

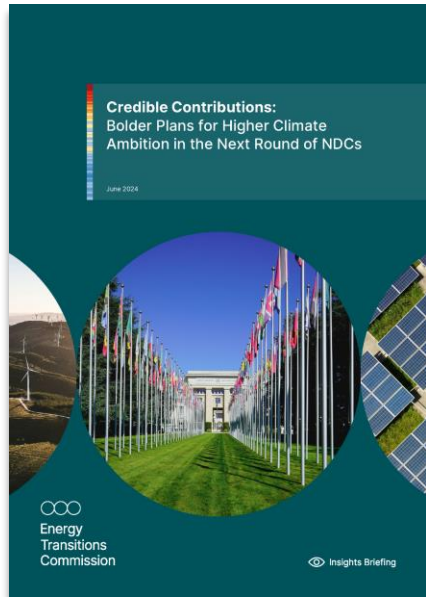


Energy
Transitions
Commission

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

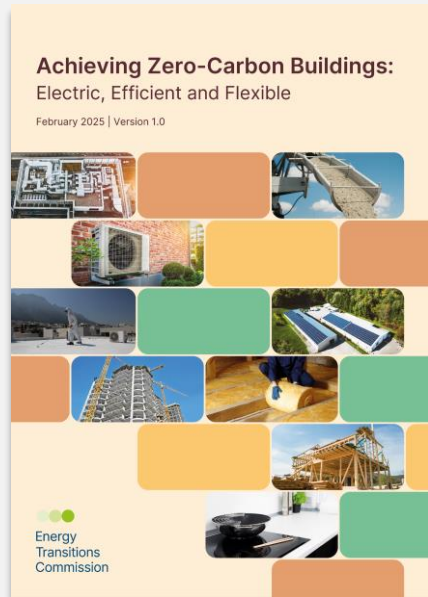
ETC Webinar
April 2025

The ETC's 2025 webinar series



February 13th

Credible Contributions: Bolder Plans for Higher Climate Ambition in the Next Round of NDCs



April 10th

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

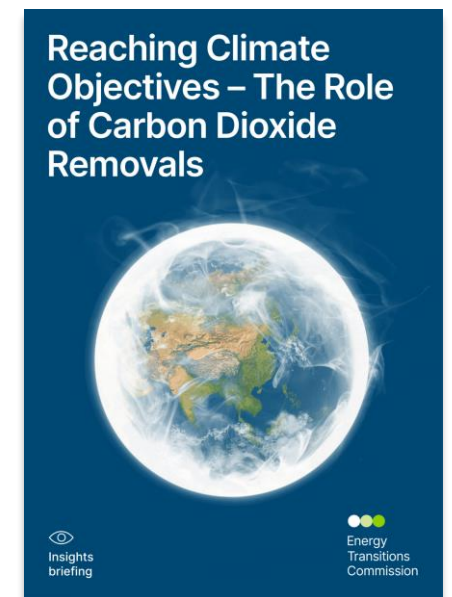


July 15th

Insights across our "Barriers to clean electrification" series

October 1st

The Role of Hydrogen & Bio energy



November 25th

Reaching Climate Objectives: the role of carbon dioxide removals



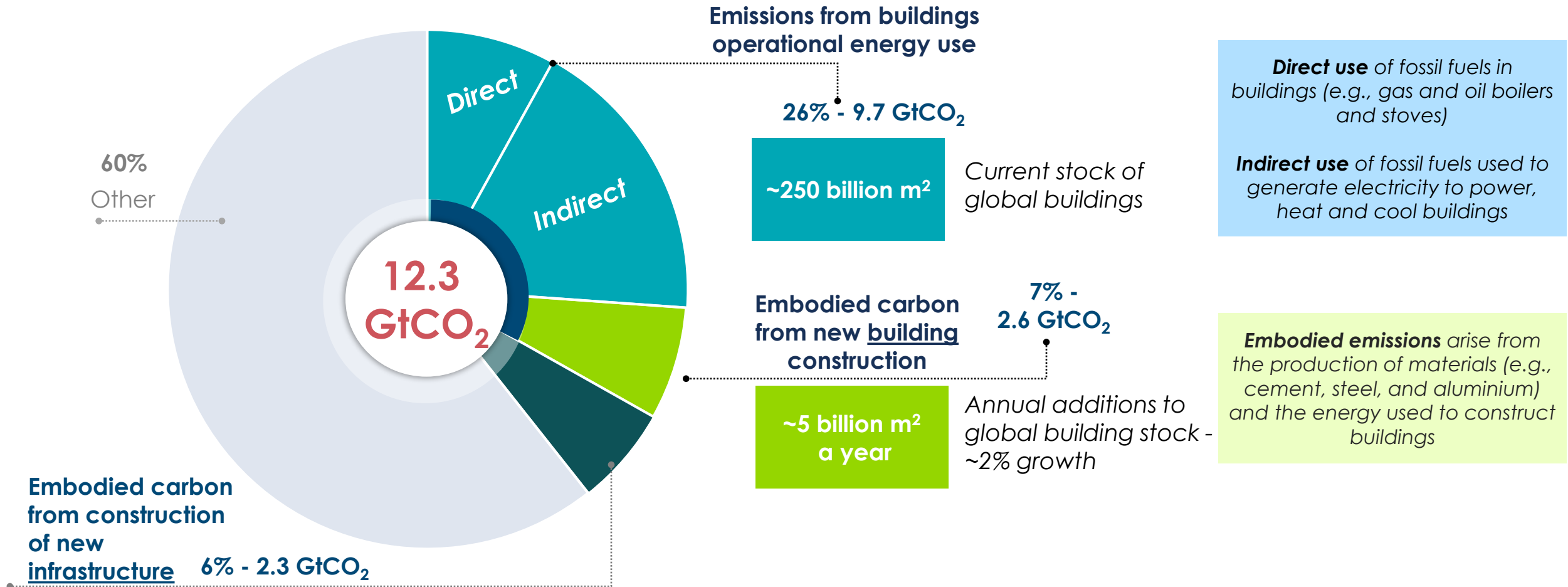
The building decarbonisation challenge



Buildings account for 33% of global emissions; around three-quarters of this relates from energy use to operate buildings, a quarter is from the annual construction of new buildings

Global emissions by sector, 2022

GtCO₂



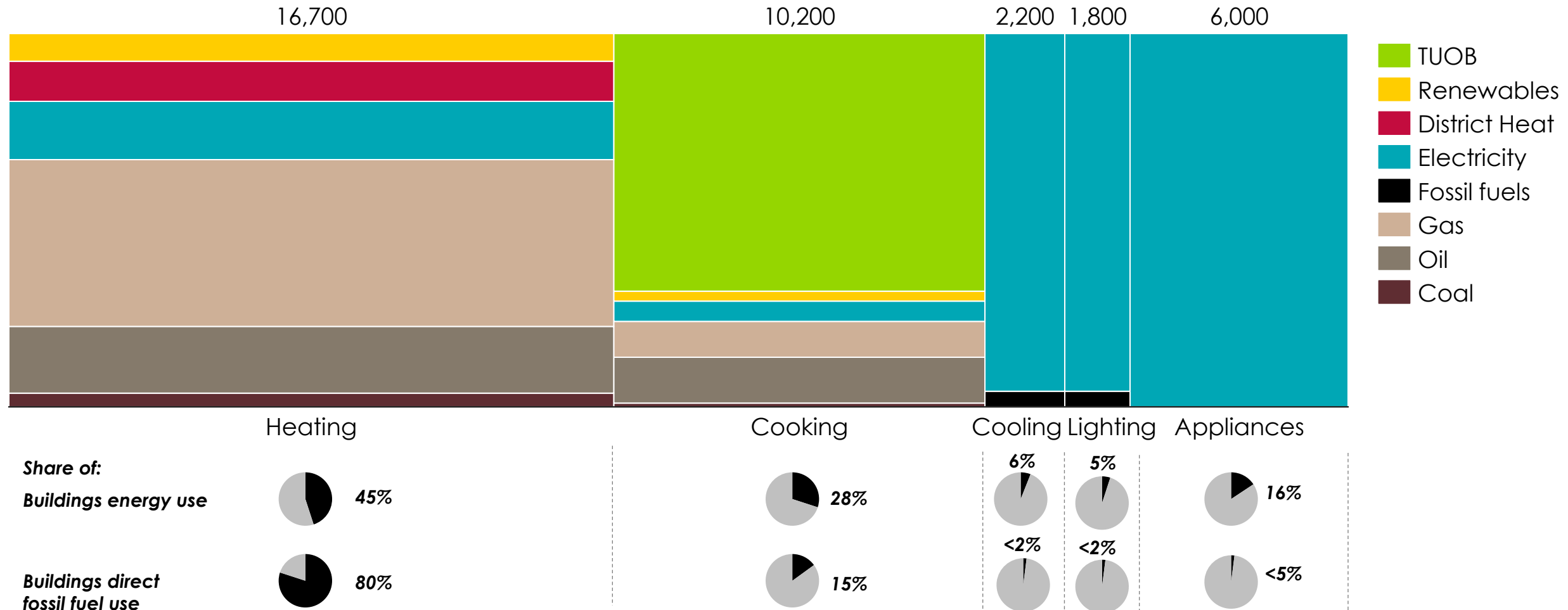
Note: This shows annual carbon flows as opposed to stock. Infrastructure includes roads, pipes, airports, railways.
Source: IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action*.

The direct use of fossil fuels in buildings accounts for ~40% of energy use, followed by electricity at 35%, and the traditional use of biomass for cooking at 20%

Global buildings operational energy use by end-use and fuel, 2022

TWh

Total buildings energy use ~37,000 TWh

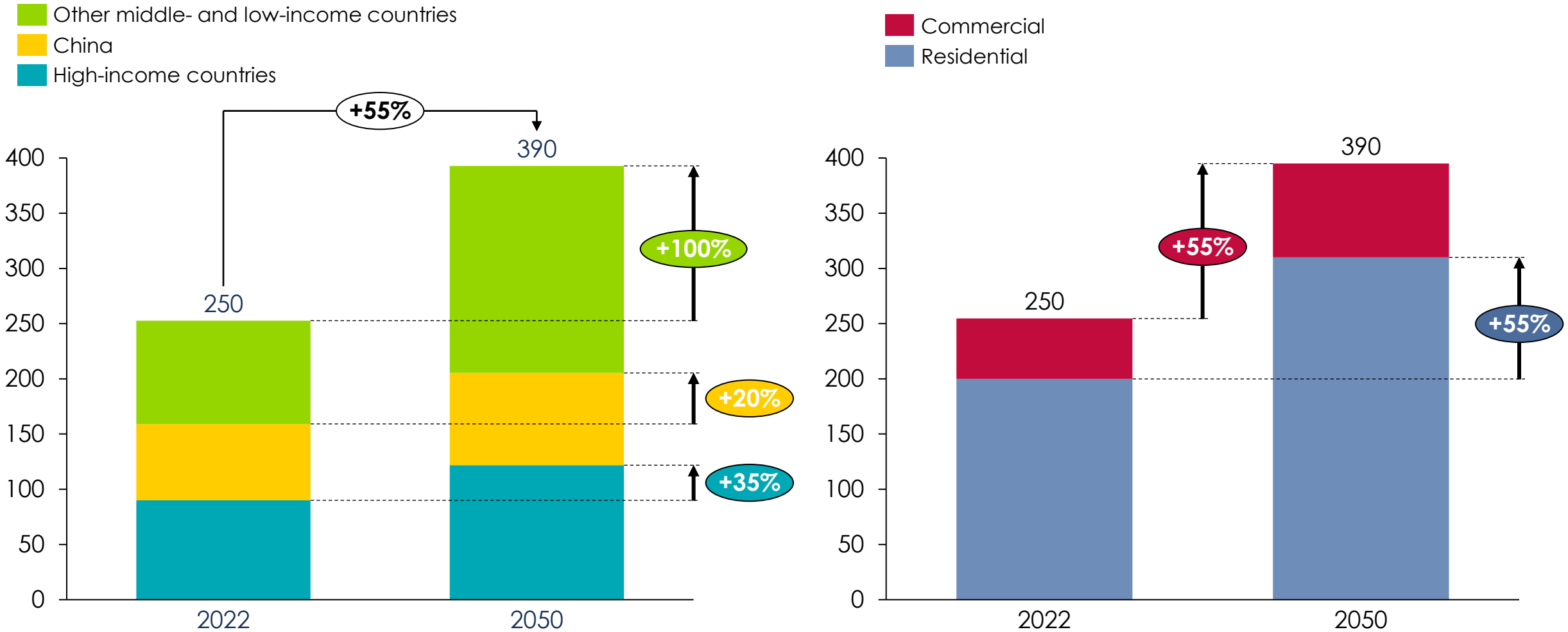


Note: Shares of building energy by end use from 2021 applied to 2022 actuals. Heating includes both space and water heating.
 Source: Systemiq analysis for the ETC; IEA (2022), *World Economic Outlook 2021*; IEA (2023), *World Economic Outlook 2022*.

Global floor area is set to increase 50–60% by 2050, driven by a doubling of the building stock in middle- and low-income countries

Growth in global floor area, projections to 2022 to 2050

Billion m²

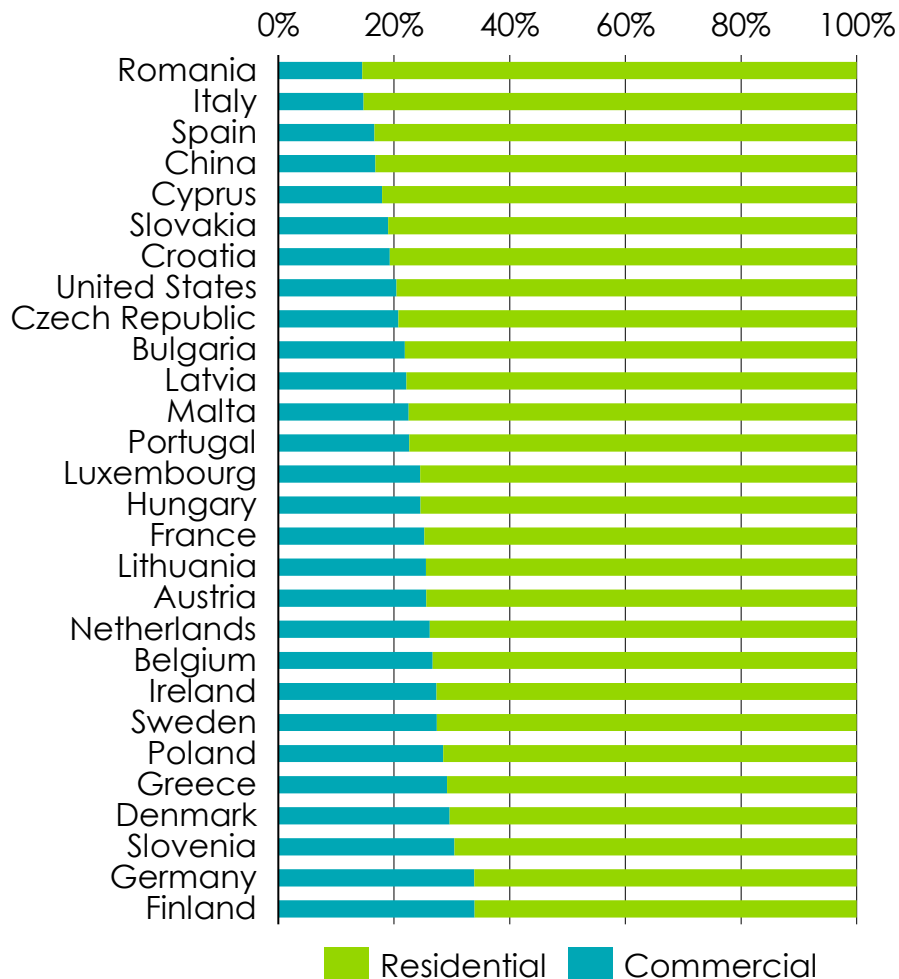


Note: Projections from the IEA's Net Zero scenario.
 Source: IEA (2023); World Energy Outlook, <https://www.iea.org/reports/world-energy-outlook-2023>, re-used under license: CC BY 4.0.

“Commercial buildings” refers to a very large and heterogenous group of sectors including schools, hotel and retail; offices only account for 25–40% of building stock

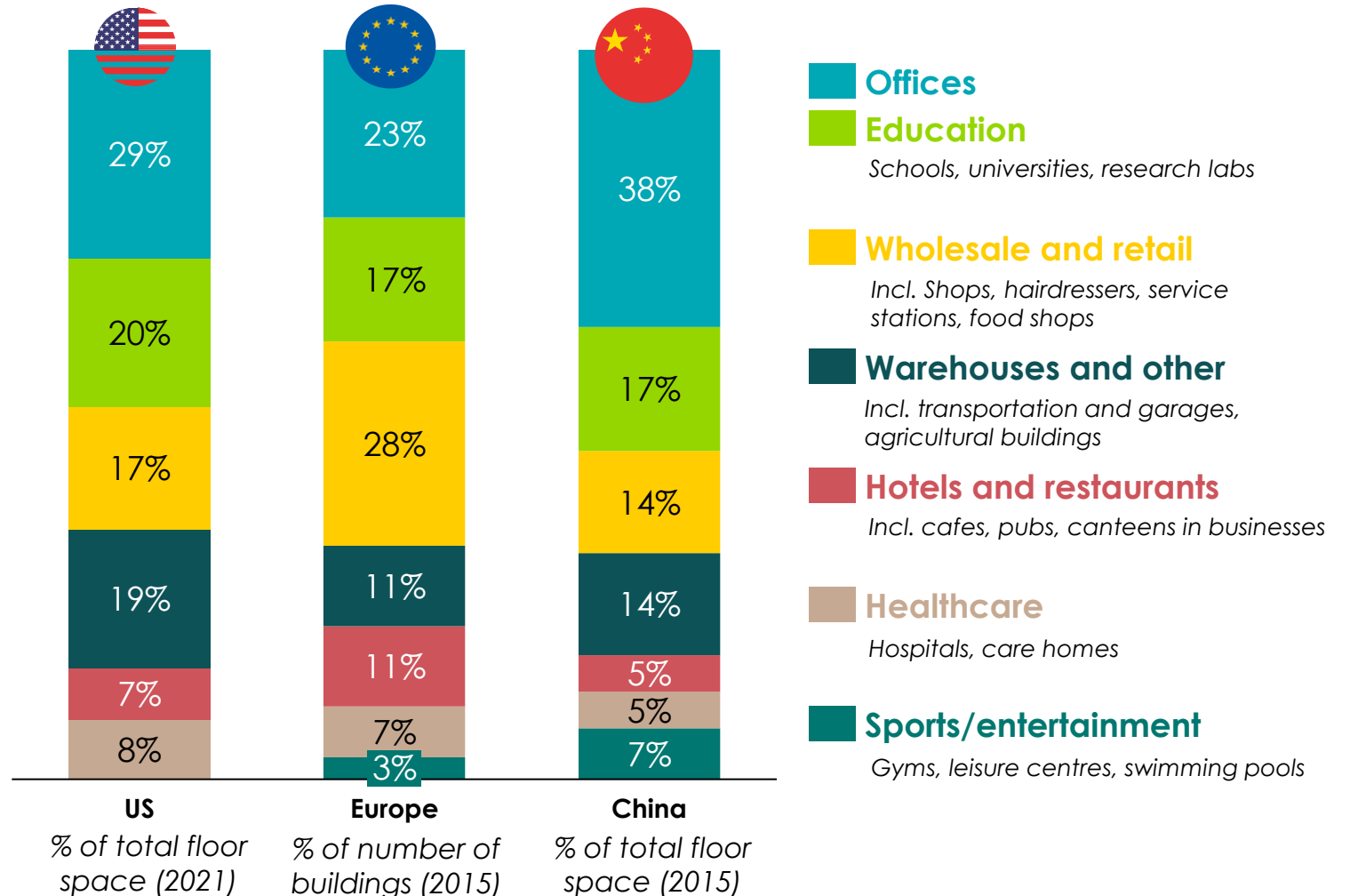
Built floor area by residential / commercial, 2015

% of total floor area



Commercial buildings by sector

% of total floor area for the US and China, % of number of buildings for Europe

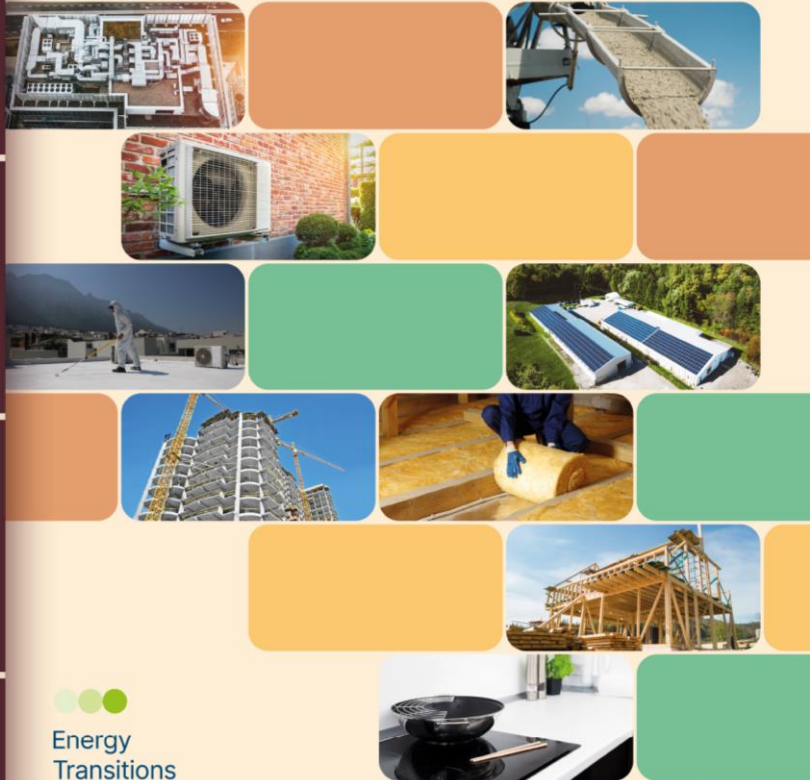


Note: For the US, sports facilities are included in “warehouses and other”.

Source: National Renewable Energy Laboratory (2022), US Building Stock Characterization Study; Building Performance Institute Europe (2015), Europe’s Buildings Under the Microscope; Baijiahao (2018), Real estate and constructions: What are the sub-sectors? What are the sizes?; Eurostat, available at

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

February 2025 | Version 1.0




Energy
Transitions
Commission

1

The heating decarbonisation challenge

2

Increasing access to affordable cooling

3

Improving access to clean cooking

4

Efficient lighting and appliances

5

Decarbonising commercial buildings

6

Buildings within a clean energy system

7

The new build opportunity

Section A: Decarbonising the energy used to operate buildings

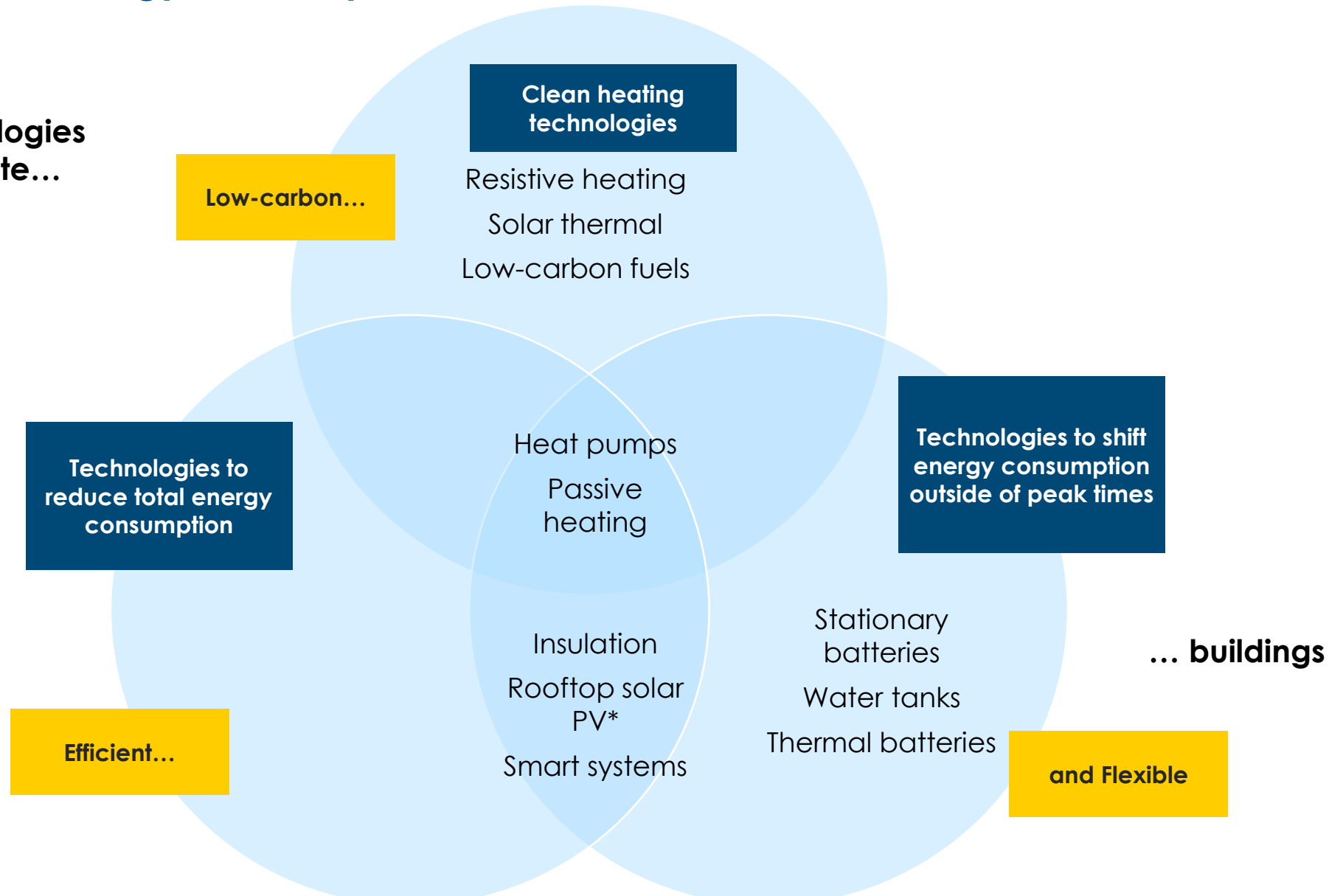


Heating



The net-zero transition will require buildings to become lower-carbon, more efficient and more flexible in their energy consumption habits

Three sets of technologies are required to create...






Note: *Rooftop solar PV does not reduce overall energy consumption from buildings, but reduces imports from the grid.
Source: Systemiq analysis for the ETC.



There are four main groups of clean heating technologies; heat networks do these at scale

Full set of possible clean heating technologies:

Key



-  Space heating
-  Water heating
-  Space cooling

1



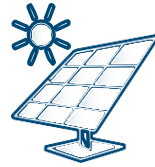
Electric technologies

Relies on clean electricity generation

- Heat pumps

- Resistive heating


Technologies in individual buildings

2



Zero-carbon heat sources

Entirely renewable



- Solar thermal


3



Low-carbon fuels

Relies on access to sustainable bio resources
Hydrogen must be "green", produced with renewable electricity

- Sustainable biomass boiler

- Hydrogen boiler


4



Secondary heat sources



Entirely renewable; although in the long-term, also important that urban and industrial heat is produced using clean fuels





- Renewable energy sources (e.g., river and sea water)
- Urban and tertiary sector waste heat (e.g., sewage water, data centre, transport)
- Industrial waste heat

Technologies and heat sources in heat networks

- Networked ground source heat pumps

- Centralised large-scale heat pumps


- Solar thermal

- Geothermal


- Biomethane

- Hydrogen


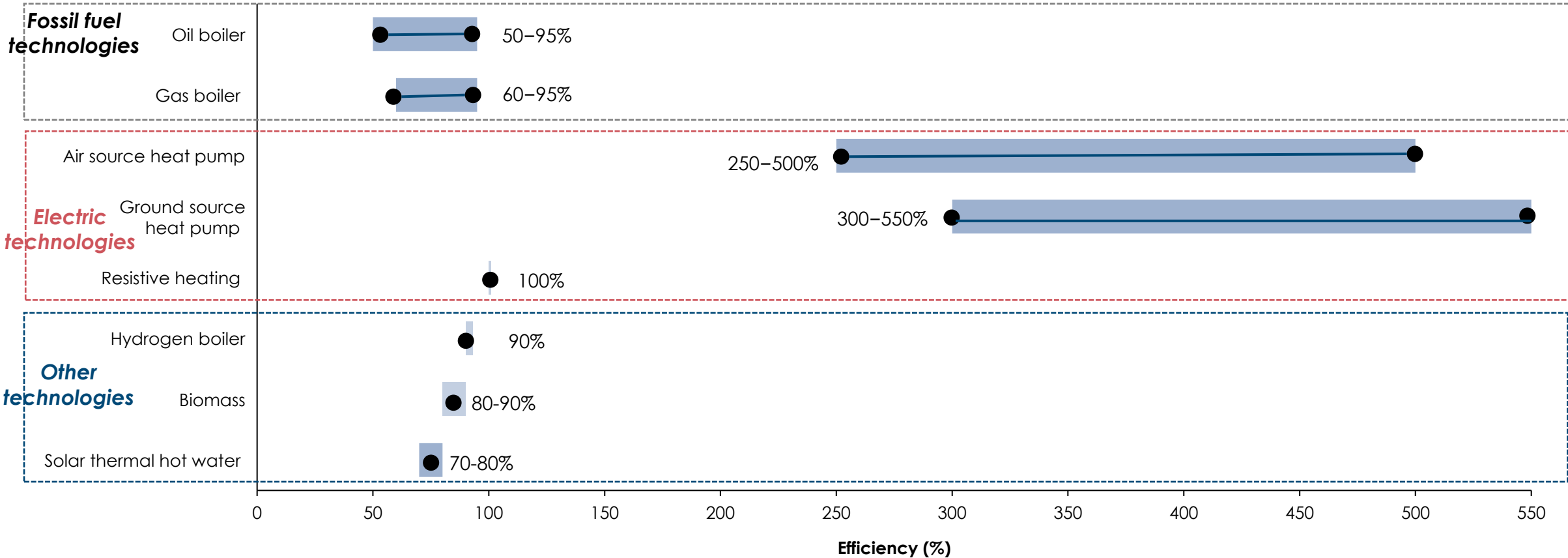


Source: Systemiq analysis for the ETC.

Heat pumps are 3–5 times more efficient than gas boilers, while resistive heating converts 100% of electric energy to heat

Efficiency (primary energy to final energy) of space heating technologies

%



Note: The efficiency of heat pumps depends more on the differential between the outside temperature and desired indoor temperature than technical efficiency, resulting in a huge range of possible efficiencies.

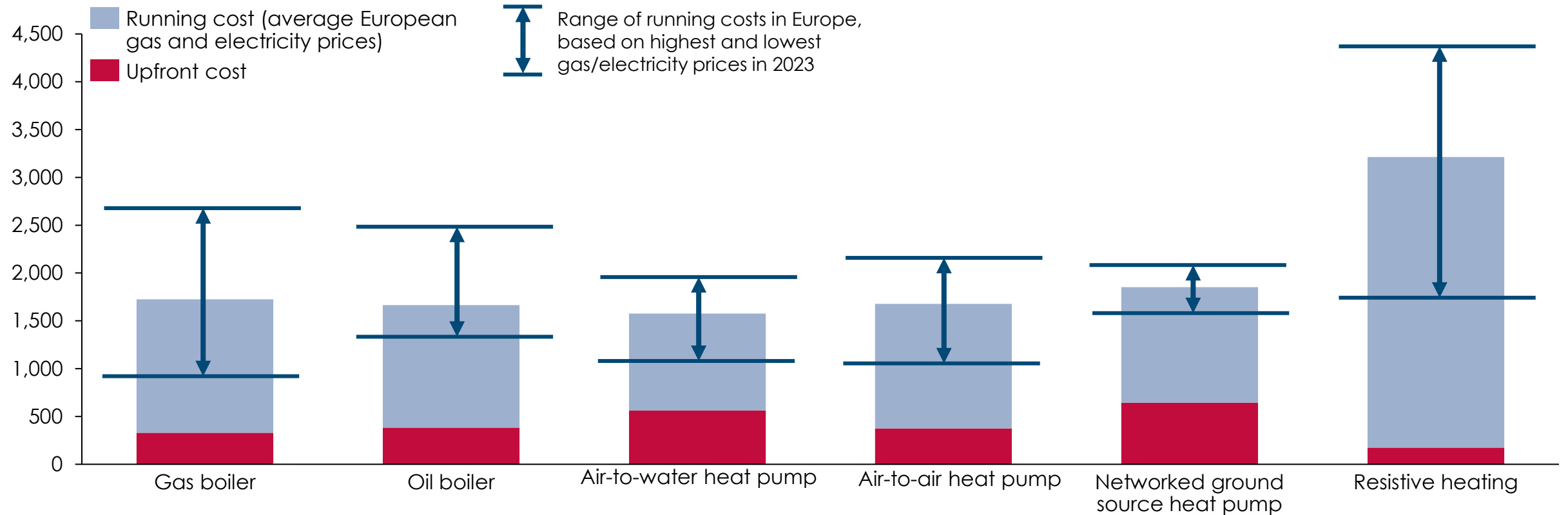
Source: Systemiq analysis for ETC; IEA (2022), *Future of Heat Pumps*; IRENA (2022), *Heat Pump Market and Costs*; IEA (2023), *Energy Efficiency Database*.



The competitiveness of electric heating technologies depends massively on the relative cost of gas and electricity prices

Equivalent annual cost of ownership (technology, installation and running costs) – Europe
 € per year

2023 average European prices:
 Gas: €0.12/kWh
 Electricity: €0.29/kWh → 2.5x more expensive



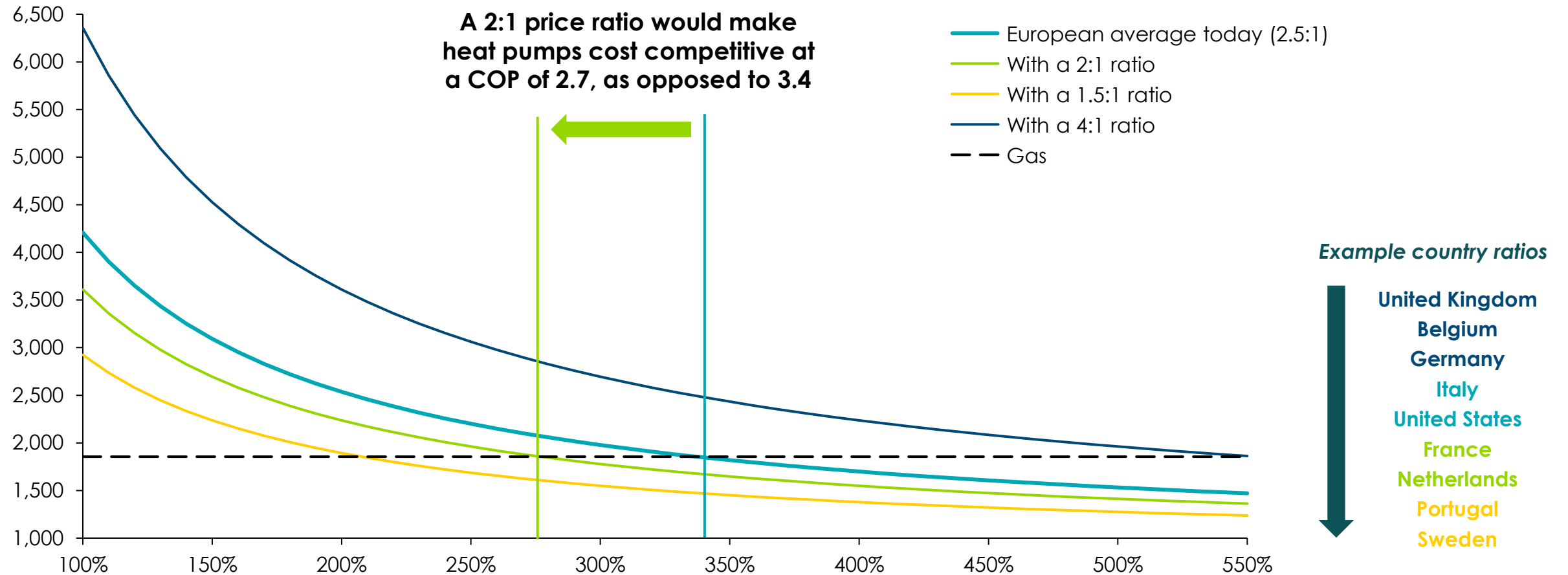
Note: Assumes an average heat demand of 11,500 kWh a year per household, based on an average across the US and select European countries. Average, min and max running costs are based on 2023 retail prices. Assumes 5% discount rate. Excludes subsidies and maintenance costs. Networked ground source heat pumps – we assume a €50 a month standing charge fee for the shared ground arrays.
 Source: Systemiq analysis for the ETC; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024].

Fossils
 Electric

The smaller the differential between gas and electricity prices, the lower the efficiency that a heat pump needs to achieve for cost parity

Equivalent annual costs (technology, installation and running costs) at different electricity to gas price ratios

€ a year



Note: Assumes an average heat demand of 11,500 kWh a year per household, based on an average across the US and select European countries. Fuel prices reflect averages from 2023. Assumes a discount rate of 5%.

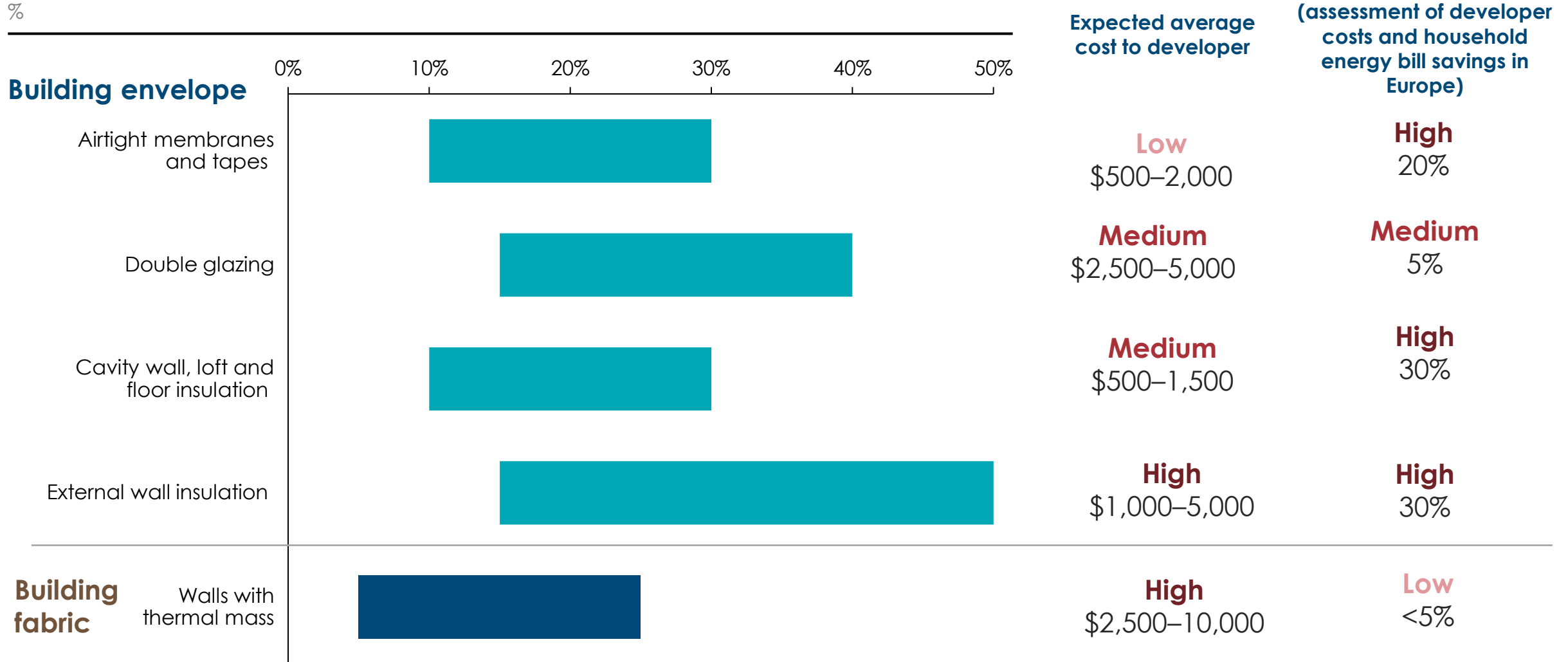
Source: Systemiq analysis for the ETC; Eurostat Database, available at: <https://ec.europa.eu/eurostat/data/database>. [Accessed 01/08/2024].

Passive heating



Passive techniques in new buildings can reduce heating energy consumption by 15–30% on average

Impact on annual heating energy consumption of passive heating techniques



Note: IIRR analysis assumes a discount rate of 5%. Based on an average single-family house of 100 m². Rate of return = Assessment of developer costs and household energy bill savings in Europe.

Source: Systemiq analysis for the ETC; Energy Saving Trust (2024); Checktrade (2024); The Eco Experts (2024); Department of Energy and Climate Change (2014), National Energy Efficiency Data-Framework; Kattenberg, L., et al. (2023), *The Efficacy of Energy Efficiency: Measuring the Returns to Home Insulation*; Adan, H., Fuerst, F. (2014), *Do energy efficiency measures really reduce household energy consumption? A difference-in-difference analysis*; Hamilton, L., et al. (2013), *Energy Efficiency in the*



3 aspects to creating “net-zero ready” buildings: all buildings must have clean heating and smart/flexible technologies, and assess the most appropriate building fabric improvements

Possible interventions

Install clean heating technologies

Heat pumps, resistive heating

New buildings

All buildings in high-income countries from 2025. In other countries, from 2035

Existing buildings

All buildings by the early-mid 2040s in high-income countries.

In other countries, the aim should be 2050.

Improve building fabric

Insulating walls (internal, external, cavity), lofts and ceilings, double glazed windows, draught proofing, ventilation improvements

All buildings should be built to much higher energy efficiency standards – the additional cost to developers of achieving a 20% reduction in kWh/m² is typically around 1-5%, which can often be recouped via a higher selling price

Light retrofit: easy to access improvements (e.g., low-cost or less disruptive)

Inefficient buildings



Average building



All buildings should explore low-cost measures

Medium retrofit: 2-4 interventions



Most buildings can take a balanced approach to further insulation; deep retrofit is not a pre-requisite for a heat pump in the average house

Deep retrofit: package of whole-house interventions



Retrofitting the least efficient buildings must be a government priority

Install smart and flexible tech

Solar PV, batteries, smart systems

All buildings in high-income countries should be smart-ready and solar-ready

With falling costs, rooftop solar PV and smart systems offer huge opportunities to lower energy bills

Time of use tariffs are needed to incentivise investment in batteries and water storage

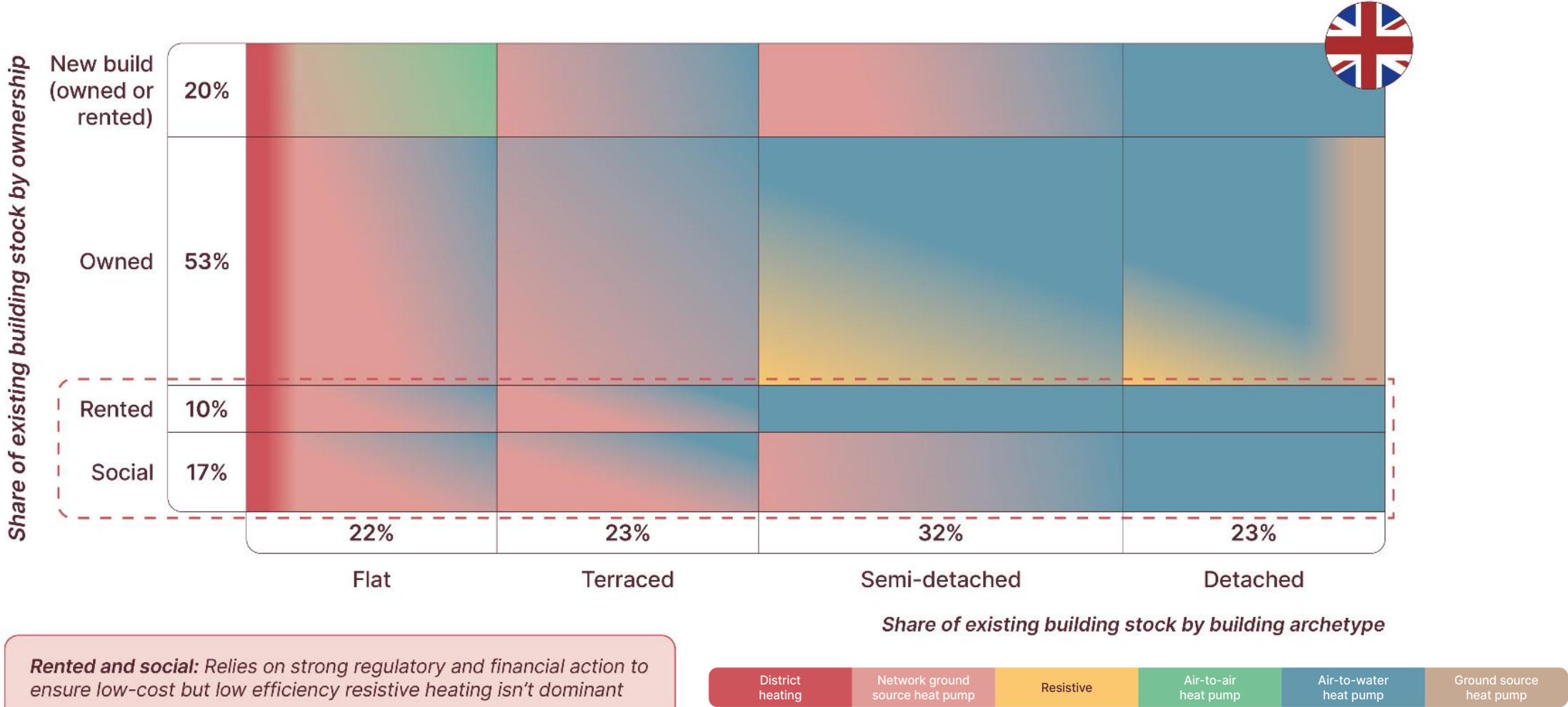
Implications for technologies and energy demand



While it is not possible to estimate an exact tech mix, there is huge value in understanding the broad trajectory of clean heating technologies to guide policy, investment and skills

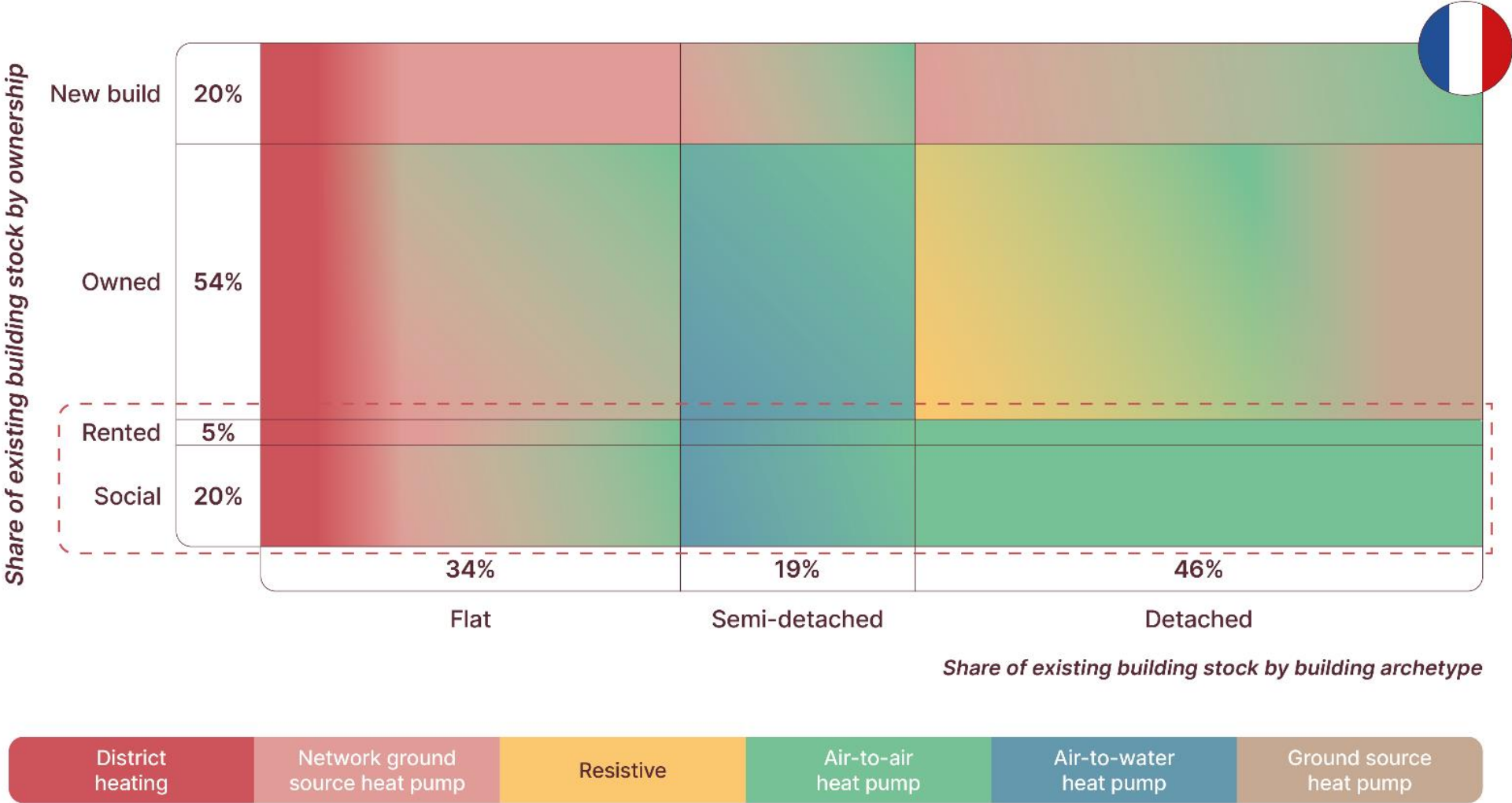
Illustration of probable dominant space heating technologies across different building archetypes and ownership – UK

% of stock in 2050



While it is not possible to estimate an exact tech mix, there is huge value in understanding the broad trajectory of clean heating technologies to guide policy, investment and skills

Illustration of probable dominant space heating technologies across different building archetypes and ownership– France
 % of stock in 2050



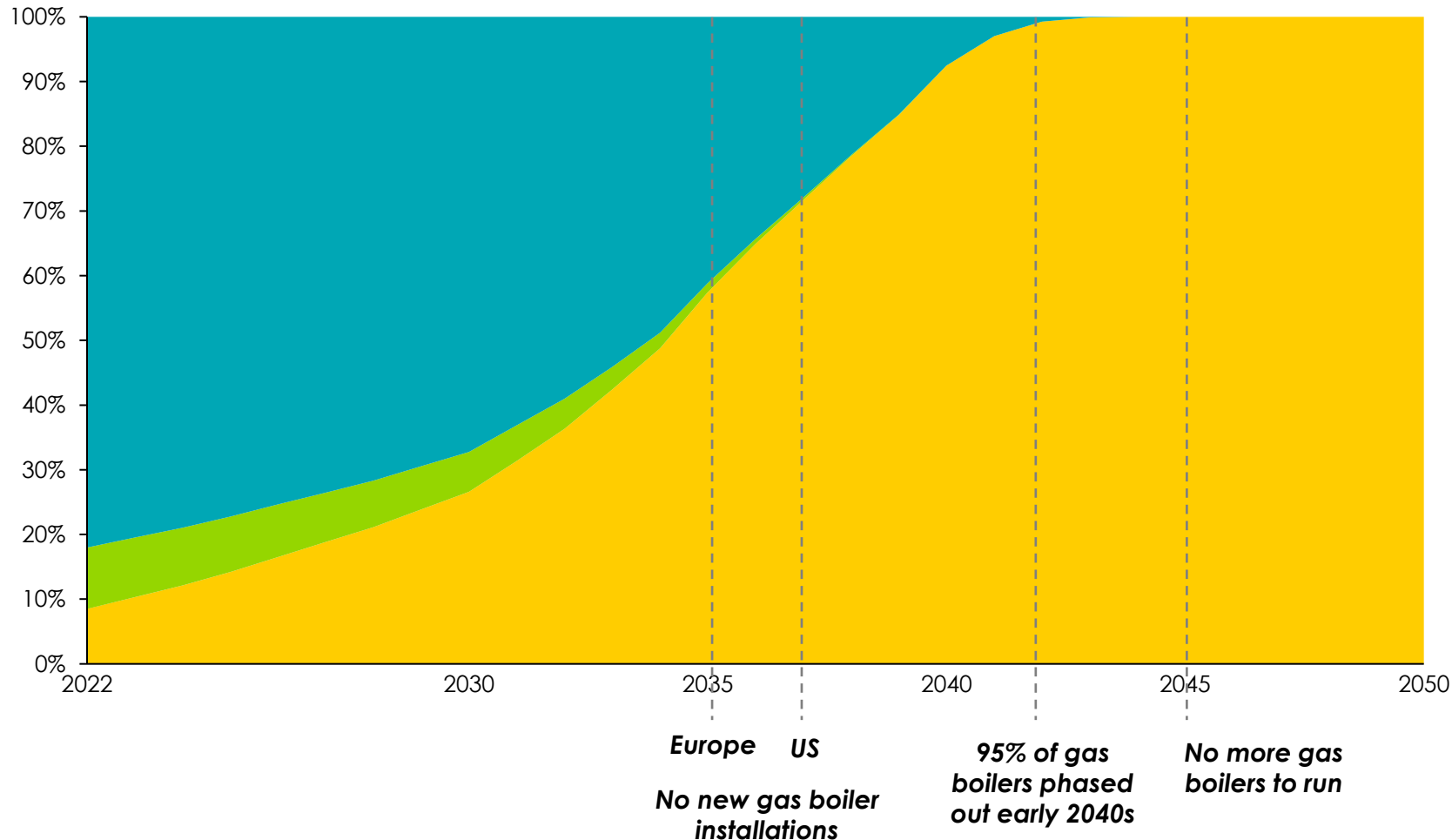
Source: Systemiq analysis for the ETC.

In Europe and the United States, 95% of gas boilers could be phased out by the early 2040s, with no more gas boilers to run by 2045

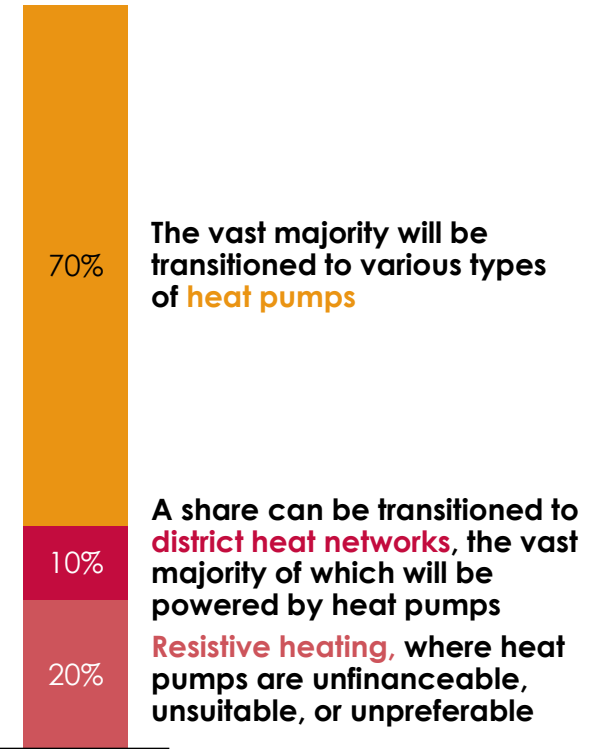
Building heating technology stock

% of stock of technologies in individual homes

Gas Oil Electric technologies



Indicative 2050 mix



The vast majority will be transitioned to various types of **heat pumps**

A share can be transitioned to **district heat networks**, the vast majority of which will be powered by heat pumps

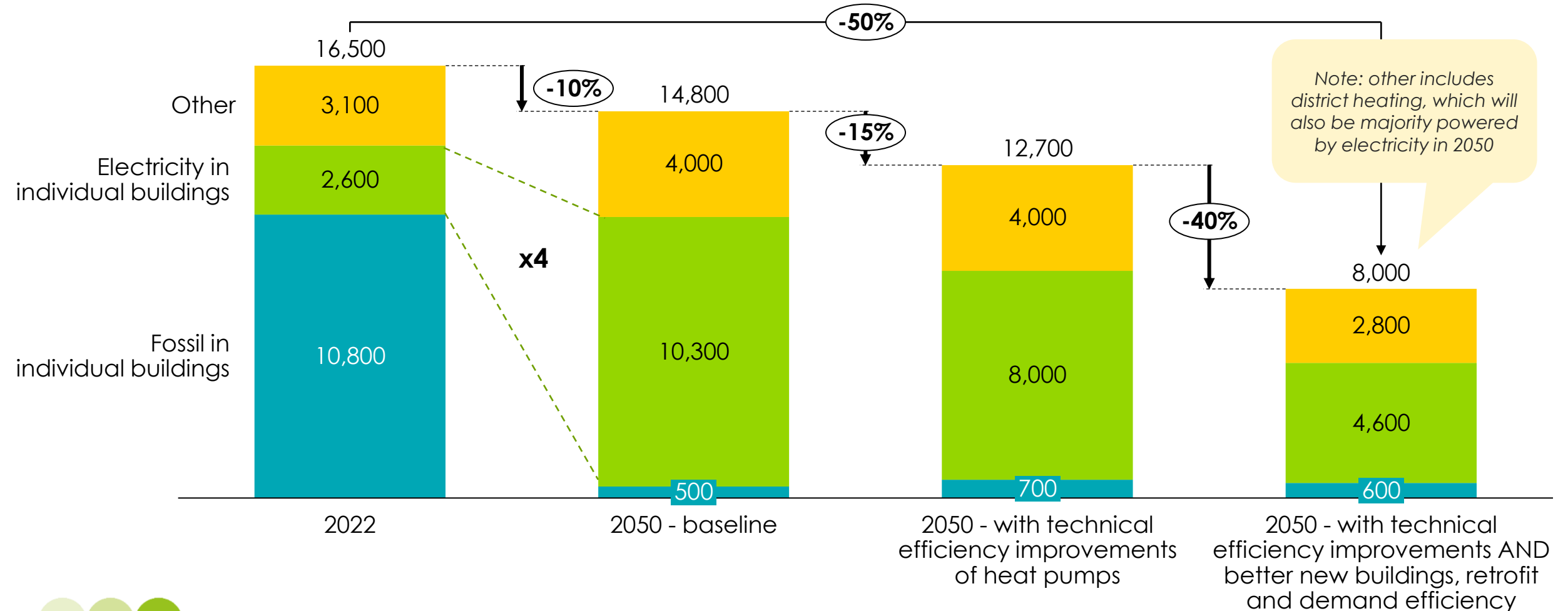
Resistive heating, where heat pumps are unfinanceable, unsuitable, or unpreferable

Source: Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China*.

Electricity demand from heating could be 4 times higher than it is today, but with strong action on energy productivity, the increase could be less than double

Global final energy demand for heating by fuel in 2050

TWh



Note: Other includes district heating and renewables.
Source: Systemiq analysis for the ETC; IEA (2023), World Energy Outlook 2023; IEA (2021), Net Zero by 2050.

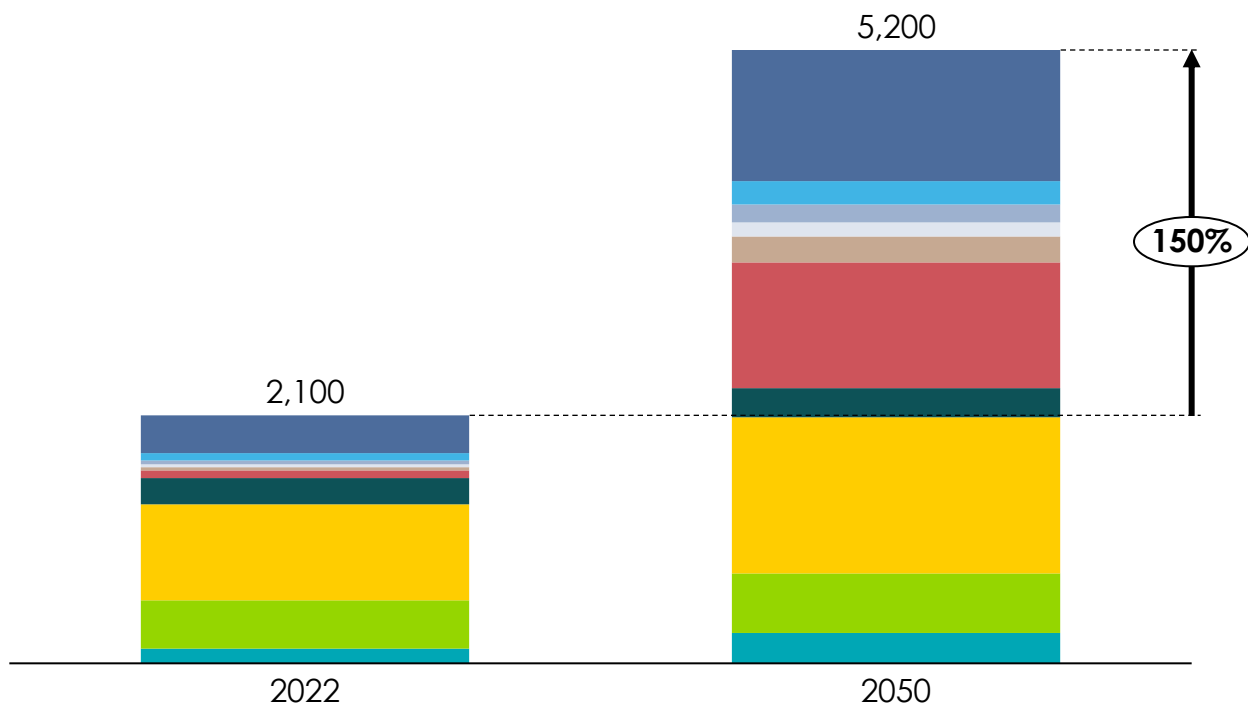
Cooling



Cooling is the fastest growing operational end-use, with global cooled floor area set to overtake heated floor area by 2050

Space cooling (residential + commercial) energy consumption by region, IEA baseline scenario, 2022-50, TWh

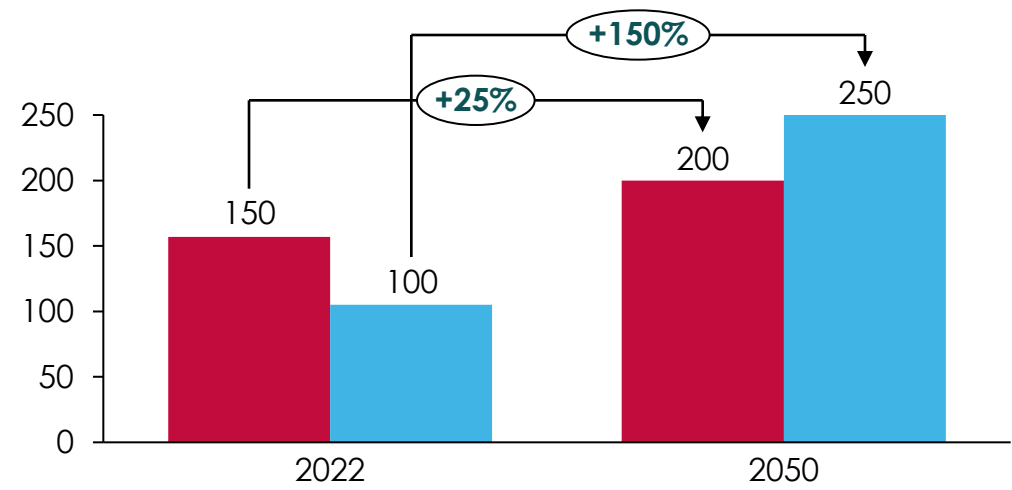
- Europe
- China
- India
- Mexico
- Middle East
- US
- Japan and Korea
- Indonesia
- Brazil
- Rest of world



Heated floor area vs. cooled floor area (residential + commercial), IEA Net Zero scenario Billion M²

- Cooled floor area
- Heated floor area (space heating)

Cooled floor area is growing at a higher rate than heated, driven by 1) **GDP per capita growth**; 2) **increase in building floor area**, particularly in developing economies; 3) **warming climates**



Rapid growth in cooling demand in countries with carbon-intensive electricity grids highlights the importance of rapidly scaling up renewables across the world.

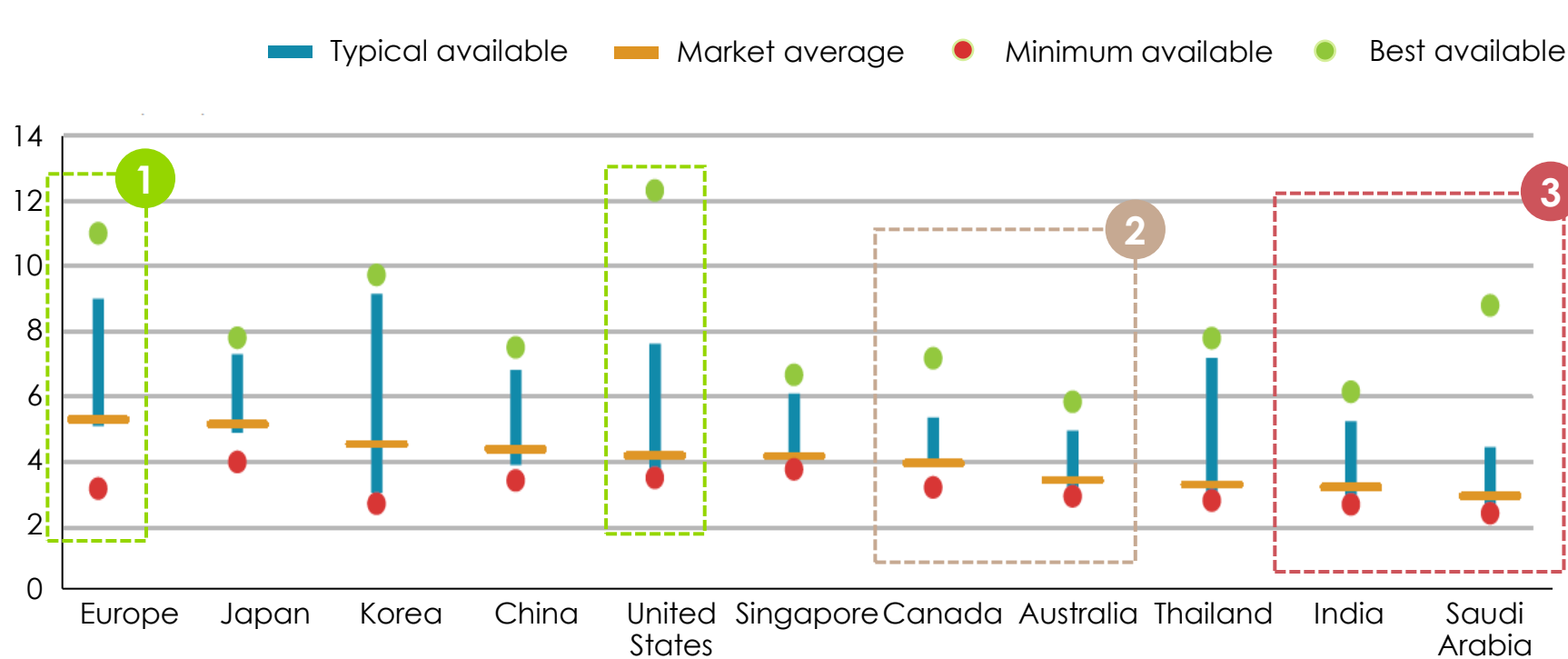


Note: IEA estimates of global cooling energy use in 2050 split into regions using IEA projections of AC stock in different countries in 2050. Source: Systemiq analysis for the ETC; IEA 2023; World Energy Outlook, <https://www.iea.org/reports/world-energy-outlook-2023>, re-used under license: CC by 4.0.

There is a huge opportunity to increase the efficiency of ACs on the market, with the best available technology typically twice as efficient as the market average

Seasonal energy efficiency ratio (SEER) of market available residential AC units in selected regions, 2018

Watt of cooling output per watt of energy input



1 There is a substantial ambition gap in European and US regulation - the market average is ~3 times less efficient than the best available tech

2 Some developed countries, such as Australia and Canada, have average efficiency. Improvements in developed markets are key to driving progress in less developed countries

3 Countries with lower average efficiencies tend to be ones with weaker regulations but also those with higher cooling needs

In all countries, noticeable variation exists – in some countries this reflects price dynamics, but in other countries a low efficiency AC can cost the same as a very efficient one

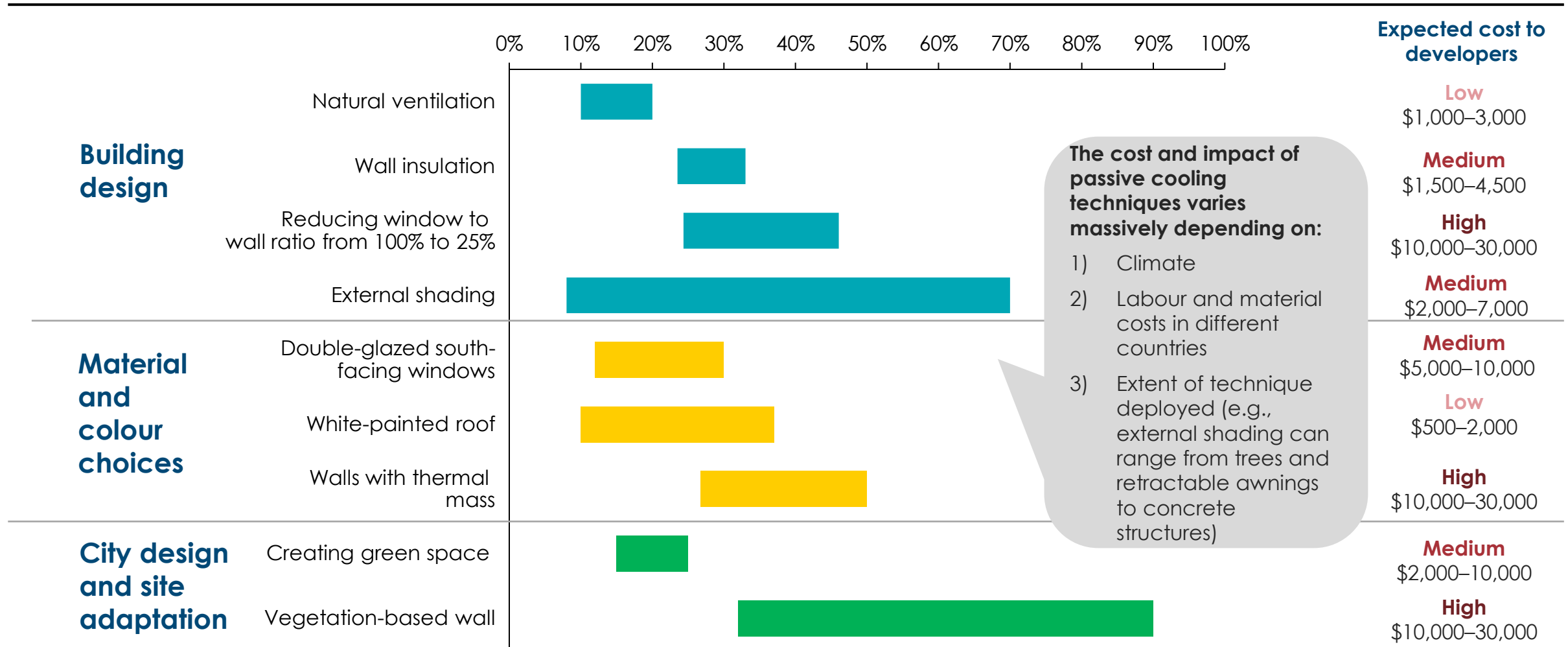
Source: IEA (2018), *The Future of Cooling*.
 Note: SEER is calculated by cooling output divided by energy input over a typical cooling season.



Passive techniques can reduce cooling energy consumption in buildings by 25–40% on average and many of these are very low-cost, such as painting roofs white and planting trees

Impact on annual cooling energy consumption of passive cooling techniques

%



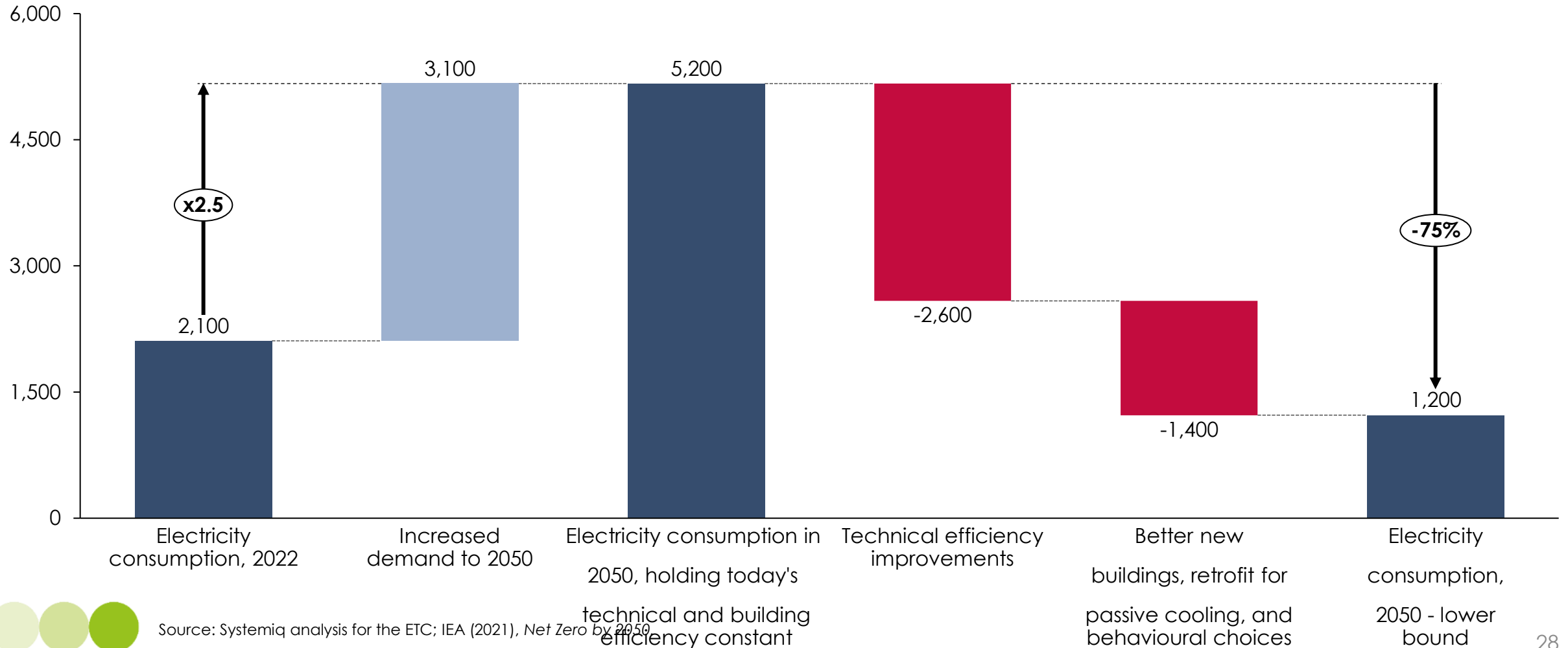
Note: IRR analysis assumes a discount rate of 5% over 50 years. Based on an average single-family flat/house of 60–80 m².

Source: Systemiq analysis for the ETC; Ahmed et al. (2023), *The impact of window orientation, glazing, and window-to-wall ratio on the heating and cooling energy of an office building: The case of hot and semi-arid climate*; Song et al. (2021), *A review on conventional passive cooling methods applicable to arid and warm climates considering economic cost and efficiency analysis in resource-based cities*.

Improving the technical efficiency of AC and deploying passive cooling techniques in new buildings could more than offset the increase in electricity demand - but relies on strong policies

Global electricity consumption from cooling, 2020 to 2050

Annual TWh



Source: Systemiq analysis for the ETC; IEA (2021), Net Zero by 2050

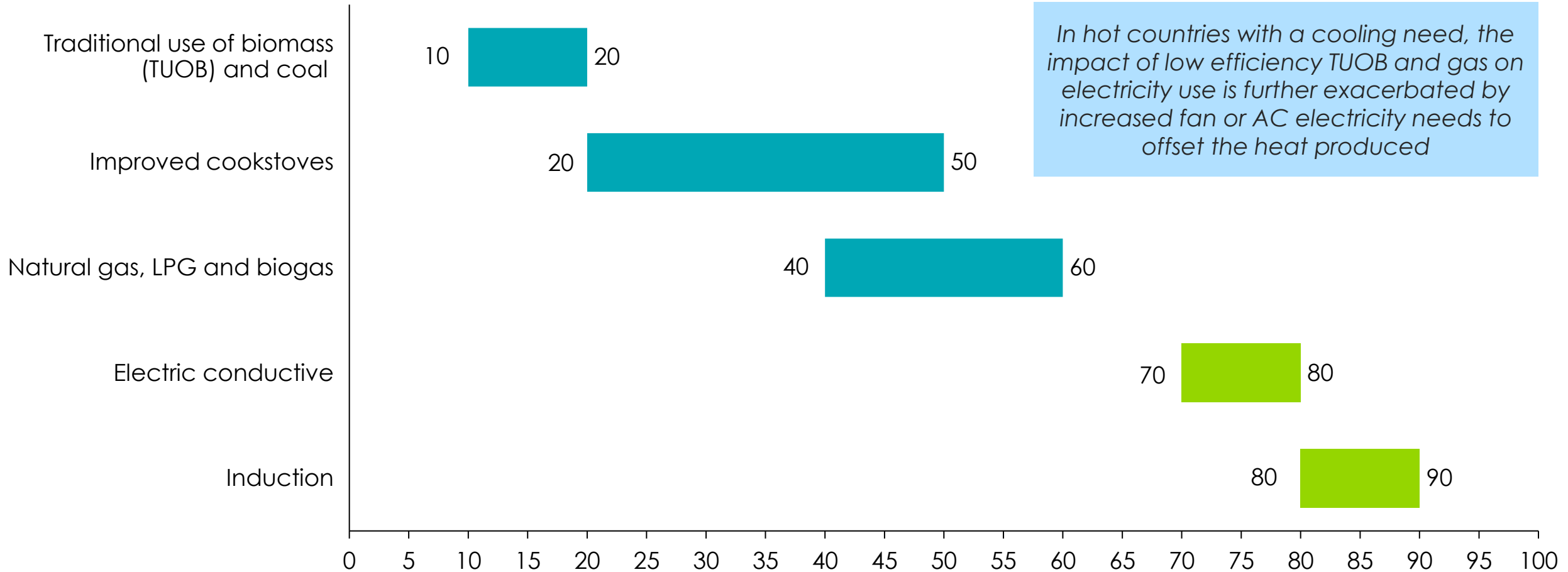
Cooking



High-carbon cooking fuels are also the least efficient; electric induction hobs are by far the most efficient cooking technology

Energy efficiency of cooking fuels and technologies

%

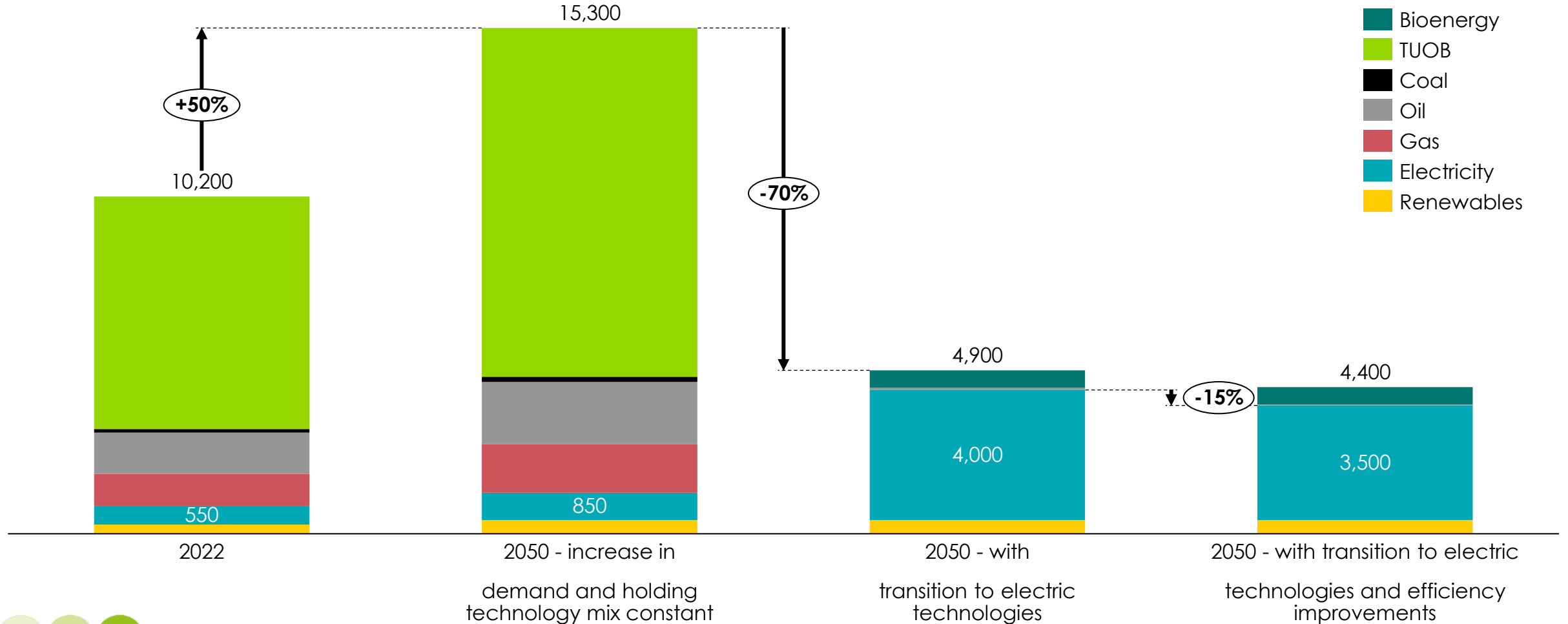


Note: LPG = Liquefied petroleum gas.
Source: Systemiq analysis for the ETC; IEA (2023), *A Vision for Clean Cooking Access for All*.

The transition from inefficient biomass to electric cooking will more than halve final energy demand for cooking, but this could increase electricity demand 7-fold relative to today

Global cooking energy demand by fuel, 2022 and 2050

TWh



Note: TUOB = Traditional use of biomass.
Source: Systemiq analysis for the ETC; IEA (2023), *A Vision for Clean Cooking for All*.

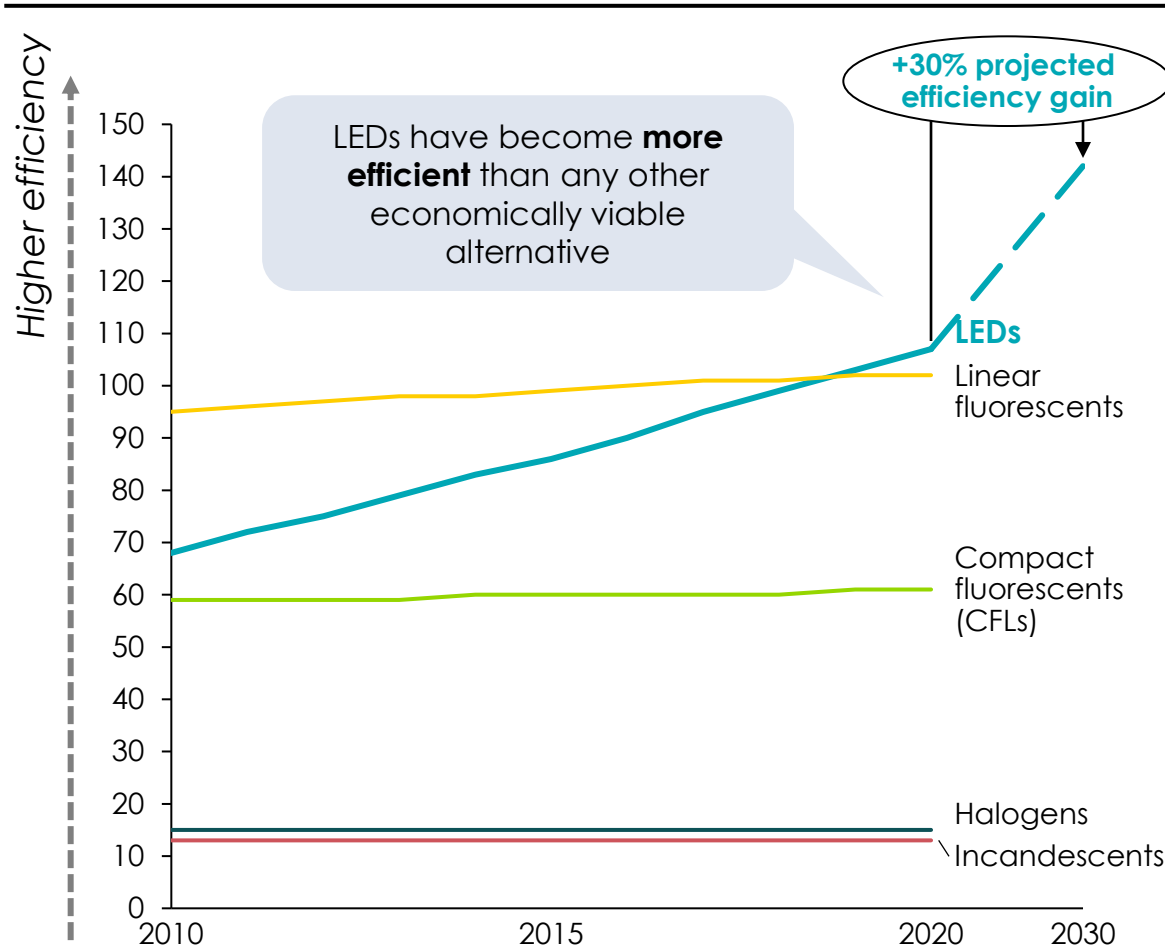
Lighting and appliances



LEDs are the leading lighting technology, but only account for half of global sales; with well-designed policies and incentives, this could be 100% by 2030

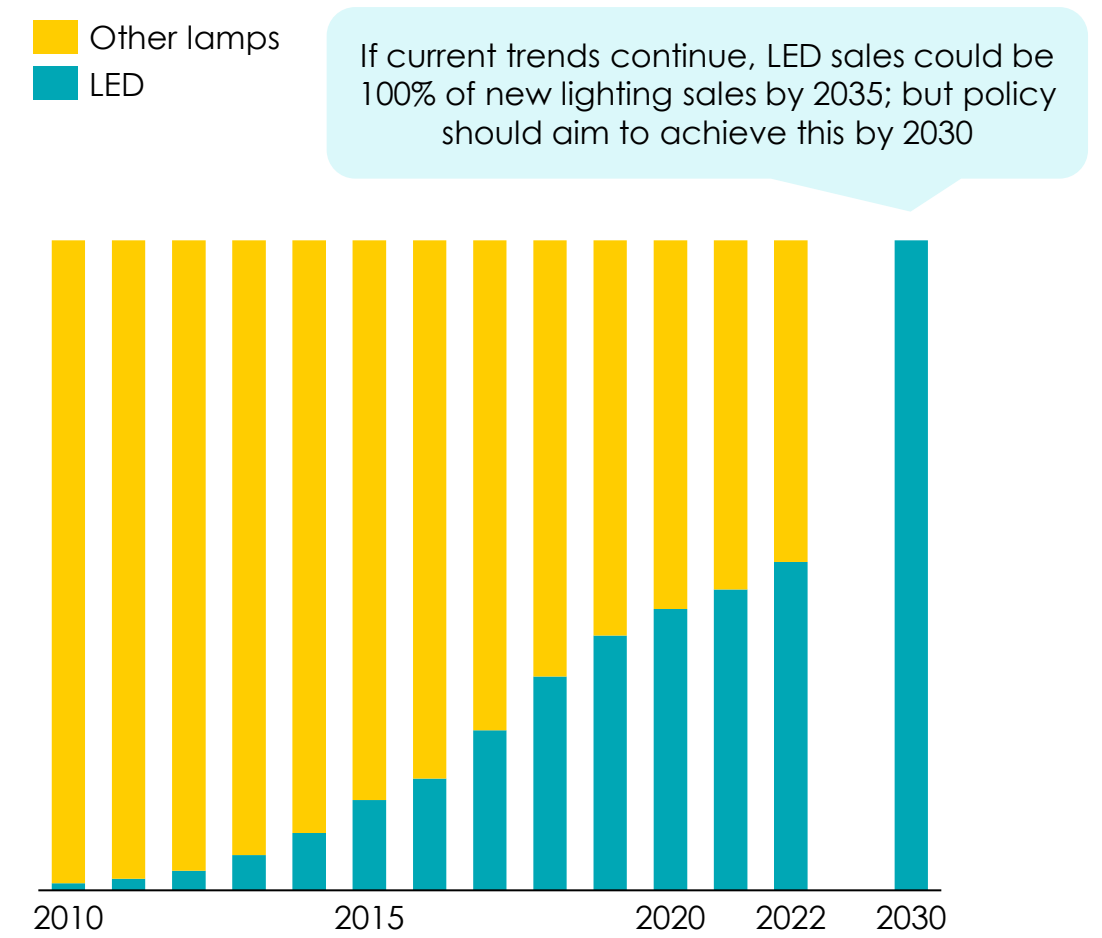
Global lighting efficacies

Lumens per Watt



Global residential lighting sales share by technology

Proportion of sales (%)

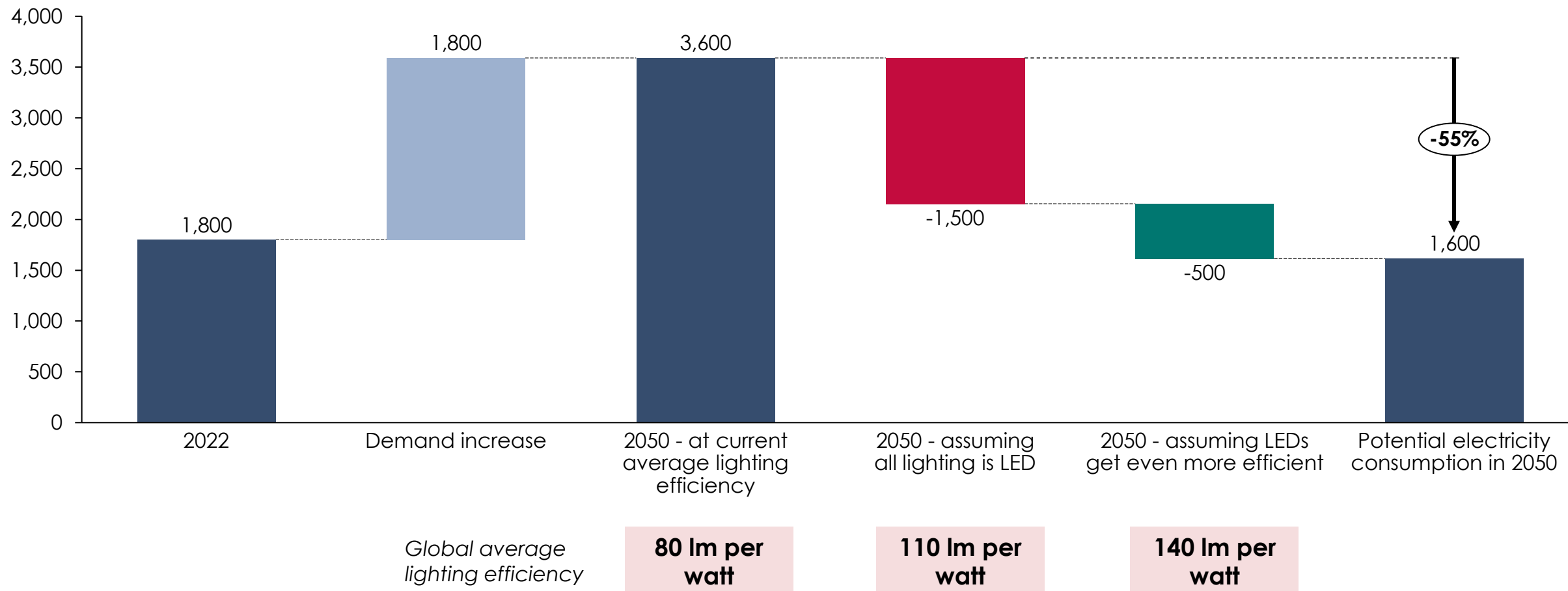


Note: Efficacy is a measure of how much light is produced (lumens) compared to the electricity put in (watts).
 Source: IEA 2023; Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030, <https://www.iea.org/data-and-statistics/charts/global-residential-lighting-sales-share-by-technology-in-the-net-zero-scenario-2010-2030>, re-used under license: CC BY 4.0; IEA 2023; Lighting efficacy by technology in the Net Zero Scenario, 2010-2030, <https://www.iea.org/data-and-statistics/charts/lighting-efficacy>, re-used under license: CC BY 4.0.

With regulation to phase out inefficient non-LED lightbulbs and continued improvements to LEDs, efficiency improvements could more than offset the rise in demand for lighting

Global annual lighting electricity consumption, 2022 to 2050

Annual TWh



Note: Lm per watt (lumens per watt) is a measure of how much light is emitted per watt of energy used.
 Source: Systemiq analysis for ETC; IEA (2023), *Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030*; IEA (2023), *Lighting efficacy by technology in the Net Zero Scenario, 2010-2030*; IEA (2021), *Net Zero by 2050*.



Commercial buildings

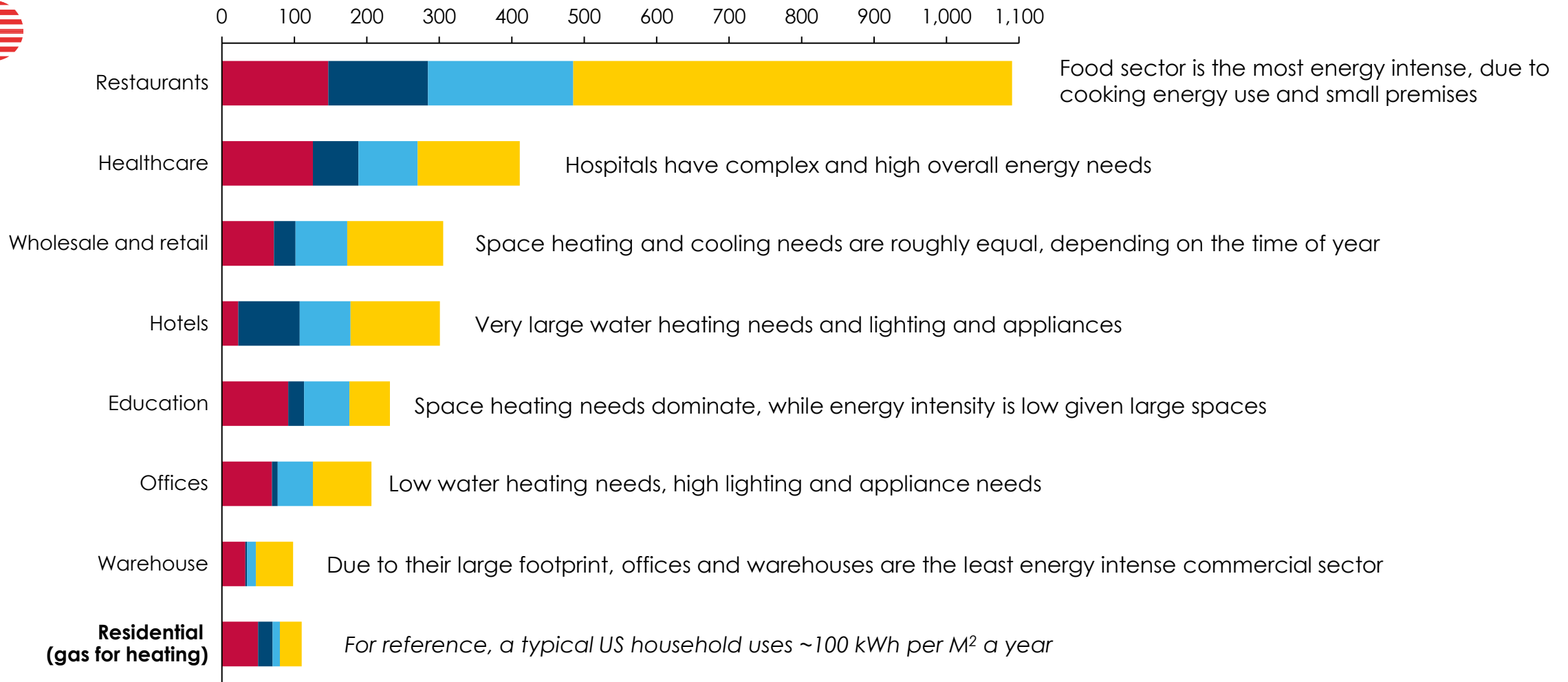


Energy needs vary significantly across different types of commercial building meaning there is no one-size-fits-all decarbonisation pathway

Energy intensity by subsector and energy end-use in the US, 2018

kWh per M² per year

Space heating Water Heating Space cooling Cooking, lighting, appliances



Source: US Energy Information Administration (2018), Commercial Buildings Energy Consumption Survey 2018.



The opportunity to decarbonise commercial buildings faster than residential buildings

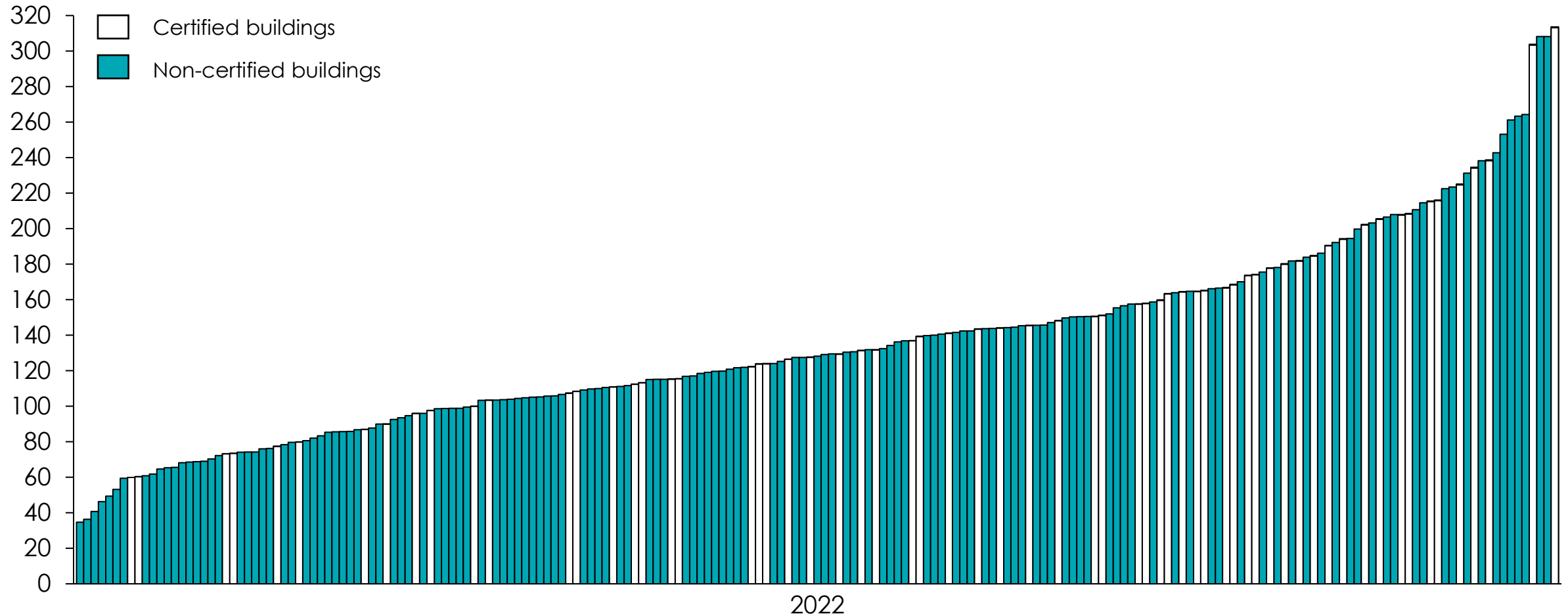
1. **Ambition:** There is a strong case for high-income countries to set earlier targets for the transition away from fossil fuel heating in commercial buildings than residential. This could involve immediate bans on the installation of gas or oil boilers in new commercial buildings, and by 2030 in existing buildings.
2. **Regulation:** There is a clear opportunity for more ambitious and better designed regulation to increase the energy efficiency of new commercial buildings and to require energy efficiency improvements at points of retrofit. This requires addressing the deficiencies of many existing building regulations which are often not based on quantitative measures of building energy performance (e.g., energy use per m²).
3. **Voluntary action:** Alongside strong regulation, voluntary commitments and market incentives can play a greater role in commercial buildings than in residential. This reflects the facts that:
 - There are cost savings and revenue streams associated with more efficient and flexible buildings.
 - Commercial building owners need to de-risk their assets against future carbon and energy regulation; the expectation of future regulation or carbon pricing can therefore drive voluntary action today.
 - Some major commercial businesses, investors and building owners will have their own net-zero and financed emissions commitments.



There is currently no correlation between green building certifications and energy performance of commercial buildings

Energy use intensity of office buildings in Europe and the United States, by green building certification status

kWh per M² per year



Source: LOTUF (2024), *Seeing is Believing: Unlocking the low-carbon real estate market*.



Refrigerant leakage



There are two ways to reduce harmful refrigerant emissions – a) reduce how much refrigerant is released into the atmosphere, and b) transition to low GWP refrigerant

What are refrigerants?

Found in AC and heat pumps, refrigerants contribute to climate change if leaked and/or vented. Refrigerants differ in their global warming potential (GWP):

HFCs (Hydrofluorocarbons)

Most commonly used	GWP
R-134a	1430
R410a	2088
R-32	675

Low-GWP HFOs (Hydrofluoroolefins)

Alternatives to HFCs	GWP
R1234ze	7

Natural Refrigerants

Emerging solutions	GWP
CO ₂	1
Propane	3
Ammonia	0

Industry transition



Driven by the 2016 global Kigali Agreement to phase out high GWP HFCs

What is the challenge with refrigerants?

Leakage

A small amount of refrigerant typically escapes from AC and heat pump systems through leaks or improper handling.

2–5%
a year

Key risk factors include:

- Older or poor quality equipment
- Poor quality of installation
- Lack of maintenance

Venting

Refrigerant is often intentionally released into the atmosphere during servicing and at end-of-life.

90%+
of refrigerant at end of life

Key risk factors include:

- Improper servicing practice
- Lack of training and awareness of technicians
- Improper disposal

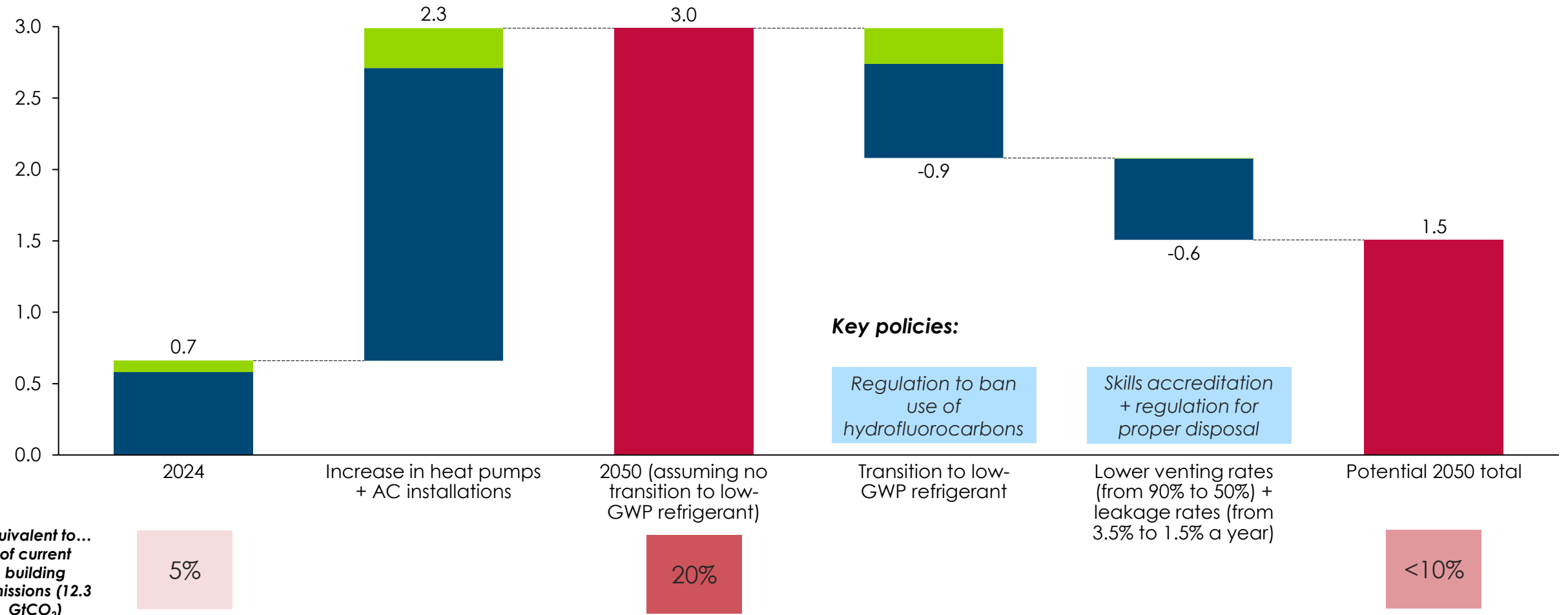
Note: Global Warming Potential (GWP) – global warming impact relative to the impact of the same quantity of CO₂ over a 100-year period.
Source: IEA (2023), *Energy Technology Perspectives*; BSRIA (2020), *BSRIA's view on refrigerant trends in AC and Heat Pump segments*; Net Zero Carbon Guide, *Refrigerants and their Contribution to Global Warming*, available at www.netzerocarbonguide.co.uk/guide/designing-and-building/heating-your-building/refrigerants-and-their-contribution-to-global-warming. [Accessed 10/08/2024]; IEA (2018), *The Future of Cooling*; Carbon Containment Lab (2022), *Managing Refrigerants in a Warmer World*.

Emissions from refrigerant leakage and venting could reach 2 GtCO₂ in 2050, but could be 50% lower with regulation on proper disposal and a transition to low-GWP refrigerant

Scenarios of potential annual global emissions relating to refrigerant leakage and venting

GtCO₂e

■ AC ■ Heat pumps ■ 2050 total



Equivalent to... of current building emissions (12.3 GtCO₂)

5%

20%

<10%

Note: The figures are based on reasonable assumptions about how the type of refrigerant in the stock of ACs and heat pumps might change over time, and use the IEA's AC projections for 2050 and the ETC's estimates on heat pumps. Assumes an average of 10 lb refrigerant charge and a 15 year lifetime for equipment.

Source: Systemiq analysis for the ETC; BSRIA (2020), BSRIA's view on refrigerant trends in AC and Heat Pump segments; Net Zero Carbon Guide, Refrigerants and their Contribution to Global Warming, available at www.netzerocarbondesign.co.uk/guide/designing-and-building/heating-your-building/refrigerants-and-their-contribution-to-global-warming. [Accessed 10/08/2024]; IEA (2018), The Future of Cooling; UNEP Ozone Secretariat (2015), Fact sheets on HFCs and Low GWP Alternatives.

Flexible and efficient buildings

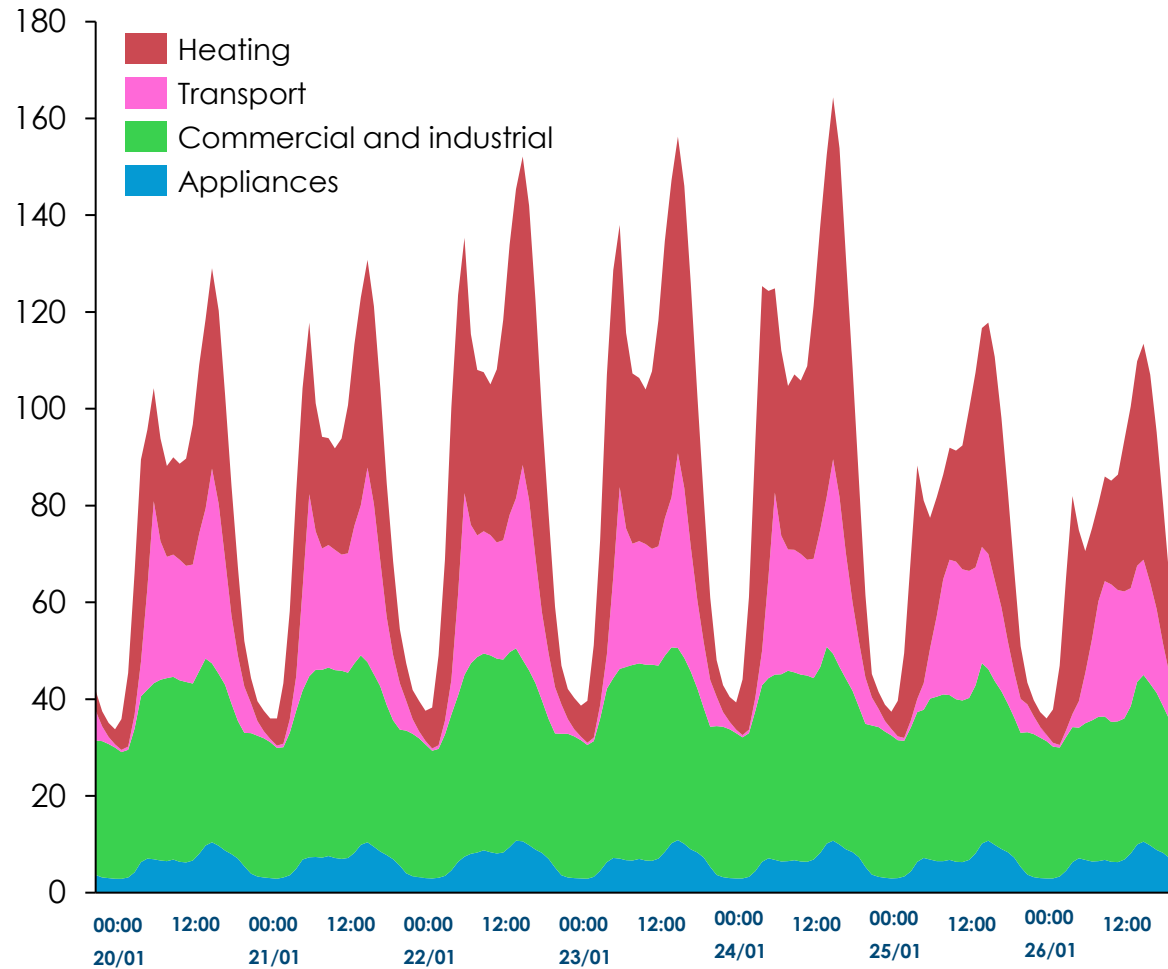


Heating needs peak in the evening and during the winter months in Northern latitude countries, while solar generation peaks in the middle of the day and during summer



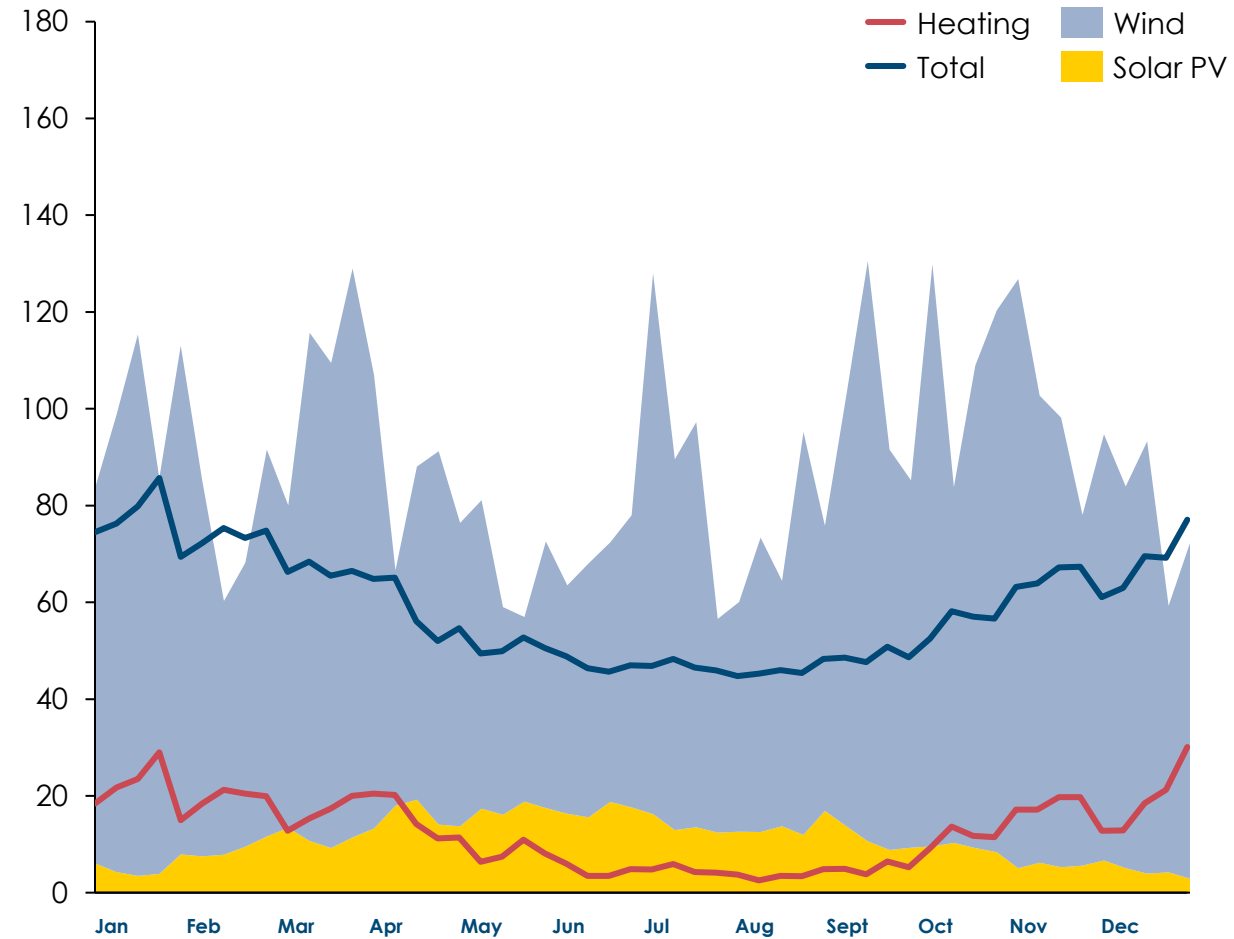
Hourly electricity demand, Great Britain, a week in January 2050

GW



Annual electricity demand and renewable supply, Great Britain, 2050

GW, averages over a week



Note: Scenario assumes installed capacity of 75GW of solar, 60GW of onshore wind, and 100GW of offshore wind, and minimum weather years out of the past 30 years (2010). Assumes a highly electrified economy, across residential, commercial and industrial sectors; excludes electricity load from storage and electrolyzers; does not assume significant demand-side flexibility. Projections (LHS) for 20/02/2050 – 26/02/2050.

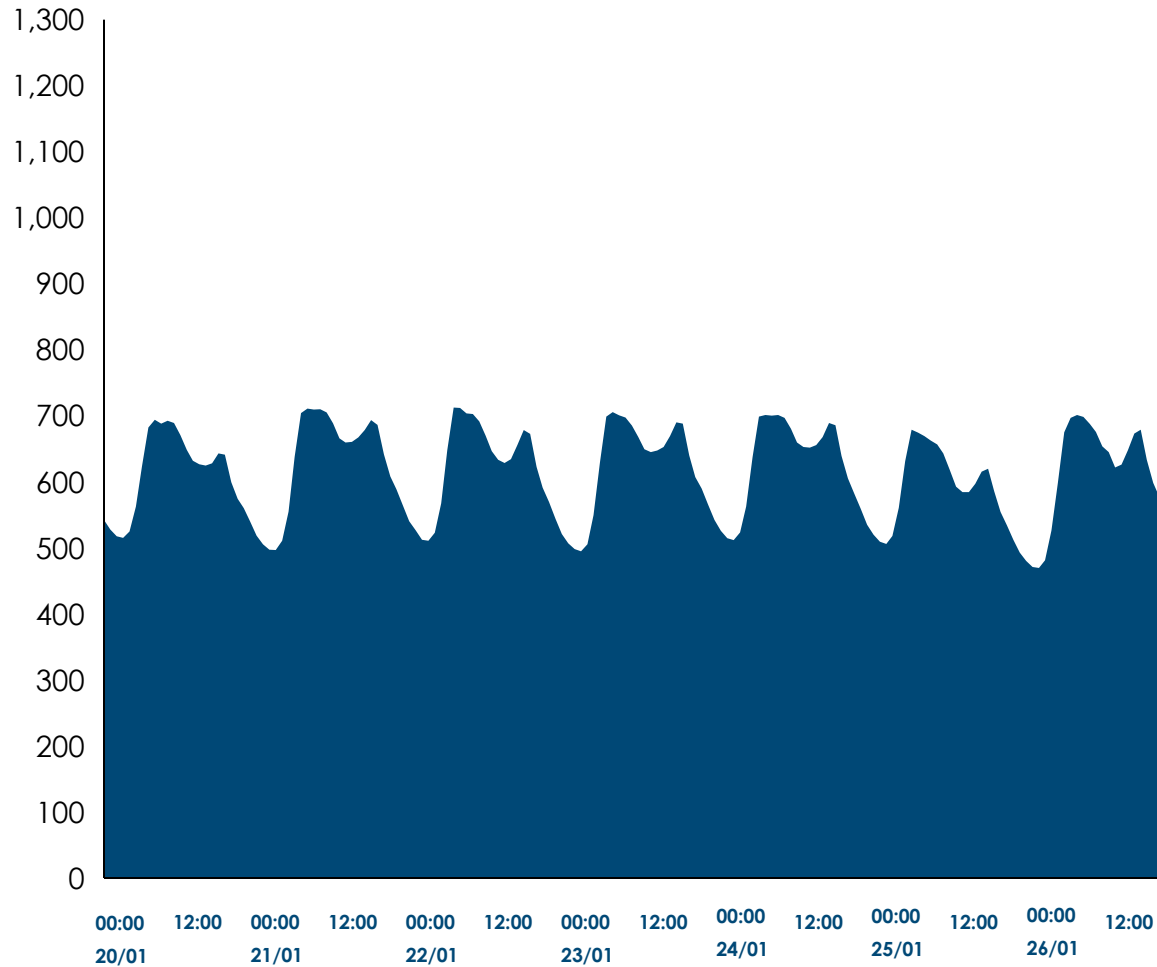
Source: Systemiq analysis for the ETC; NESO (2022), *Future Energy Scenarios 2022*.

Cooling needs tend to peak in the middle of the day and nighttime; AC is required all year round, but solar generation falls significantly during the Monsoon months



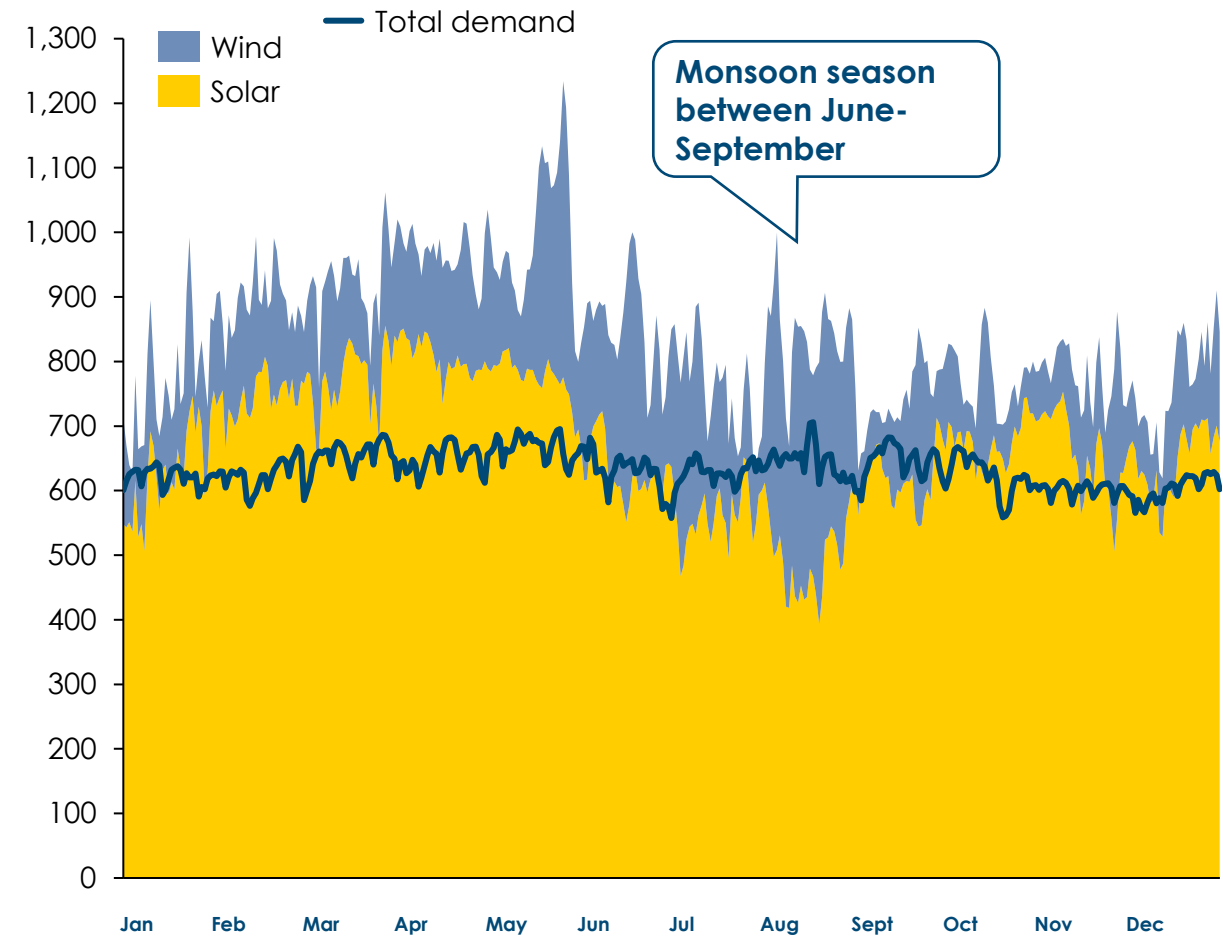
Hourly electricity demand, India, a week in January 2050

GW



Daily electricity demand and renewable supply, India, 2050

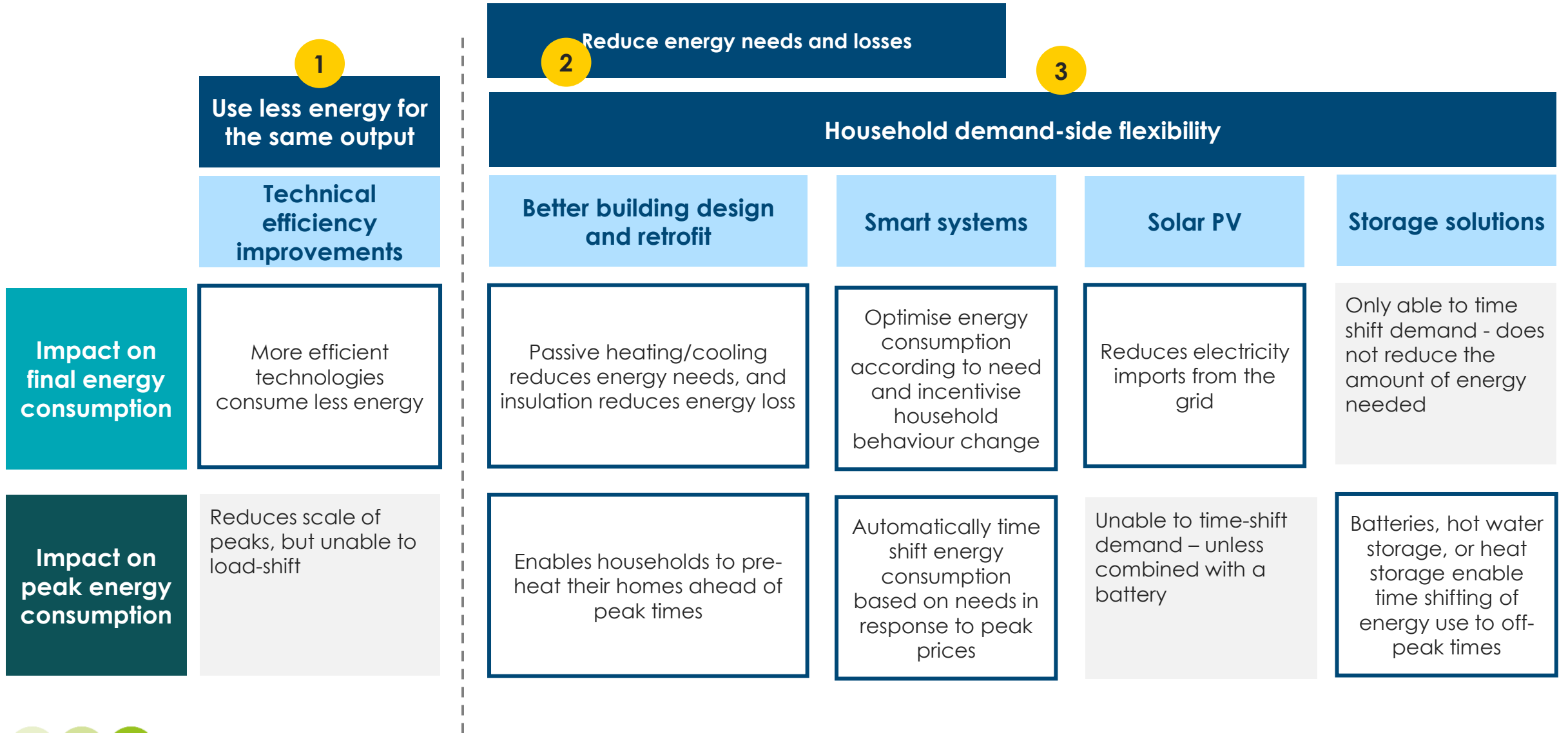
GW, averages over a week



Notes: Scenario assumes installed capacity of 2,750GW of solar, 650GW of onshore wind, and 80GW of offshore wind, and minimum weather years out of the past 30 years (2010). Assumes a highly electrified economy, with annual demand of 5,550 TWh.

Source: Systemiq analysis for the ETC; TERI (2024), *India's Electricity Transition Pathways to 2050*.

Creating efficient and flexible buildings will play a key part of managing household electricity demand in an energy system of variable renewables

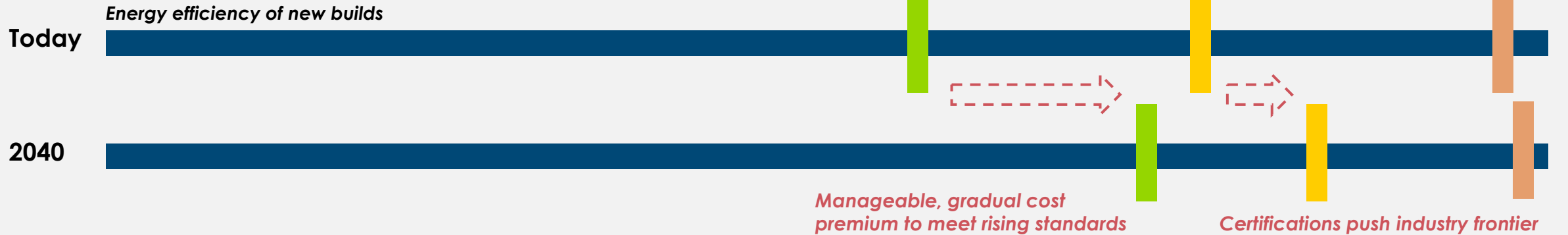


Source: Systemiq analysis for the ETC.

Building codes should move towards certification level over time, driving the industry frontier forward, while the Passive House standard defines the technical potential

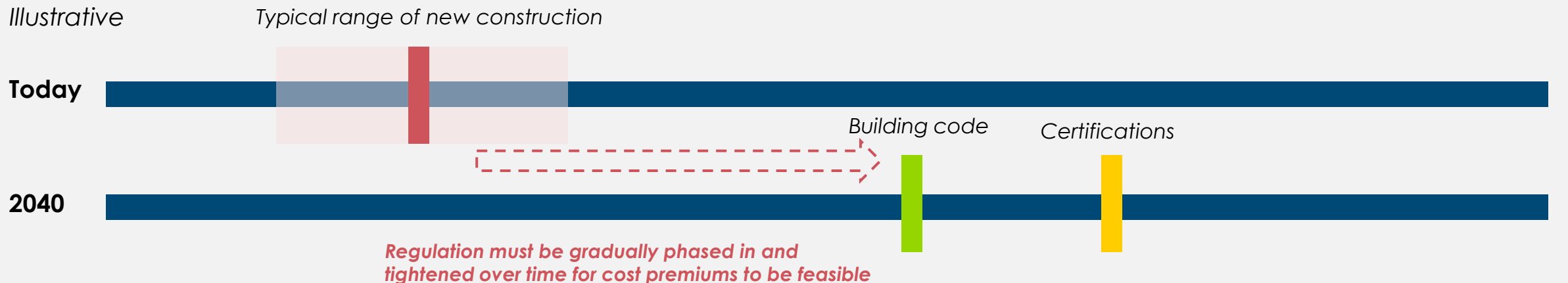
Country with long established building energy codes

Illustrative



Country with no established building energy codes

Illustrative

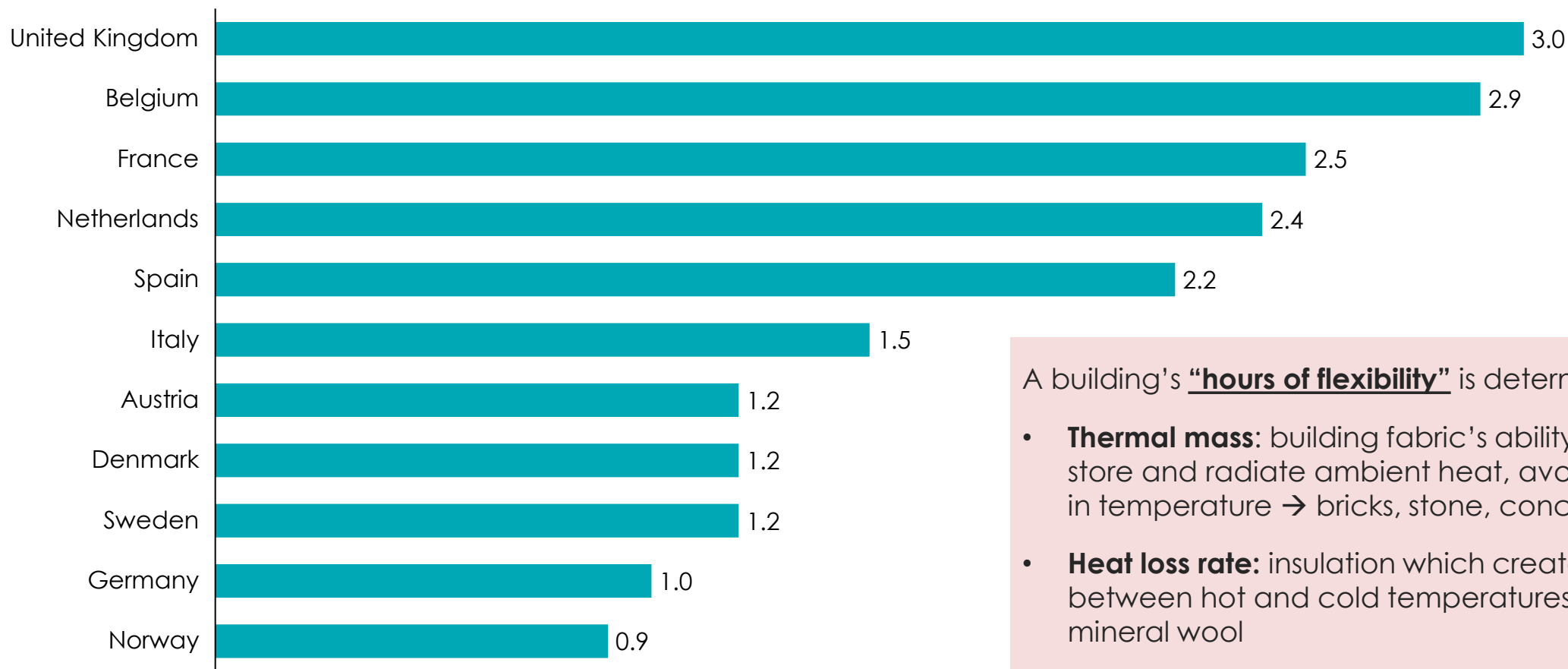


Source: Systemiq analysis for the ETC.

Homes vary significantly in terms of their ability to retain heat, with big implications for the ability of households to “pre-heat” their homes ahead of peak needs

Home temperature loss after 5 hours

°C



A building's “**hours of flexibility**” is determined by its:

- **Thermal mass:** building fabric's ability to slowly absorb, store and radiate ambient heat, avoiding sudden spikes in temperature → bricks, stone, concrete
- **Heat loss rate:** insulation which creates a barrier between hot and cold temperatures → fibreglass, foam, mineral wool

Note: Tested in 2019/20 with a temperature of 20°C inside and 0°C outside.

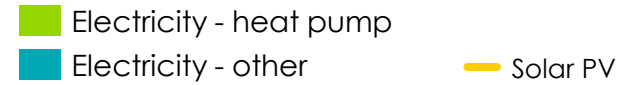
Source: Tado, UK homes lose heat up to three times faster than European neighbours, Available at www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours. [Accessed 01/08/2024].



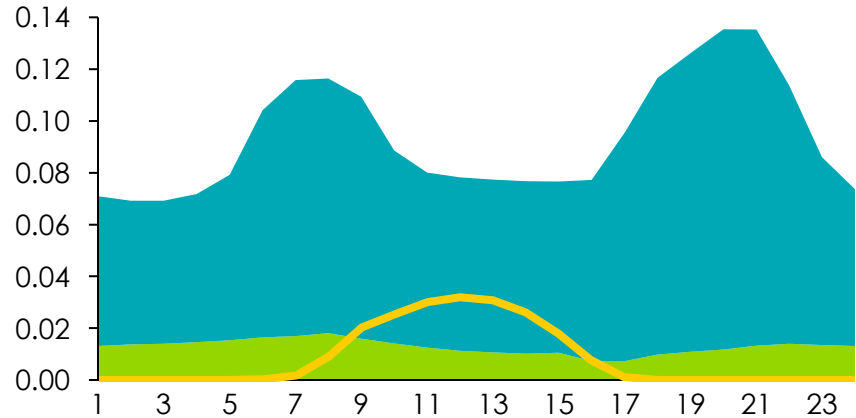
Rooftop solar PV will be a key solution in commercial buildings with large roof space relative to floor space (e.g., warehouses)

Average hourly winter energy use, by commercial building – Europe

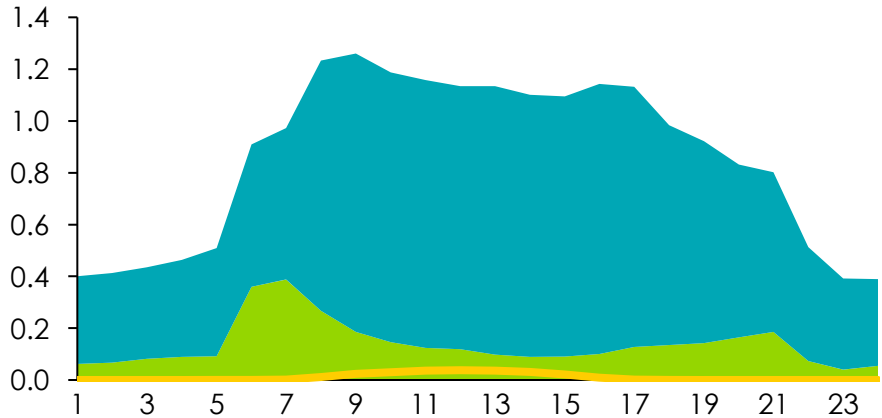
kWh



Small hotel – roof space: 1,000 M², 4 floors



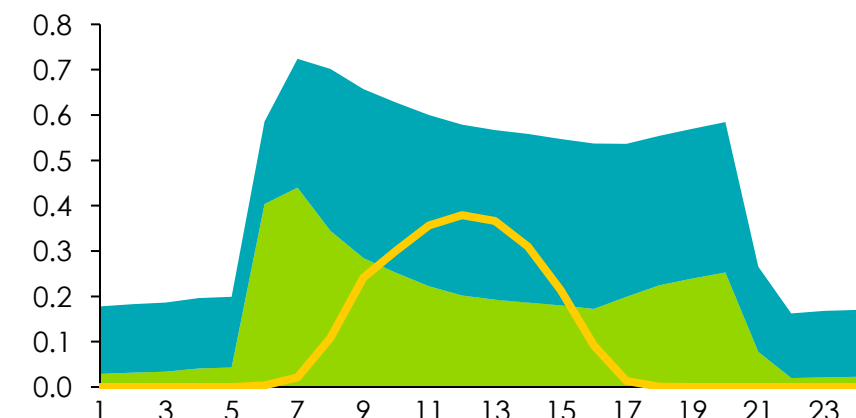
Large office – roof space: 3,500 M², 12 floors



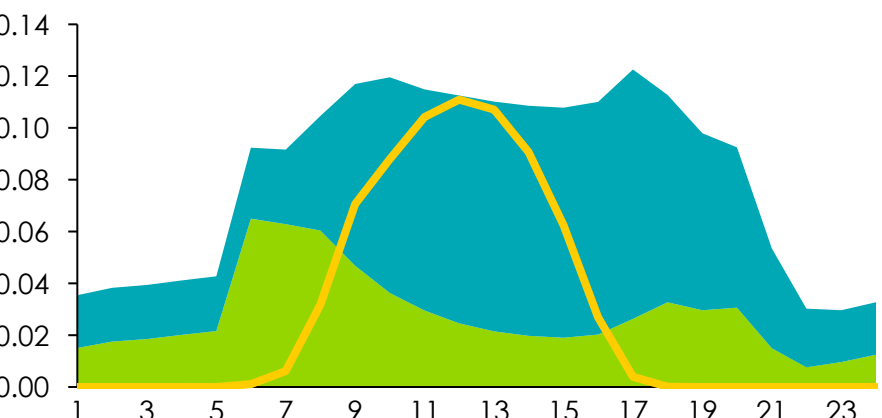
Less likely to install solar PV

- Small roofs relative to floor space (roof : floor ratio <20%)
- Roof space further limited by HVAC equipment
- Solar PV can meet:
 - ~10% of needs in small hotel
 - ~1% of needs in large office

Secondary school – roof space: 12,000 M², 2 floors



Warehouse – roof space: 2,100 M², 1 floor



Highly likely to install solar PV

- Warehouses have a 100% roof to floor ratio
- Solar PV can meet:
 - 25% of needs in secondary school
 - 35% of needs in warehouse

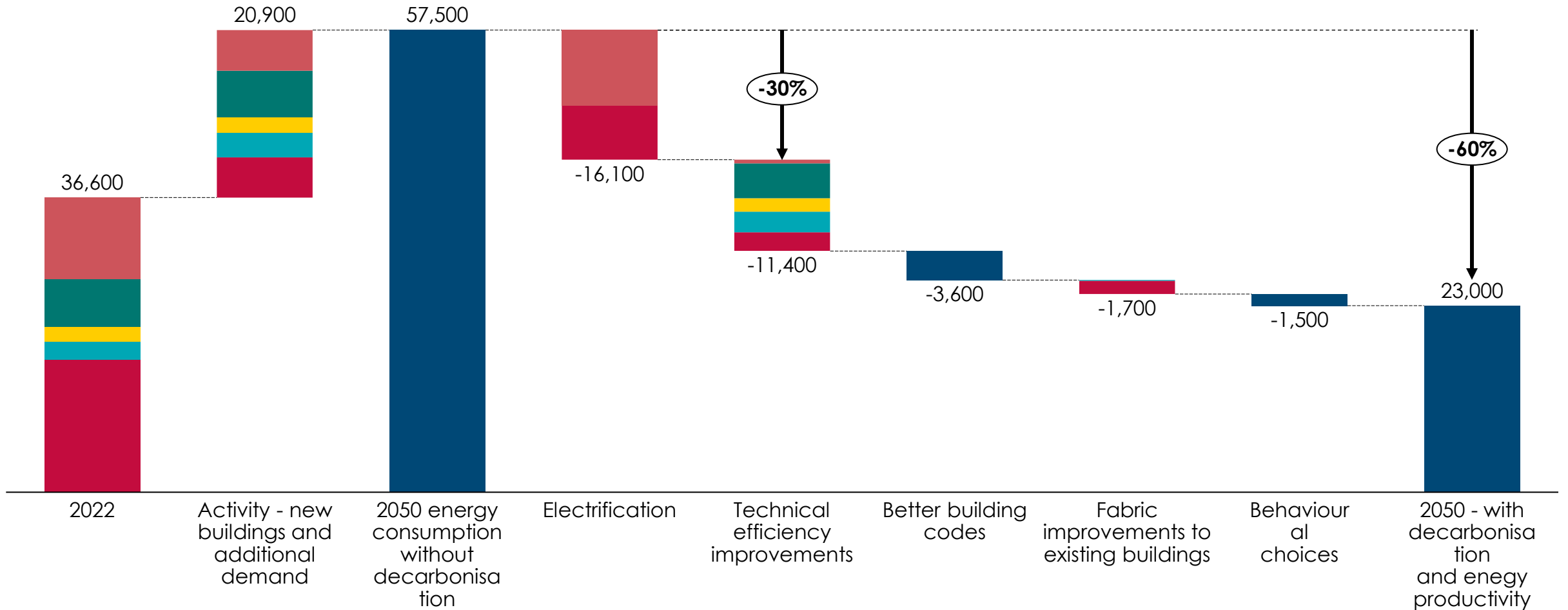


Note: Winter is defined as November to February.
Source: Systemiq analysis for the ETC; Schneider Electric Sustainability Research Institute.

Electrification, technical efficiency gains, and improving building fabric could reduce final energy demand by 60%

Impact of energy productivity on final energy demand in 2050 – residential + commercial buildings

TWh



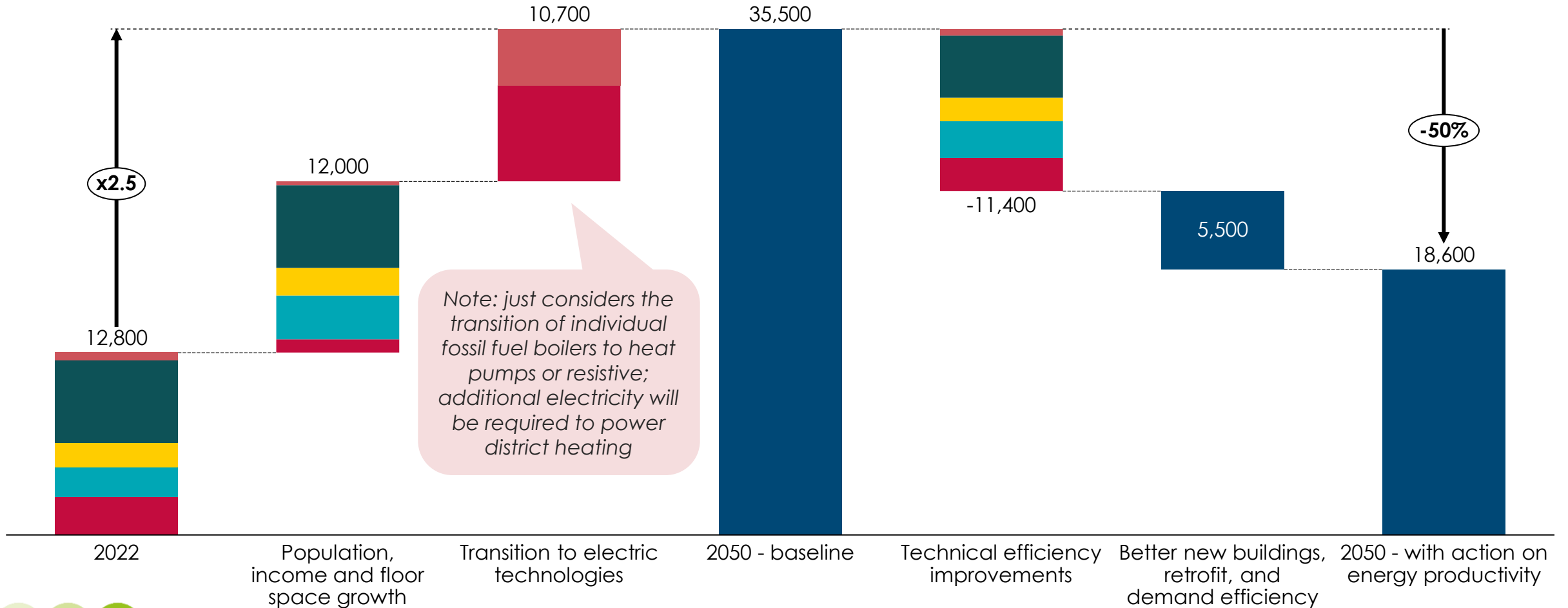
Note: The increase in activity to 2050 includes both an increase in fossil fuel energy use (e.g., new fossil fuel boilers and cookers largely in lower-income countries) and new electric heating and cooking appliances, largely in high-income countries and China. The electrification lever then refers to the transition of the existing stock of fossil fuel heating and cooling to clean technologies.

Global buildings electricity demand could more than double by 2050 from 13,000 TWh to over 35,000 TWh – but strong action on energy efficiency could cut this in half to ~19,000 TWh

Electricity demand in 2050 and impact of efficiency levers – residential + commercial

TWh

- Heating
- Lighting
- Cooking
- Cooling
- Appliances
- Total building

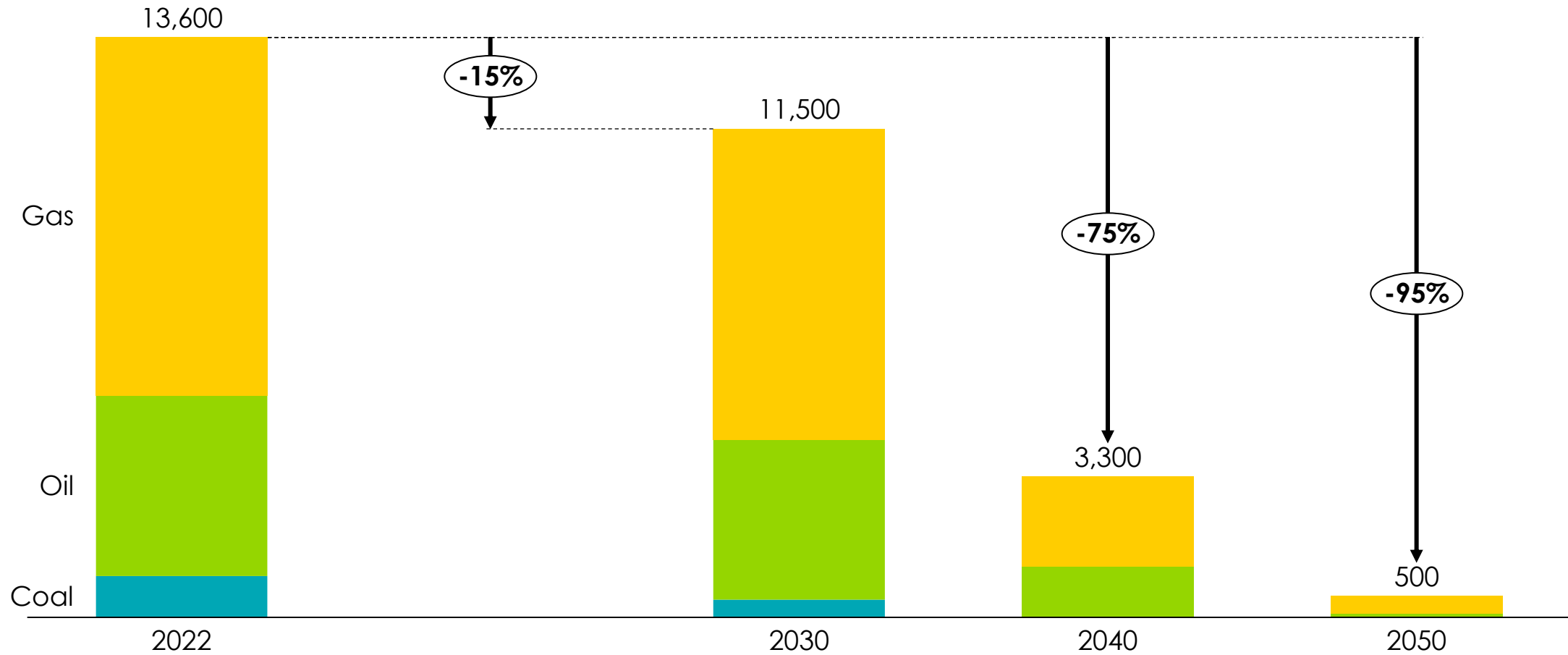


Source: Systemiq analysis for the ETC; IEA (2023), *World Energy Outlook 2023*; IEA (2021), *Net Zero by 2050*.

The direct use of fossil fuels in buildings could be virtually eliminated by 2050, with a reduction of 15% by 2030 and 75% by 2040 as heating and cooking electrify

Fossil fuel demand in buildings, projections to 2050

TWh



Section B: Embodied carbon

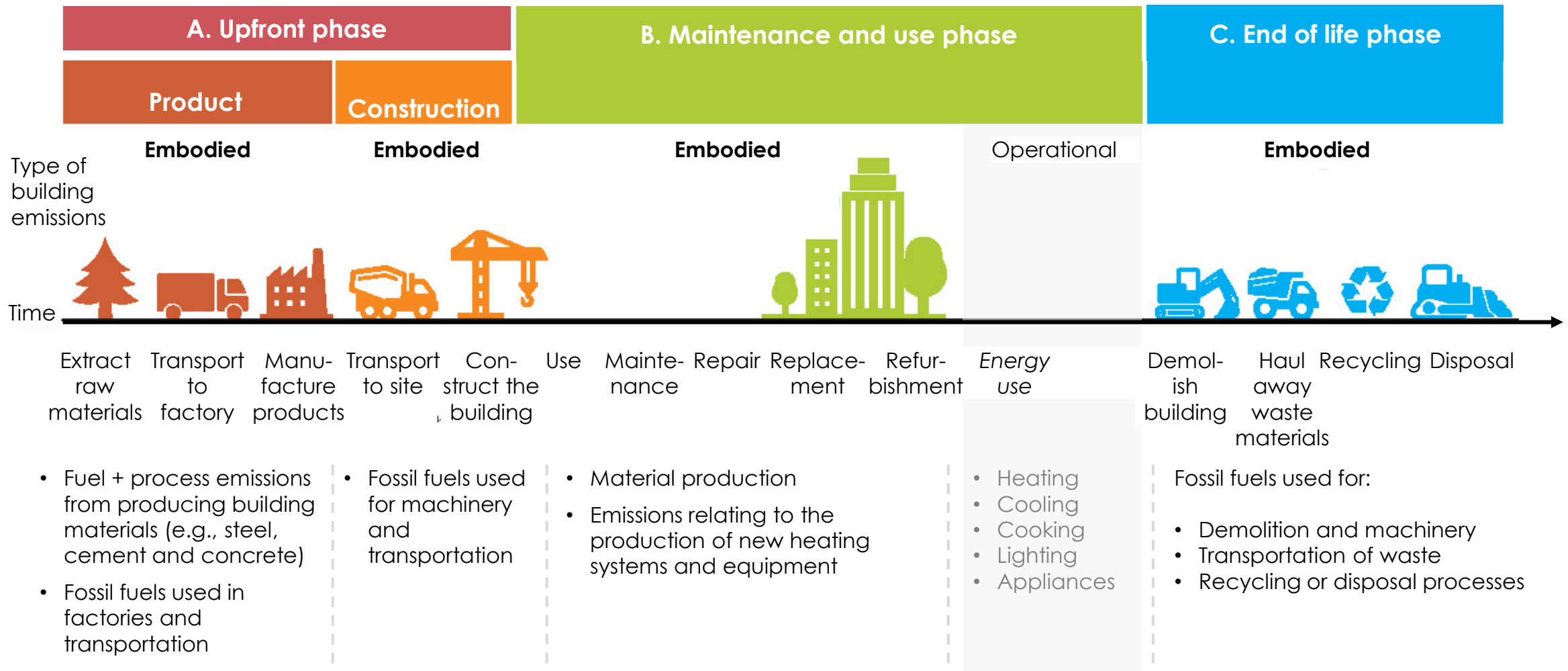


Understanding emissions across the building lifecycle



Embodied carbon refers to the emissions arising from the construction, maintenance and demolishing of buildings

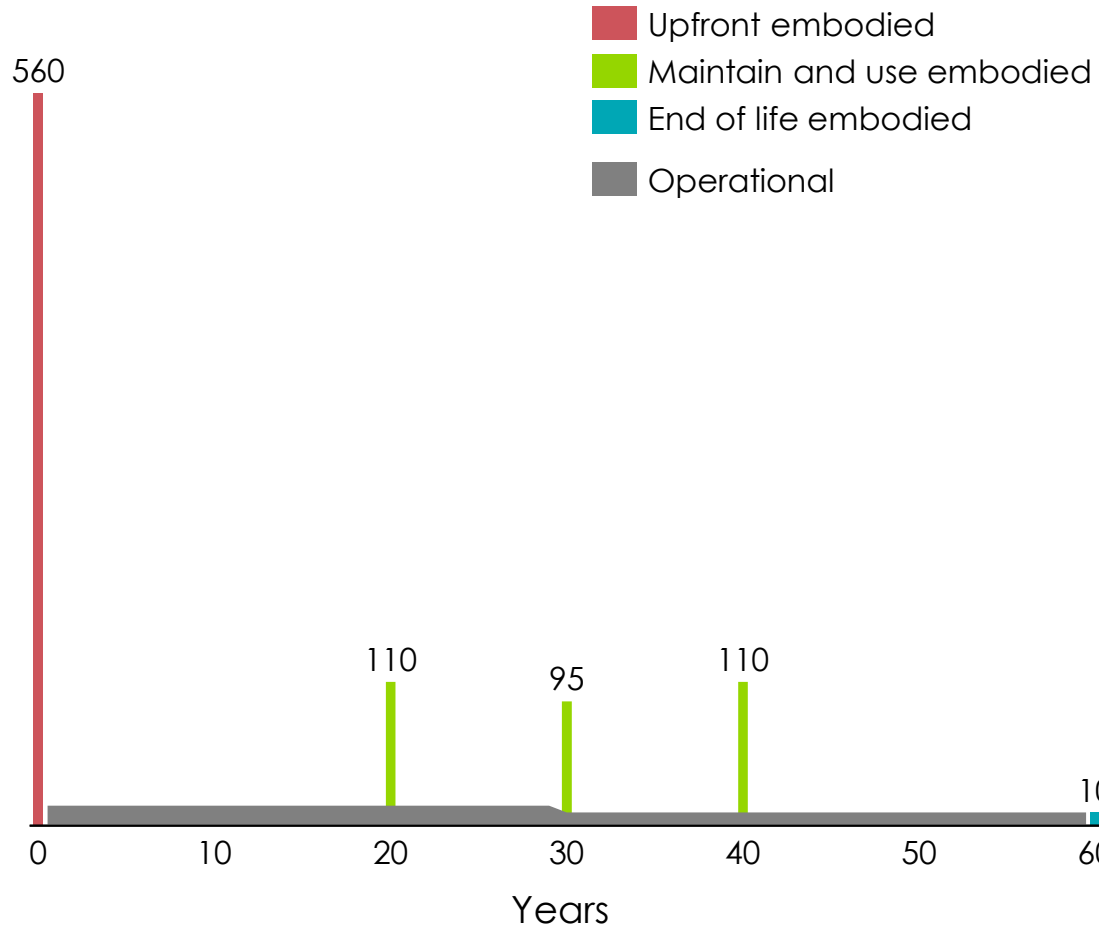
Sources of embodied and operational emissions across the building life cycle



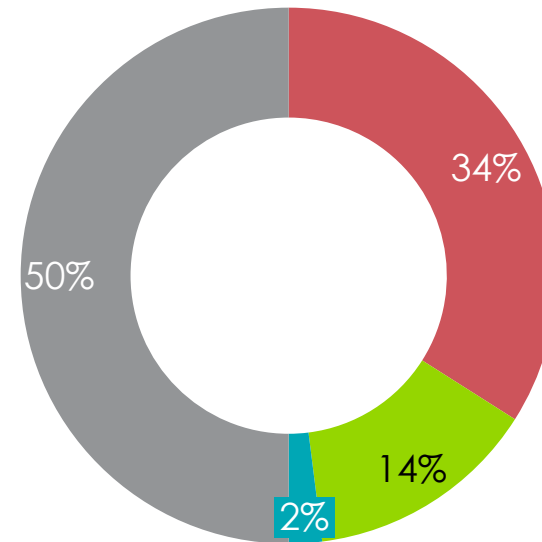
Embodied emissions are large, one-off bursts of emissions at a few points in a building's lifecycle; operational emissions occur every year a building is in operation

Whole life carbon emissions – Europe

kgCO₂e per m²



Share of total lifecycle emissions over 60 years



- There is a lack of data and **no consensus** on the level of embodied carbon emissions globally today
- European case studies suggest that embodied carbon accounts for **~50% of a building's lifecycle emissions** – but this can vary across countries depending on the carbon intensity of the grid, heating technology, and materials used
- The **vast majority** of embodied carbon emissions are in the **upfront stages (product + construction)**



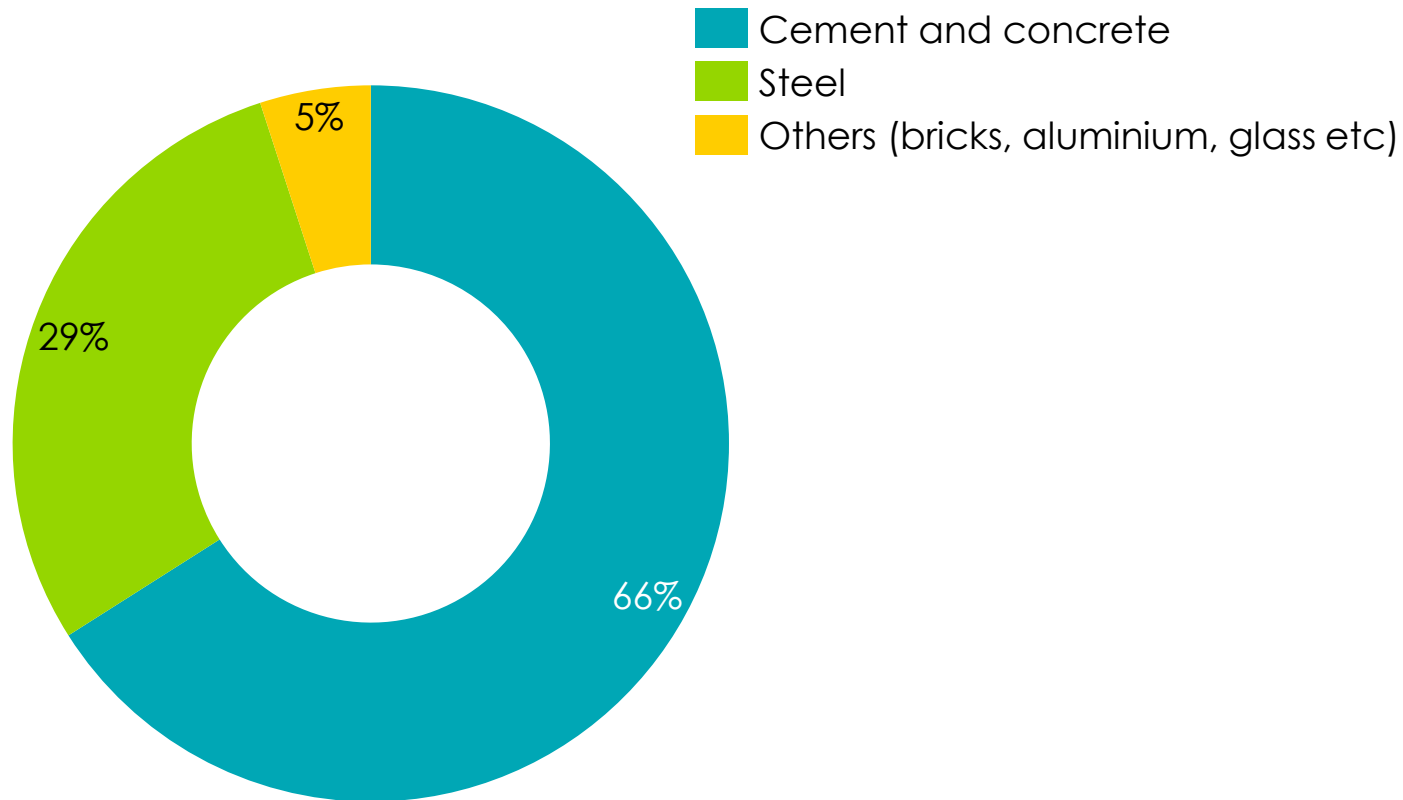
Note: Based on an assessment of six buildings in Europe.

Source: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*; RMI (2023), *Embodied Carbon 101: Building Materials*.

Cement, concrete and steel account for 95% of embodied emissions relating to material production

Cement and steel contribution to global construction material carbon impact

% of total



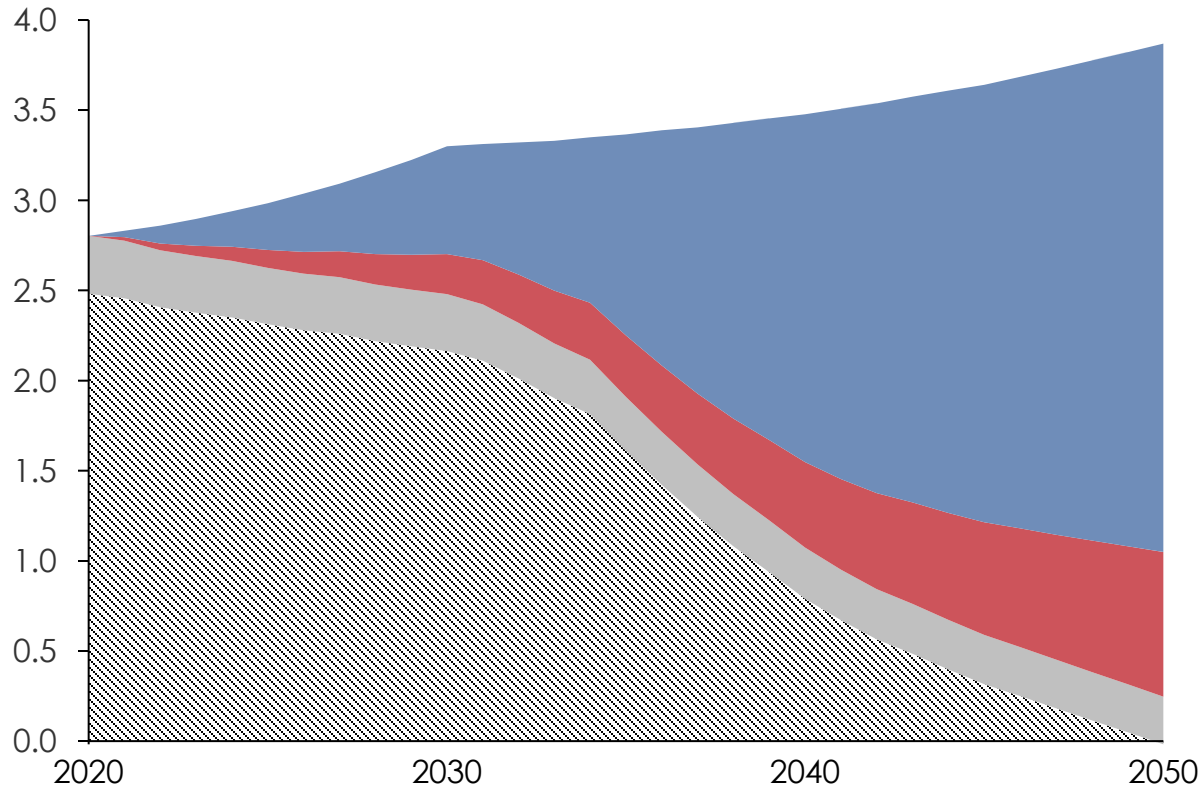
Source: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

Addressing process and production emissions will have the biggest impact on embodied carbon, but reducing material demand is also critical to achieve net-zero by 2050

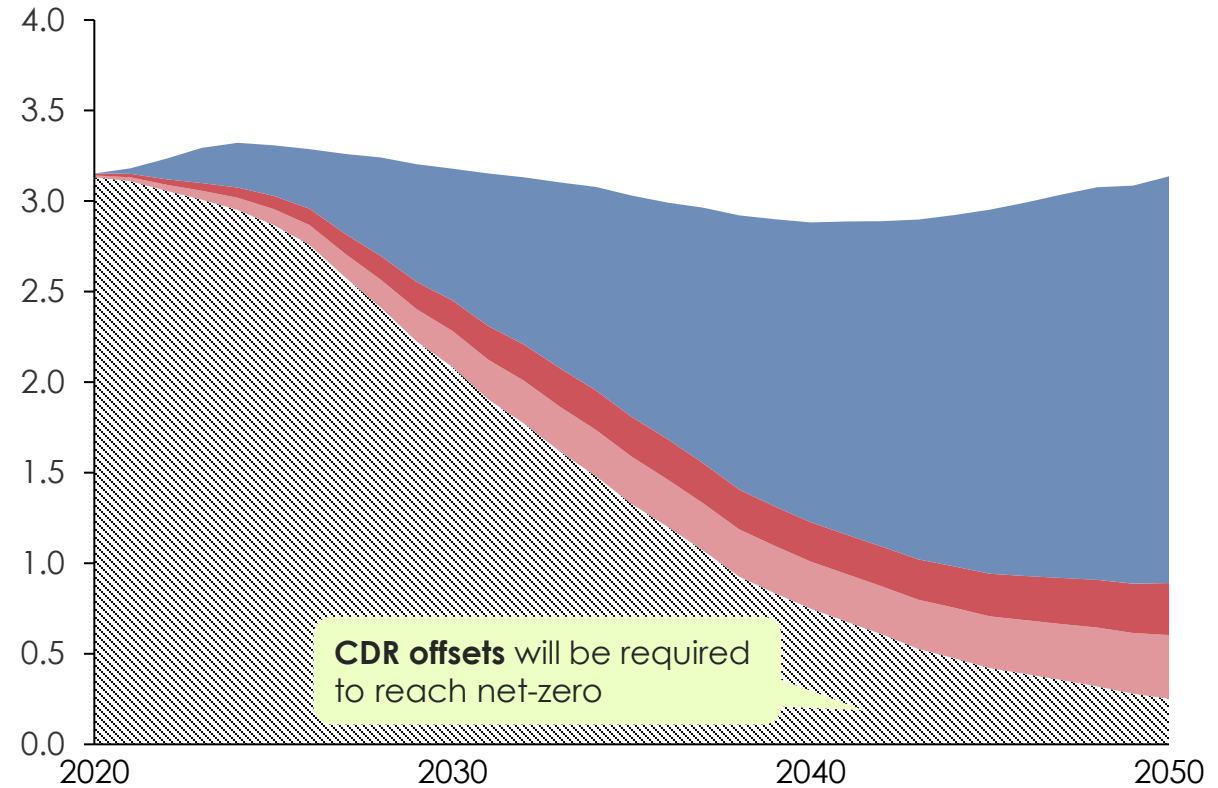
1.5°C aligned pathways to net-zero
GtCO₂ per year

■ Low-carbon technologies ■ Demand efficiency (other industries)
■ Demand efficiency levers (construction) ▨ Unabated emissions

Cement and concrete



Steel



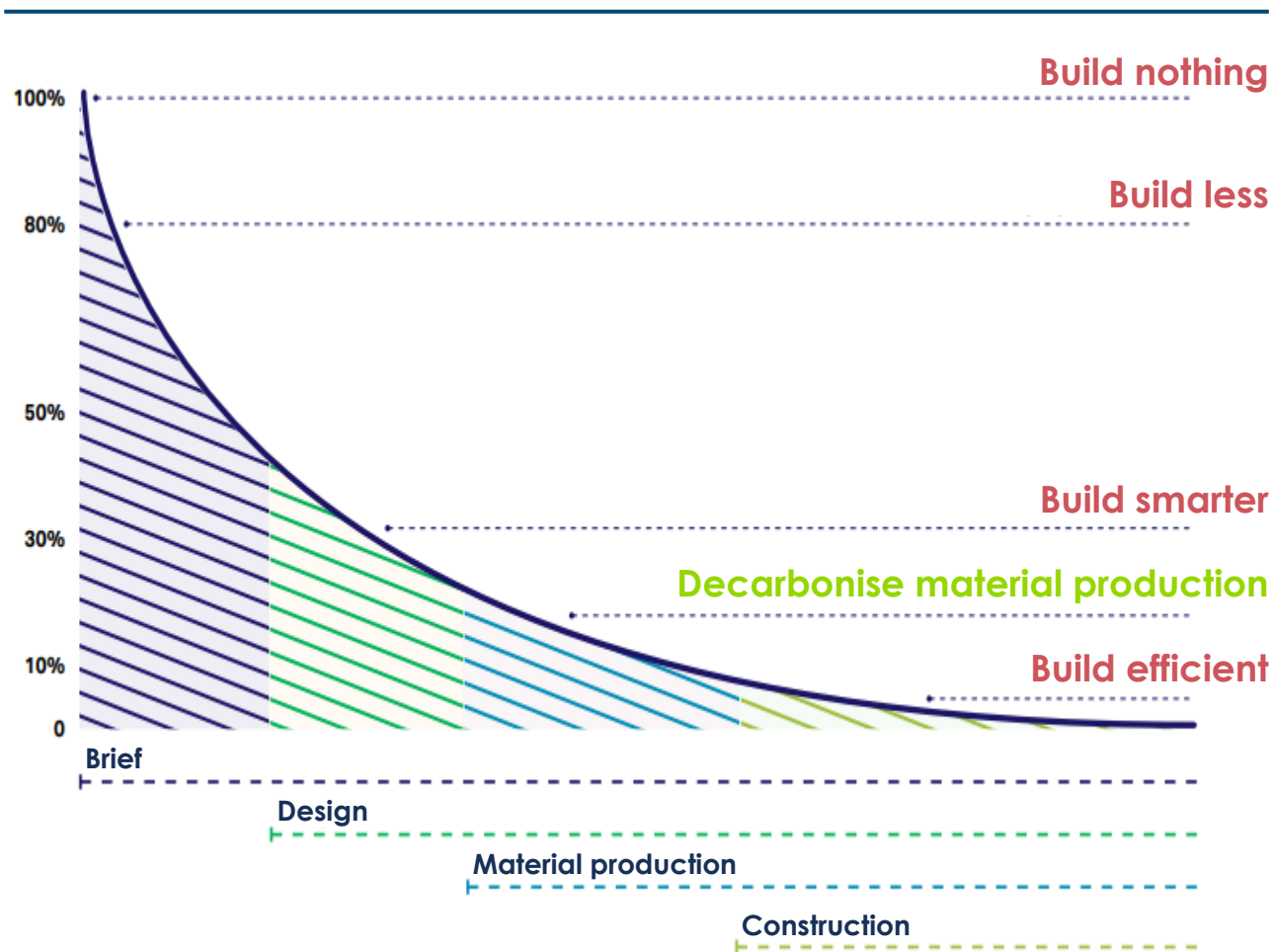
Note: Demand efficiency refers to strategies which reduce the demand for high-carbon cement, concrete and steel, for example through building design strategies which reduce material efficiency, substituting for lower-carbon materials such as timber and hempcrete, and building less.

Source: Systemiq analysis for the ETC; Mission Possible Partnership (2023), *Making Net Zero Concrete and Cement Possible*; Mission Possible Partnership (2022), *Making Net Zero Steel Possible*.

The biggest opportunity to reduce embodied carbon is to build less in the first place; but there are many ways to “build clever” and “build efficient” without restricting urbanisation

Impact of embodied carbon reduction strategies

Reduction potential, %



Build nothing

- Re-use or extend use of existing buildings

Build less

- Optimise building use and service efficiency
- Better urban planning

High impact – but much harder to implement

Build smarter

- Material intensity
- Innovative construction solutions
- Material substitution

Build efficient

- Efficient construction methods
- Circularity approach

Relatively lower impact – but easier to implement

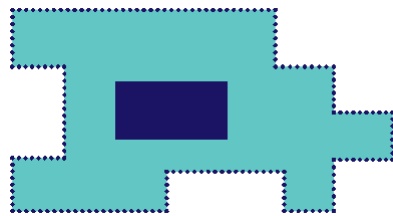
Source: Systemiq analysis for the ETC; Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

Taller buildings and those with a high wall-to-floor ratio are more embodied carbon intensive

Wall-to-floor ratio

Illustrative

Wall Floor



W2F = 0.50 (poor)



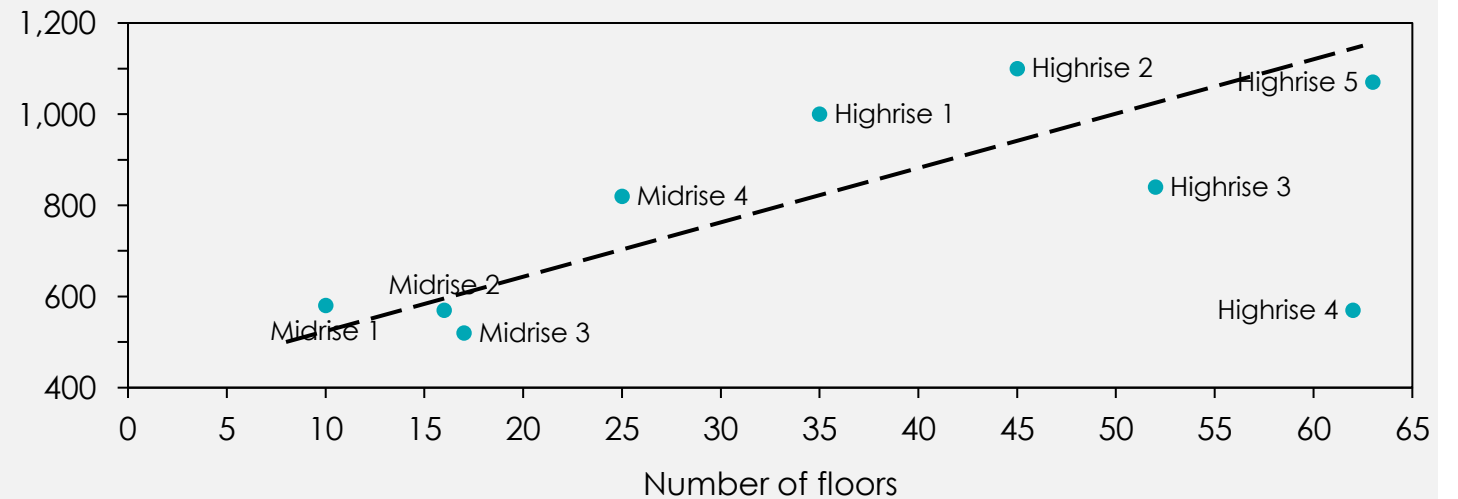
W2F = 0.35 (good)

Lower Wall to floor (W2F), lower embodied carbon

Building height

Upfront embodied carbon of high-rise buildings in London

kgCO₂e per m² (gross internal area)



Taller buildings typically require:

- More structure – thicker core walls, bigger columns, larger foundations
- More space and equipment – lifts and stairs
- More building services

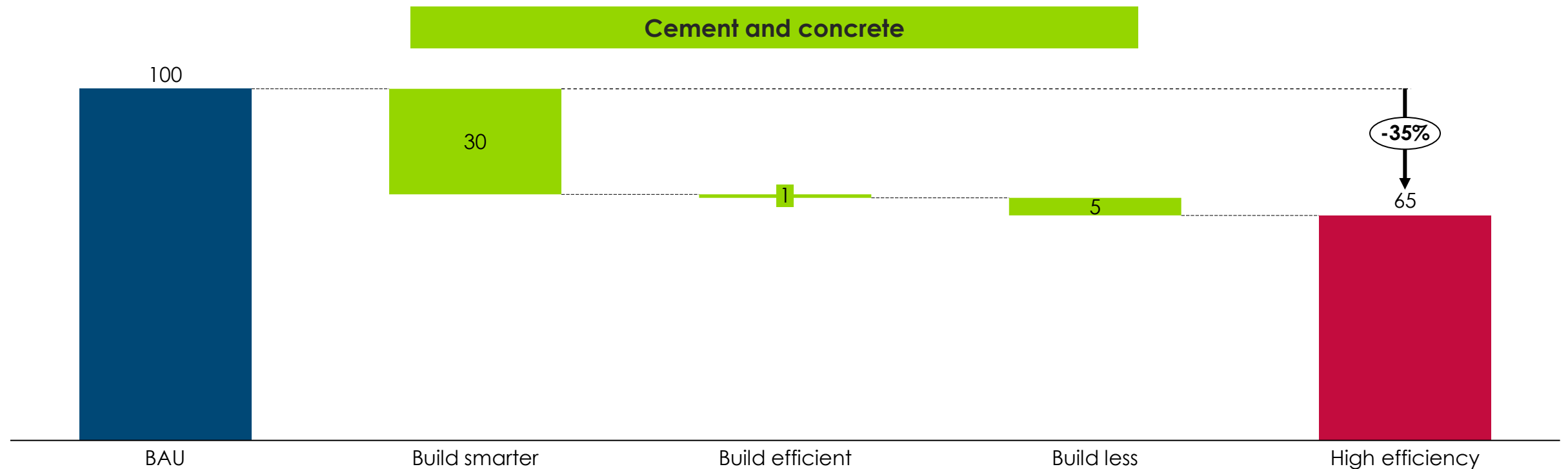
Embodied carbon per m² can be **50% higher** to provide the same net useable area between high-rise and low-rise construction



Strategies to reduce material demand, minimise waste and extend building lifetimes could cut demand for cement and steel by 30–35% to 2050

Potential reduction in cumulative demand for cement, concrete and steel to 2050

%



Build smarter: Building design choices; innovative construction solutions; material substitution

Build efficient: Efficient construction methods; circularity approach

Build less: Extend building lifetimes



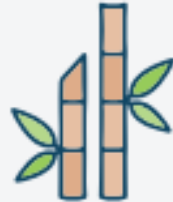
Note: The impact of the levers in steel reflect the impact on total global steel demand, including construction, transport and machinery. Source: Systemiq analysis for ETC; Mission Possible Partnership (2023), *Making Net Zero Concrete and Cement Possible*.

There are many alternative materials to cement, concrete and steel, but to have a lower whole-life carbon impact, they must be sustainably sourced and dealt with correctly at end of life

USE ALTERNATIVE, LOW-CARBON MATERIALS



Timber



Bamboo



Hempcrete



Rammed earth

3 conditions for bio-based materials to have lower whole-life carbon:

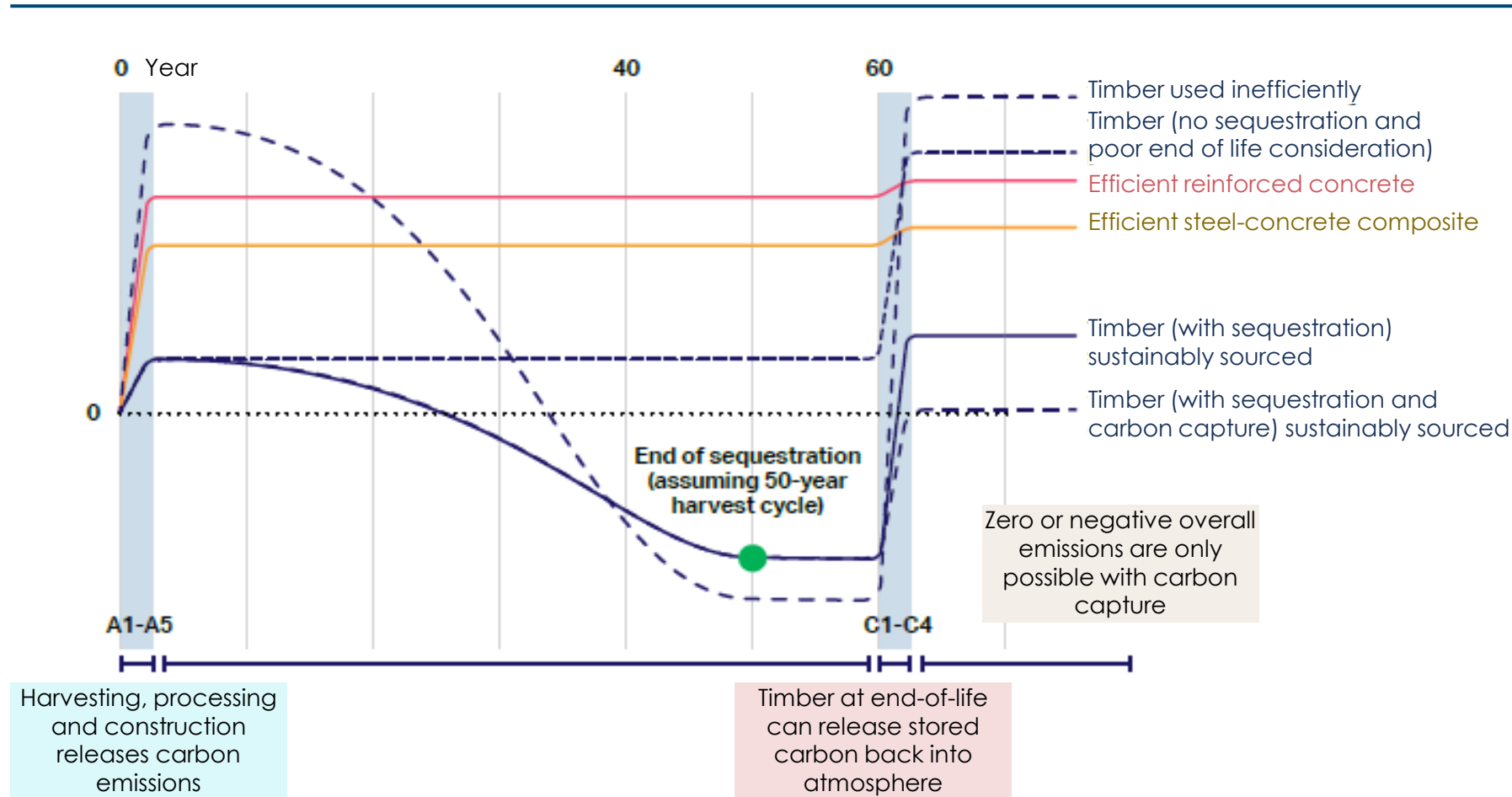
- 1 **Sustainably sourced:** *Harvested at the right time and replanted*
- 2 **Store carbon while in building**
- 3 **Dealt with properly at end-of-life:** *Recycled or burnt with carbon capture*



Used in the right way and with proper end of life consideration, modern engineered timber can significantly lower a building's embodied carbon

Cumulative embodied carbon of sustainably sourced timber and timber used inefficiently

kgCO₂e/m²



For timber to have lower lifetime emissions compared to high-carbon concrete and steel, it must be:

- Sustainably sourced from standing forest which is replanted, ensuring **sequestration**
- Dealt with properly at end of life (e.g., recycled, or burned + **carbon capture**)

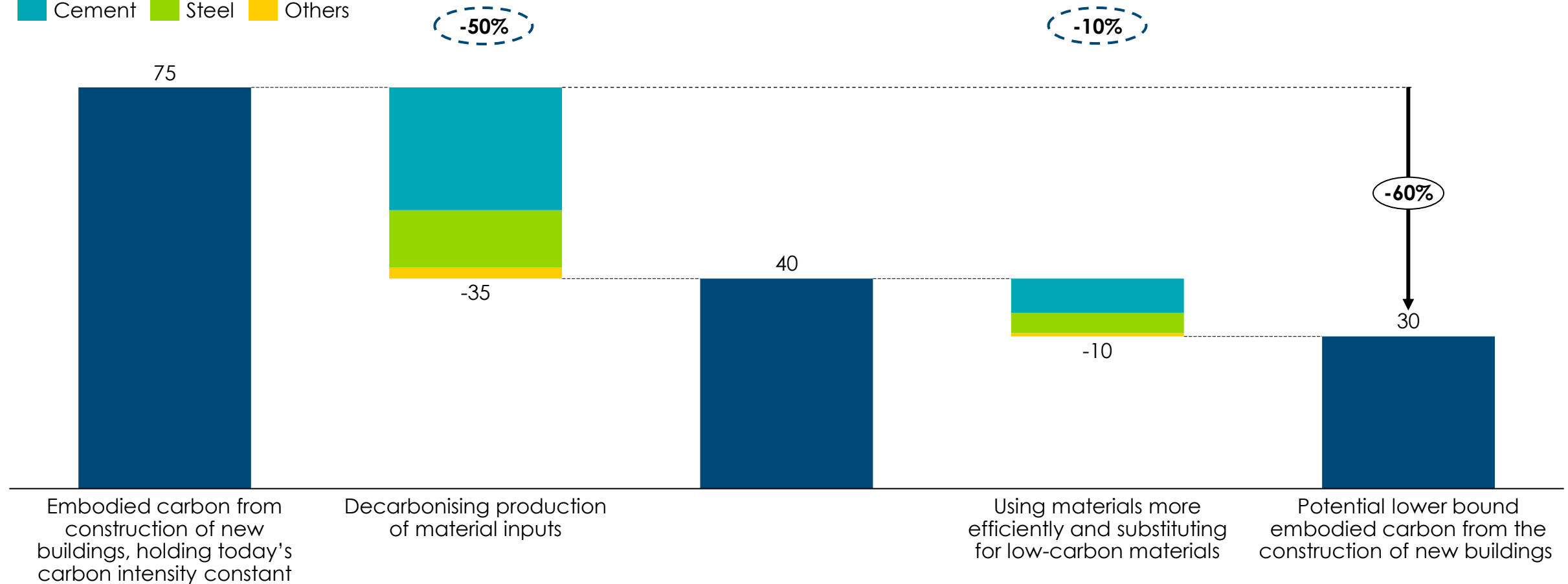
Source: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

The total embodied carbon from building 140 billion m² by 2050 could be reduced by 65% with action to decarbonise material inputs and with material efficiency and substitution

Potential reduction of embodied carbon from the construction of new floor space, cumulative emissions 2023–50

GtCO₂e

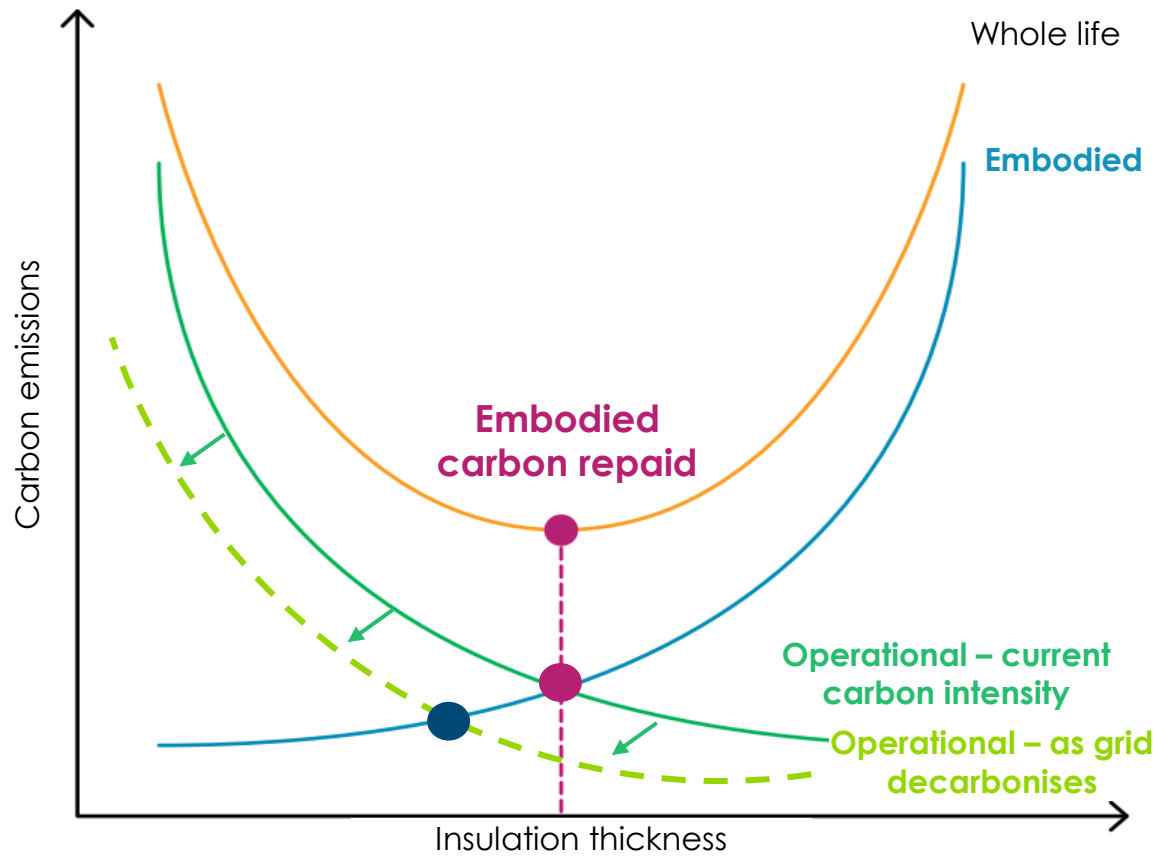
■ Cement ■ Steel ■ Others



Source: Systemiq analysis for ETC; MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.

Embodied carbon from retrofitting existing buildings will be offset by avoided operational energy emissions; but as the grid decarbonises, this trade-off will become more challenging

Illustration of the balance between embodied carbon and operational carbon from insulation



- Understanding the whole life carbon from retrofitting requires weighing up **embodied carbon** and avoided **operational emissions**
- Beyond a certain **point**, further insulation will have a negative net impact on carbon emissions
- This **point** will shift over time, as **operational emissions** are **decarbonised** – creating trickier trade-offs for retrofit

If built to the highest embodied carbon standards, lifecycle emissions from rebuilding old buildings could be as high as retrofitting

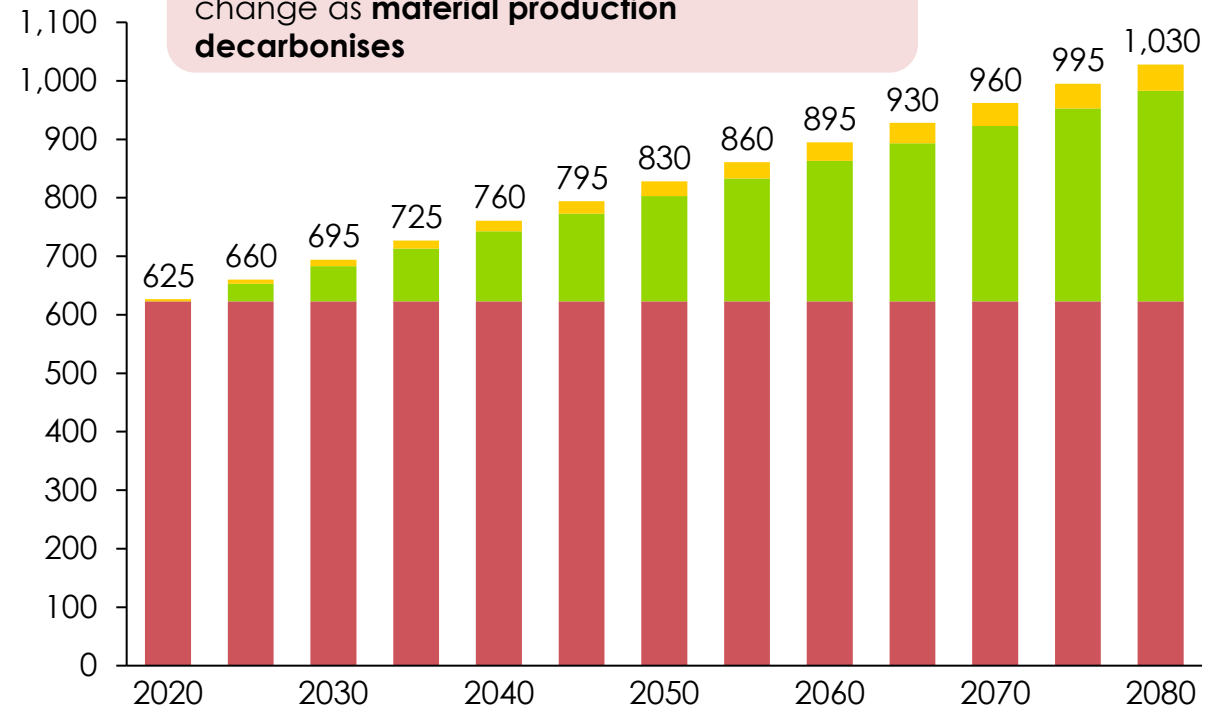
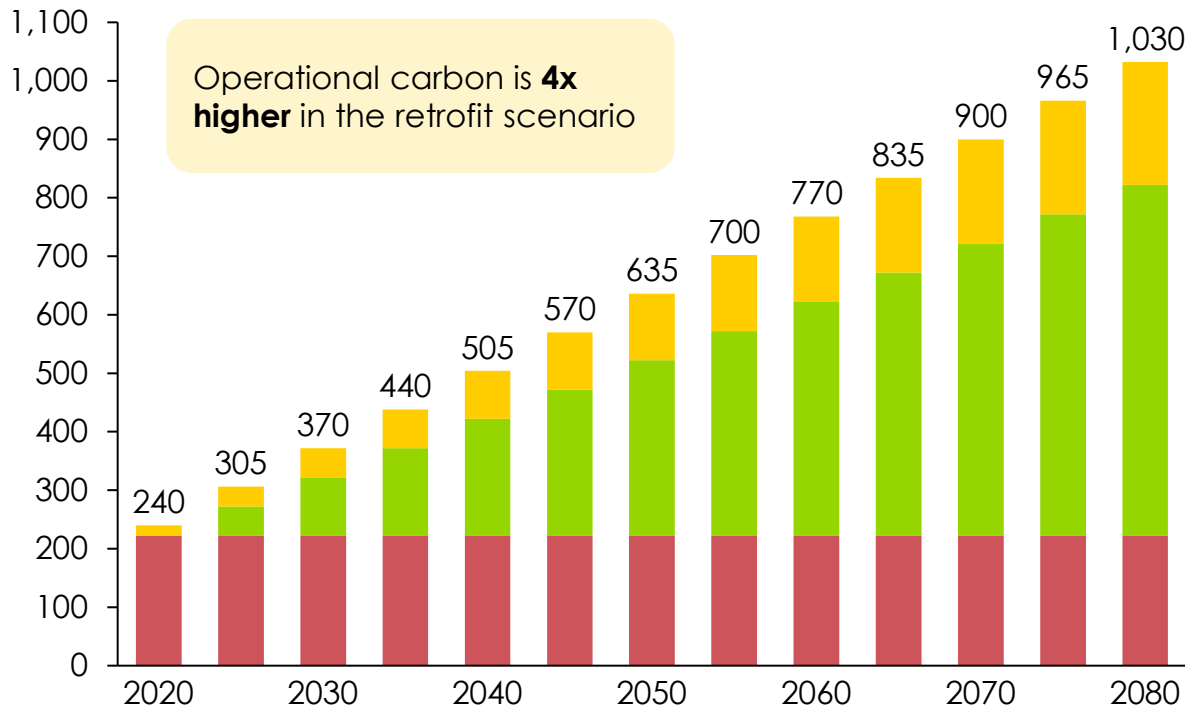
Cumulative whole life carbon emissions of a commercial building in Europe over 60 years

kgCO₂e per m²

Retrofitting building for energy efficiency

Rebuilding building to very high operational and embodied carbon standards

■ Upfront embodied carbon ■ In-use embodied carbon ■ Operational carbon



Critical actions to accelerate the buildings energy transition



Critical actions (1/2)



Heating



Cooling



Cooking



Lighting



Appliances



Embodied carbon

RELEVANT ENERGY END-USE

KEY ACTIONS

Set out a clear vision for the building energy transition, supported by local delivery plans



Ban fossil fuel boilers in new builds from 2025, and their sale from 2035 in high income countries + China



Develop street-by-street decarbonisation plans and city-wide passive cooling programmes (e.g., planting trees and white roofs)



Commitments to reduce whole-life carbon emissions in buildings that are built, financed, and owned

Underpin incentives for, and trust in, clean and electric technologies



Carbon pricing (e.g., on high-carbon construction materials)



Ensure consumers benefit from low-cost renewable electricity generation (e.g., rebalancing gas and electricity prices)



Investment in innovation, skills and supply chains to drive down costs and improve efficiency



Ban the use of refrigerants with high global warming potential



Provide advice on clean technologies + insulation + smart and flexible technologies (e.g., solar, batteries, smart systems)

POLICY MAKERS



FINANCIAL INSTITUTIONS

DEVELOPER & CONSTRUCTION



BUILDING OWNERS & COMMERCIAL BUSINESSES

ENERGY & TECH COMPANIES



Critical actions (2/2)



Heating



Cooling



Cooking



Lighting



Appliances



Embodied carbon

Create strong frameworks and standards for measuring and reducing whole-life carbon of new buildings



Regulations and certifications to set ambitious limits for operational energy efficiency (kWh / m²) and use actual, not modelled, data



Develop frameworks to measure whole-life carbon, mandate assessments, and set ambitious embodied carbon limits



Upskill on how to design lower carbon buildings (e.g., capabilities to use low-carbon materials, material efficient construction)

Manage new and peaky electricity demand with flexible and efficient buildings



Minimum energy performance standards for AC, heat pumps, appliances and lighting



Commitments to retrofitting the least energy efficient buildings by 2035 with low-cost finance and guidance



Rollout of smart meters and introduction of time-of-use tariffs

Deliver a fair and just transition for households



Low-cost finance and new financial products for retrofits, heat pumps, clean cooking and efficient AC



Early planning for location-specific and co-ordinated gas grid phase down



Investments in improving the energy efficiency of social housing and implement minimum standards for rental properties

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Upcoming ETC 2025 Webinars (UK time)

15 July 2025	13.00-14.30	ETC Webinar – Insights across our “Barriers to clean electrification” series
1 October 2025	13.00-14.30	ETC Webinar – The Role of Hydrogen & Bio energy
25 November 2025	13.00-14.30	ETC Webinar – Reaching Climate Objectives: the role of carbon dioxide removals





Energy Transitions Commission

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