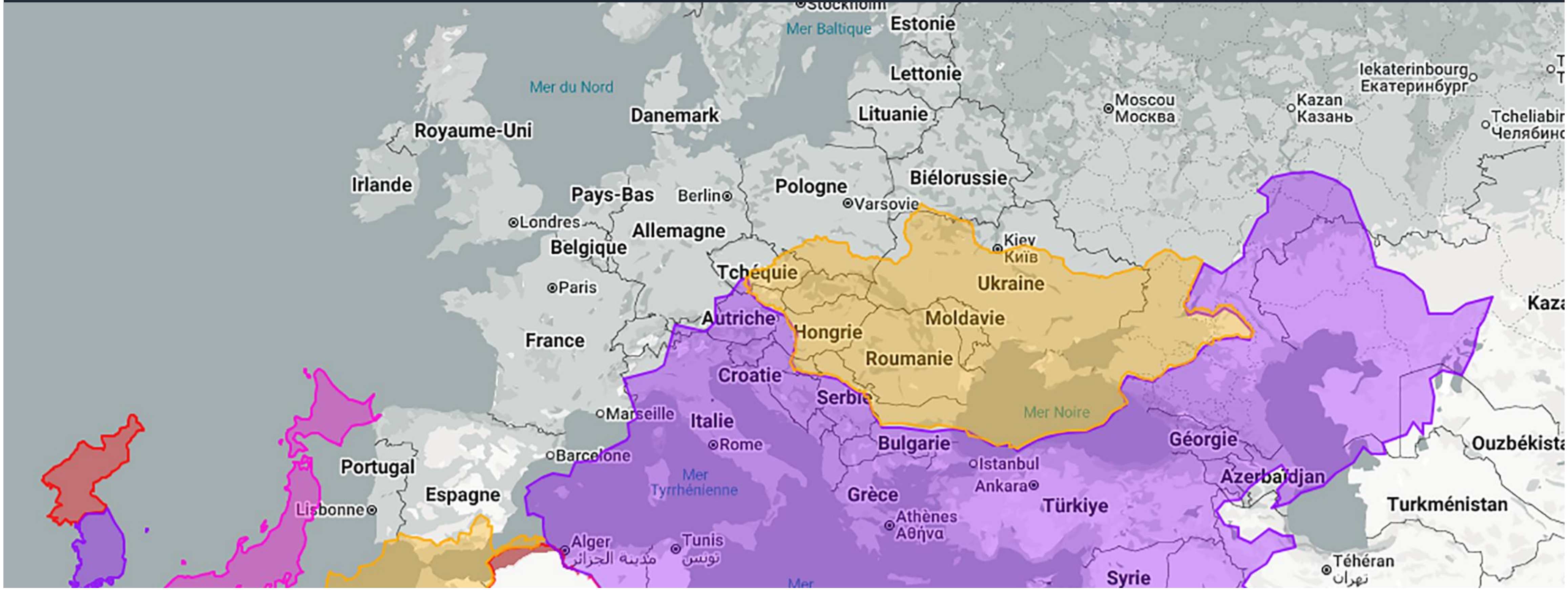
# Comparison of Zero Carbon Heating and Cooling Pathways in China and Europe

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# Acknowledgment

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Tsinghua University

Building Energy Research Center Tsinghua University

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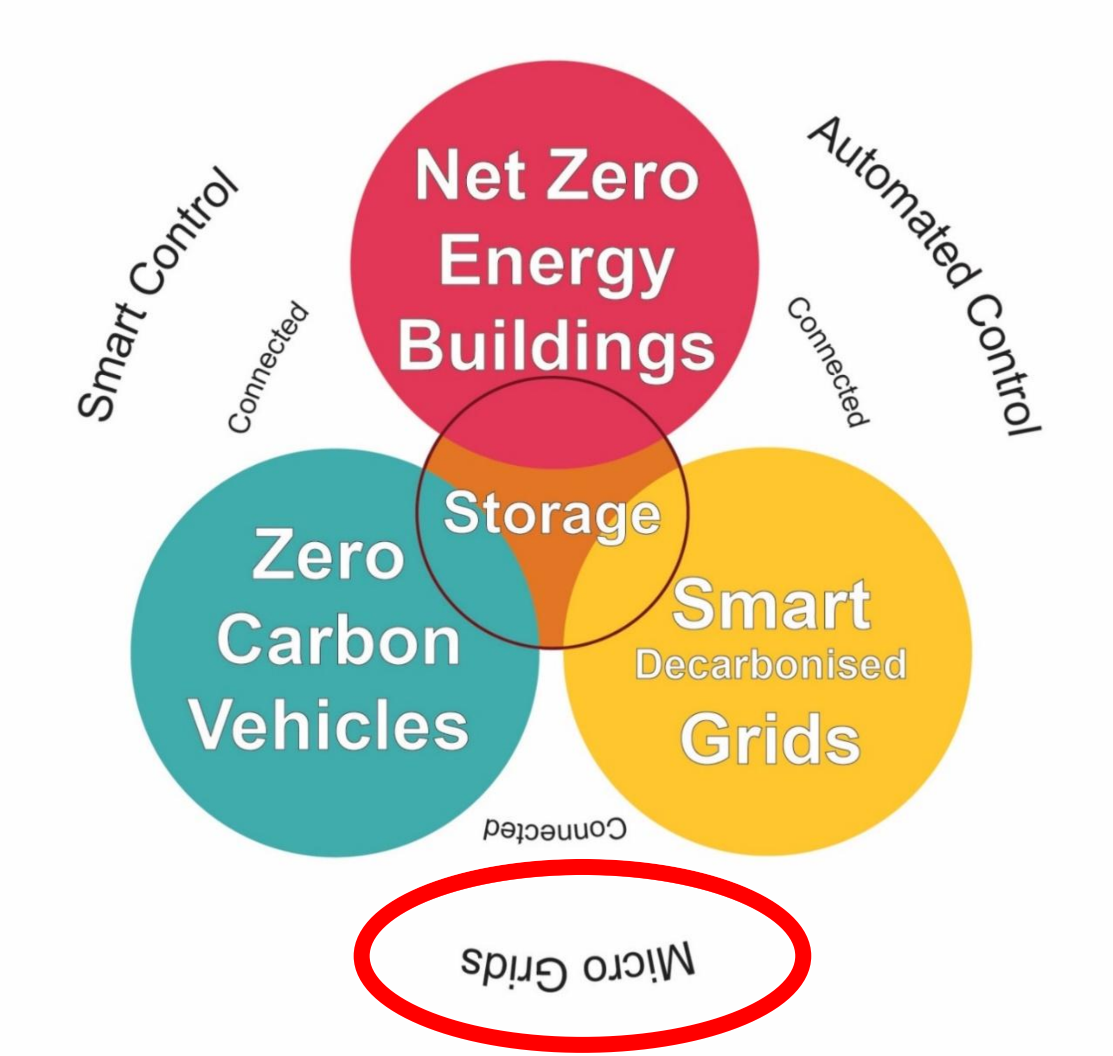
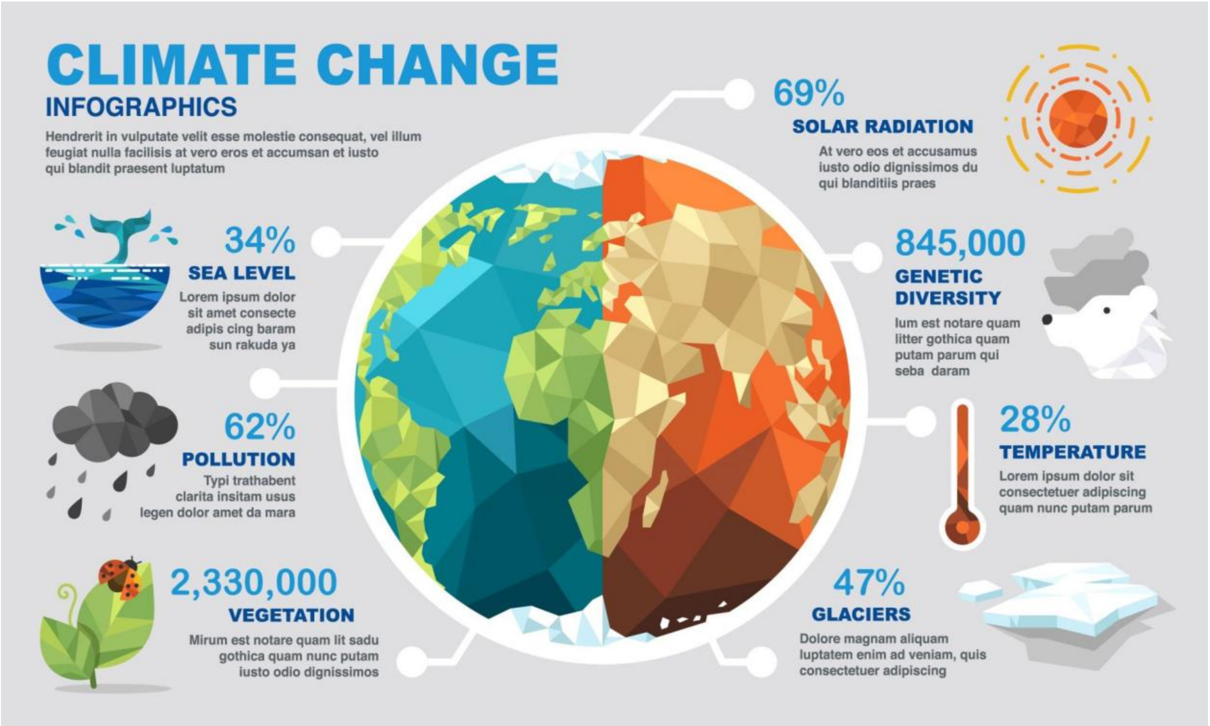
# Carbon Neutral Communities

## Storage & Scale the Core of Carbon Neutrality




**Resilience**

Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier

# China vs. EU: Basic Features Comparison

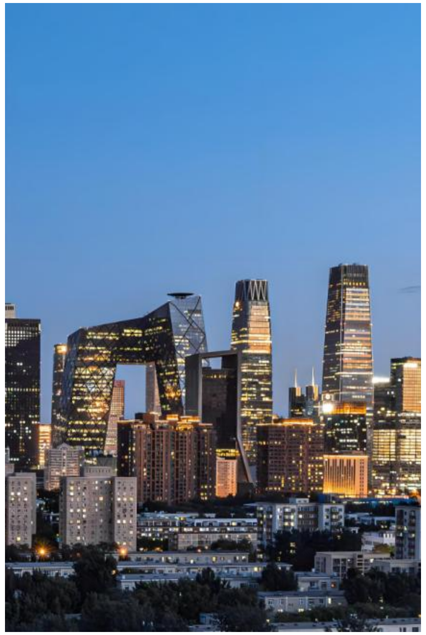
# China vs. EU: Basic Features Comparison

## Background

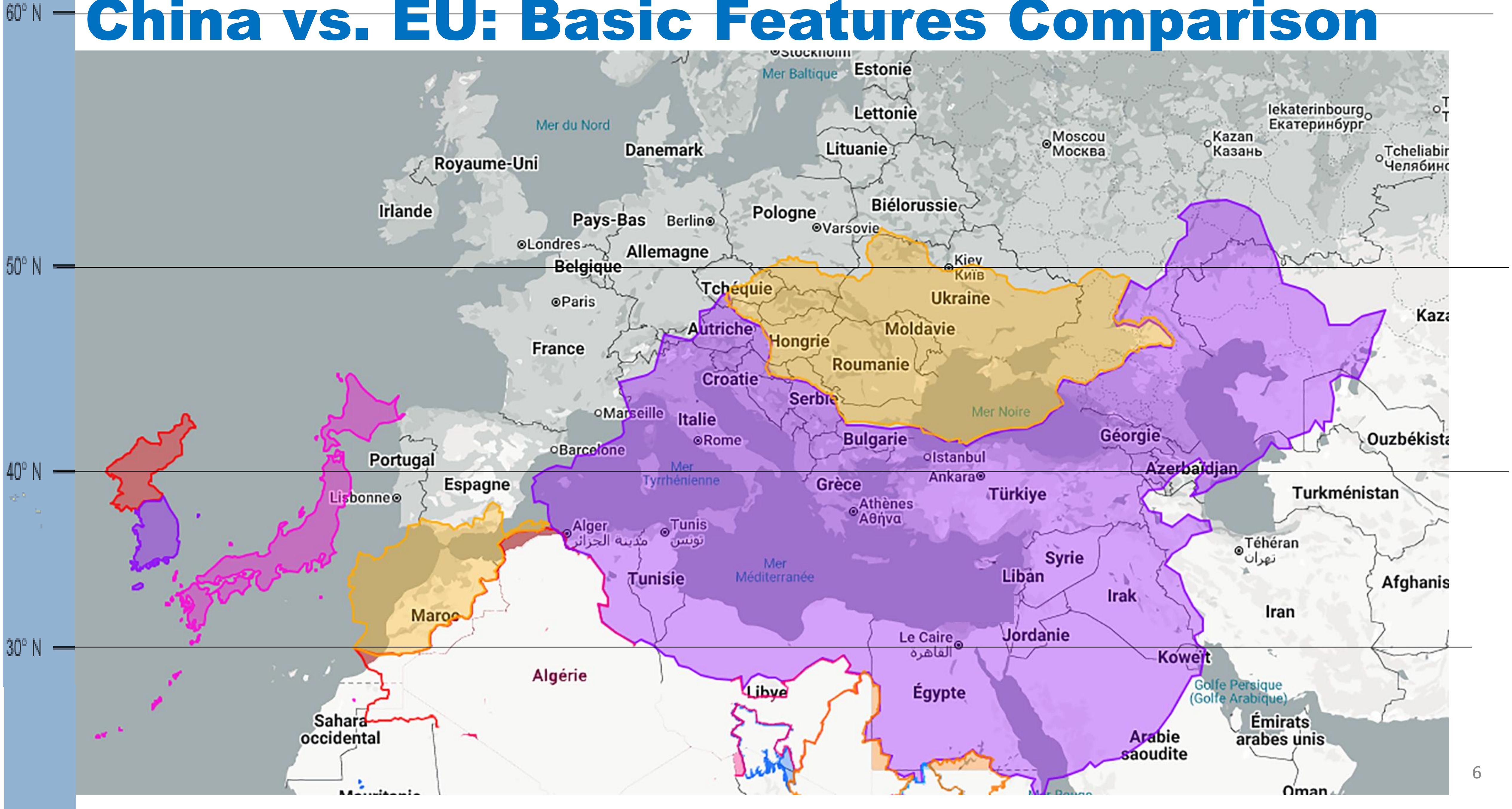
| | China | EU |
|---|---|---|
| Area | ~9.6 million km² | ~4.23 million km² |
| Population | ~1.42 billion | ~0.448 Billion |
| Climate | Southern tropical, northern subarctic | Mediterranean climate in the south, temperate and continental climate in the east |

- City size：
  - China's cities tend to be larger
  - Beijing covers **~16,400 km²** with **~22 million** residents



# China vs. EU: Basic Features Comparison



# China vs. EU: Basic Features Comparison

## Background

| | China | EU |
|---|---|---|
| Natural Resources | Wind energy resources are concentrated in the northern region, and solar radiation intensity is high in Northwest and North China. | Resource distribution is limited, and the development level is high |
| Electricity consumption | 9.22 trillion kWh (2023), per capita 6,540 kWh/year | 2.70 trillion kWh (2023), per capita 6,100 kWh/year (Ember,2024) |
| Energy consumption characteristics | Manufacturing industry accounts for a large proportion | More focused on the service |

- China's electricity consumption hits global record:

- In July 2025, China's monthly electricity consumption exceeded 1 trillion kWh for the first time.
- **Equivalent to the annual electricity consumption of ASEAN (Association of Southeast Asian Nations) countries**

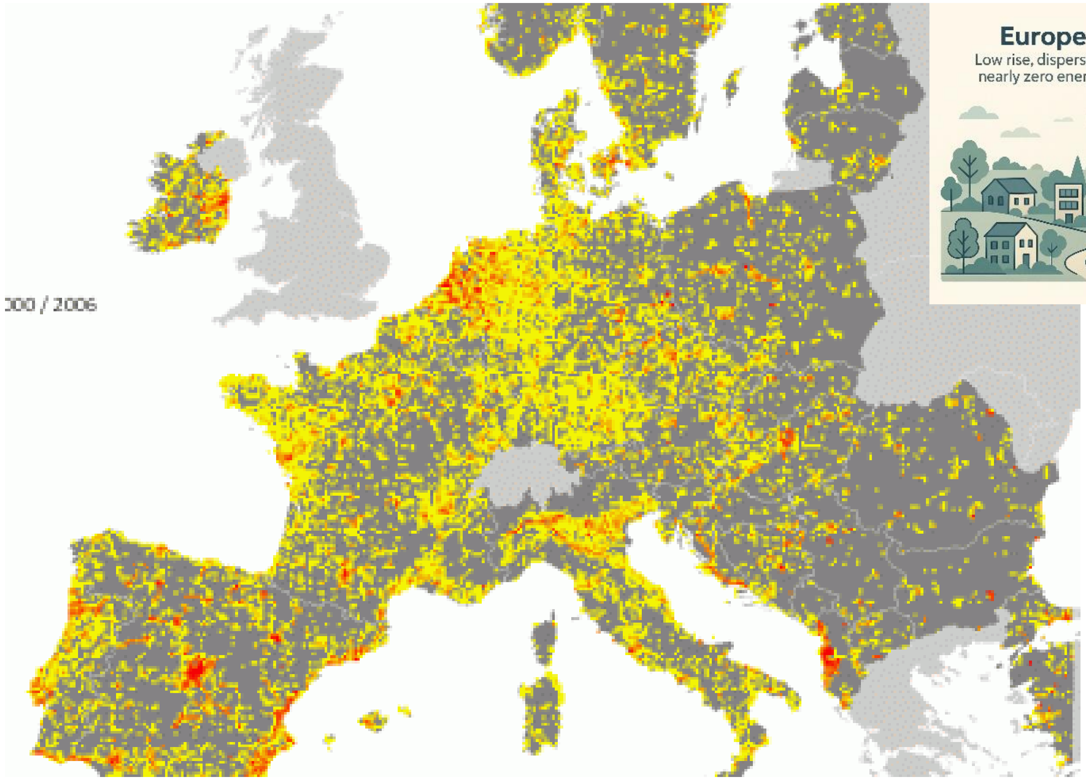
Abundant wind and solar resources in Northwest China


Hu Huanyong Line / 黑河–腾冲线

# China vs. EU: Basic Features Comparison

## Background

- European cities are generally low rise, urbanely dispersed, and shaped by nearly zero energy performance standards, while Chinese cities tend to be high rise, very dense, and strongly influenced by the demographic and spatial divide marked by the Hu Huanyong Line.



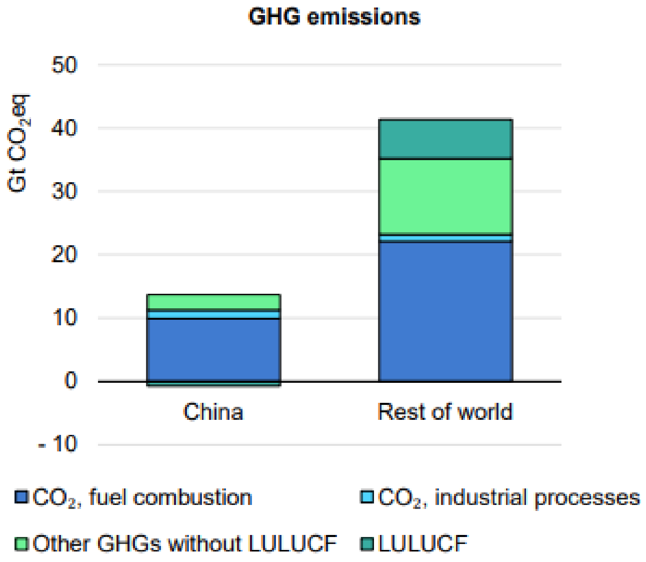


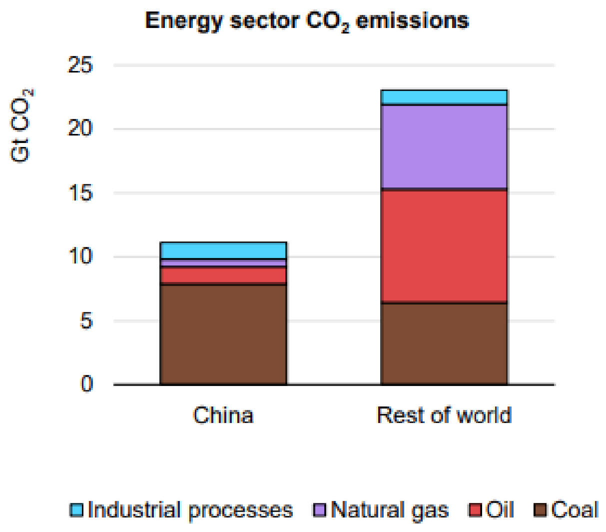
Hu Huanyong Line / 黑河–腾冲线

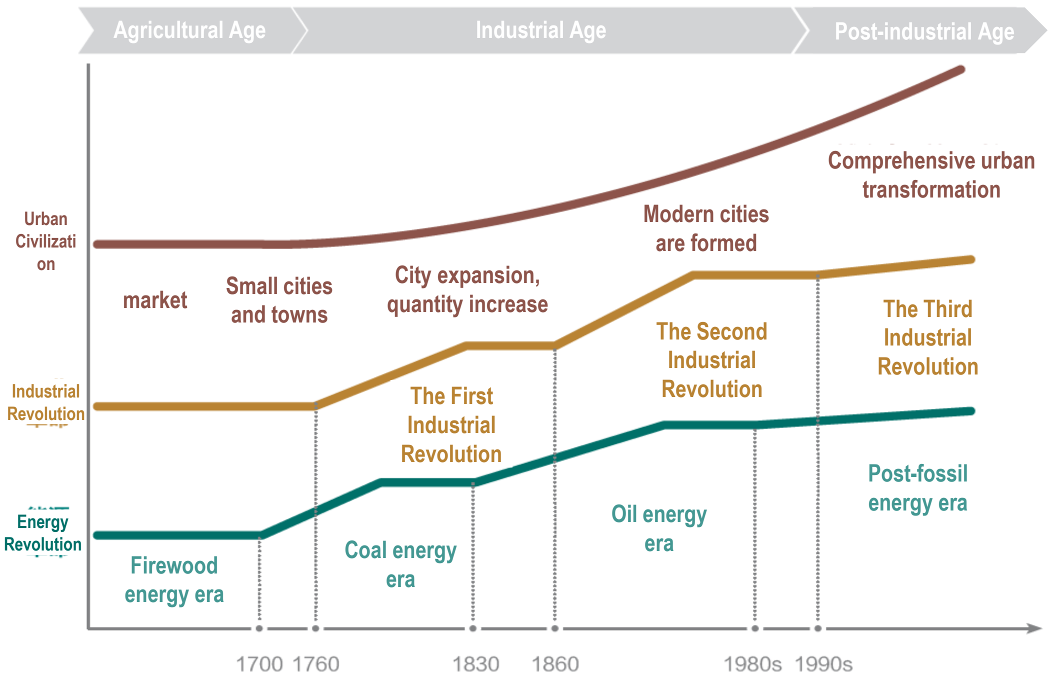
# China's energy system: Low-carbon transition

## Background

- China has pledged to reach peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060.
  - About 90% of global $CO_2$ emissions stem from energy, ~83% from fossil fuels.
  - China, the world's largest energy producer and consumer, is moving from a coal-dominated system toward renewables.




Greenhouse gas emissions in China and other parts of the world in 2020[1]

[1] IEA (2021), An energy sector roadmap to carbon neutrality in China, IEA, Paris

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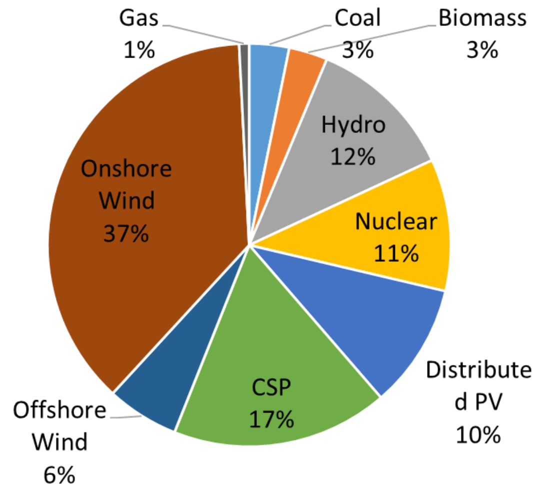
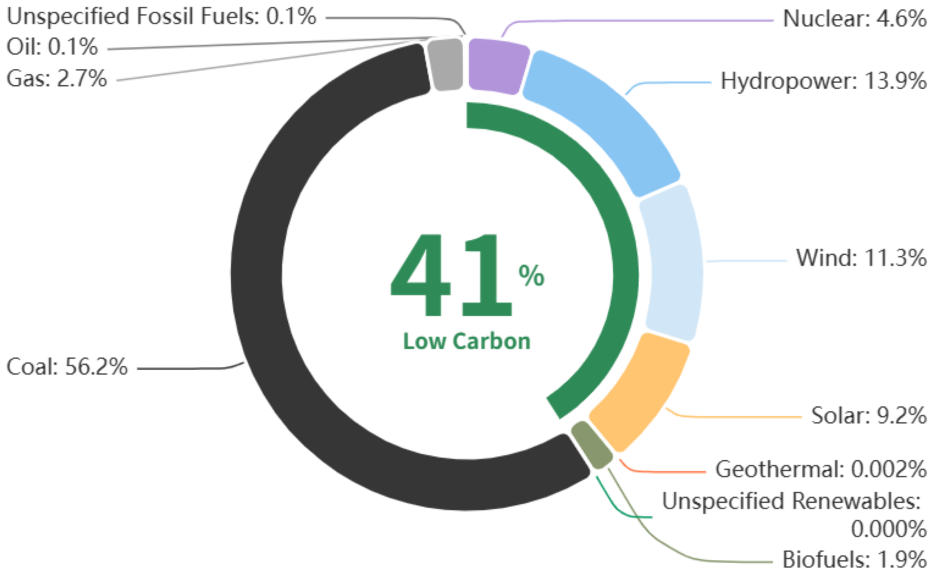
# Overview of China's energy system **Background**

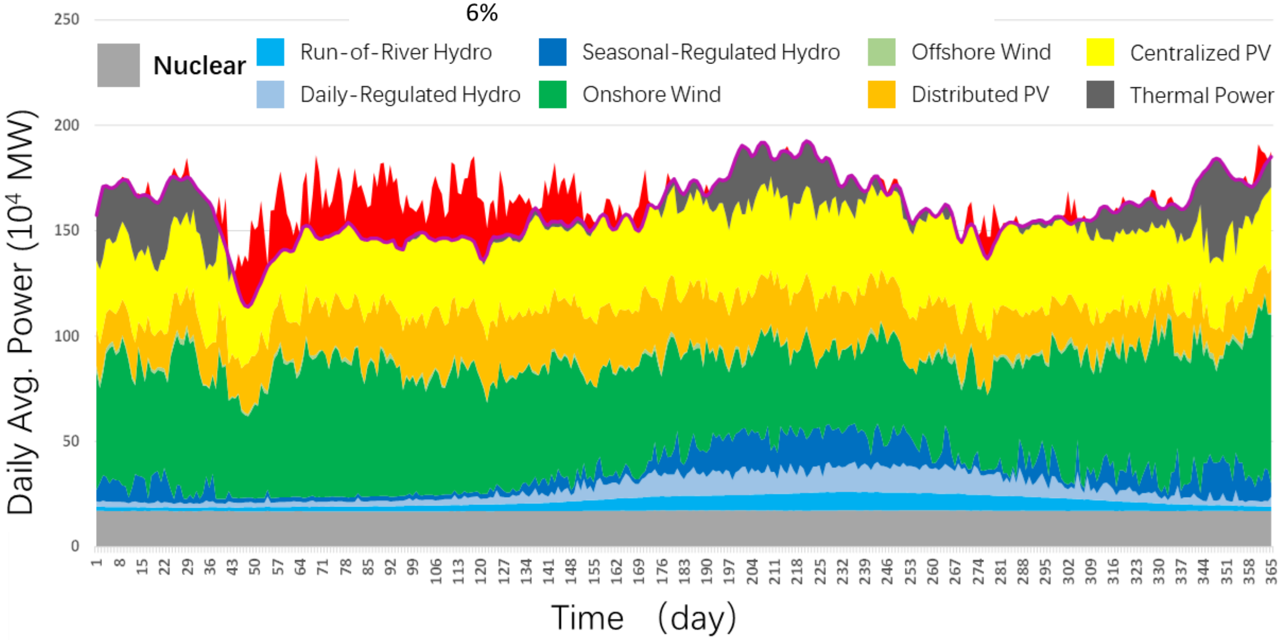
- **China's total energy use (2023) : 5.72 billion tce, 12.5 $GtCO_2$ emissions.**
- Low-carbon power generation capacity (2024):

| | Hydro | Wind | Solar | Biomass | Nuclear |
|---|---|---|---|---|---|
| Capacity （GW） | 436 | 521 | 887 | 46 | 61 |
| Global proportion | 30% | 51% | 40% | 31% | 16% |




**Electricity generation in China in 2024/2025**




**Daily Power Structure under 2060 carbon neutrality scenario (BERC, 2022)**

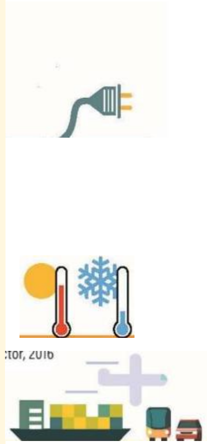
# Technological State-of-the-Art

# China’s & Europe's latest Energy Policy

## Background

- Energy consumption dual control shifts to carbon emission dual control

| | Globe 2021 vs 1990 (fossil $CO_2$) | EU27 2021 vs 1990 (fossil $CO_2$) |
|---|---|---|
| Power industry | + 87 % | - 39 % |
| Other industrial combustion | + 65 % | - 41 % |
| Buildings | + 2 % | - 32 % |
| Transport | + 65 % | + 16 % |
| Other sectors | + 101 % | - 23 % |



- Policy has shifted from **energy-consumption controls** to the **dual control of total emissions and intensity**

**Intensity Control** — 2015 Paris Agreement: 40%-45% reduction in $CO_2$ emissions per unit of GDP by 2020

**Total quantity control** — 2020 Dual Carbon Commitment: Carbon peak by 2030 and carbon neutrality by 2050-2060

**dual control of total emissions and intensity** — 2023: "Opinions on Promoting the Gradual Shift to Dual Control of Energy Consumption to **Dual Control of Carbon Emissions**"

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# Europe's: District Heating

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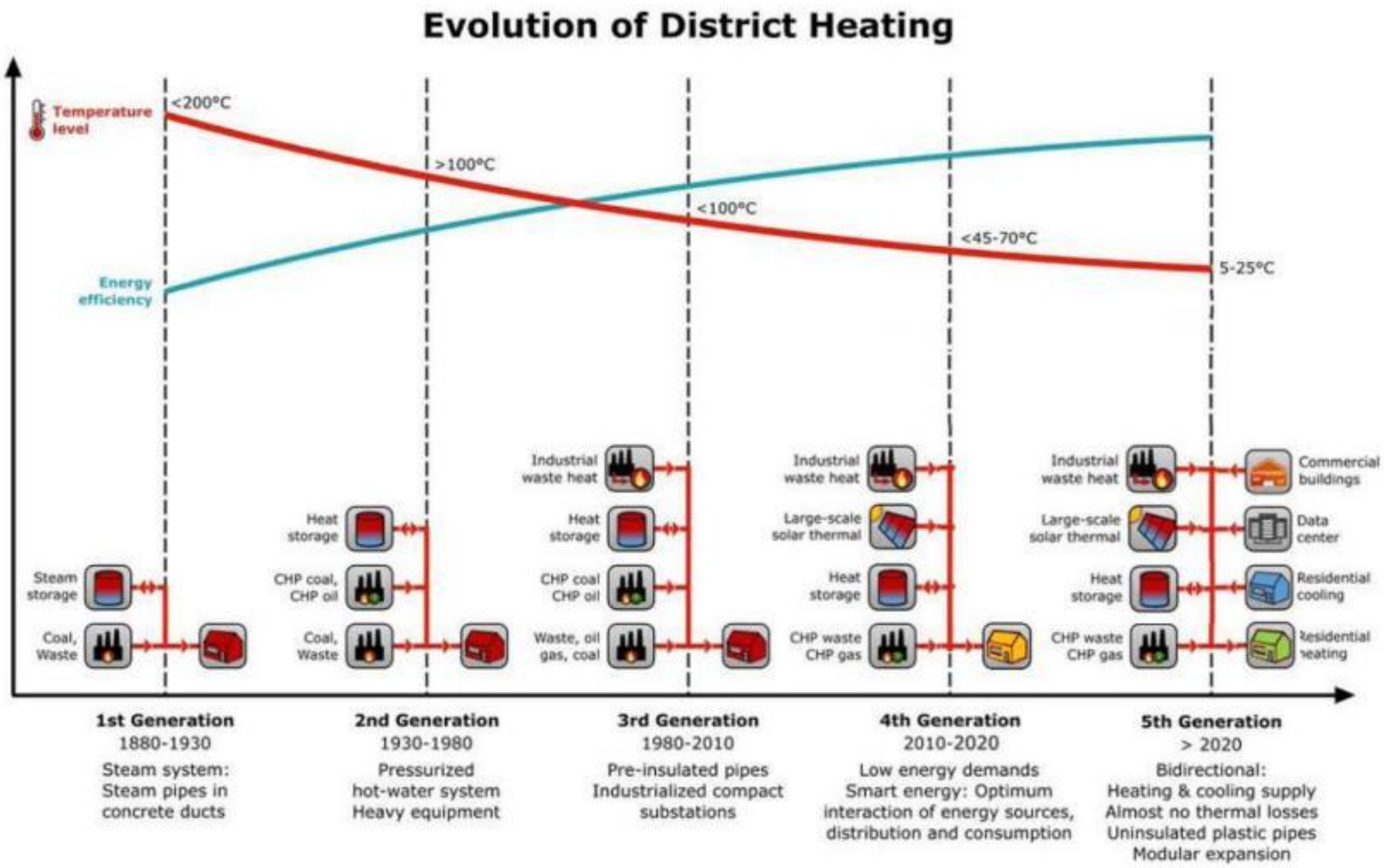


**4th Generation:**
District heating grid with a collective source

**5th Generation:**
Thermal energy directly from the subsurface
(T 5 – 25 ° C)

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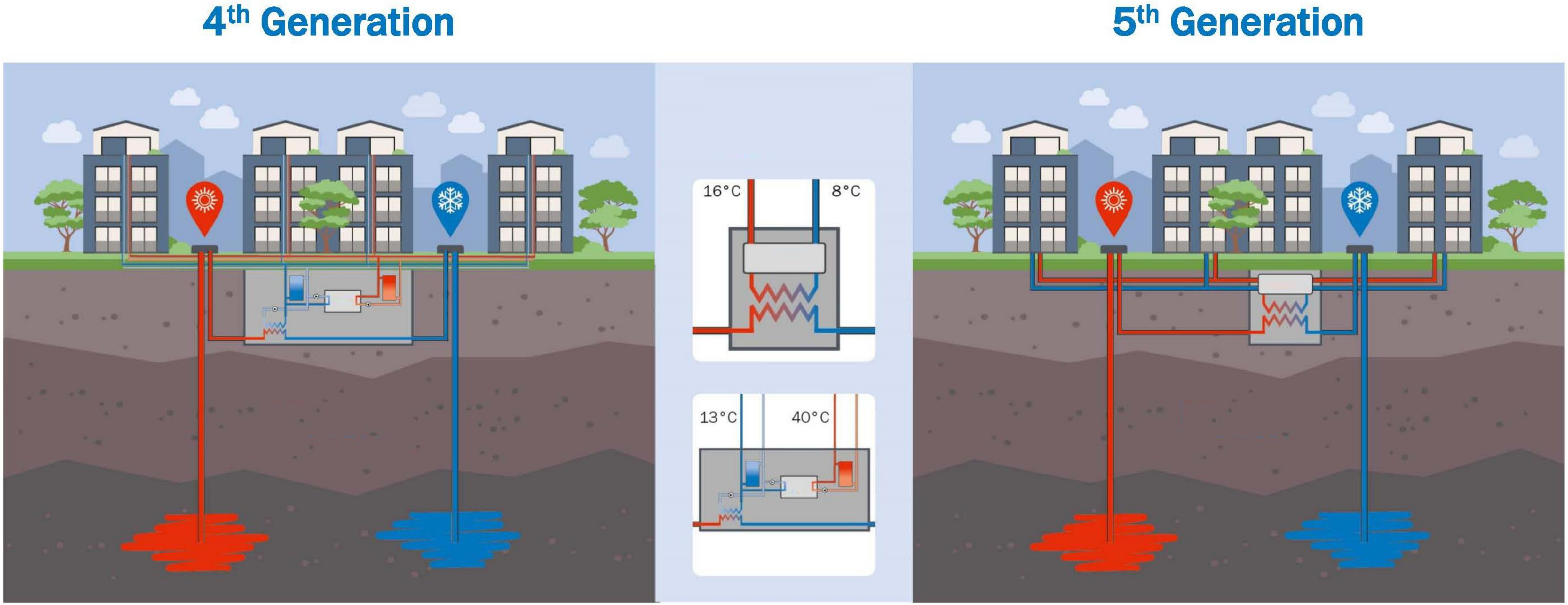
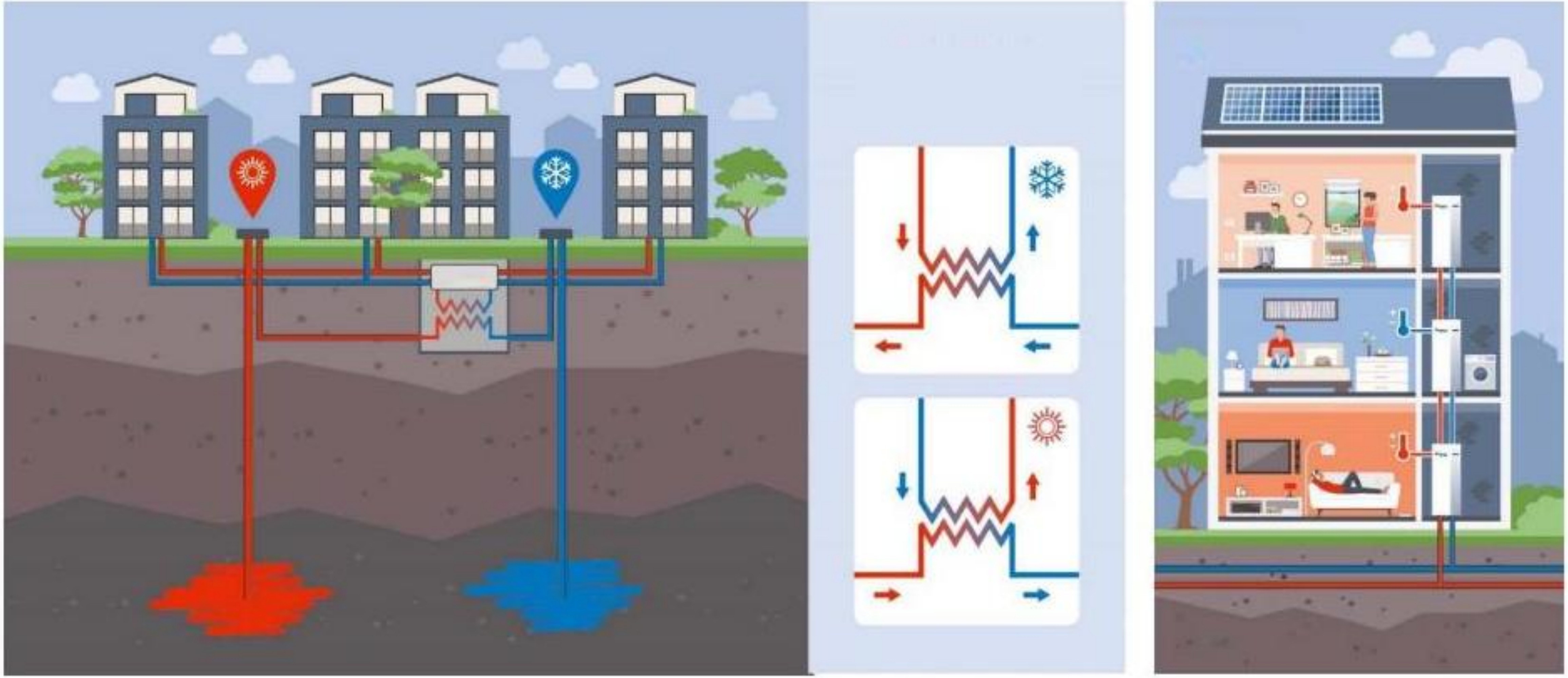
# 4th Generation vs. 5th Generation



# District Heating Grid: $5^{th}$ Generation

## The Neutral Grid: Is from Individual Heat Pumps to…



# District Heating Grid: 5th Generation

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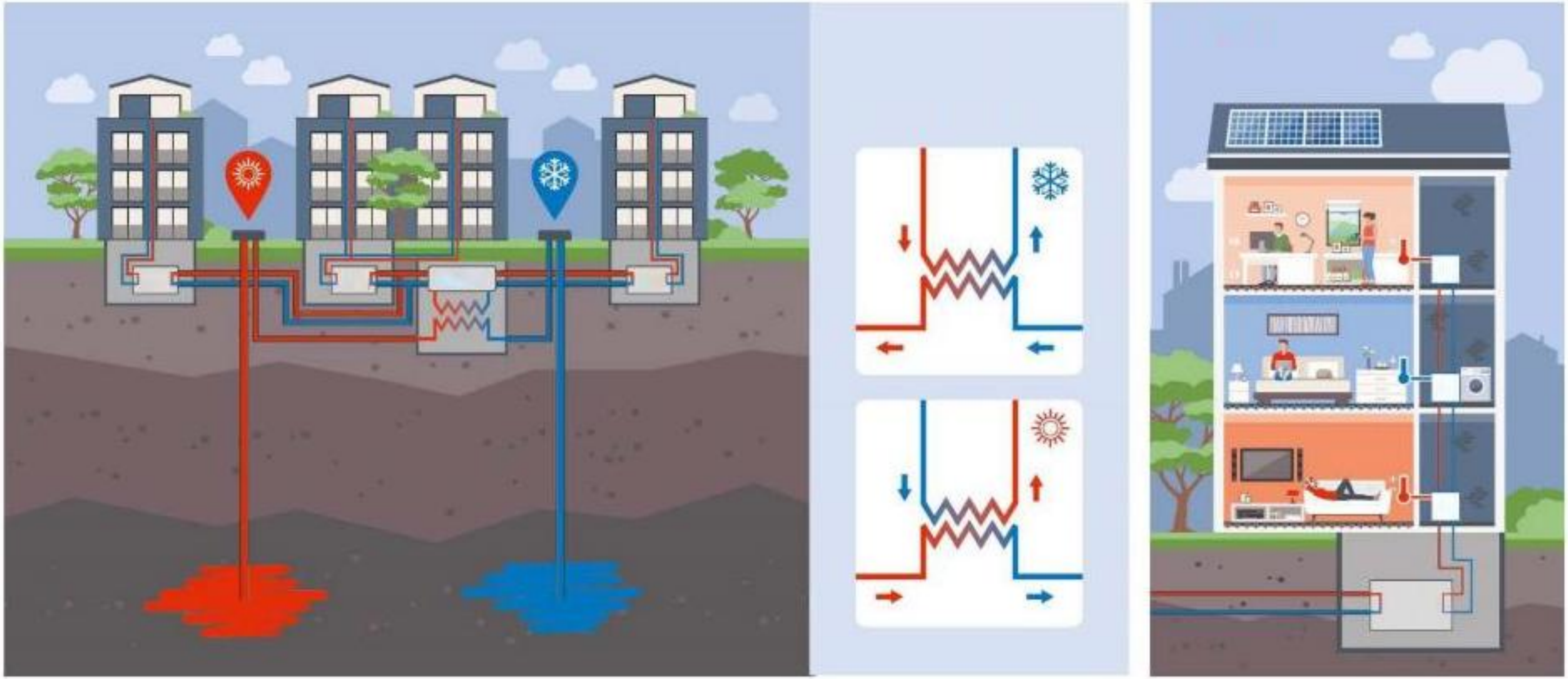
## The Neutral Grid: Centralized Heat Pumps



# District Heating Grid: $5^{th}$ Generation

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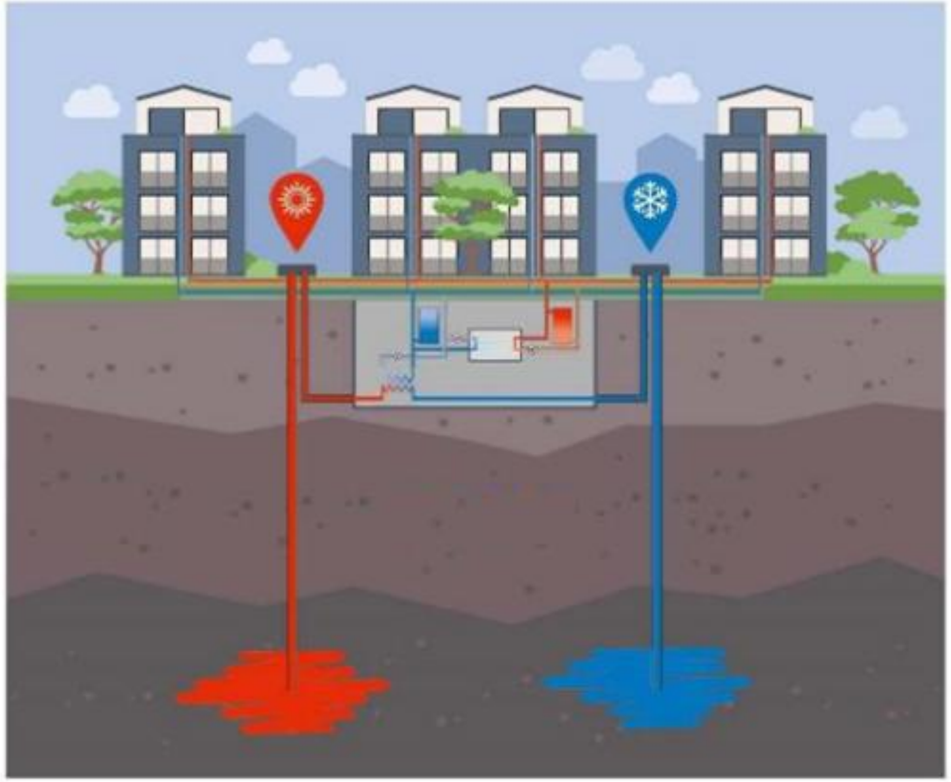
## PRODUCTION OF HEAT AND COLD WITHIN A CENTRALIZED PLANTROOM

- ATES/BTES connected to the centralized plantroom
  - Geothermal heatpumps provide the required higher temperatures (30 – 55 °C)



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# District Heating Grid: 5th Generation

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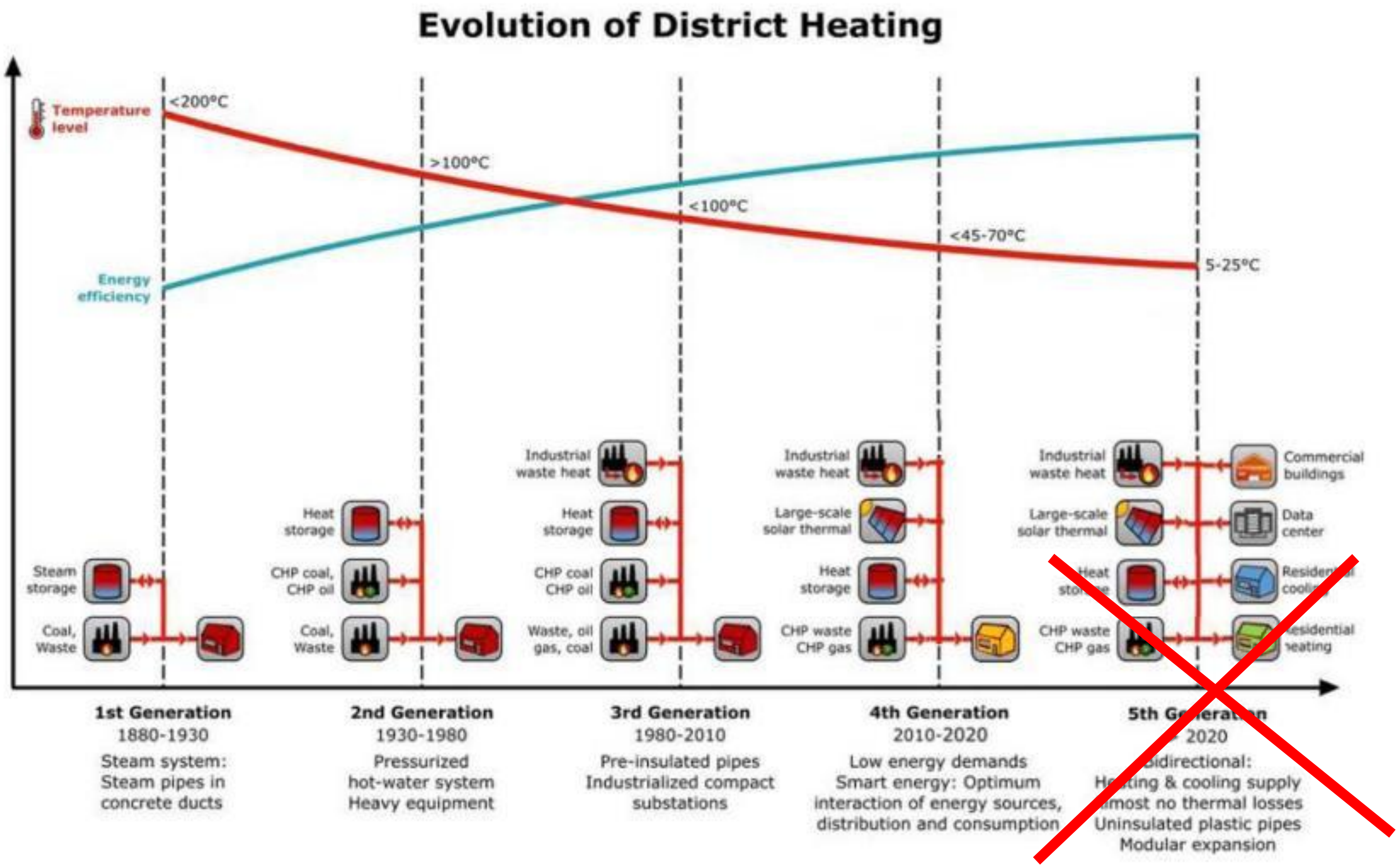
## The Neutral Grid: Individual Heat Pumps

# China: District Heating




## 4th Generation:

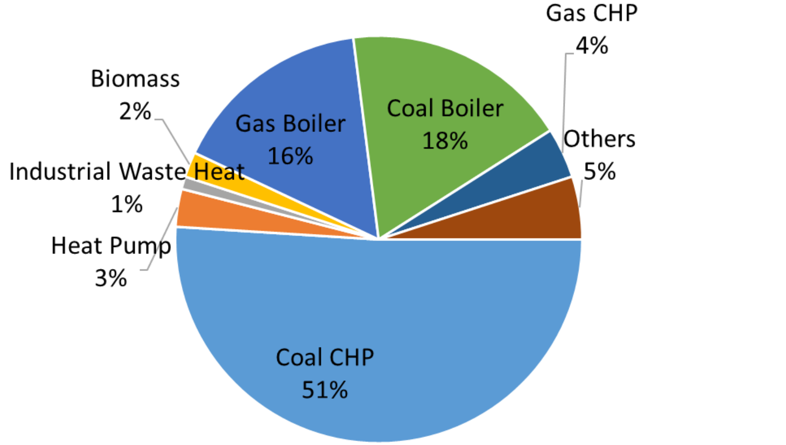
District heating grid with a collective source

## 5th Generation:

Thermal energy directly from the subsurface (T 5 – 25 ° C)

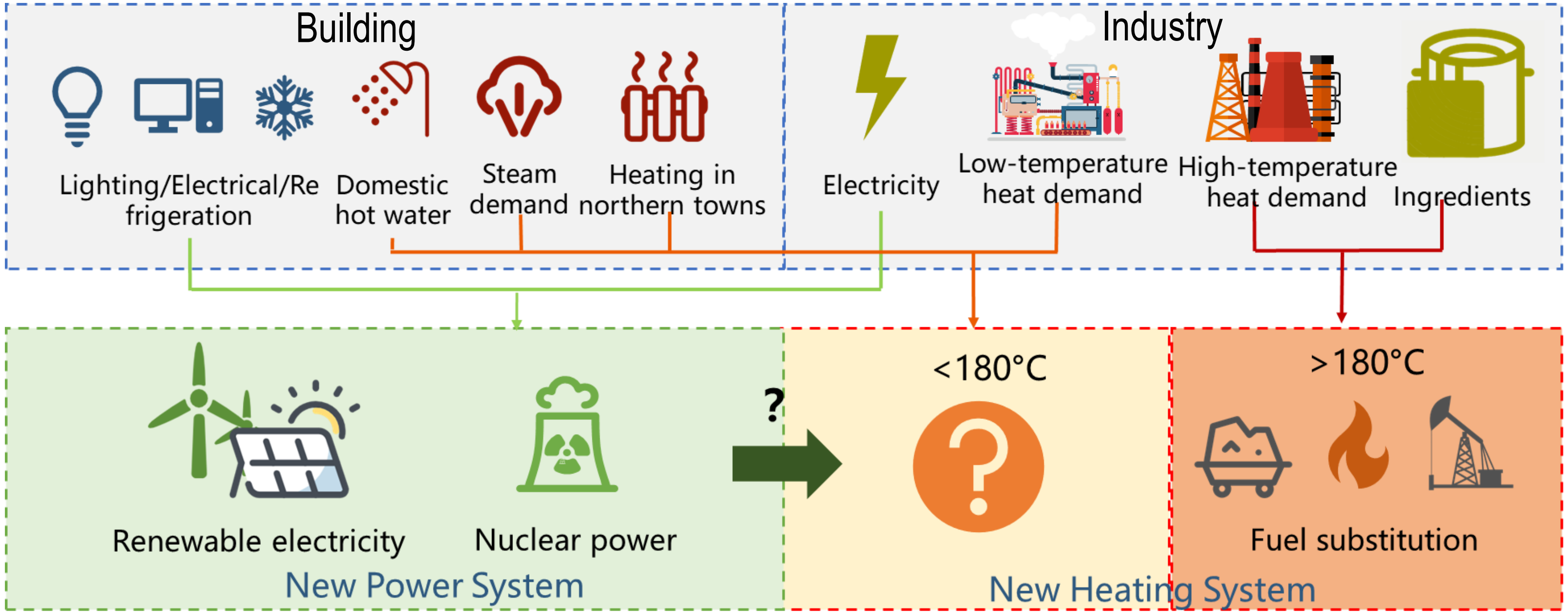
# China's heating system: Technical path for medium-low temperature heat demand

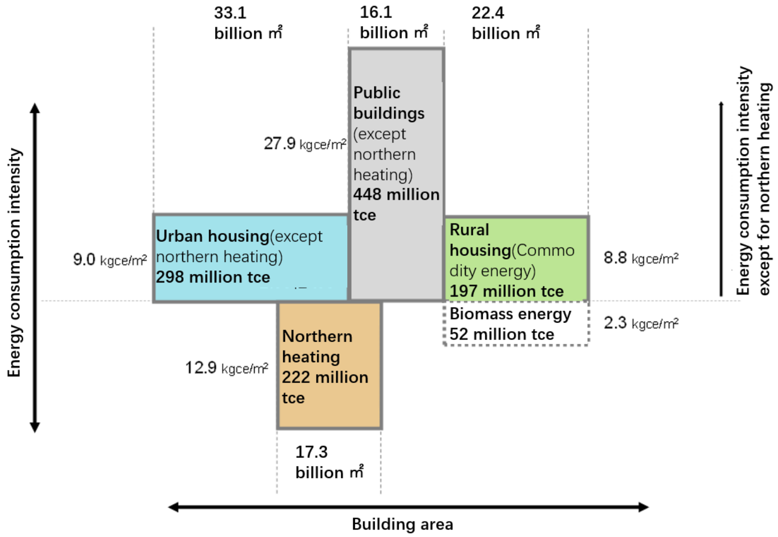
- **China has a heavy carbon reduction task for heating system,**
  - High heating demand (2022)
    - 9 billion GJ for industrial process,  9.3 billion GJ for building




Heat Source Structure of DH in Northern China 2022–2023

- **How to meet the enormous heat demand?**

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# Comparison of Heating Systems

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# Comparison of Heating Systems

## Zero Carbon Heating

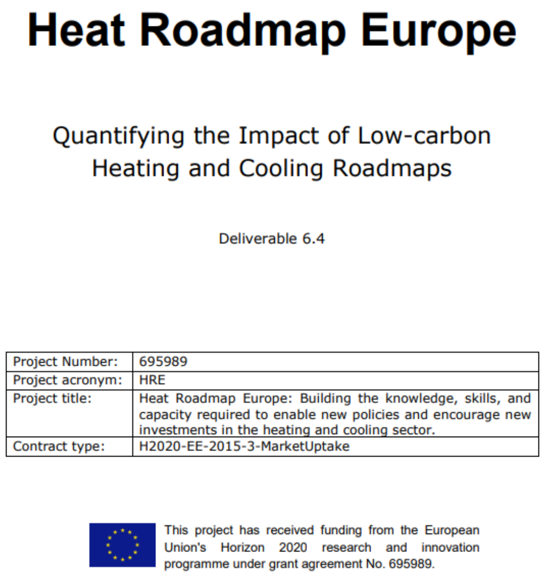
**Conclusion: energy efficiency; large heat pump + district heating; decentralized heat pump.**

■ **Heat Roadmap Europe**

➢ By 2019, heat decarbonization strategies and heat atlases covering 14 countries are formed

2050
Heat Roadmap Europe
A low-carbon heating and cooling strategy

- Investigating **heat demand** and **clean energy supply**
- Design different heating routes
- Simulate calculations and compare various indicators
- Multi-objective optimization, selecting the optimal solution



**Heat Roadmap Europe**

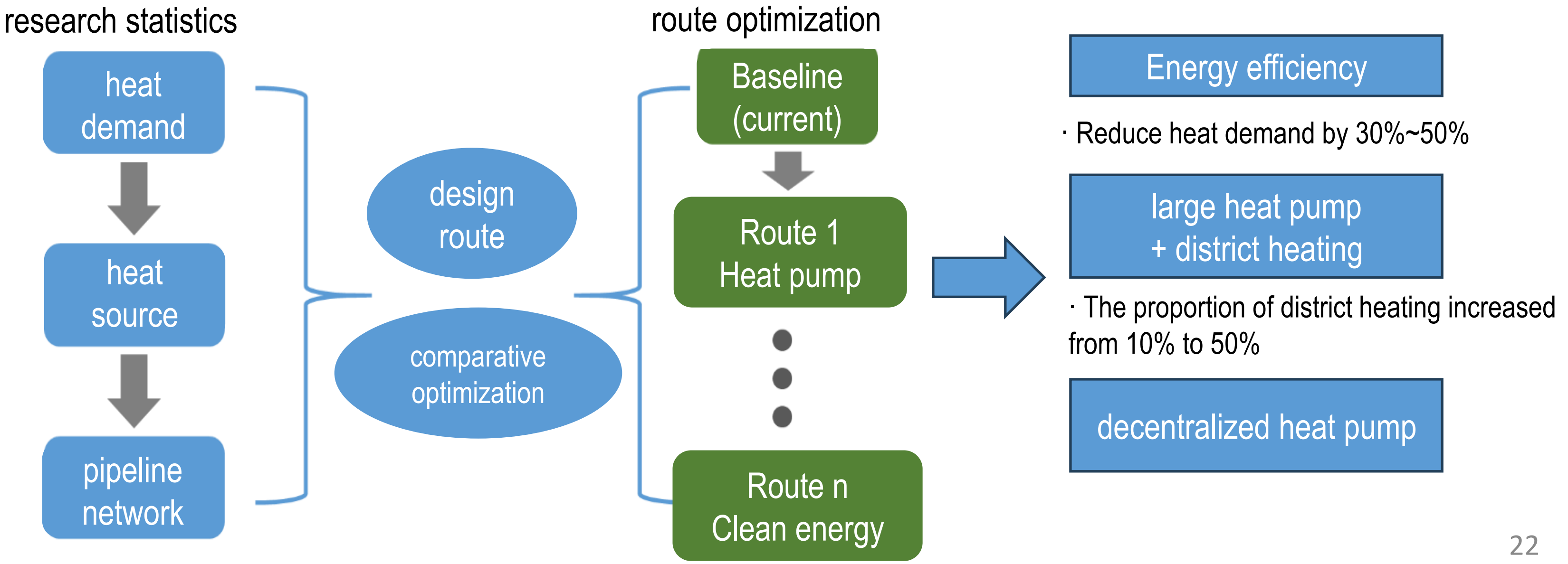
Quantifying the Impact of Low-carbon Heating and Cooling Roadmaps

Deliverable 6.4

| | |
|---|---|
| Project Number: | 695989 |
| Project acronym: | HRE |
| Project title: | Heat Roadmap Europe: Building the knowledge, skills, and capacity required to enable new policies and encourage new investments in the heating and cooling sector. |
| Contract type: | H2020-EE-2015-3-MarketUptake |

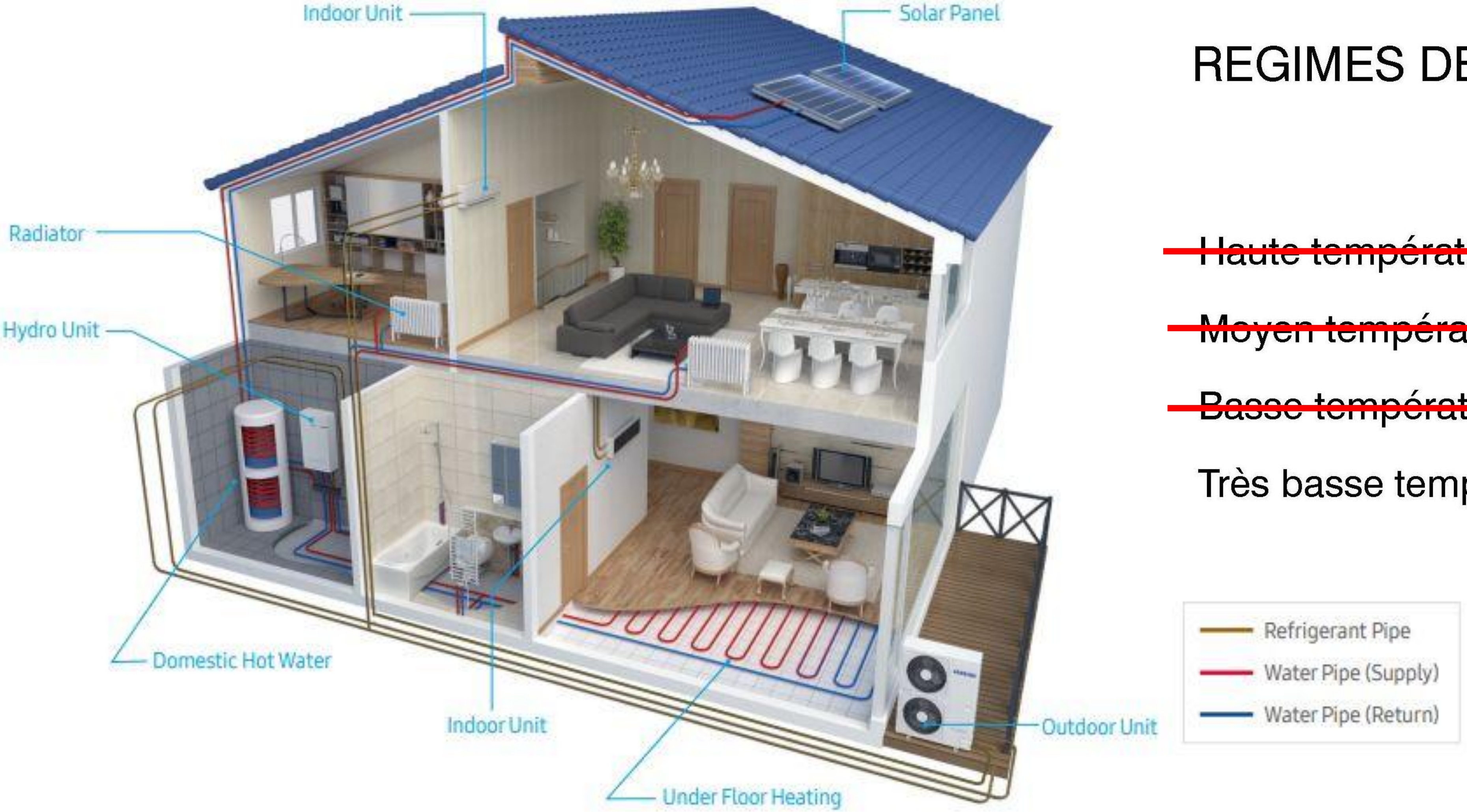
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

**European zero-carbon heating roadmap**



# Net Zero Carbon Buildings

## Low Temperature Systems



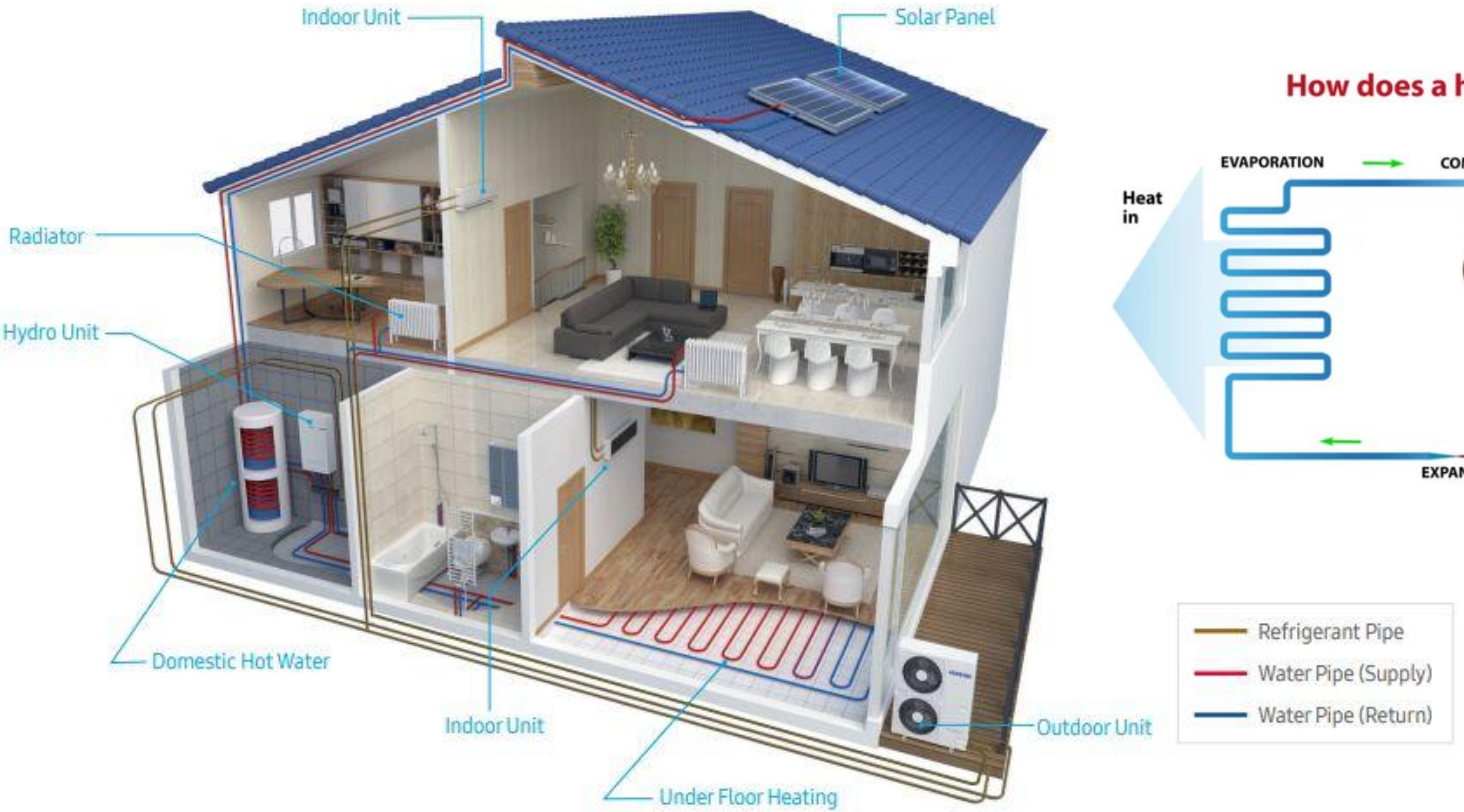

REGIMES DE TEMPERATURE

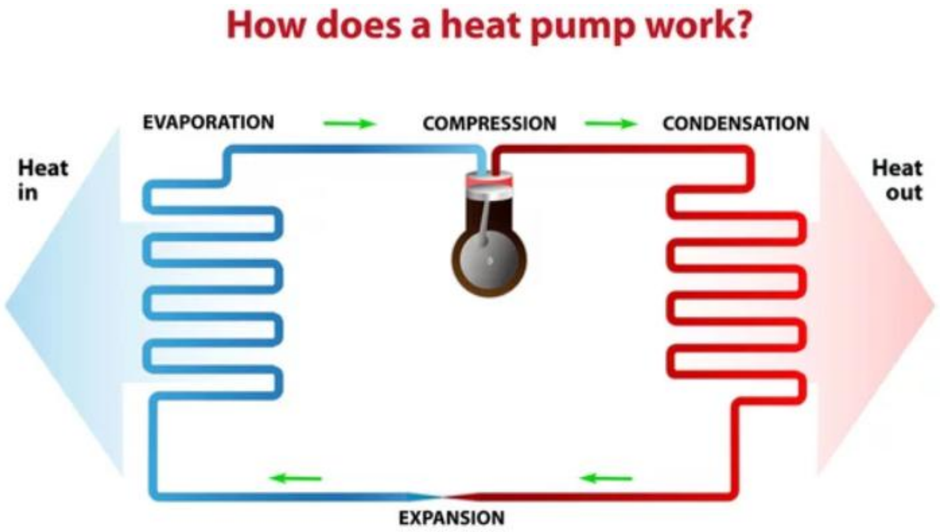
| | T aller |
|---|---|
| ~~Haute température~~ | ~~90°C~~ |
| ~~Moyen température~~ | ~~70°C~~ |
| ~~Basse température~~ | ~~55°C~~ |
| Très basse température | 30°C |

Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier

# Net Zero Carbon Buildings

## All Electric with Heat Pumps

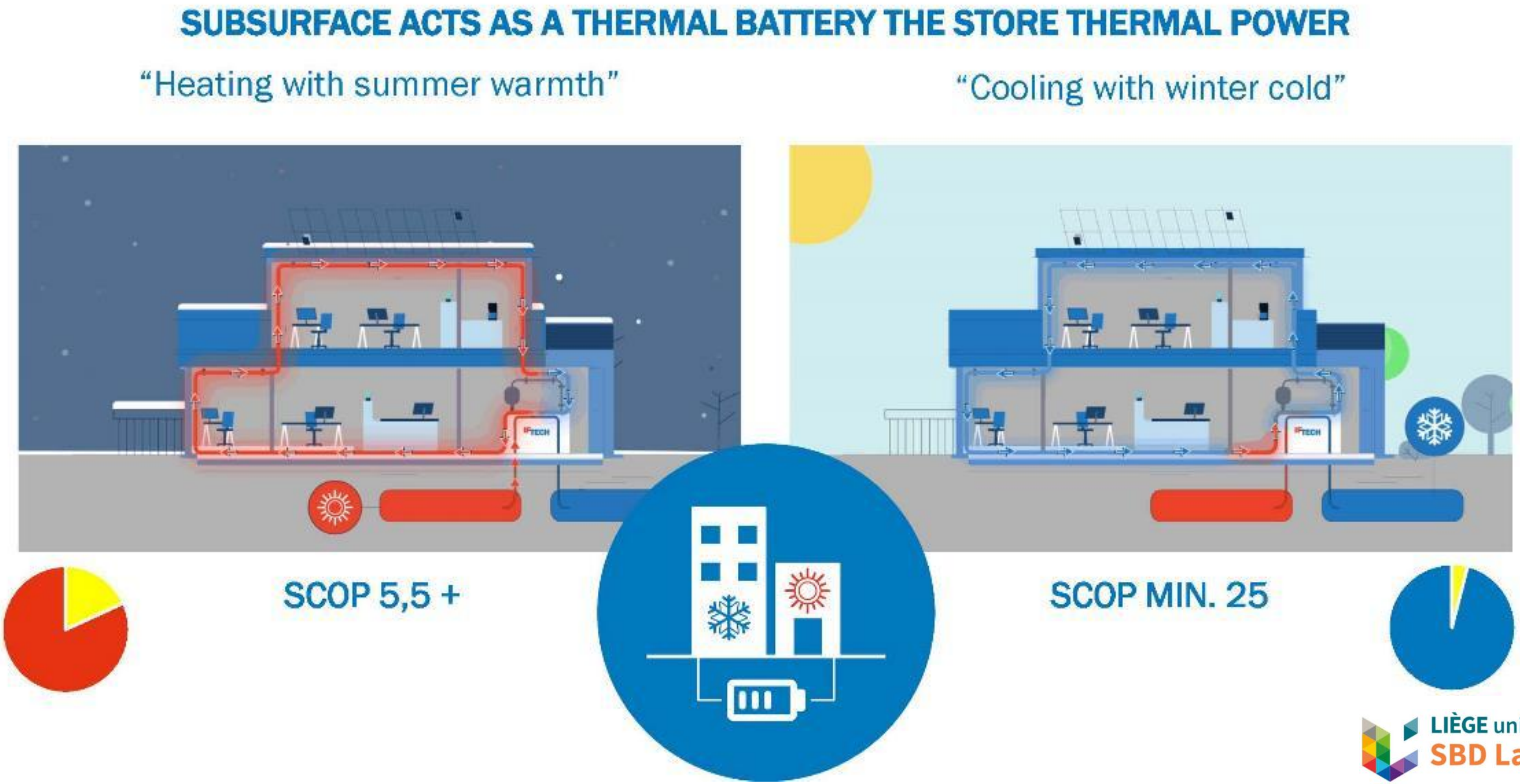



Attia, S. (2018) **Net Zero Energy Buildings (NZEB)** , Elsevier

# Shallow Geothermal Energy

## Lowest Primary energy Use

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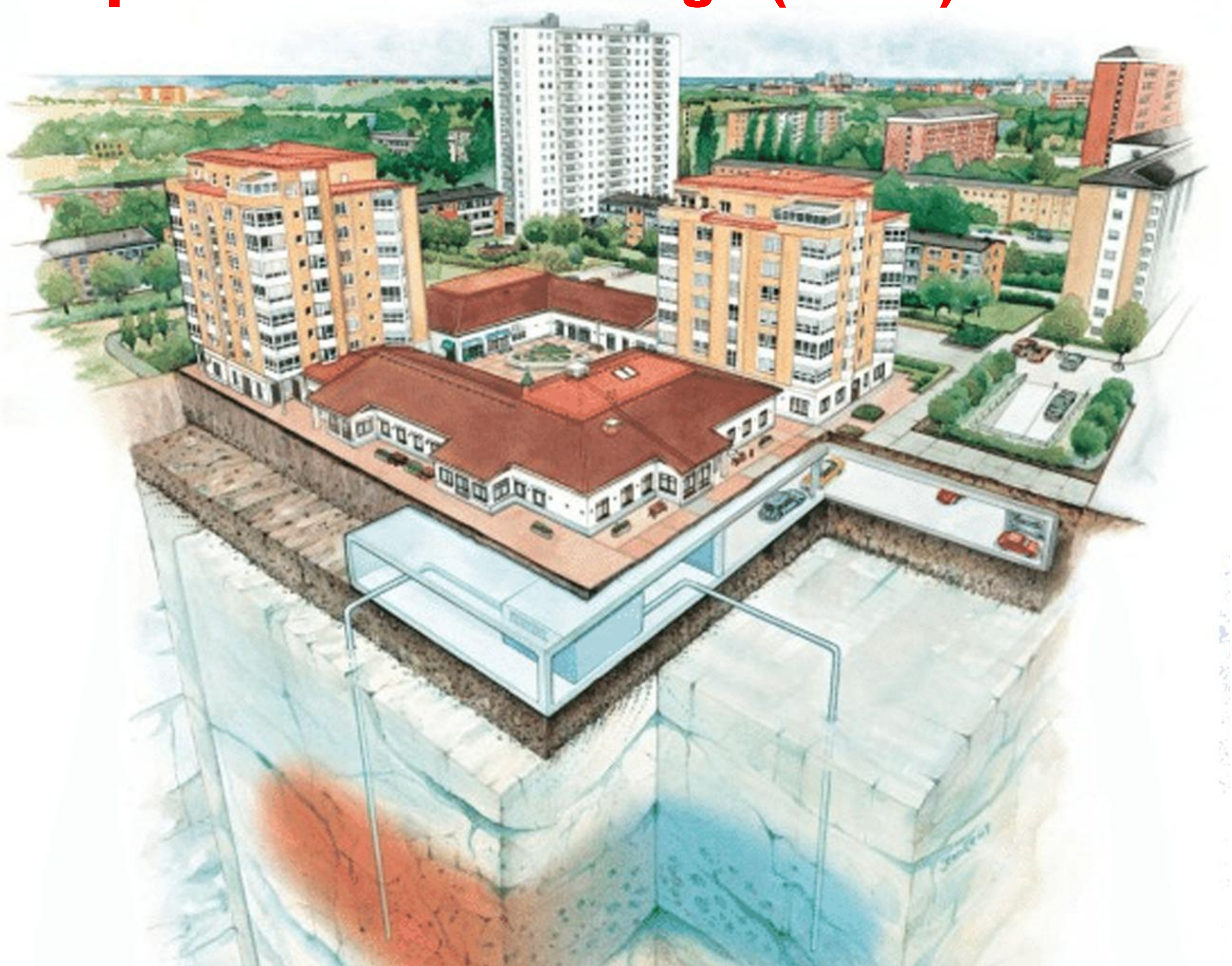
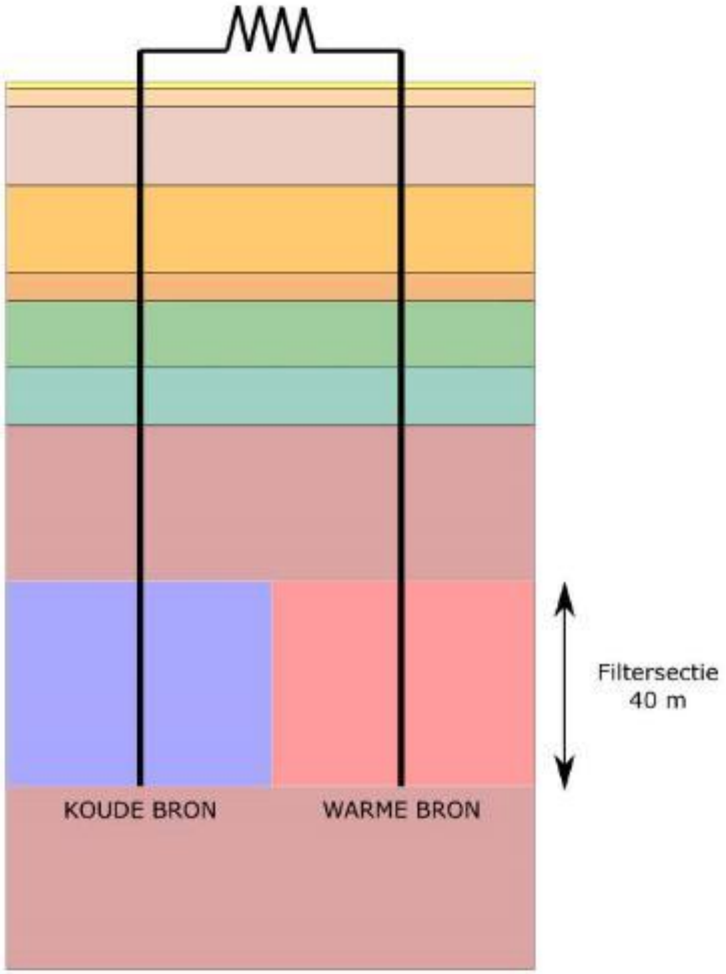
# Shallow Geothermal Energy

## Aquifer Thermal Storage (ATES)





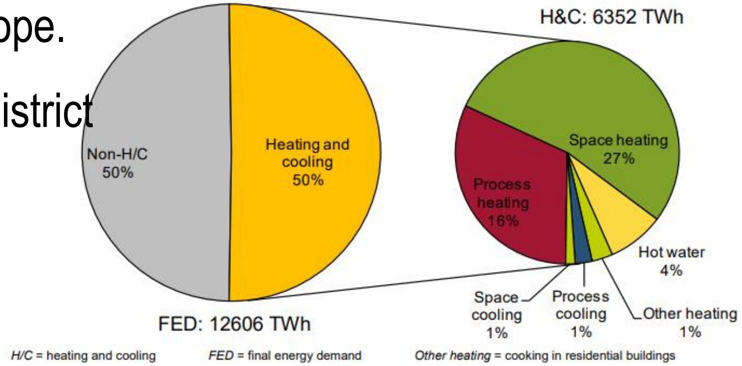
# Comparison of Heating Systems

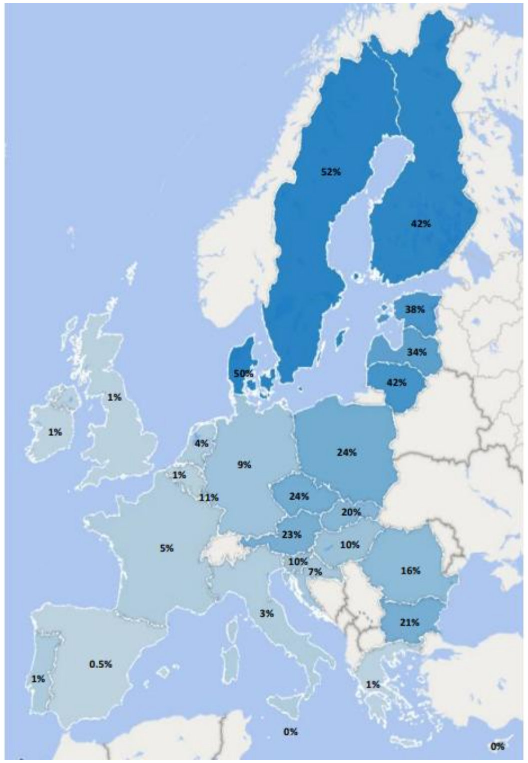
## Zero Carbon Heating

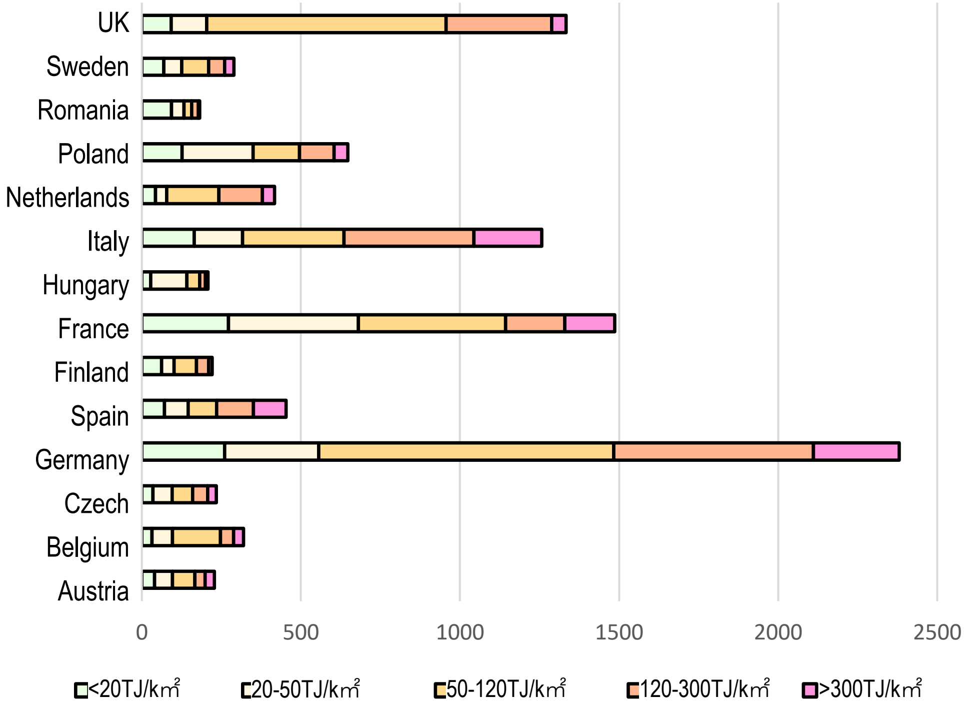
Demand side: high proportion of building heat, but low heat intensity
Supply side: low coverage of central heating, high proportion of natural gas and biomass

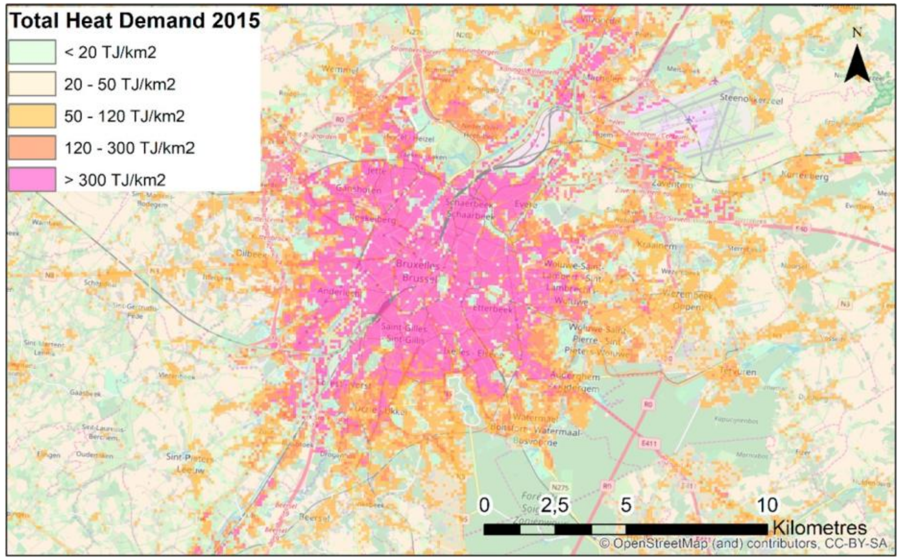
### ■ Heat Roadmap Europe

- ➢ Heat demand for buildings accounts for the majority of final energy consumption in Europe.
- ➢ The heating source is mainly CHP, gas, biomass and waste etc, and the proportion of district heating is less than 15 %.



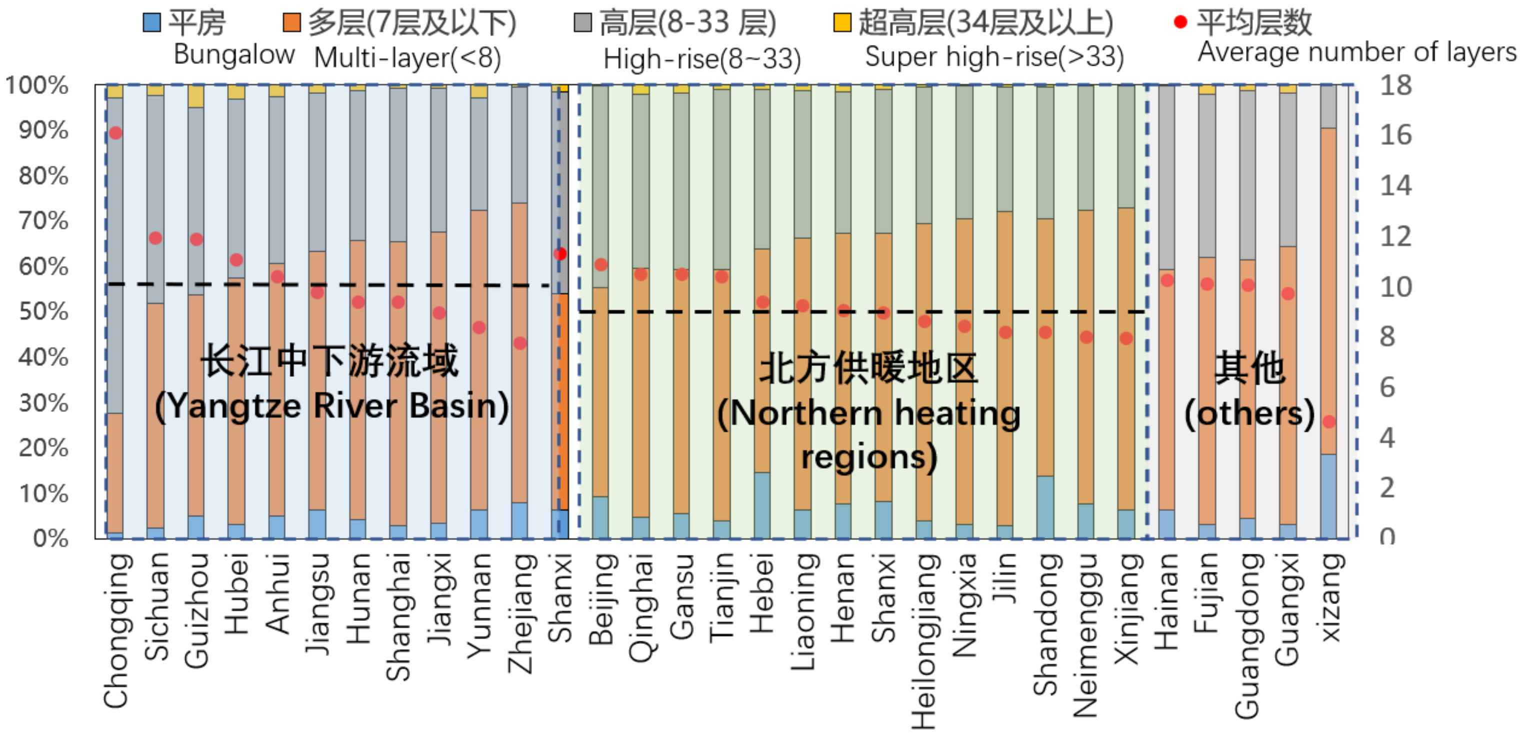

Heating density distribution in Brussels, Belgium, in 2015 （Resolution 100m）

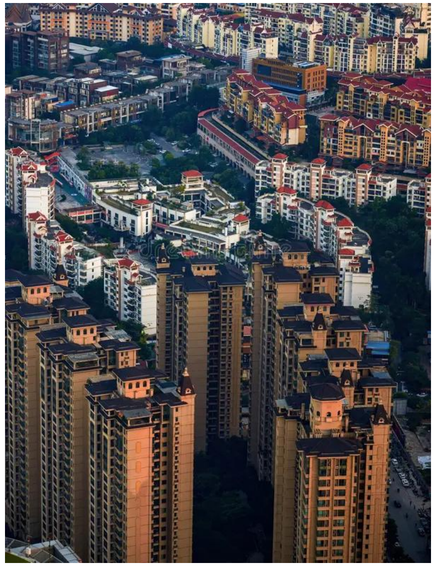

[1] HRE: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps
[2] Möller B ,Wiechers E ,Persson U , et al.Heat Roadmap Europe: Identifying local heat demand and supply areas with a European thermal atlas[J].Energy,2018,158281-292.

# Comparison of Heating Systems

## China's characteristics: large total heat demand and high intensity

- Most residential buildings in Chinese cities are multi-story or high-rise buildings with high building density.
  - More than 35% of urban residential buildings have more than 8 floors, Plot Ratio(FAR)>3
- Low heating density of rural residential buildings



Chinese urban residential buildings

Chinese rural residential buildings

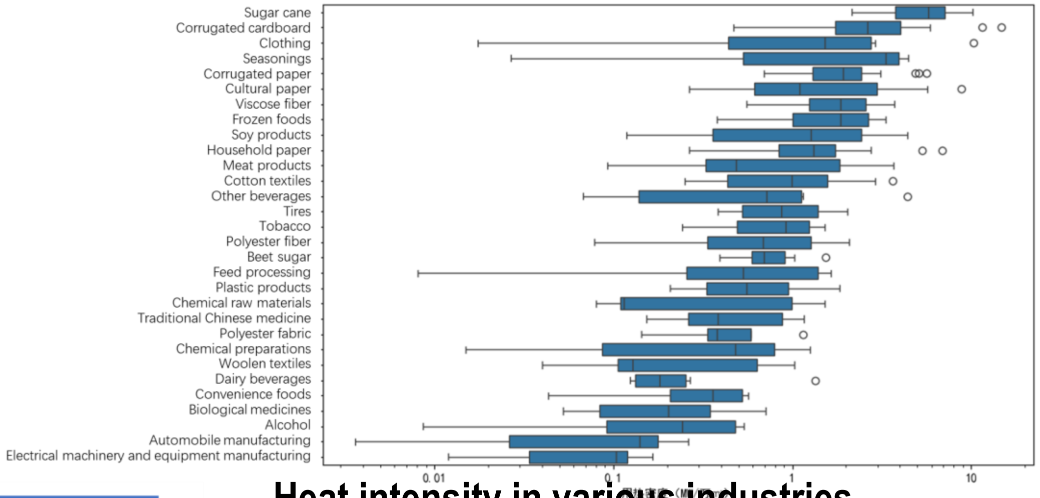
[1] National Bureau of Statistics of China. (2021, May 11). Communiqué of the Seventh National Population Census (No.1).

# Heating Systems Design

## China's characteristics: large total heat demand and high intensity

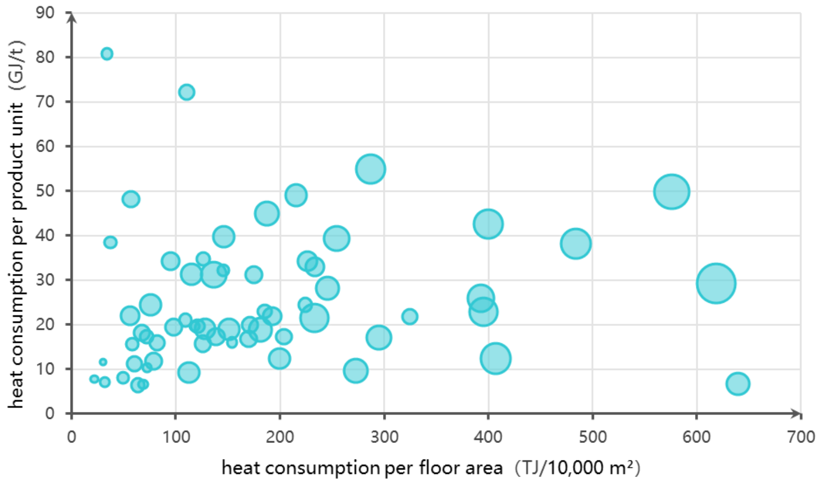
- Currently **16 ExaJ of urban heat demand,**
- more than 90% by fossil fuels
- **A heat pump could be the solution, but the heat intensity of different heat demands needs** to be considered.


IEA, Tsinghua. The Future of Heat Pumps in China, 2024




Heat intensity in various industries

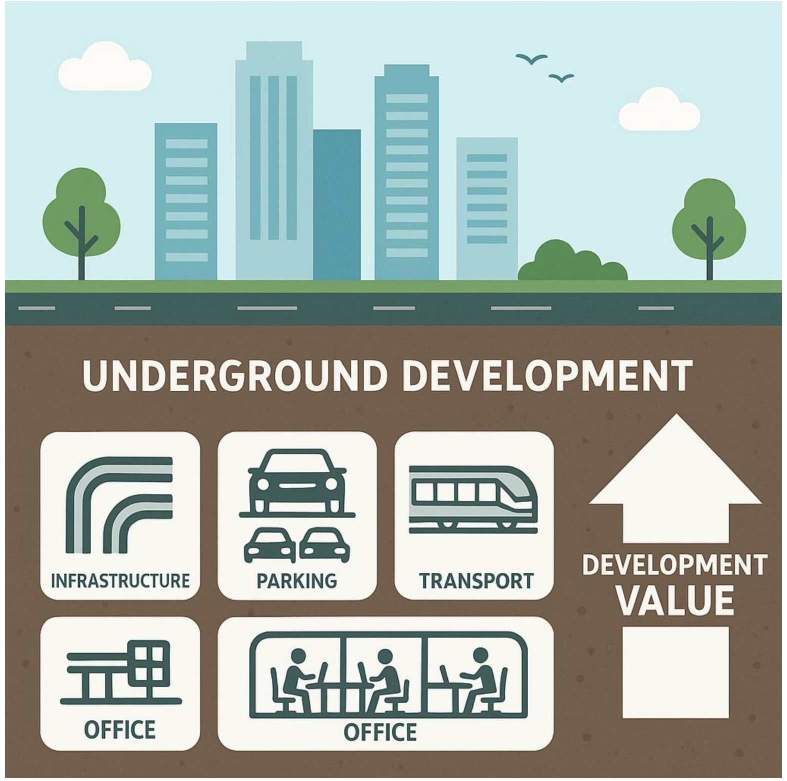
| | Estimation (EJ) | | Temperature | heat intensity TJ/10000㎡ |
|---|---|---|---|---|
| | 2020 | 2050 | | |
| District heating in Northern China | 5.95 | 5.4 | 18℃ | 11.3 |
| Heating in the HSCW | 0.89 | 2.1 | 18℃ | 0.81 |
| Domestic hot water | 1.33 | 1.42 | 40℃ | 0.8 |
| Steam for public buildings | 0.1 | 0.11 | 130℃, 160℃ | 4.8 |
| light industry | 8 | 12.5 | 60%≤150℃ | ＞50 |




Heat intensity for textile printing and dyeing industry

# Heating Systems Design

## Limitations of natural source heat pumps: not suitable for high-density heating




- **Shallow buried pipes: unbalanced heat intake and heat discharge in winter and summer[1]**
  - Shallow buried pipes will cause thermal creep and thermal consolidation of the soil, causing ground subsidence[2]
- **Medium-deep buried pipes: Long-term heat extraction has thermal attenuation problems**
  - The heat flux density from the depth of the earth's crust is less than 0.08W/m2. The rest of the heat can only come from the sensible heat of the soil and rocks around the pipes.
- **Common problems: Seriously affecting the development and utilization of underground space**

- ☐ Ground source heat pumps are only suitable as efficient heat sources for **low-density heating demand**
- ☐ In urban areas (floor area ratio>3), medium-deep buried pipe heat pumps are **not suitable as main heat source for high-intensity heating demand**


[1] IEA, Tsinghua. The Future of Heat Pumps in China, 2024
[2] Geotechnical Considerations in the Design of Borehole Heat Exchangers， Canadian Geotechnical Journal， Volume 58, Number 9, September 2021

# Heating Systems Design

## Limitations of natural source heat pumps: not suitable for high-density heating

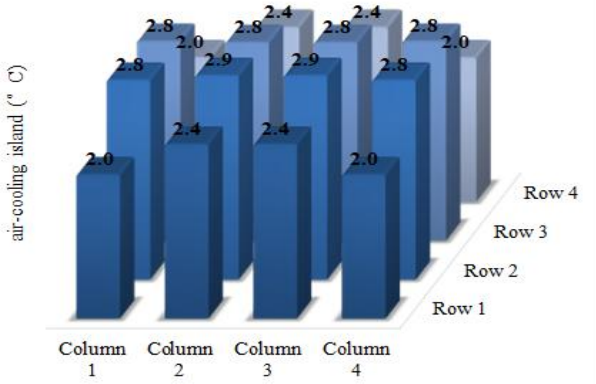
- **Impact of air source heat pump heating on urban microclimate[1]**

➢ **Impact of air source heat pump units on the surrounding thermal environment**

- A unit with a customized heating capacity of 70kW and a heating season COP of 2.3: arranged in a group of more than 16, with an average local cold island intensity approaching 3℃.
- Considering the building area restrictions in residential areas, green spaces, and public facilities, **the maximum building FAR** range for air-source heat pumps in northern cities is approximately **1.5~2.5**.

➢ **Affecting the dispersion of pollutants**

- Vertical air flow between buildings can effectively enhance the diffusion of pollutants.
- Compared with district heating, household decentralized heat pump heating is **not conducive to the diffusion of pollutants**




Average cold-island effect intensity per unit in a still wind array

☐ In urban areas, air source heat pump systems are only suitable as a heat source for **low-density heating demand**

[1] IEA, Tsinghua. The Future of Heat Pumps in China, 2024

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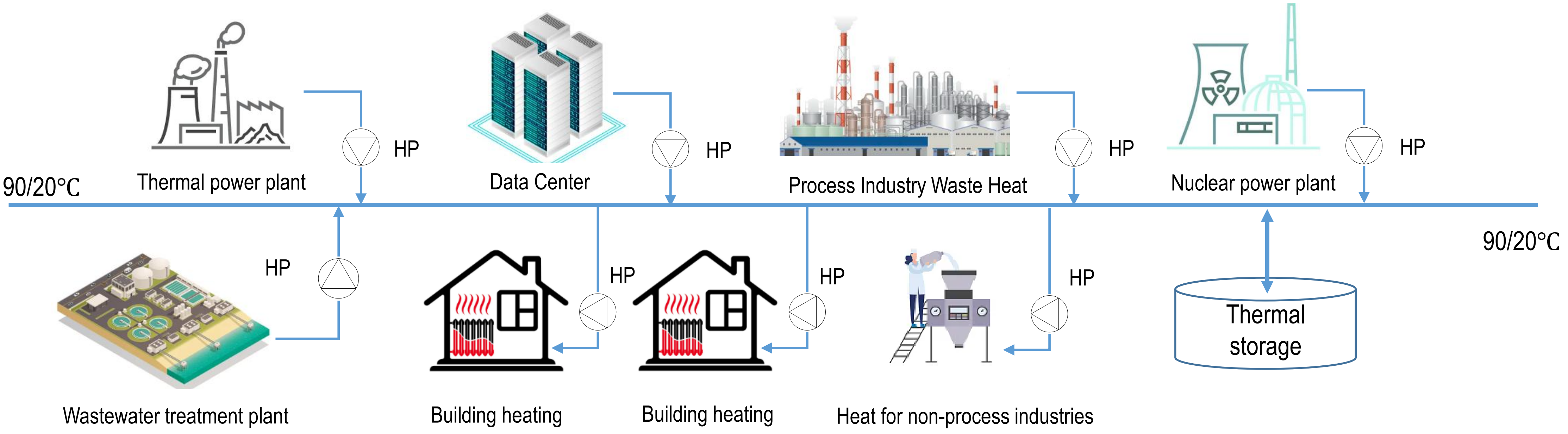
# Heating Systems Design

## Build waste heat sharing systems to provide heat for space heating and process

■ Schematic diagram of a waste heat sharing thermal network




**Issue:**

**① Quantity of waste heat resources VS the demand?**

**② How to solve technical obstacles: Spatial, Temporal, and Temperature**

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# Comparison of Cooling Systems

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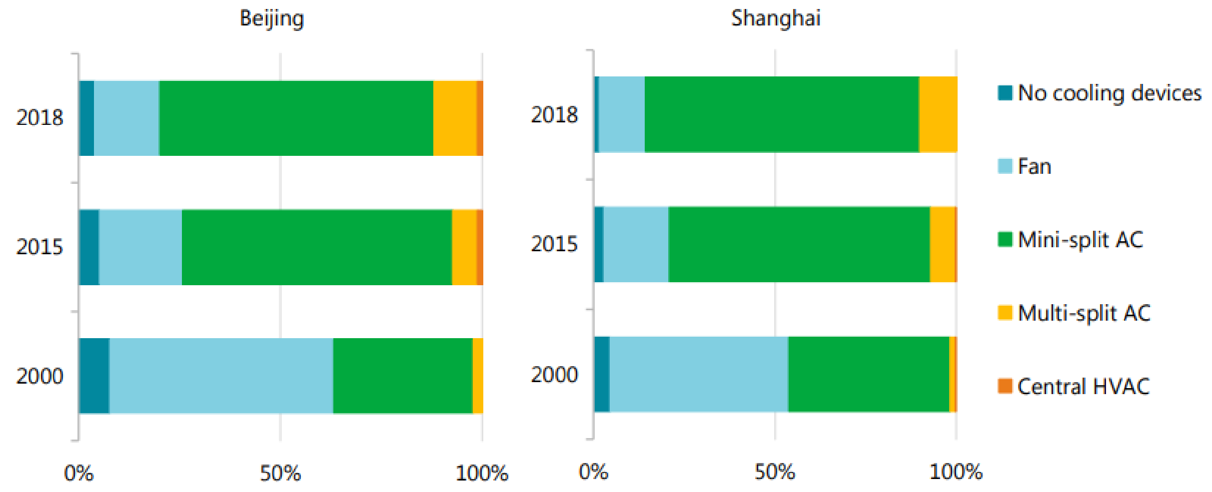
# Comparison of Cooling Systems

## Zero Carbon Cooling

- Cooling energy demand in China reached just under 400 TWh in 2017, roughly 8% of total electricity demand in the buildings sector.
- Direct electric cooling (splits system and chillers) are the most commonly used cooling technology in China

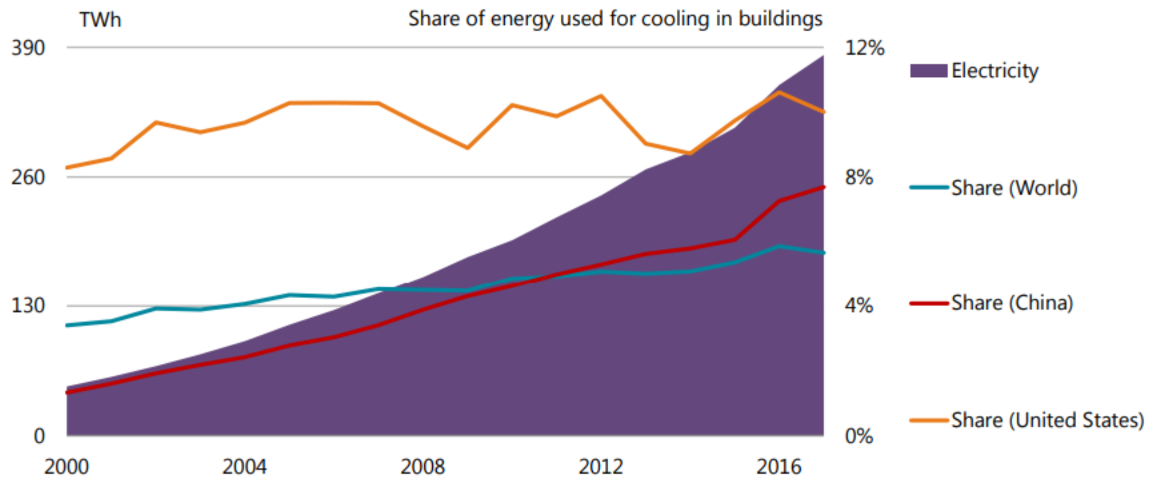
Figure 2. Evolving equipment choice in urban households in Beijing and Shanghai, 2000-18




Source: Derived with 2015 and 2018 data from Tsinghua University Building Energy Research Center household surveys on the status of energy use of urban households in China.

Choice of cooling equipment in urban households has changed in many cities since the early 2000s.

Figure 1. Energy consumption for space cooling in buildings in China, 2000-2017






ıte: Natural gas (not shown here) represented a tiny share (0.024%) of cooling energy consumption in 2017.

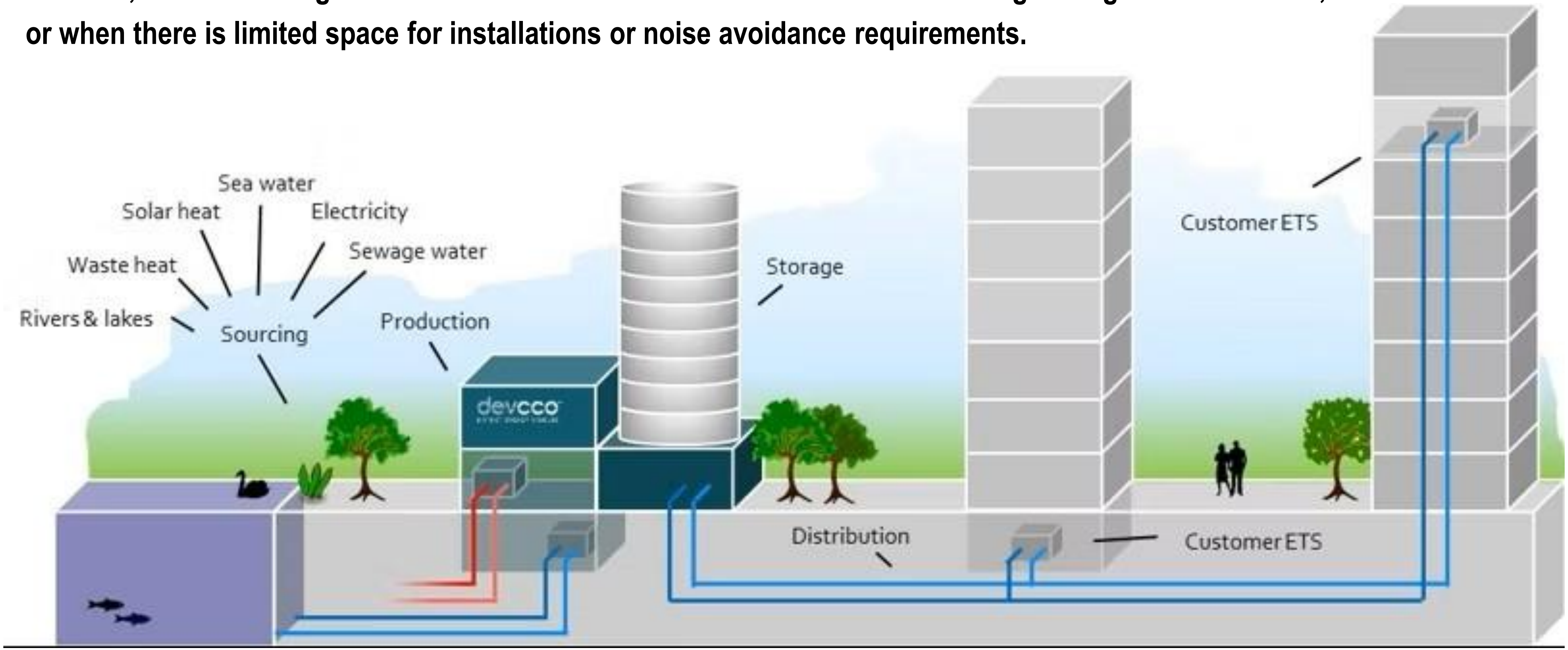
- Choice of cooling equipment in urban households has changed in many cities since the early 2000s.

[1] 2019, The Future of Cooling in China Delivering on action plans for suistainable air conditioning

# Comparison of Cooling Systems

## Zero Carbon Cooling

- In China, district cooling is not common unless there is a source for free cooling through rivers or lakes, or when there is limited space for installations or noise avoidance requirements.




[1] 2019, The Future of Cooling in China Delivering on action plans for sustainable air conditioning

# Conclusion

# District Heating Grid: 5th Generation

## Neutral Grid with collective ATES-boreholes

### NEUTRAL GRID

- Connecting different buildings (from different owners) throughout public terrain.
- Operated for a fee by a private-public partner, who's responsability is to maintain the system.

### COLLECTIVE ATES WELLS

- ATES wells on (public) domain

### INDIVIDUAL & COLLECTIVE HEAT PUMPS

- Every building pays a fixed + variable fee depending on their heating & cooling demand

# Summary

## Comparison of the Carbon Neutrality Pathways

- More than **seventy percent of European cities are above forty degrees latitude**, which limits cooling loads and allows widespread use of **shallow geothermal and groundwater systems for cooling**. More than **80% of major Chinese cities lie below 40° latitude**, which increases cooling demand and keeps **direct electric cooling** as the dominant solution.

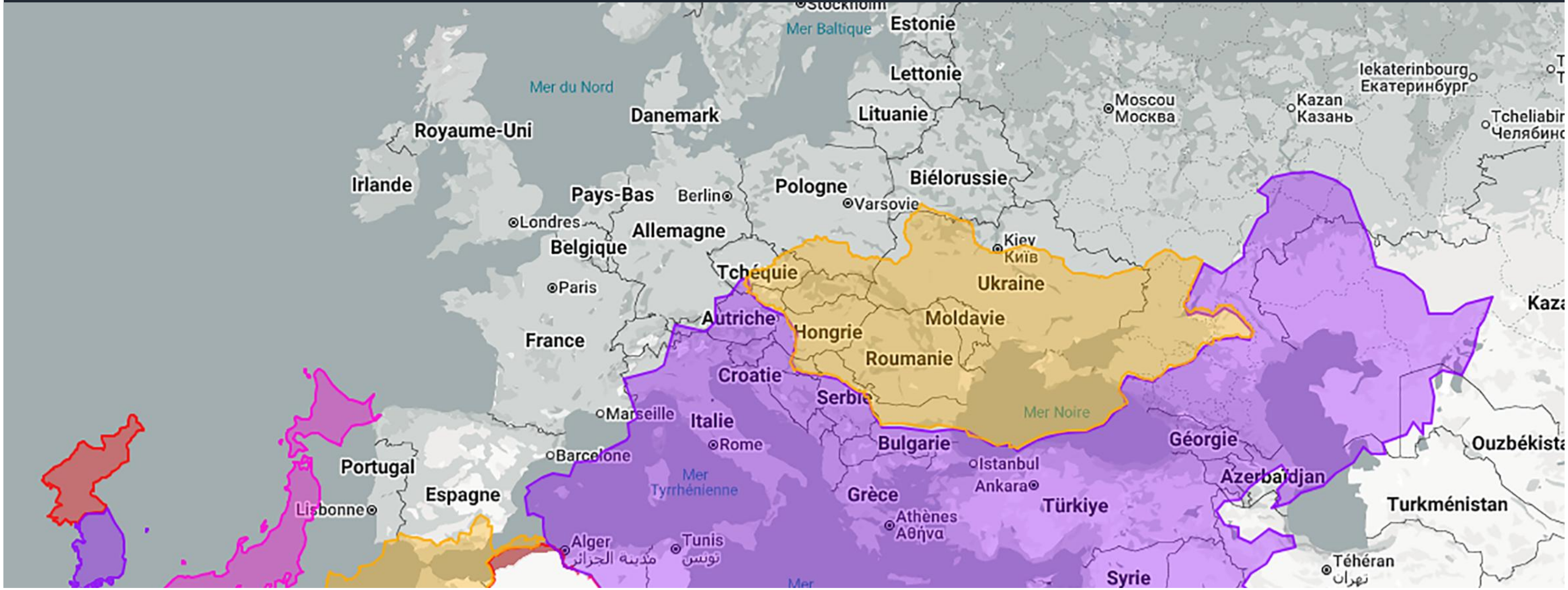
- **China's major cities lie mostly below 40° latitude, which increases cooling demand and keeps direct electric cooling dominant**, with district cooling appearing mainly where rivers or lakes provide free cooling or where space and noise constraints block decentralised units.

- Europe's building stock follows **nearly zero-carbon standards** that **lower heat intensity** and make **low-temperature heating** feasible, while China's dense, **high-rise urban** form, shaped by the Hu Huanyong Line, results in **high heat intensity** & **demand**.

- China requires **supply temperatures up to 90 °C for industry** and for its **less efficient buildings.** This supports **high-temperature district heating, concentrated in the northeast,** where winter heating is mandatory, whereas in Europe, **district heating and cooling** are common across many countries due to lower building heat intensity.

- **Europe deploys district heating and district cooling widely** because its **dispersed urban fabric** and **lower heat intensity suit neutral grids, groundwater resources and seasonal thermal storage,** while China relies mainly on **direct systems and targeted district networks** aligned with geographic and resource constraints.

# Comparison of Zero Carbon Heating and Cooling Pathways in China and Europe

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