: Rosenow and Hamels 2023

SOLUTION FOR THE BUILT ENVIRONMENT?



Source: IEA Net Zero 2050 Roadmap, 2023

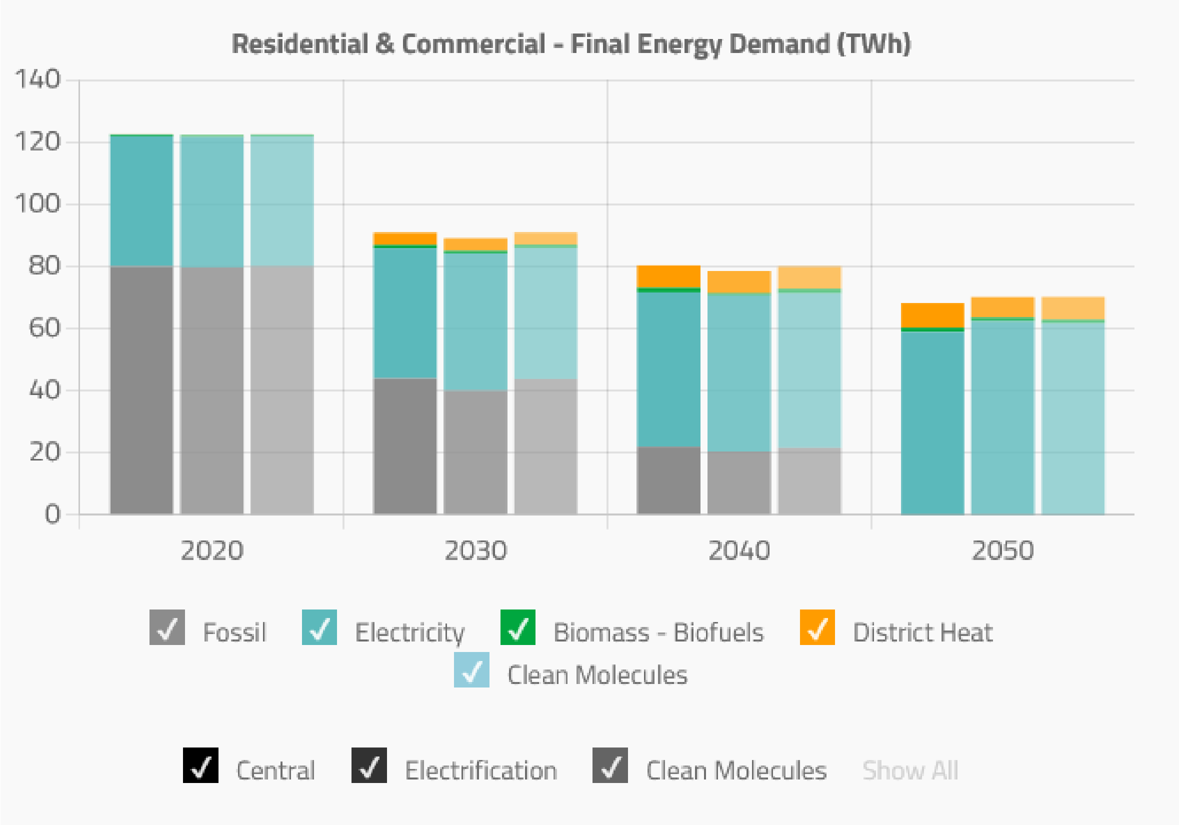
PATHS 2050

The Power of Perspective

Towards a climate-neutral Belgium

3 Scenarios

1. Central
2. Electrification
3. Clean molecules



By 2030, heat pumps are installed in

1,5 million

residential homes and commercial buildings.

By 2030, renovation, insulation and

fuel oil phaseout

realise 50% CO_2 reduction

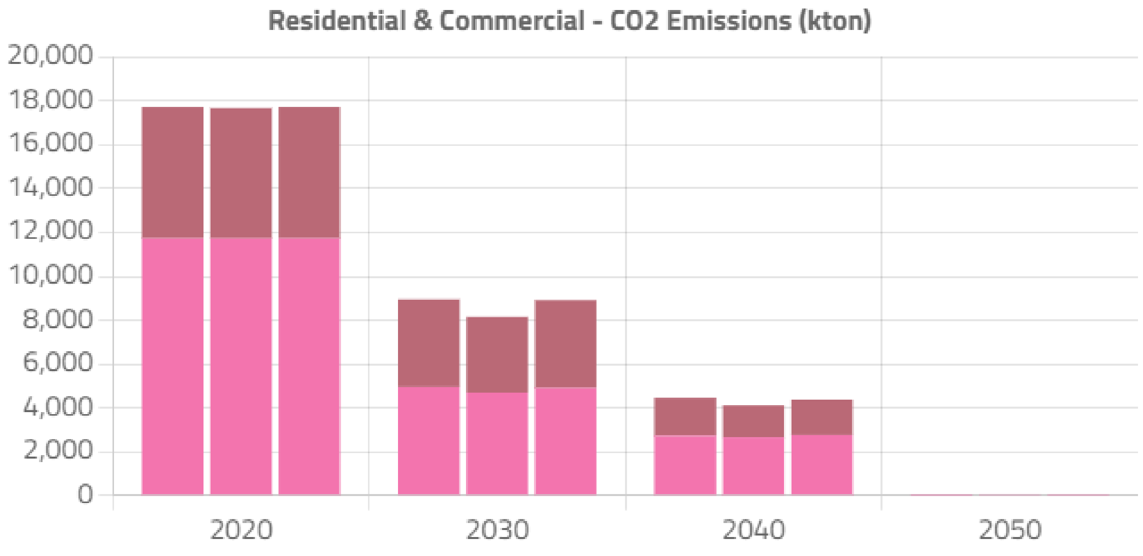
By 2050, district heating (8TWh) fulfills the demand of at least

800.000 homes

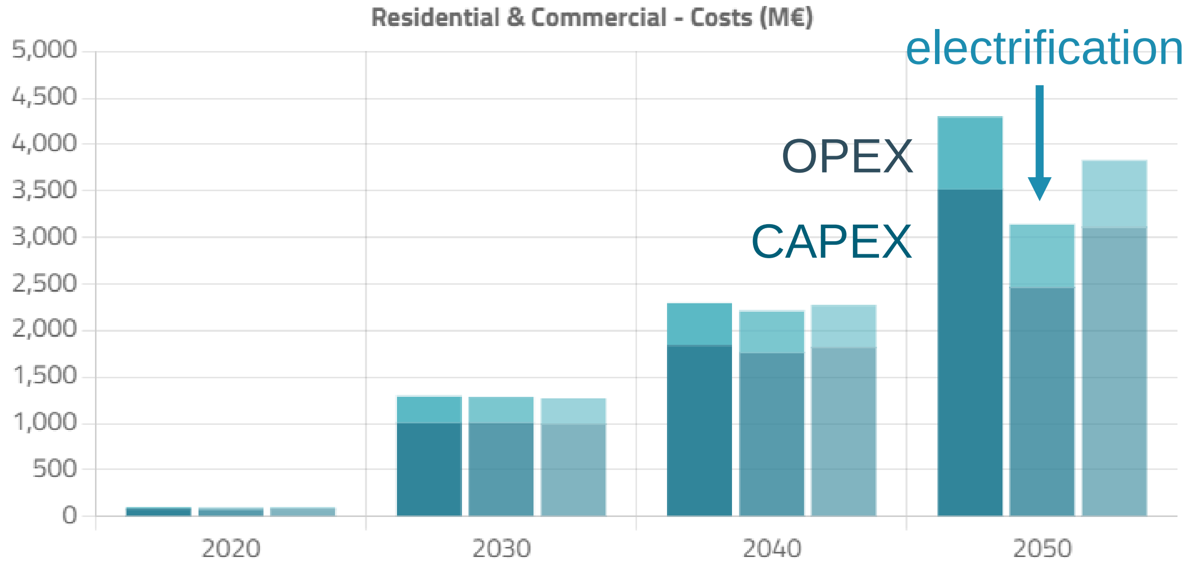
based on geothermal and waste heat.

Source: EnergyVille

CO_2 emissions are comparable



But costs differ …

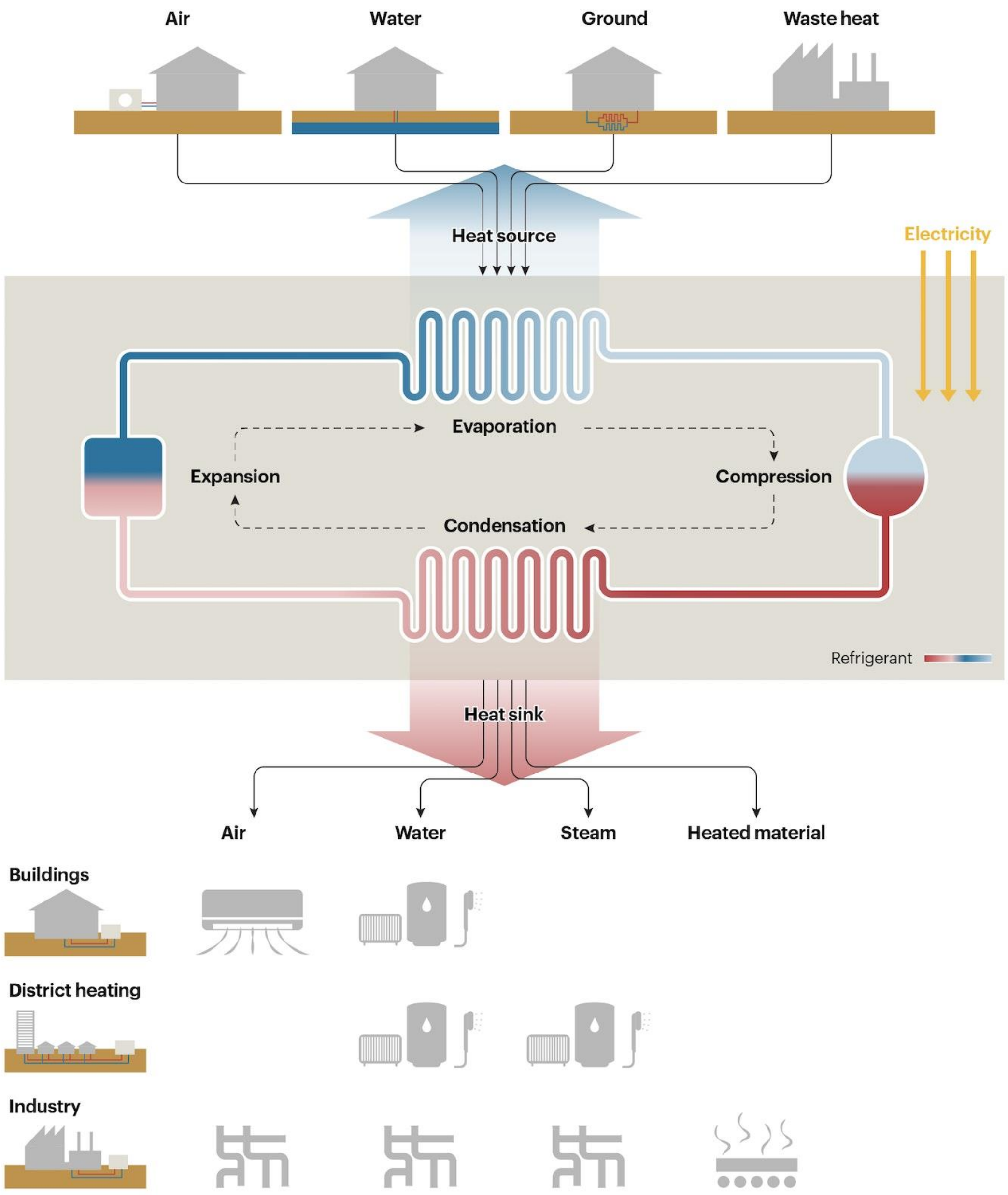


Electrification scenario:
access to more offshore wind and the option to invest in new nuclear technology

Source: EnergyVille

ELECTRIFICATION or HEATPUMPIFICATION

- Same technology as refrigerators (> 200 years)
- Generates heat and cold simultaneously
- Advanced technology for higher COP
- Alternative refrigerants
- Carbon-neutral if ELEC is R$^{(2)}$ES-based
- Lower COP in cold climate, but always > 1
- Water and ground: more stable source temp
- Sizing is crucial: often HP oversized, heat emitters and pipes undersized
- Viable solution in many dwellings



Source: IEA 2022

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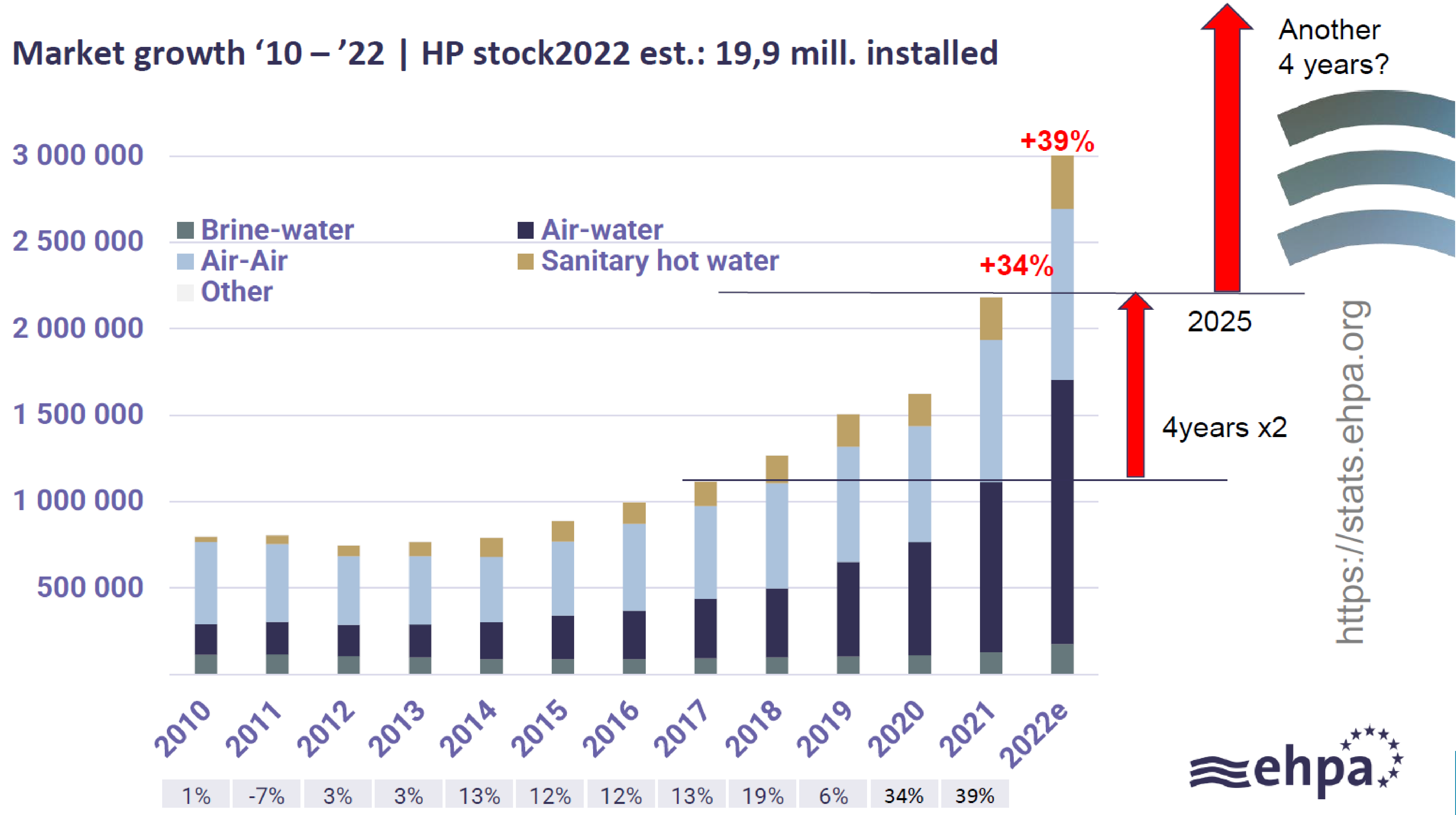
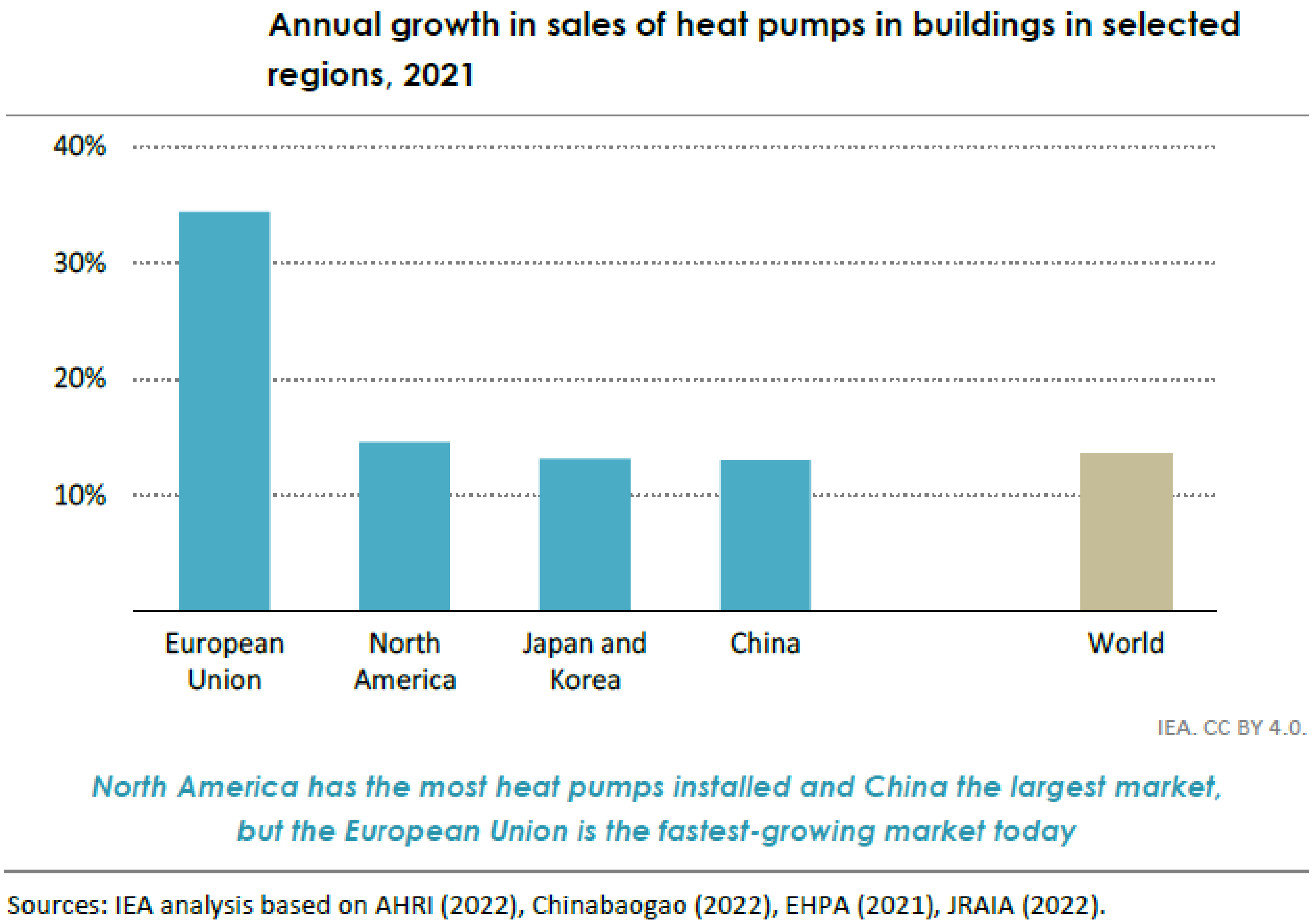
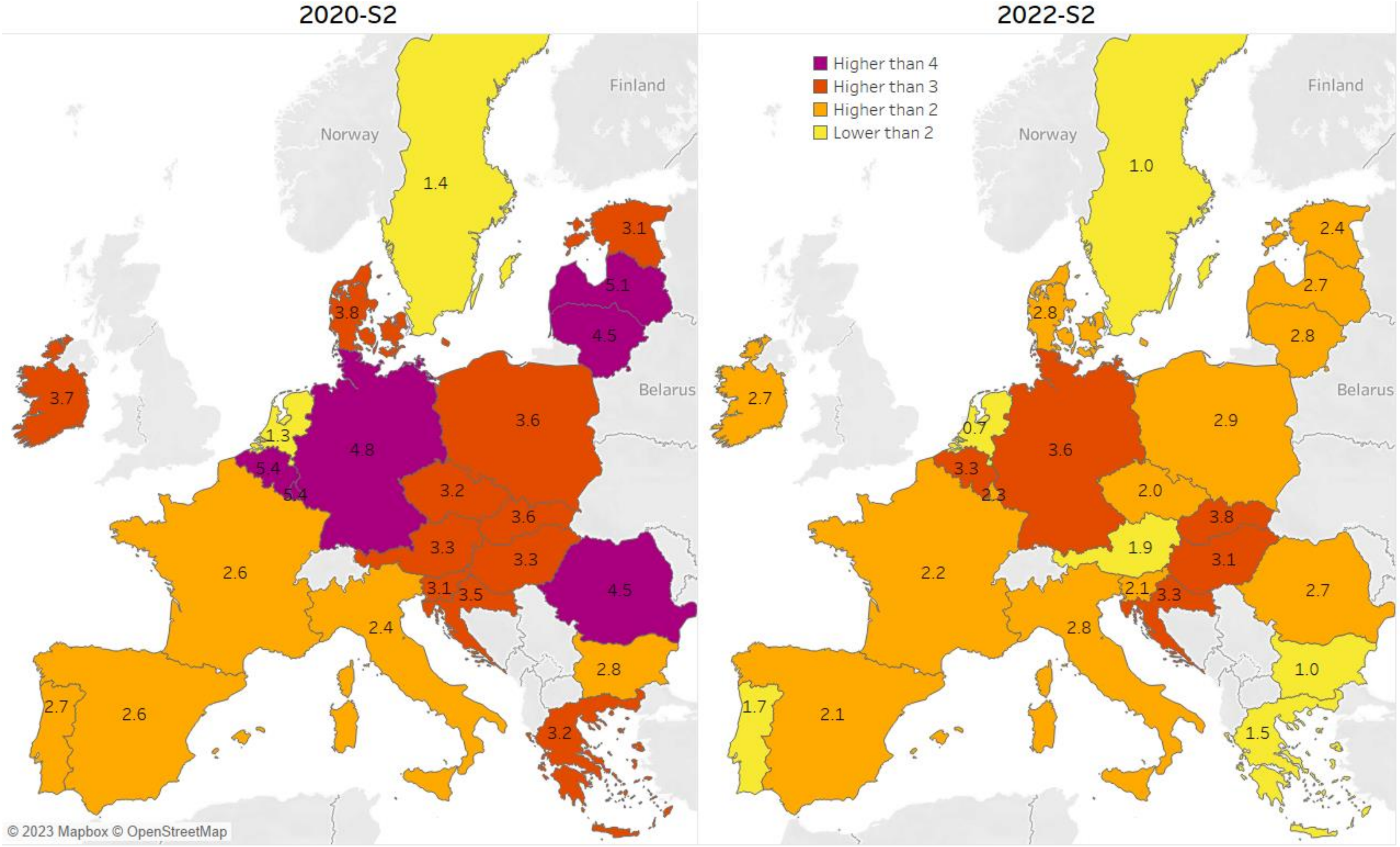
Market growth '10 – '22 | HP stock2022 est.: 19,9 mill. installed





Source: IEA 2022

ELECTRICITY/GAS PRICE RATIO (2020 vs 2022)

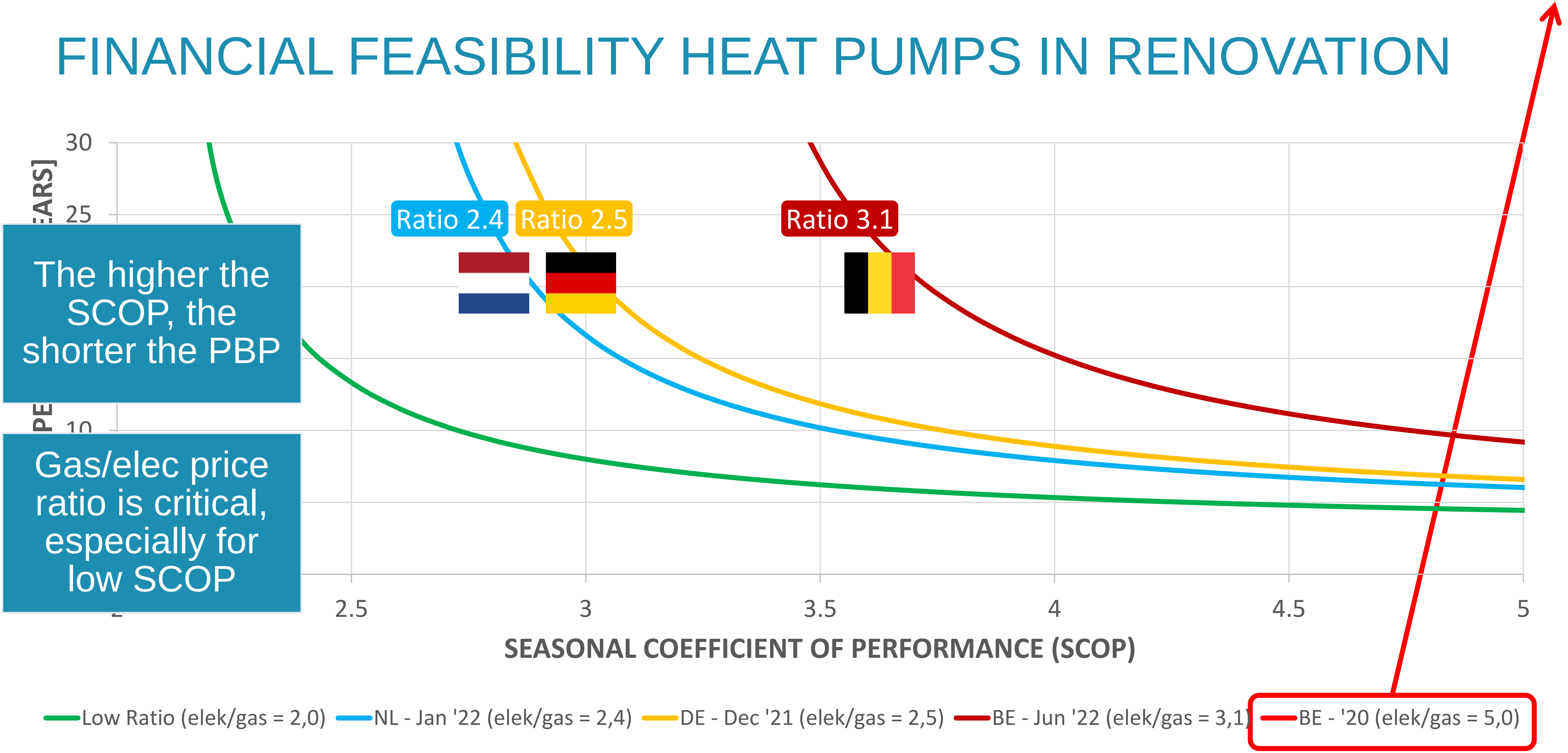


Source: Eurostat

Household consumers Band DC : > 2 500 kWh and < 5 000 kWh; Band D2 : > 20 GJ and < 200 GJ; All taxes and levies included

Source: Eurostat

FINANCIAL FEASIBILITY HEAT PUMPS IN RENOVATION



The higher the SCOP, the shorter the PBP

Gas/elec price ratio is critical, especially for low SCOP

Source: Vito

HEAT PUMPS IN RENOVATION - BE

Fraction of heat supplied by heat pump

Simulations with radiators

After renovation

Case X: Vb. Prijsniveau 3.5, schaalfactor 1.3

Insulation level	a	b	c	d	e	f
a	OK					
b	OK	?				
c	OK	OK	NOK			
d	OK	OK	NOK	NOK		
e	OK	OK	?	NOK	NOK	
f	OK	OK	OK	?	NOK	NOK

Before renovation

Numbers = fraction of heat supplied by heat pump (1 = 100%)

Policy adaptation

Elec/gas price ratio = 4.5						
level	a	b	c	d	e	f
a	0.13					
b	0.13	0.10				
c	0.13	0.10	0.08			
d	0.14	0.11	0.09	0.07		
e	0.15	0.12	0.09	0.07	0.06	
f	0.19	0.14	0.11	0.09	0.08	0.06

Elec/gas price ratio = 3.5						
level	a	b	c	d	e	f
a	0.93					
b	0.93	0.71				
c	0.93	0.71	0.42			
d	0.95	0.76	0.47	0.28		
e	0.96	0.78	0.49	0.31	0.25	
f	0.98	0.85	0.60	0.40	0.33	0.23

Elec/gas price ratio = 2.5						
level	a	b	c	d	e	f
a	1.00					
b	1.00	1.00				
c	1.00	1.00	0.93			
d	1.00	1.00	0.96	0.74		
e	1.00	1.00	0.98	0.78	0.68	
f	1.00	1.00	1.00	0.90	0.83	0.62

Elec/gas price ratio = 1.8						
level	a	b	c	d	e	f
a	1.00					
b	1.00	1.00				
c	1.00	1.00	1.00			
d	1.00	1.00	1.00	0.97		
e	1.00	1.00	1.00	0.99	0.94	
f	1.00	1.00	1.00	1.00	1.00	0.90

Elec/gas price ratio = 4.5

- Pre '22
- Heat pumps nowhere

Elec/gas price ratio = 3.5

- Q1, Q4 '22
- a-level: heat pump
- b-c-level: hybrid
- d-f-level: gas boiler

Elec/gas price ratio = 1.8

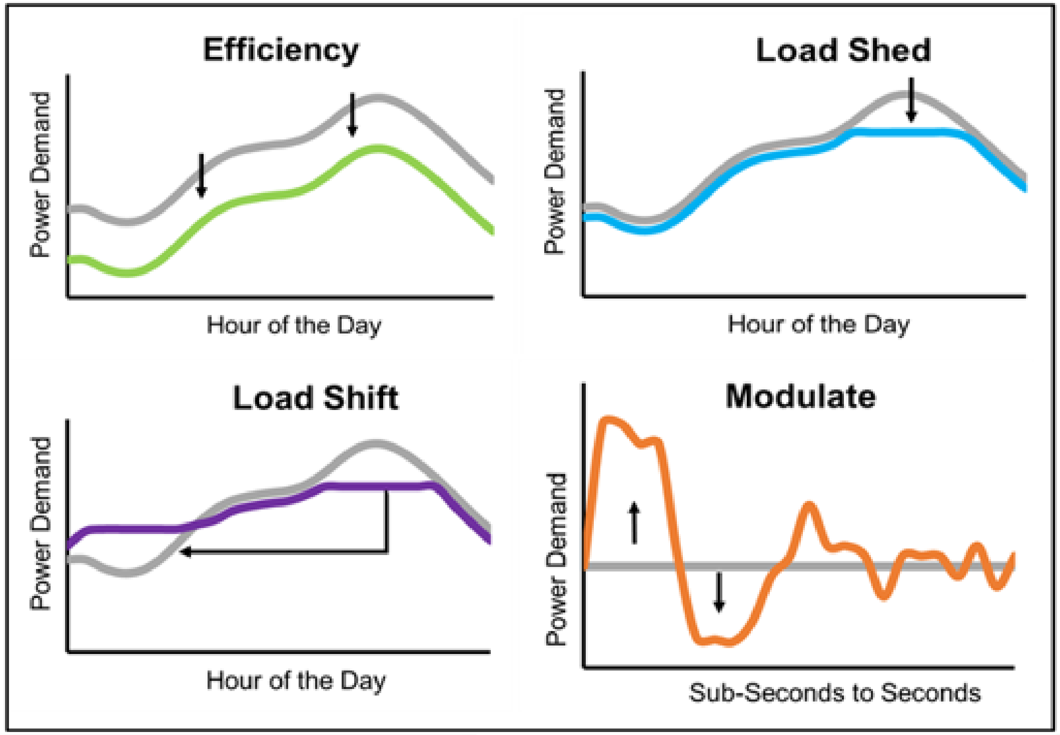
- Heat pumps everywhere

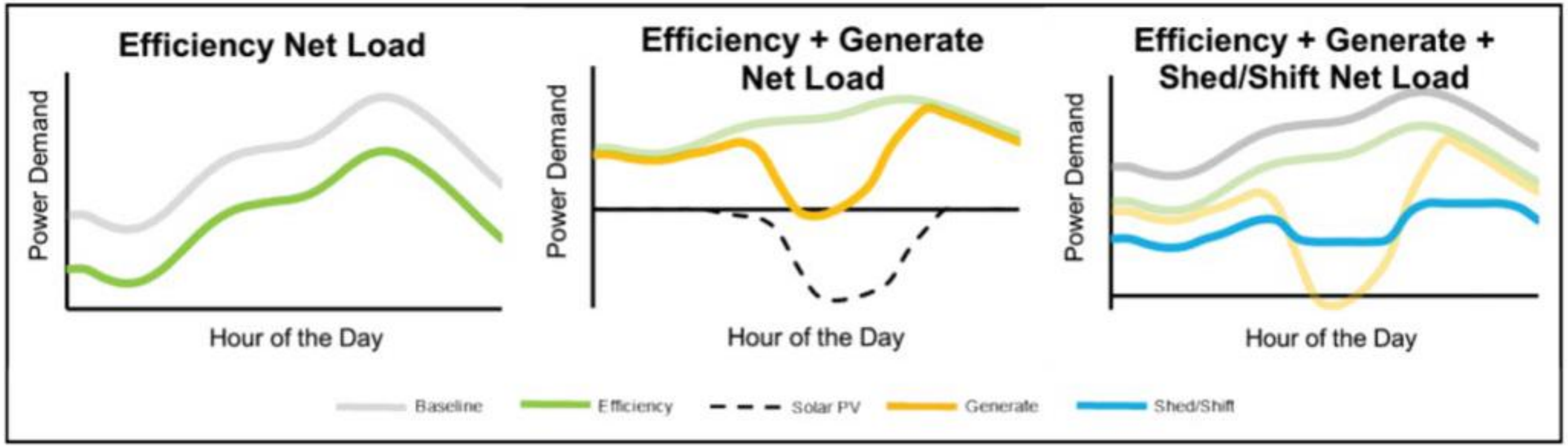
Source: Vito

IMPACT ON THE GRID?

LOADS

- Peaks!
- Not just an input
- FLEX!





Source: DOE

NEED FOR DEMAND FLEXIBILITY

Co-optimizing to serve occupants and the grid thanks to **system integrator**

- System
  - Grid-interactive efficient (smart) buildings (with thermal mass)
  - Electricity system with high share of variable RES
  - District heating networks (collective and hybrid, R^2ES and storage)
  - Heat pumps (centralized and local)

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  = FLEXIBLE RESOURCES enabling heat demand shifts

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NEED FOR DEMAND FLEXIBILITY

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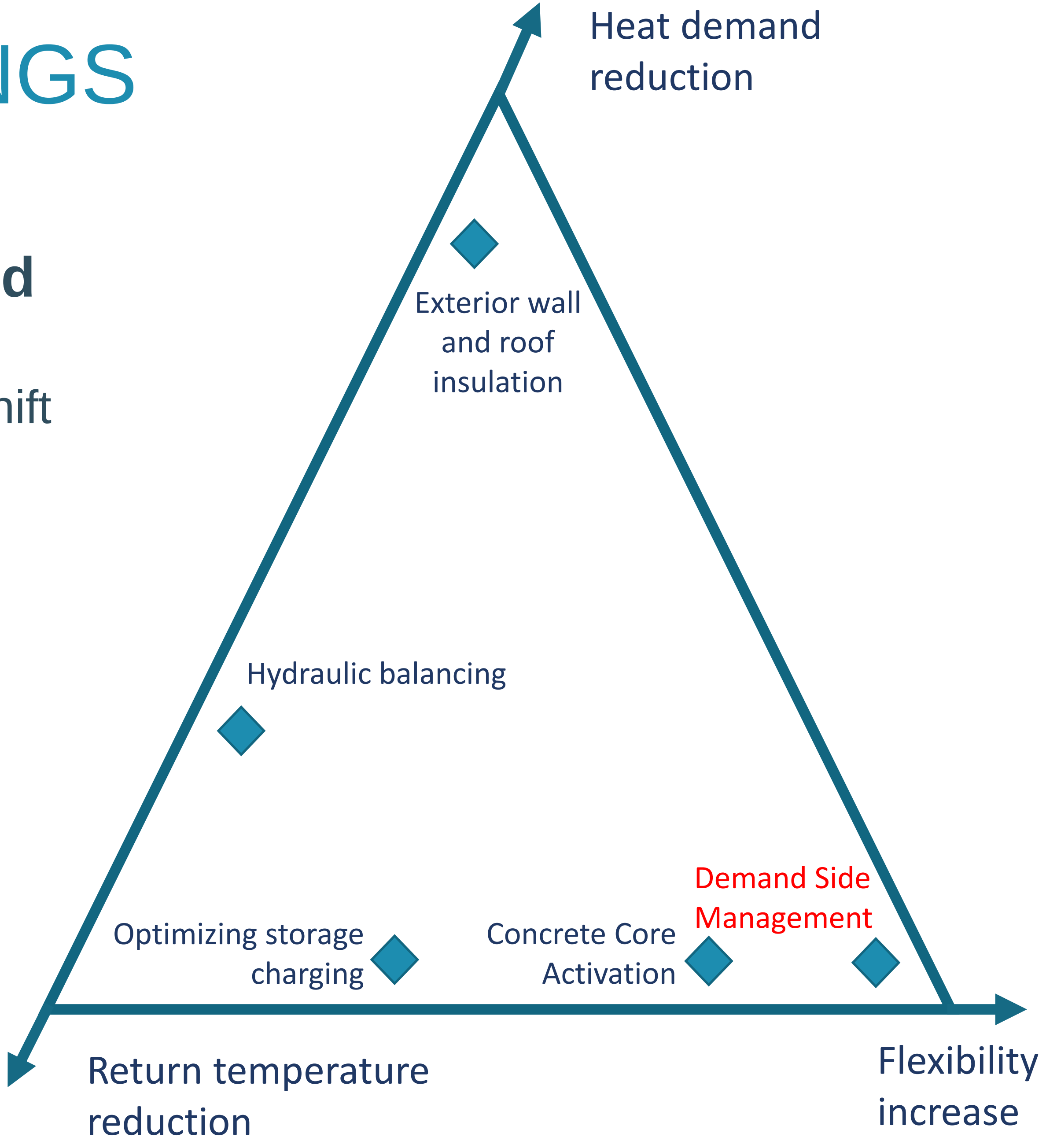
  = FLEXIBLE RESOURCES enabling heat demand shifts
- Gains (although they come with challenges, a.o. human behavior):
  lower cost, enhance reliability and resilience, reduce emissions, reduce peak loads, moderate demand ramping, provide grid services, enhance energy efficiency, integrate DER and RES

GRID-FRIENDLY BUILDINGS

Building and HVAC system integrated

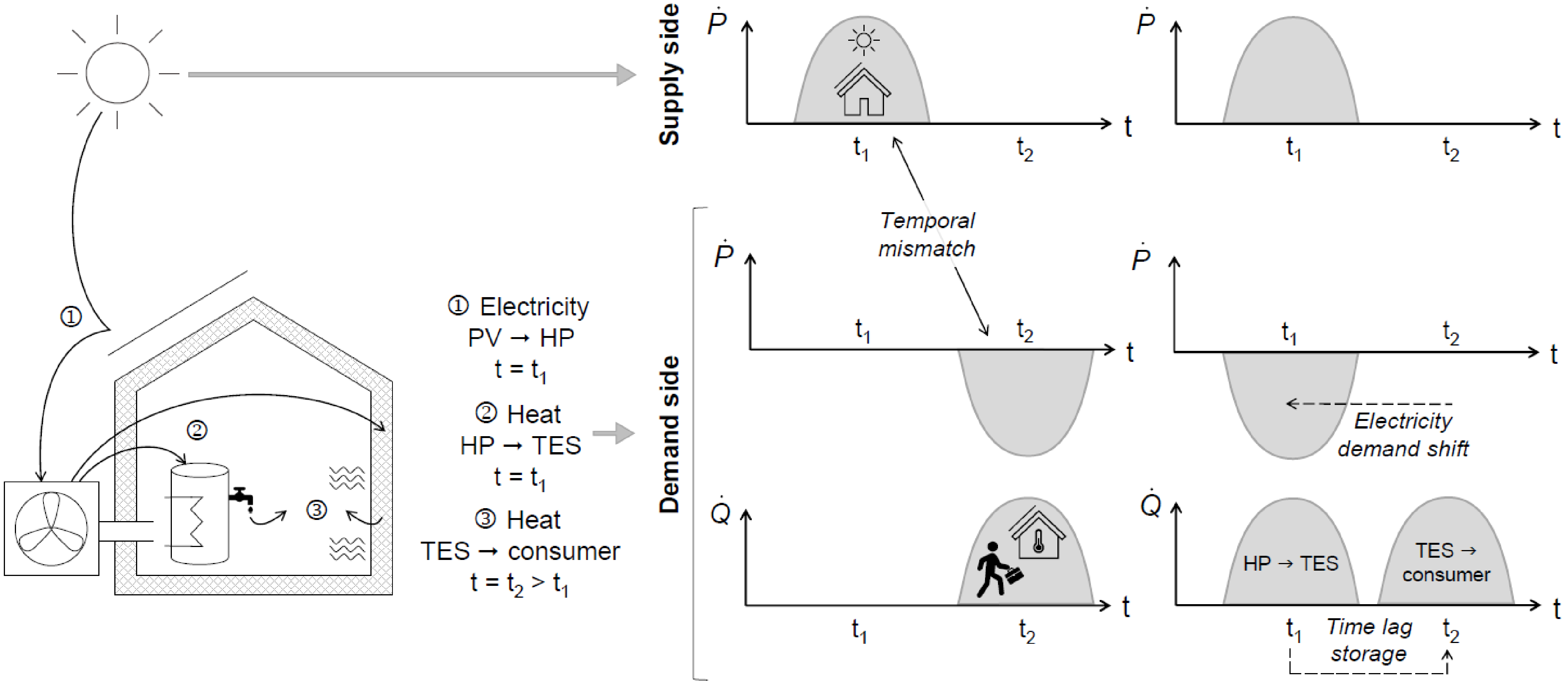
- Light-weight building and fast emission system (e.g. air-based): tiny window to shift
- Heavy-weight building and inertia (e.g. GEOTABS): potential for storage
- HP + PV
  - Temporal mismatch for heating
  - Temporal match for cooling, but mismatch in power



Source: adapted from Ralf-Roman Schmidt

DEMAND SIDE FLEXIBILITY

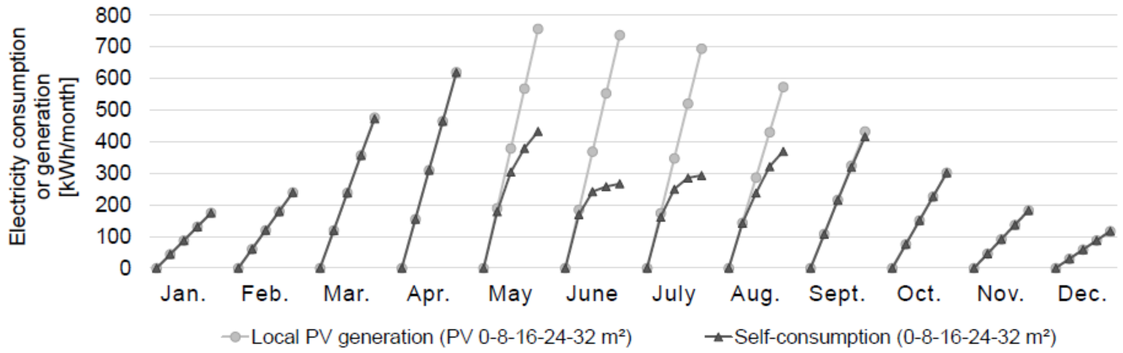
in energy efficient smart buildings



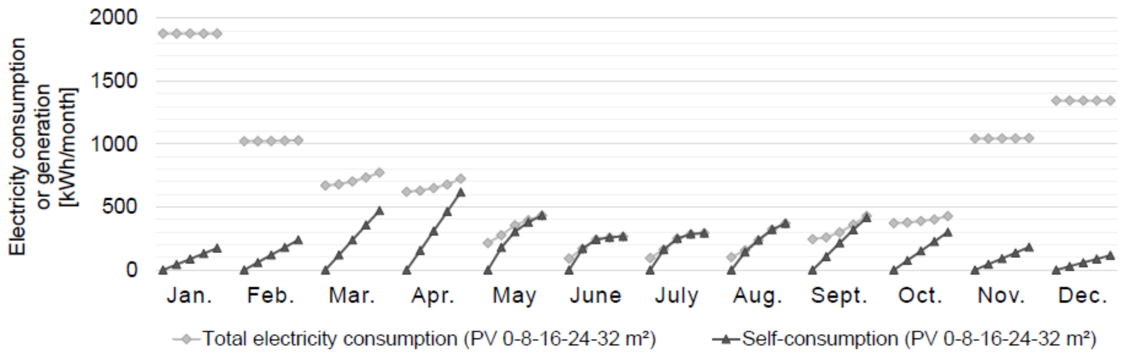
Source: Anke Uytterhoeven 2021

DEMAND SIDE FLEXIBILITY – building-level

Without active cooling

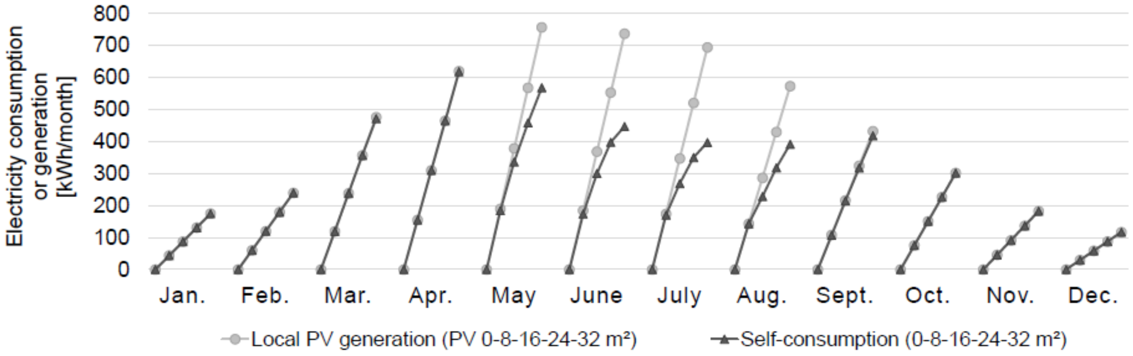


(a) The monthly self-consumption versus the monthly local PV generation.



(b) The monthly self-consumption versus the monthly total electricity consumption.

With active cooling



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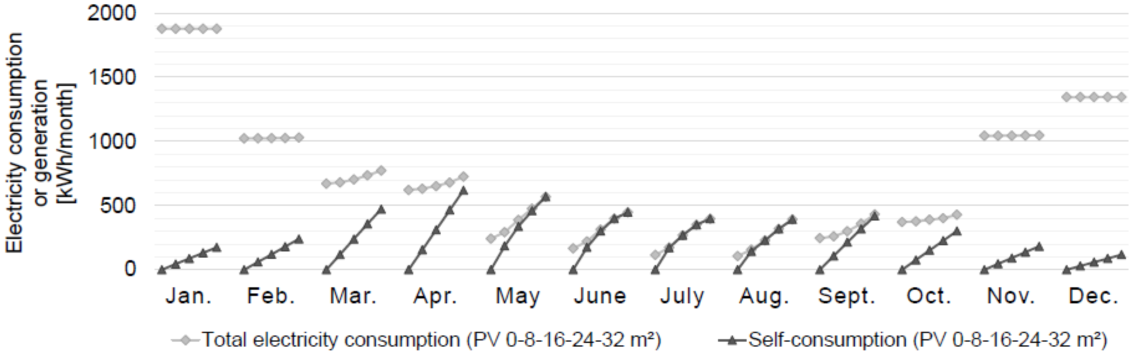


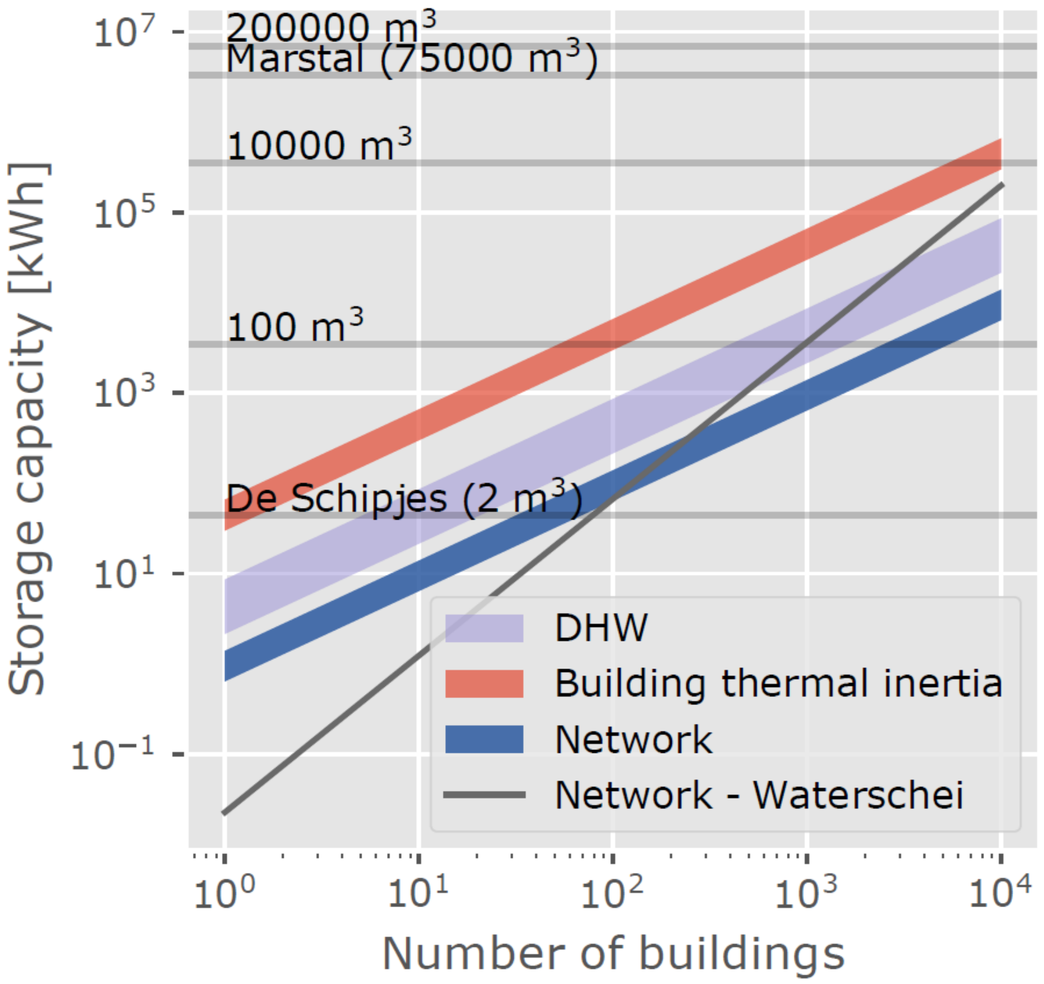
(b) The monthly self-consumption versus the monthly total electricity consumption.

Source: Anke Uytterhoeven 2021

BUILDING CLUSTER

To increase efficiency synergy
by unlocking increased flexibility

- Between building functions
  Exchange of thermal energy
- Between power and heat sectors
  DHC networks and HPs support ELEC grids
- Smart connections
  BUT AI has a footprint as well



Source: Annelies Vandermeulen 2020

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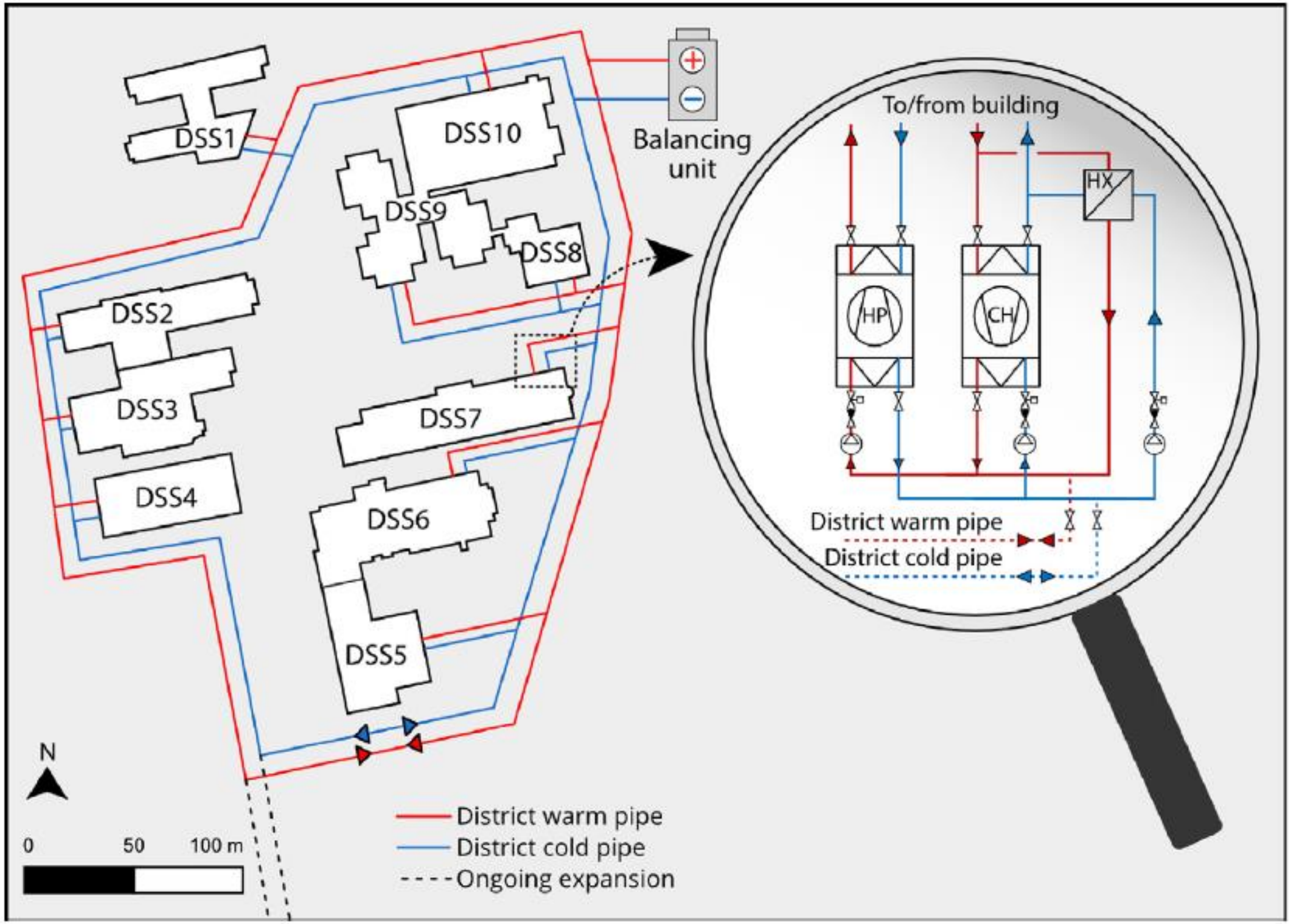
CIRCULAR

Be smart with what you have
(locally available clean resources)

Less resources to reach the same

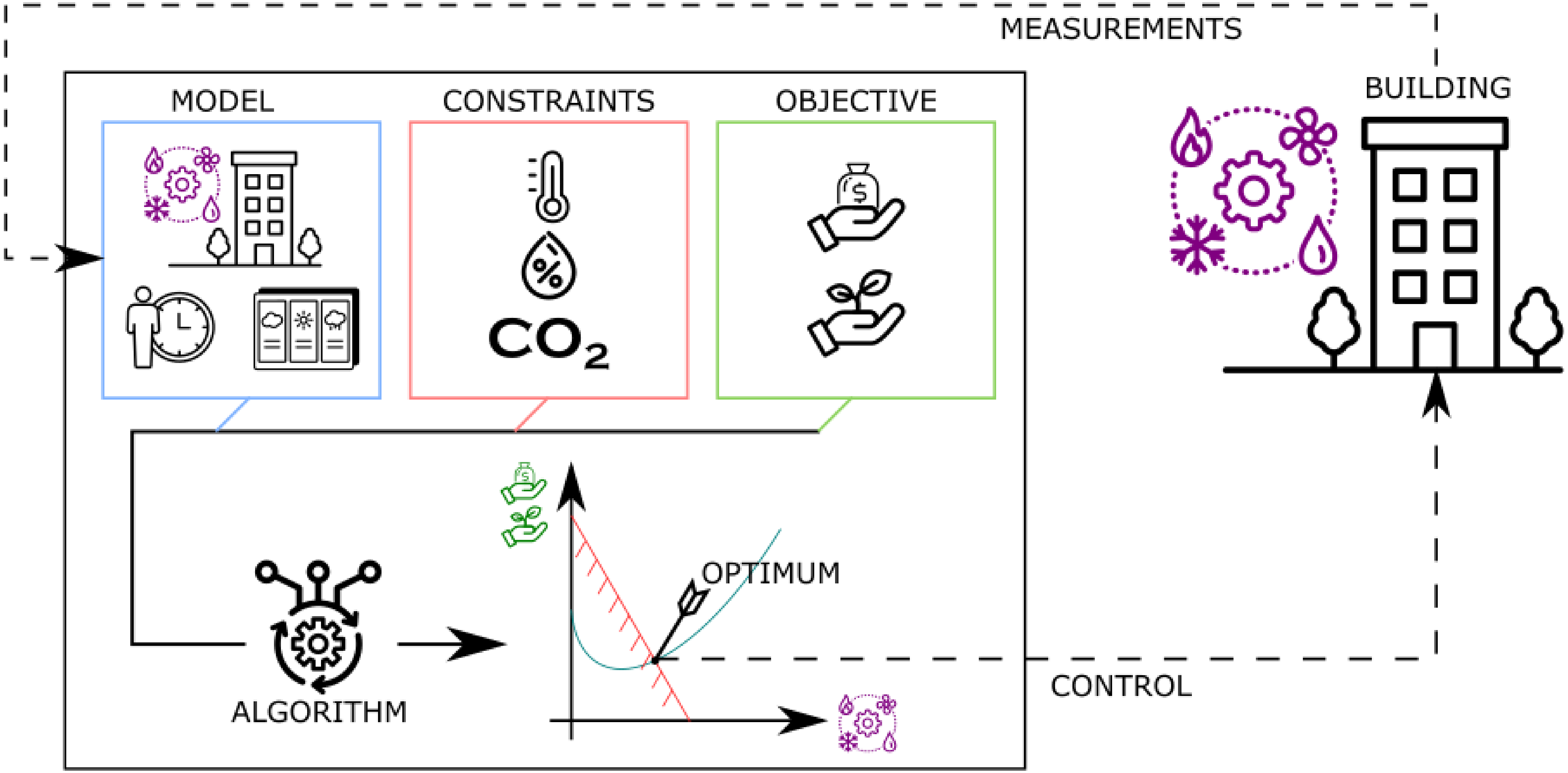
Hybrid & Collective

Air is no longer the thermal waste bin



Source: Marwan Abugabbara 2023

SYSTEM INTEGRATOR – Model Predictive Control



Source: Damien Picard & Filip Jorissen 2021

APPLIED TO BUILDING LEVEL

hybrid GEOTABS

Funded by the European Union

White-box MPC (TACO): up to 55 % saving

BUILTWINS
Sustainable Building Control

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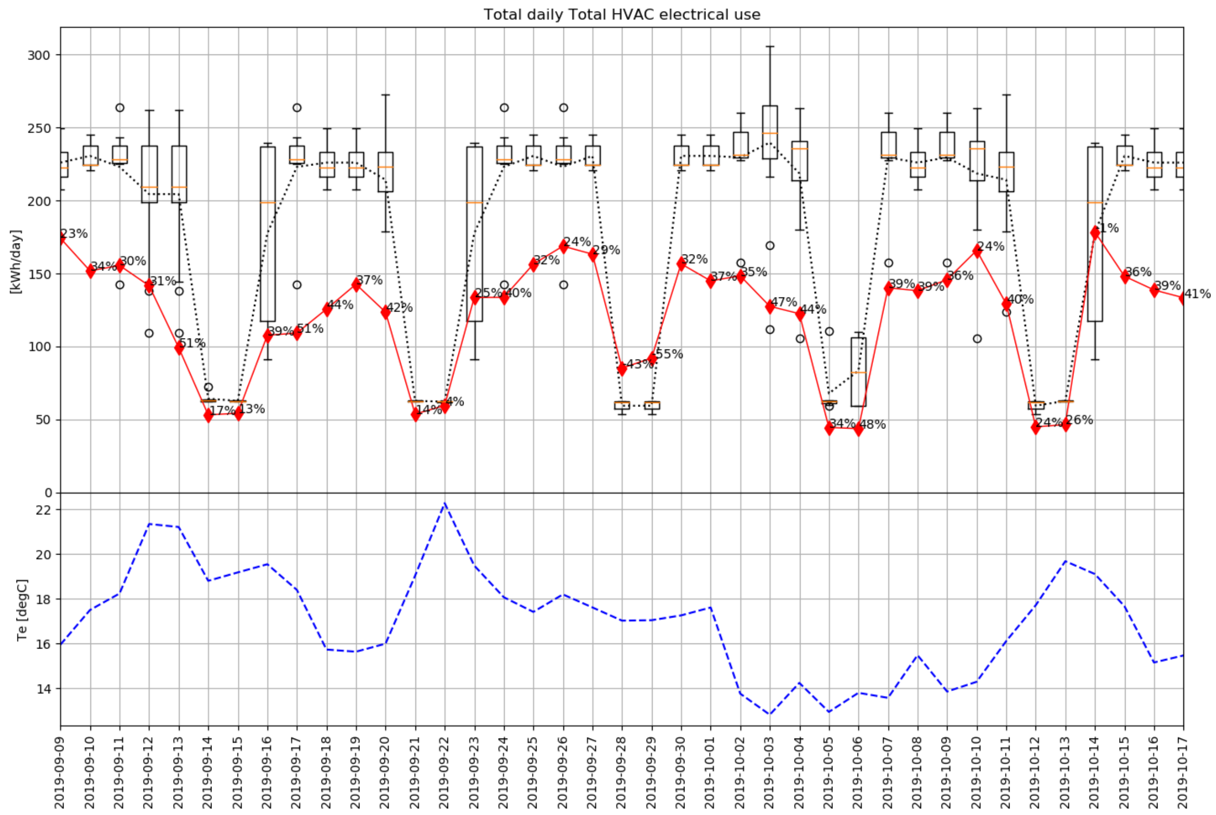


Day – date in 2019

PRIVA DeltaQ fluvius. boydens engineering part of Sweco

Source: Filip Jorissen et al. 2019

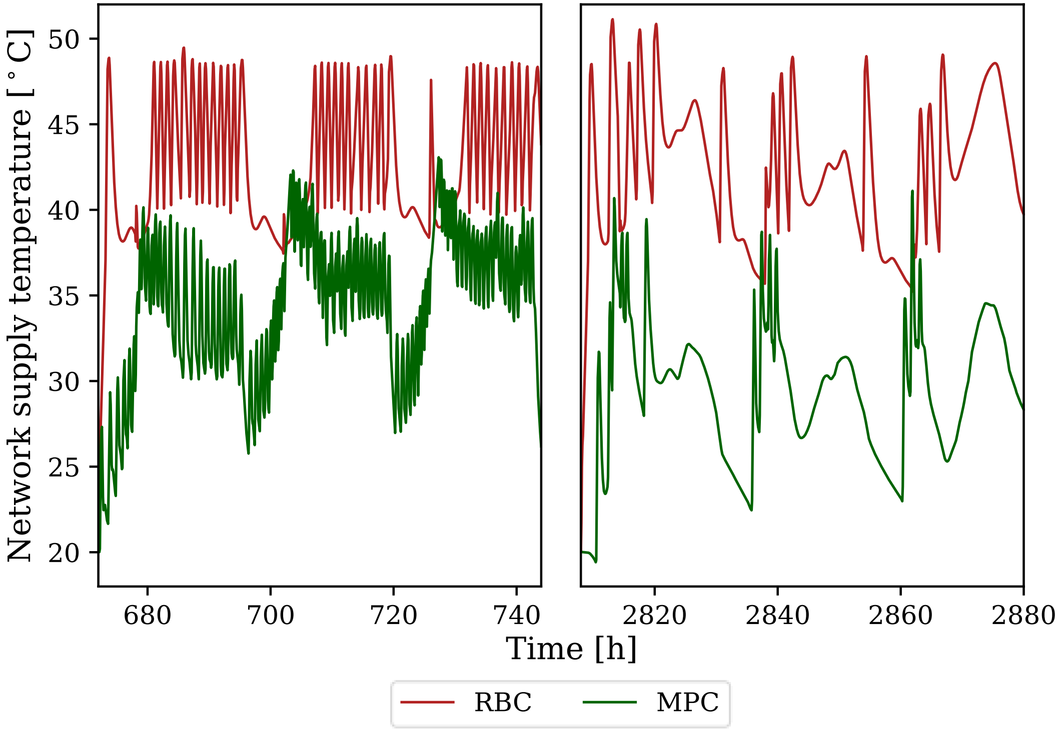
APPLIED TO THERMAL NETWORK

Simulation based comparison

Model Predictive Control (MPC) versus Rule Based Control (RBC)

Winter Controller	Mean thermal discomfort per building [Kh]	E_{el} [kWh] January 28-31
RBC	6.7	578
MPC	0.6	505
Δ	better	-13%

Spring Controller	Mean thermal discomfort per building [Kh]	E_{el} [kWh] April 27-30
RBC	0.1	164
MPC	0.4	107
Δ	equivalent	-35%



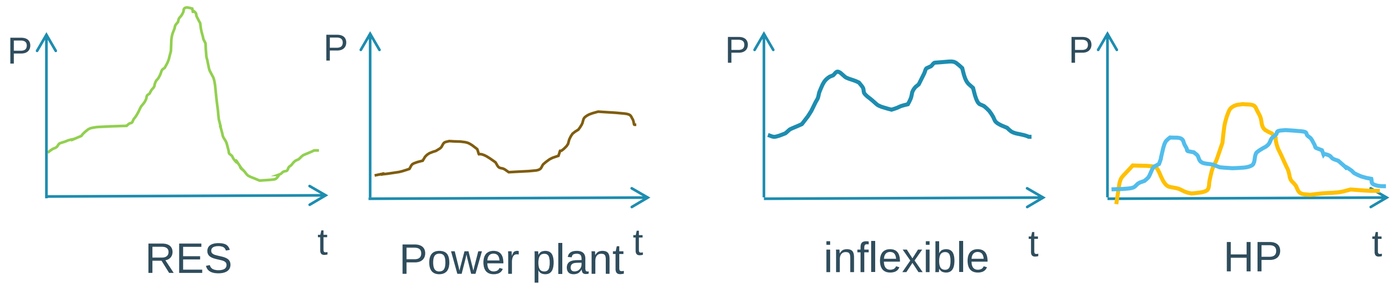
Source: Jelger Jansen 2022

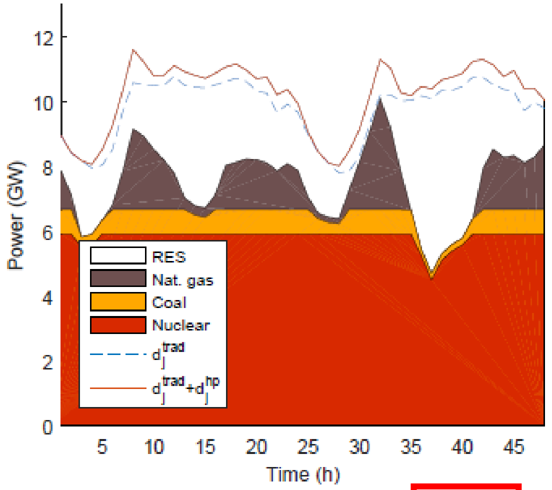
APPLIED TO THE SYSTEM LEVEL - DSM

Integrated operational model

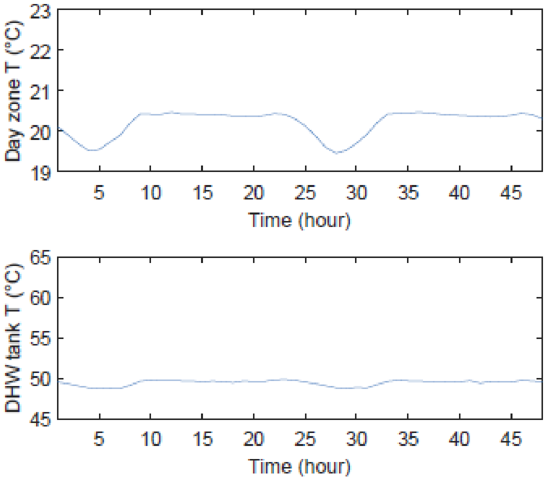
Minimizes system cost
taking limited potential as a constraint
(tank size, building thermal mass)

Supply **Demand**

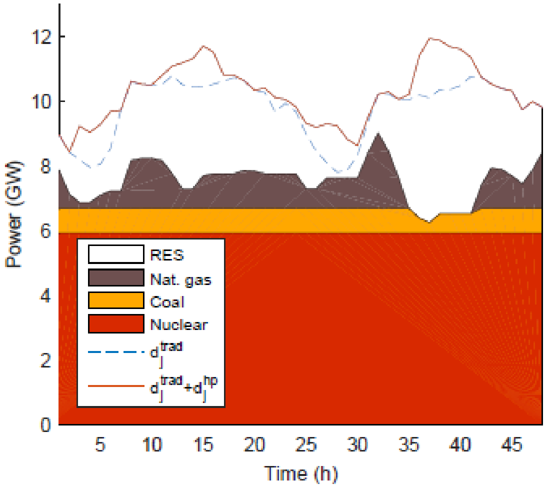




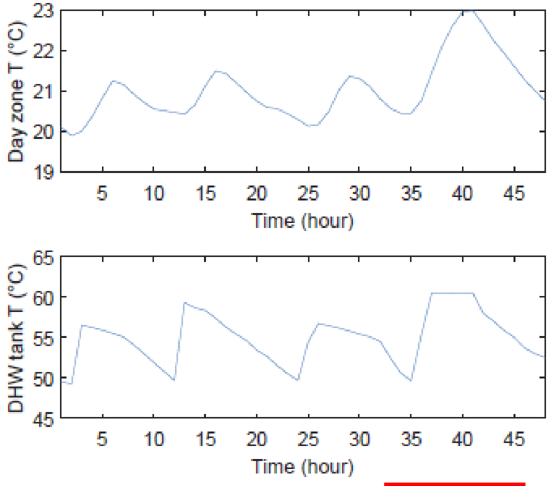
(a) Electricity generation, no DR



(b) Mean temperatures, no DR



(c) Electricity generation, with DR



(d) Mean temperatures, with DR

Source: Dieter Patteeuw 2016

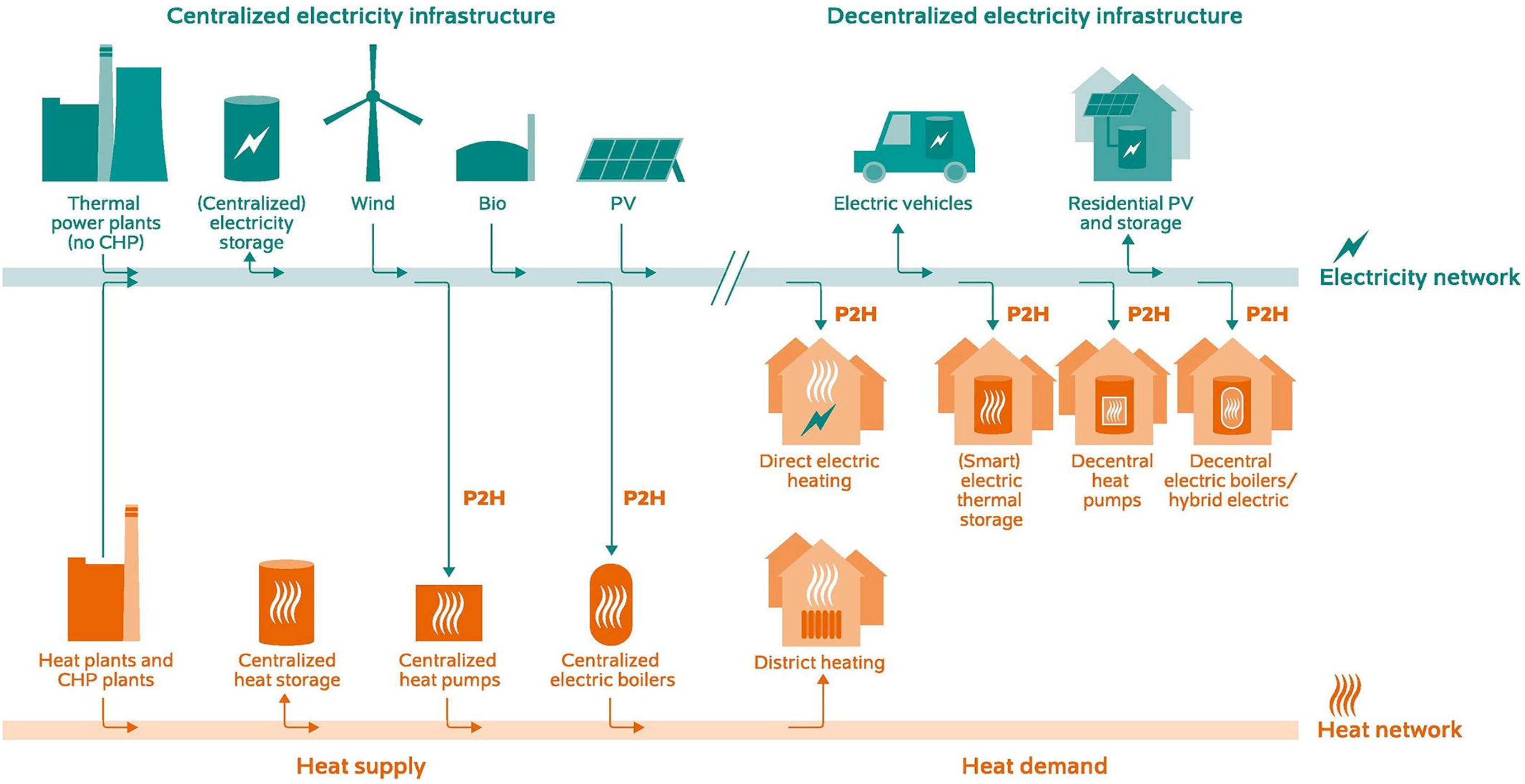
FLEX is an asset – drive for SECTOR COUPLING

Example: residential

Integrated energy system

Benefits:

- FLEX for RE systems (thermal helps electrical)
- Decarbonization (emission reduction)
- Reduced dependency (oil & gas)
- Total cost reduction (smart system integrator)

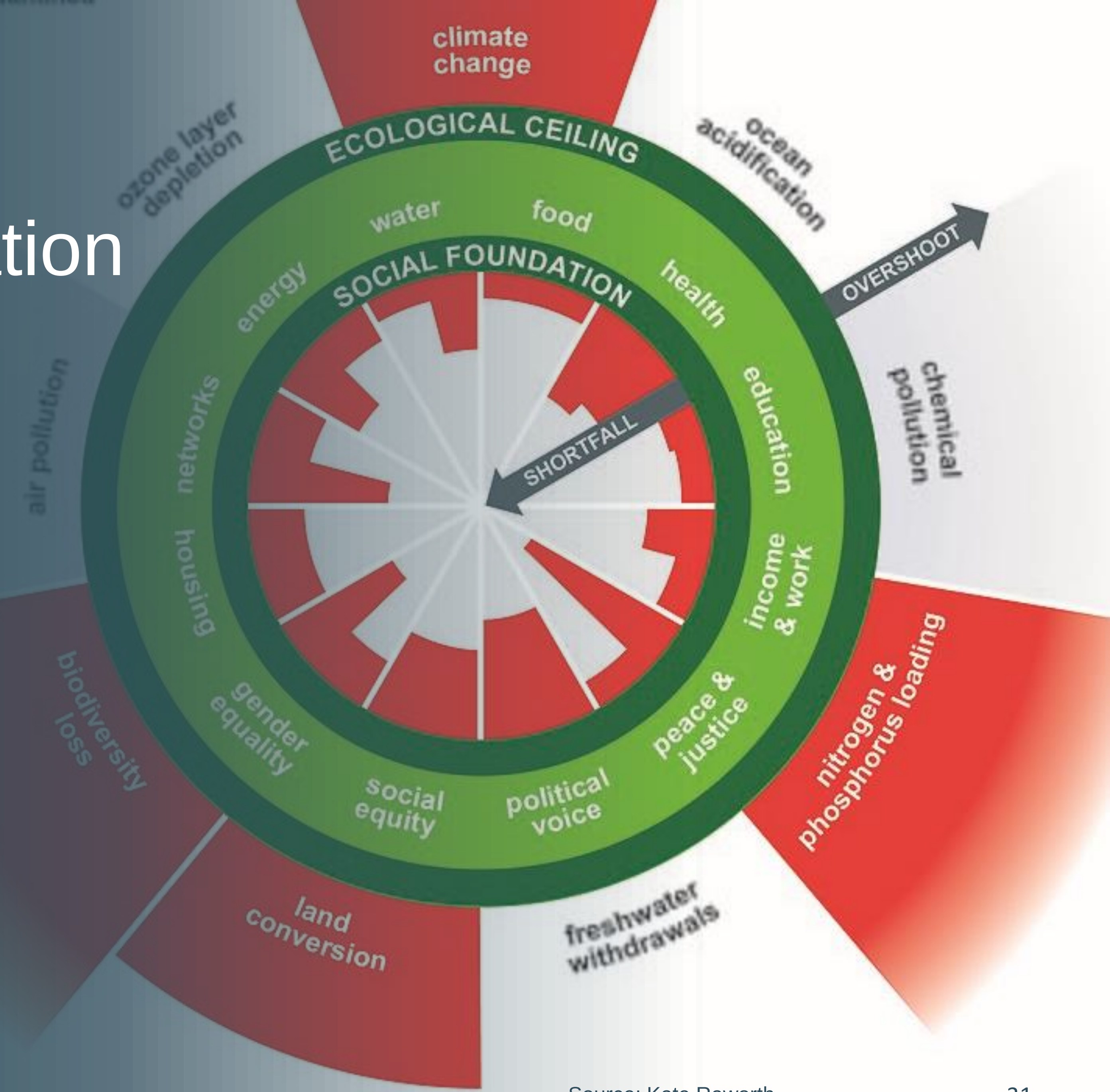


WIREs Energy & Environment, Volume: 10, Issue: 4, First published: 04 February 2021, DOI: (10.1002/wene.396)

Source: Bloess et al. 2018

Thanks to system integration BEYOND EFFICIENCY

Climate neutrality
Energy security
Resiliency
Equity
Affordability
Healthy environment
…
All captured in **SUSTAINABILITY**

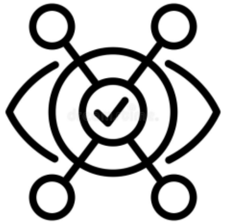


Source: Kate Raworth

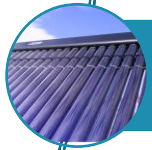
Buildings and their HVAC have an active role to play in the global energy system

Efficiency and decarbonization go hand in hand

Concept designs should aim for grid-friendly buildings and circular approaches



Thermal grids and heat pumps can support electrical grids



Temperature levels of heat supply and heat demand should be matched

Smart solutions do not count on AI only, they use locally available clean energy sources

Hybridization of technologies and approaches is key to capture wider system benefits

Opportunity for HVAC in the Building Sector

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