Energy Transitions Commission

Frequently Asked Questions – *Achieving Zero-Cabon Buildings: Electric, Efficient and Flexible*

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Section 1: About the ETC

What is the Energy Transitions Commission and what is its mission?

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century in order to limit global warming to well below 2°C and as close as possible to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. Our ambition is to inform the decisions of public and private decision-makers and support the leaders at the forefront of climate action to speed up the deployment of low and zero-carbon solutions.

A list of our commissioners can be found here: http://www.energy-transitions.org/who/
Our ambition is set out here: https://www.energy-transitions.org/ambition/

Who funds the ETC?

The ETC is primarily funded by the organisations with which our Commissioners are affiliated. Membership fee levels depend on the size and nature (for-profit or not-for-profit) of the organisation. Commissioners all have equal voice and representation on the Commission regardless of whether their affiliate organisation finances the ETC or not. In addition, some of the ETC's work programmes, in particular in China and India, are funded by philanthropic organisations.

The funding we receive finances the ETC's secretariat, analytical programmes, stakeholder outreach and communications.

Who are the Commissioners and how were they selected?

As of January 2025, the Commission's membership includes 60 leaders coming from energy companies, energy-intensive industries, technology providers, financial institutions, environmental NGOs and academia. They operate across developed and developing countries and play different roles in the energy transition. Commissioners are selected based on their commitment to working towards a net-zero-emissions economy by mid-century.

We endeavour to diversify the Commission's membership in terms of sector, nationality and gender. The Commission is chaired by Lord Adair Turner who works alongside the ETC's senior leadership

team. A list of Commissioners can be found on our website at: http://www.energy-transitions.org/who/

Are the organisations with which your members are affiliated backing this report?

This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this report but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report.

How does the ETC balance achieving impact with the demands of fossil fuel members?

Commissioners all have equal voice and representation on the Commission. We believe it is critical that the ETC brings together voices from across all sectors, including energy-intensive industries, in order to design realistic yet ambitious pathways to net-zero emissions and mobilise all key stakeholders towards this goal. All members of the ETC have agreed to work together to pursue a global net-zero emissions target by mid-century. Our reports are anchored in robust quantitative and qualitative analyses, which are stress-tested and refined with a large panel of experts coming from both our members' organisations and a broader network. The ETC creates a unique space for open dialogue, creating the right conditions for change and advancing the climate agenda.

Does the ETC speak to the challenges of both developed and developing countries?

The ETC develops global roadmaps while highlighting differences between regional pathways, especially between developed and developing countries. We work with local partners – in Australia, Canada, China, Europe, India, Japan, India, Indonesia and the United States – who have deep country knowledge and play a key role in strengthening and stress-testing our global analyses in light of regional specificities.

Our scenarios are designed to be compatible with a world in which economic growth enables rising prosperity in developing and emerging economies. Since our scenarios build on bottom-up sectoral analyses, and from country-specific studies of power system decarbonisation, they are not based on an explicit forecast of global GDP, nor its regional breakdown. But each of the scenarios reflects the rapid growth in energy services demanded across the world, and in particular in emerging and developing economies, with for instance:

- Demand for air conditioning and space cooling is set to more than double by 2050, driven by rising incomes in lower-income countries and warming climates.
- The traditional use of biomass (TUOB) in cooking is entirely eliminated by 2050, and replaced by universal access to modern bioenergy or electricity.
- Electricity consumption in both our scenarios increases 4-5 times in just 27 years in lower-middle-income countries such as India, and far faster in low-income regions such as Sub-Saharan Africa.
- And consistent with the principle of common but differentiated responsibilities enshrined in the Paris Agreement, in all sectors we describe pathways in which rich developed economies decarbonise at a faster pace than emerging and developing countries. Therefore, in our power model, the US and the EU reach near-zero carbon electricity systems by 2035, while many emerging economies only achieve this objective by 2050.

Section 2: About the report and its impact

Who is the paper aimed at? Who is your target audience?

This report sets out recommendations for governments, building developers, construction companies, financial institutions, energy companies, technology companies, commercial businesses, and professional building owners. Collectively these bodies are the target audience for the report, alongside the wider climate community and public.

The report also includes information that is of interest to homeowners and renters, including myth-busting on the applicability of heat pumps to different buildings and climates, the types of energy efficiency improvements that can be made to homes, and the likely direction of government policy. However, this report does not constitute advice to households on the specific technology or retrofit investments they should make, as this is building-specific.

Which countries and regions is the report aimed at?

The report explores the global buildings sector, outlining analysis and recommendations which are relevant both globally and to specific regions. In the buildings sector, the very nature of how buildings are designed and powered varies considerably across regions and climates. For example, heating needs are concentrated in Northern latitude countries that have cold winters. Energy use also varies considerably by income level, with households and businesses in higher-income countries typically owning more appliances and heating/cooling their buildings for much longer.

As such, this report describes the decarbonisation pathways for each end-use (e.g., heating, cooling, cooking, lighting, and appliances) and how the technologies and actions will differ across different regions and countries.

What is the main focus of this report?

This report sets out how the global buildings sector can decarbonise and achieve net-zero by 2050. It covers both residential and commercial buildings and sets out:

1. *The clean technologies required to decarbonise the energy used to operate buildings, including the energy efficiency improvements that can be made to buildings themselves, and the potential for greater technical efficiency in air conditioning, lighting and appliances.*
2. *The implications of electrifying building energy use for overall electricity demand and the role that buildings can play within a clean energy system based on variable renewables, for example being able to flex demand to different times.*
3. *The opportunity to reduce embodied carbon in the next generation of new buildings, including how steel, cement and concrete can be decarbonised, alternative low-carbon building materials, and strategies to use fewer materials and to build less.*
4. *Actions required from policymakers, industry and financial institutions.*

What makes this report different to others?

Achieving zero-carbon buildings requires action in many sectors and from a wide variety of actors, from concrete and steel companies, developers and construction companies, to heat pump and AC manufacturers, energy companies, professional building owners, the real estate sector, and households.

This report brings all of this together, outlining clear recommendations for specific actors and highlights where policy and private sector action is critical to accelerating progress.

The report's coverage is different in three main ways, covering:

- **Both "operational" and "embodied" emissions**. A combined and comprehensive discussion of both how to decarbonise the energy used to operate buildings (e.g., space and water heating, space cooling, cooking, lighting and multiple forms of appliances) and the construction of new buildings, reducing embodied carbon.
- **Both supply-side and demand-side levers for decarbonisation**. Energy supply-side levers include switching from gas boilers to electric heat pumps for residential heating, which will reduce emissions if accompanied by power sector decarbonisation. Demand-side measures increase "energy productivity" by reducing the amount of energy needed to deliver end energy services, and thus human welfare (e.g., via improved building insulation).
- **The impact of building electrification on the overall electricity system.** Electrifying building heating and cooking will increase not only overall electricity demand, but electricity demand at peak times. It is therefore essential to identify and implement actions which can achieve time-specific power supply/demand balance in future electricity systems based on variable renewables. This report discusses the many actions – such as improved insulation, decentralised storage and demand-side flexibility – which can be deployed at the building level, rather than within the electricity supply system.

How much of the paper constitutes new analyses vs. integration of previous publications?

In a series of major reports over the last 7 years, the Energy Transitions Commission (ETC) has demonstrated how net-zero emissions can be achieved across the economy, with a focus on the power and industry sectors. We have previously evidenced the potential to electrify building heating in our 2021 *Making Clean Electrification Possible* report, the global investment required to decarbonise buildings in our 2023 *Financing the Transition* report, and developed scenarios for the decline of direct fossil fuel use in buildings in our 2023 *Fossil Fuels in Transition* report.

The Mission Possible Partnership (MPP) has also developed detailed sector transition strategies to decarbonise cement and concrete, steel and aluminium. While buildings is a key source of demand for these materials, these strategies are broader than just the buildings sector.

However, this report focuses for the first time on the buildings sector. It expands and builds upon previous ETC analysis, as well as developing new analysis on additional aspects of the buildings energy transition (e.g., lighting and appliances, better building design, embodied carbon). It brings all of these aspects into one comprehensive pathway to achieve 'zero-carbon buildings'.

Who has carried out the underlying analysis?

The ETC secretariat, provided by Systemiq. The analysis has also been tested with relevant experts, both within ETC members and externally. The ETC has a large and growing membership of businesses operating directly or indirectly in the buildings sector, including but not limited to Arup, Saint Gobain, Schneider Electric, Octopus Energy, and HSBC. This work therefore leverages their expertise and utilises the unique opportunity to bring these voices from all aspects of the buildings sector together.

The underlying analyses in the report also builds on the ETC's existing body of work since 2017, as well as the work and data of MPP, the IEA and others.

How does this report contribute to the ETC's wider work on energy productivity?

Throughout this report, one key issue which we address is the relative importance of decarbonising energy supply to the building sector (via the combination of electrification and the decarbonisation of

power systems) versus reducing energy use while still meeting, or increasing, human welfare – both improved comfort in a changing climate and lowering operating costs – (via for instance building insulation and equipment technical efficiency improvements).

Our conclusions on the latter opportunity will feed into ETC's wider report on the role of "energy productivity" improvements in achieving a zero-carbon economy, which will cover all sectors of the economy, assess the combined potential for improvement and launch in 2025.

Throughout 2024, we analysed the productivity improvement potential in each major sector (road transport, buildings, and key industries) and identified policies required to seize this potential. We will then aggregate the sectoral opportunities into an assessment of the total economic-wide opportunity, publishing a final report in 2025. This report sets out our analysis of energy productivity improvement in the buildings sector.

Section 3: Achieving Zero-Carbon Buildings – key challenges and actions

Why has the ETC decided to cover this topic?

Constructing and operating buildings accounts for 33% of global annual emissions, 12.3 $GtCO_2$, and 10% of direct fossil fuel use, equal to ~14,000 TWh (with additional fossil fuels used to generate the electricity which itself powers 35% of buildings energy use). It is therefore essential that any national or local government or private sector commitment to reach net-zero includes action on how to decarbonise buildings.

However, globally, progress in decarbonising the buildings sector has been slow. In Europe, for example, a number of policies to end the sale of gas and oil boilers have been weakened in recent years. This report aims to contribute to a crucial debate about how to accelerate progress across the world in decarbonising both how buildings are built and how they are powered.

In some countries, one of the biggest challenges is the prevalence of misinformation and negative reporting on the quality and cost of heat pumps and home retrofit. This report also aims to tackle this, by laying out clear conclusions on the applicability and lifetime cost of such investments.

With the right policies, the buildings energy transition will ultimately lead to improved outcomes for society, through lower and more stable energy bills, improved housing quality and living standards, positive air quality and health impacts, and a reduction in GHG emissions. However, realising these positive outcomes requires households to, in some cases, incur upfront costs (although lifetime costs can almost always be lower) and/or make changes to their home. It is critical that these impacts are fully understood and that public policies must be designed to address these distinctive implementation challenges and distributional effects in the buildings sector.

How does the challenge of reducing emissions from buildings' energy use differ across the operation and the construction of buildings?

Constructing and operating buildings accounts for 33% of global annual emissions, 12.3 $GtCO_2$:

- Emissions from the **operation of buildings**, which account for 26% of global emissions, or 9.8 $GtCO_2$. The direct use of fossil fuels accounts for 3 $GtCO_2$ (8% of global emissions); this includes the use of gas and oil for heating, plus the traditional use of biomass (TUOB) for cooking in low-income countries.[1] The indirect use of fossil fuels for electricity used in

[1] IEA (2023), *World Energy Outlook 2023.*

buildings accounts for 6.8 $GtCO_2$ (18% of global emissions). Operational emissions are produced by the world's total *stock* of buildings, around 250 billion m^2.[2]

- Emissions from the **construction of new buildings**, which account for a smaller but significant share of buildings emissions - 7% of global emissions, or 2.5 $GtCO_2$. These emissions are referred to as **embodied carbon**, and arise from the production of materials - predominantly steel and cement/concrete - and the use of fossil fuels in transportation and construction. Embodied emissions relate from the *additions* to the global building stock in a given year, around 5 billion m^2.

How is the decarbonisation challenge different for the buildings sector compared to other industries and how does this challenge vary across regions?

Achieving two main avenues of building decarbonisation – installing clean technologies and improving the energy productivity of buildings - poses some distinct implementation challenges not found in other sectors:

- In the residential building sector, individual households will need to decide between multiple possible clean technologies - both "active" (e.g., heating and cooling systems) and "passive" (e.g., improved insulation). Across both of these, the installation will entail some disruption within their homes. And while clean heating technologies (in particular heat pumps) can deliver lower operating costs, installing them currently comes with higher upfront investment in most countries. But the availability and cost of finance varies greatly between low and high income households. More generally indeed, feasible and optimal solutions vary greatly by specific household circumstances, such as the availability of space and current quality of insulation. There is also a huge disconnect between the incentives of landlords, who are motivated to install the cheapest clean heating technology, vs tenants, who benefit from the most efficient technology and lower energy costs.
- In the construction sector, building a low-embodied carbon building entails a complex array of decisions and trade-offs across different materials and decision-makers (e.g., developers, suppliers, material produces, construction companies). Compared to the industry and transport sectors, where products are relatively standardised and mass-produced, there are limits to how far new developments, material and design choices can be standardised. The sector is typically highly fragmented (e.g., high levels of sub-contracting), compared to other sectors with a relatively small number of large corporates operating in the space.

What are the critical actions for governments, policymakers and industry?

There are six key cross-cutting priorities to decarbonise both the operation of existing buildings and the construction of new ones:

1. Set out a clear national vision for the building energy transition, with targets for heat pump deployment and clear bans on fossil fuel heating and cooking, supported by local street-by-street delivery plans.
2. Underpin incentives for, and trust in, clean, electric technologies by creating early demand for low-carbon technologies, rebalancing gas and electricity prices, and providing time-limited subsidies for deployment.

[2] Ibid.

3. Create strong frameworks and standards for measuring and reducing whole-life carbon of new buildings, particularly around embodied carbon.
4. Manage new and peaky electricity demand with flexible and efficient buildings with time-of-use tariffs, minimum energy performance standards and labelling regulations, financial incentives for insulation, and encouraging the uptake of smart systems, rooftop solar PV and batteries.
5. Introduce carbon prices or equivalent regulation to drive the decarbonisation of material production, and create incentives for the more efficient use of carbon-intensive construction materials.
6. Deliver a fair transition for households, with targeted support for low-income households, investment in social housing, clear regulations on the energy efficiency of rented properties, and education and awareness of low-cost passive heating and insulation improvements.

Do heat pumps really work?

A heat pump works exactly like a fridge or an air conditioner, but in reverse. Despite being a proven technology for decades and there being a strong general case for heat pumps, there continues to be scepticism – largely amongst homeowners – about their effectiveness, leading to significant opposition to their deployment. This reflects a number of myths which are unfounded today and which will become even less valid as heat pump technology improves and costs reduce:

- **"Heat pumps cannot deliver the same heat as gas boilers":** In comparison to gas boilers which are able to quickly provide heat on demand, heat pumps work by being turned on for longer but at lower temperatures. This does not mean heat pumps are less effective at providing heat or comfort, but reflects how heat pumps operate. This is because today's air-to-water heat pumps typically operate with lower flow temperatures than gas boilers (i.e. the water which runs through central heating systems is 35–50°C, compared to 60–80°C for gas boilers) – although, innovation is seeing heat pumps reach higher and higher flow temperatures. Attaining the same levels of comfort is not an issue, provided heat pumps are sized and installed correctly, though in some cases additional changes to building heating will be required. For example, many existing buildings will require radiators to be replaced and upsized, enabling more heat to be transferred into the room.
- **"Heat pumps don't work in cold climates":** It is true that the efficiency of air-to-air or air-to-water heat pumps declines as air temperature declines, but the impact in all but the most extreme temperatures is sufficiently small that it does not undermine the case for air-based heat pumps in almost all climates. Refrigerants are liquid at very low temperatures (e.g., below -30°C), meaning they can extract heat even in below zero temperatures. As a result Norway and Finland – which have average January temperatures of around -8°C – have the highest number of heat pumps per 100 households in the world, at more than 40.[3]
- **"Heat pumps won't work in old buildings without very extensive expensive retrofit":** Given the lower temperatures at which heat pumps typically operate, it is often asserted that they cannot deliver sufficient warmth to offset rapid heat loss from poorly insulated buildings. This argument has been hugely overstated, as long as radiators and heat pumps are properly sized.

[3] Carbon Brief (2024), *18 misleading myths about heat pumps.*

How much more do heat pumps cost compared to gas boilers?

The cost competitiveness of heat pumps varies hugely across countries and parts of the world and across different households. Our analysis suggests that, average across Europe for example, the total cost of ownership of fossil fuel boilers, air-to-air heat pumps, and air-to-water heat pumps over their lifetime are very similar.

However, the precise cost efficiency of heat pumps depends on many factors:

- **Upfront costs:** The upfront cost of an air-to-air heat pump plus an electric water heater is generally slightly more expensive than a gas boiler (€4,000-5,000 compared to around €3,000), but is cost competitive already in many countries, especially those who have a big market for ACs. Air-to-water heat pumps typically cost around 2-3 times more to install, although there are some countries where they are cheaper (e.g., Sweden and Denmark).
- **Running costs:** Given the inherent efficiency of heat pumps, operating costs would be around one third to one fifth of gas boilers if electricity prices were the same per kWh as for gas; but this efficiency benefit is offset by the higher cost of electricity relative to gas in many countries today. For example, in Europe where electricity costs, on average, 2.5 times more than gas, heat pumps would have to operate with an efficiency of over 340% to be cost competitive with gas boilers (heat pumps tend to have an average efficiency of 300% today). If the price ratio was 2.0, heat pumps with an efficiency of 270% would be competitive.
- **The cost of capital:** The interest rate at which a household or business can access funds to invest in a new clean solutions, which varies greatly between specific households. This implies that public policies to reduce the cost of finance for low income households have an important role to play.

Policies which decouple consumer electricity prices from gas prices and which enable electricity prices to reflect the falling cost of renewables, through power market reform, are therefore vital to ensure that households gain maximum benefit from heat pump deployment.

Over time however, the relative cost advantage of heat pumps will improve as attainable efficiencies continue to increase, and as scale deployment makes possible significant reductions in upfront cost.

Can we use low-carbon hydrogen in gas boilers?

In countries with large natural gas networks, a number of governments and industries have been considering the use of hydrogen gas, most notably the UK and Germany. With trials underway, it is not yet possible to conclude on the physical viability of widespread hydrogen heating, though nothing so far has raised significant concern. Economic considerations, however, argue against a significant role for hydrogen in residential heating.

This report argues that hydrogen should be ruled out as large-scale option to replace existing fossil fuel boilers for the following reasons:

- **Hydrogen is not a "drop-in" replacement**: households will still need new boilers which can deal with either a gas/hydrogen blend or 100% hydrogen and in some homes, additional ventilation and pipe replacement will be needed. While hydrogen would mean existing natural gas infrastructure could be repurposed, it would still require significant retrofitting, or even rebuilding, given the fact that hydrogen and natural gas have very different physical

properties (e.g., compared to natural gas, hydrogen molecules are much smaller, increasing the risk of leakage, and are more flammable).

- **Using green hydrogen would require 5–6 times more electricity than heat pumps:** the process of producing green hydrogen (i.e. using renewable electricity) and converting this to heat in a boiler has an overall of 50-55%. This compares to 300%+ for heat pumps.
- **System costs could be 25% higher compared to electrification:**[4] this reflects higher electricity generation requirements and the cost of developing hydrogen pipelines and storage infrastructure.
- **Consumer costs could be 85% higher compared to electrification:**[5] even though the cost of a hydrogen boiler is likely 3–4 times cheaper than an air-to-water heat pump, overall costs are expected to be much higher. This is because hydrogen is much less efficient, with higher fuel costs.
- **Using clean hydrogen for home heating would delay the decarbonisation of buildings until at least the mid-2030s:** there is uncertainty over the pace of clean hydrogen supply pipelines, especially in light of recent high electrolyser prices, and hydrogen-ready boilers are not available on the market yet.

There may, however, be some circumstances where hydrogen is a viable economic solution in individual homes – specifically, in homes located close to the production of low-carbon hydrogen sites and where supply can therefore be guaranteed and cheaper.

Beyond direct use in homes, hydrogen will still play important roles in the net-zero transition of buildings:

- It is a key technology to store large amounts of energy over time, providing seasonal grid balancing in a renewables-dominated energy system.
- Hydrogen could also play both a direct role in district heat networks, for example in locations close to industrial clusters with high hydrogen use/production, and an indirect role, where waste heat from industry powered by hydrogen can be utilised.

The report outlines the huge potential to electrify building heating and cooking. What are the implications for countries with a large natural gas grid?

Phasing out gas boilers leaves big questions about what happens to the existing gas network. While the long distance gas transmission network could be used for hydrogen (whether used in industry or as a long duration energy store within power systems), the distribution network of pipes which deliver gas to homes will need to be largely decommissioned – unless they were developed into heat networks.

This poses big questions around how this is done and who pays. The key challenge is that the gas grid must be maintained and kept safe until the last building is disconnected, but as more households electrify, these costs will be shared across a smaller customer base. In addition, lower-income households may be the last to electrify due to the upfront costs of heat pumps, unless governments support their transition with subsidies and low cost finance.

[4] Jan Rosenow (2024), *A meta-review of 54 studies on hydrogen heating.*
[5] Ibid.

Analysis of the UK suggests that decommissioning the gas grid could cost up to £25 billion.[6] Leaving the private sector to bear these costs would lead to adverse equity impacts, meaning costs will undoubtedly need to be partially publicly financed, either with the government directly financing decommissioning or by providing financial support to lower-income households faced with higher bills.

It is critical that policymakers and network operators begin planning for how to cost-effectively decommission the grid. Key next steps should be:

- Setting a clear policy direction that hydrogen will not be used in homes.
- Developing local street-by-street strategies to phase out fossil fuel heating.
- Setting national targets for the phase out of fossil fuel boilers and when the gas network for buildings could be switched off.
- Working with grid owners to understand the extent to which the gas grid could be switched off in a granular fashion.

Section 4: Role of Clean Electrification

The term "net-zero" is used a great deal – but what is "net-zero" and why should we set "net-zero" targets?

The concept of "net-zero emissions" is based on the climate science and what we must do to limit global warming. The IPCC's illustrative pathways for limiting global warming to 1.5˚C indicate that CO_2 emissions need to be reduced to net zero globally by around 2050. In this expression, the "net" reflects the fact that there may still be a small amount of residual emissions by 2050 – the ETC estimates that 2-4 Gt of CO_2 might still be emitted by the energy system – and those should be compensated by negative emissions, obtained via carbon removals (for instance from afforestation or DACCS).

We must therefore aim to decarbonise the economy by mid-century, reducing CO_2 emissions from energy, industry, transport and buildings to as close to zero as possible. Net-zero goals and targets are powerful, because they give us this galvanising clarity of action for government, business, and civil society, focusing the minds on a tangible objective associated with a clear timeline. They are a vital step in accelerating progress and urgency as we must act now to deliver them.

But achieving net-zero in these sectors alone will be insufficient to limit global warming to 1.5°C for three reasons;

- First, as CO_2 accumulates in the atmosphere, it is the total cumulative amount of emissions between now and 2050, and therefore the pace of emissions reduction, that will matter for global warming; this carbon budget is currently estimated at 500 Gt from 2020 by the IPCC, 420 Gt from the beginning of 2022. Cutting emissions fast in the next decade will be necessary to avoid an "overshoot" of the carbon budget - given potential feedback loops and tipping points within the climate system, it is unacceptably risky to rely on large-scale negative emissions later in the century. IPCC pathways which avoid such reliance show that CO_2 emissions need to be cut from today's 40 $GtCO_2$ to below 25 $GtCO_2$ by 2030.
- Second, beyond the energy, industry, transport and buildings sectors, emissions from waste, agriculture, food and land use should also be taken into account

[6] Arup (2023), *Report for the National Infrastructure Commission and Ofgem: Future of Great Britain's Gas Networks.*

- Finally, non-CO_2 emissions, in particular nitrogen oxide and methane emissions, also contribute to global warming effects and need to be cut.

What is the role of clean electrification in the energy transition?
Clean electrification will be at the heart of the energy transition, enabled by the rapidly falling costs of renewable energy, with a complementary role for clean hydrogen technology in sectors that are difficult or impossible to electrify.

The ETC report ***Making Clean Electrification Possible: 30 years to electrify the global economy*** sets out why it is essential but also feasible and affordable to multiply the size of the global power system by 5, while shifting to renewable-based electricity provision. The parallel report ***Making the Hydrogen Economy Possible: Accelerating clean hydrogen in an electrified economy*** set out the complementary role for clean hydrogen and how a combination of private-sector collaboration and policy support can drive the initial ramp-up of clean hydrogen production and use to reach 50 million tonnes by 2030.

What is the impact of building electrification on the overall electricity system?
It is technically and economically feasible to almost entirely eliminate the direct use of gas and oil in buildings by 2050, primarily by electrifying heating and cooking. This means we are moving from an energy system where energy for buildings is supplied by a variety of fuels, to a system in which it is virtually exclusively electric (including district heat networks generating heat with heat pumps).

This means that annual electricity requirements for buildings in 2050 could be 2.5−3 times higher than today due primarily to electrification of heating and expansion of cooling. Electricity use in buildings could increase from 12,800 TWh to around 35,000 TWh.

Electricity demand for buildings will create peaky demand which could be challenging for clean power systems, especially local grids, to manage. Heating and cooling needs fluctuate over days, weeks and months, creating balancing challenges when this does not align with renewable generation. Electricity systems must be sized accordingly, leading to higher costs for storage and dispatchable generation.

But a whole-building approach to decarbonisation can transform buildings into energy assets. There is huge untapped potential for buildings to provide demand-side flexibility through improved insulation, water and battery storage, rooftop solar PV and smart systems. Buildings can therefore complement the increasing penetration of cheap, variable renewables, varying the time at which electricity is drawn from the grid to match when wind and solar generation is abundant.