Expanding Integrated Assessment Modelling: Comprehensive and Comprehensible Science for Sustainable, Co-Created Climate Action

Energy transition trends in the European residential sector: Outlook for the EU-27 plus the UK by 2030 and 2050

WP6 – Explaining: Policy analysis, capacity development, communication, dissemination, exploitation

26/08/2025

The IAM COMPACT project has received funding from the European Union's HORIZON EUROPE Research and Innovation Programme under grant agreement No 101056306.

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1 Introduction

IAM COMPACT is a European Union project, funded under the Horizon Europe Research and Innovation programme, with the objective to support the assessment of global climate goals, the collective progress towards them, and the feasibility space in delivering on those goals. The project aims to involve relevant stakeholders in the process to help promote acceptable, robust, and sustainable transitions, as well as to enhance trust on both ends, yielding outputs intelligible in terms of real-world implications and actionable in terms of concrete policy recommendations.

Participatory approaches have been argued to bring a more diverse range of views into the integrated assessment and the energy system modelling process, by building a better understanding of the social context and supporting more inclusive decision-making. In IAM COMPACT, we have designed a Policy Response Mechanism (PRM), a co-creation process that facilitates collaboration among modelling teams and with stakeholders. The PRM dynamically responds to changing policy priorities, aiming for policy relevance, knowledge exchange, and enhanced trust, by providing different layers of inputs and making modelling socially/politically realistic.

Stakeholder engagement in IAM COMPACT is organised into themes (for stakeholders within the European Union (EU)) and regions (for stakeholders outside the EU). The themes and regions were collaboratively determined within the project, with Bruegel coordinating the process. As part of the second PRM cycle, our project team received 46 research questions from stakeholders forming the Policy Steering Groups (PSGs), which were then grouped into seven new modelling studies. After internal discussion among modelling teams, an initial scenario design for each study was agreed and then presented to our Core Working Groups (CWGs) -a wider policy audience selected on geographical and sectoral criteria- for discussion and co-design in three separate workshops.

This policy brief is part of the theme "**Citizens in the Transition**[1]", which focused on lifestyle changes in mobility, diets, and housing, household decarbonisation, and distributional impacts of climate policies, and produced three modelling studies. The study presented here evaluates energy transition pathways in the European residential sector including the EU-27 and the United Kingdom (UK).

1.1 Background

The EU leads global decarbonisation efforts, with buildings representing a central pillar in this transition. Since 1990, greenhouse gas (GHG) emissions from the EU's buildings sector have steadily declined, from 735 $MtCO_2eq$. to 489 $MtCO_2eq$. in 2022 [1], driven by improvements in energy efficiency, the greater use of renewable energy for heating, and the adoption of heat pumps and district heating systems. Despite this progress, buildings still account for 40% of the EU's final energy consumption and 36% of its energy-related GHG emissions. Moreover, about 75% of the building stock remains energy-inefficient, and by 2050 all buildings -and almost all by 2040- must be decarbonised, requiring widespread renovation to meet climate targets [2]. Natural gas remains the dominant energy source for space heating in the residential sector, contributing roughly 39% of consumption, while oil and coal account for 11% and 3%, respectively.

The European Commission (EC) recommends an overall GHG emissions reduction target of 90% by 2040 compared to the 1990 levels, with the buildings sector expected to deliver an even higher reduction of 92% [3]. This target falls within the range of the current sectoral scenario estimates, which project GHG reductions of 88% to 99% by 2040. Achieving these reductions will rely largely on phasing out fossil fuel-based technologies and significantly improving energy efficiency through higher renovation rates. However, according to Member States' 2023 national projections, current policies are expected to reduce building-related GHG emissions by only 42% below 1990 levels by 2030 and by 53% by 2040, reaching 62% if additional measures are implemented [3,4].

[1] https://iam-compact.eu/news-events/core-working-group-workshop-citizens-transition.

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This gap between the EC's climate ambition and Member States' actual transition realities underscores that the buildings sector is still far from being on track to meet its 2030 and 2050 climate targets [5]. Key indicators, including CO_2 emissions reduction, final energy consumption, renewable energy share, and renovation investments, remain more than 40% below the required trajectories for these targets [6]. Specifically, between 2015 and 2022, emissions fell by just 14.7%, well below the required reduction of 27.9%, leading to a total of 367 $MtCO_2$eq. in avoidable emissions, had the target pathway been met. Over the same period, final energy consumption in households and services declined by only 2.8%, less than half the necessary reduction of 6.5%. Similarly, the share of renewable energy in buildings rose by just 6.3%, far short of the 18% increase needed. Cumulative investments in buildings' renovation during the period 2015–2022 totalled €2,629 billion, only 60.6% of the €4,335 billion required, indicating that overall progress remains substantially off track [6].

The EU has long pursued buildings' decarbonisation, establishing a series of regulations and ambitious targets [7]; the Energy Performance of Buildings Directive (EPBD)- first adopted in 2010 and revised in 2024- alongside the Energy Efficiency Directive (EED)- introduced in 2012 and updated in 2023- form the core of the EU's policy framework. In 2020, the EU launched the "Renovation Wave" strategy under the "European Green Deal", aiming to at least double the buildings' renovation rate by 2030 and promote deep renovations through a comprehensive action plan of regulatory, financial, and supporting measures [8]. Furthermore, in recent years, attention to buildings' performance has intensified, driven by two key events: first, the COVID-19 pandemic, which confined many Europeans to their homes and exposed widespread issues such as poor indoor air quality; and second, the energy crisis, exacerbated by Russia's invasion of Ukraine, which caused a sharp rise in energy prices and deepened energy poverty, now affecting 8 to 16% of the European population [9].

The unexpected and extreme events of the past five years have raised serious concerns about high energy prices and energy security across the EU. In response, the EU introduced the "REPowerEU" plan [10], alongside the "Fit-for-55" package [11], both underscoring the urgency of phasing out fossil fuels, particularly oil products and natural gas, in the EU's buildings sector. These policy plans primarily aim to: (i). reduce the EU's reliance on Russian natural gas, (ii). improve energy efficiency, (iii). gradually phase out fossil-fuel boilers, and (iv). implement a parallel Emissions Trading System (ETS_2) for heating fuels in buildings, which will further incentivise investment in fossil-free alternatives such as heat pumps [10,11]. This evolving policy landscape is shaping Member States' energy transition strategies, including updates to their National Energy and Climate Plans (NECPs) and National Building Renovation Plans (NBRPs, former Long-Term Renovation Strategies- LTRSs), and Social Climate Plans.

The energy crisis appears to have marked a turning point for residential gas demand in Europe. In 2022, residential and commercial gas consumption fell by over 15% compared to the previous year [12]. While ~40% of this decline was due to weather-related factors, specifically reduced heating needs during a mild winter, a significant portion resulted from deliberate gas-saving measures [13]. These measures included fuel switching, behavioural changes, energy-efficiency improvements, such as buildings' retrofits, and heat pump installations. Additionally, high energy prices forced some households and businesses to cut their energy use involuntarily [13]. This downward trend continued into 2023, with overall gas demand in the European member countries of the Organisation for Economic Co-operation and Development (OECD Europe) dropping an estimated 9% in the first three quarters compared to the same period in 2022. These developments indicate that gas demand in Europe's buildings sector is likely to decline moderately but persistently in the years ahead [14].

1.2 Motivation

Considering the abovementioned, this policy brief examines energy transition trends in the residential sector across the EU-27 and the UK towards 2030 and 2050, with a focus on decarbonisation progress and electrification prospects. Building on the identified gaps between the EU's climate targets and the current national trajectories, such as in CO_2 emissions reduction and the final energy consumption, this analysis assesses the role of electrification in closing these gaps across different scales and contexts. It also highlights the importance of reflecting on country-specific differences in buildings' quality, energy demand patterns, and heating technology use, for instance, the predominance of electricity in the Northern Europe compared to the coal reliance in parts of the Eastern Europe.

To do so, two complementary models are used: a global integrated assessment model (IAM) and a detailed, country-level, energy system model (ESM). This combined approach allows us to capture both broad market trends and specific technology choices in homes, providing a realistic picture of how the residential sector can reduce emissions under current policies. The models are carefully aligned to ensure consistent assumptions on energy prices, technology costs, and energy use. The scenario analysed by the models considers the targets envisioned in the "European Green Deal", i.e., reducing GHG emissions by at least 55% by 2030 and achieving climate neutrality by 2050 through increased energy efficiency, higher shares of renewable energy, and the gradual phase-out of fossil fuels in the residential sector.

Overall, the main question this policy brief addresses is: "*What is the decarbonisation potential in the residential sector of EU-27 plus the UK by 2050, also focusing on electrification trends?*". Findings offer insights to support policymakers and practitioners in designing effective and fair strategies tailored to actual national transition realities.

2 Scenario design

We soft-link a global IAM (PROMETHEUS) with a country-level European ESM (Aalto-EU-TIMES). **PROMETHEUS** [15] is used to provide the global-level information needed for the analysis, capturing the detailed interplay between energy demand, supply, and pricing across the different world regions. The model is designed to explore medium- and long-term energy transition pathways by examining how various low-emission strategies and climate policies affect energy markets, emissions, and economic outcomes. By simulating both sides of the energy equation- how energy is produced and consumed- the model finds market equilibrium at regional levels, then aggregates these to reflect global fuel markets. Regional systems are linked through international trade, technological progress, and diffusion effects, so changes in one area, such as wider uptake of renewables, or shifts in consumption patterns, spill over elsewhere. PROMETHEUS calculates future energy demand, supply mixes (including power generation technologies), carbon emissions, energy prices, and investment needs up to 2050. It provides detailed energy balances and quantitative indicators (e.g., emissions, fuel prices, technology shares) to assess how specific policies reshape both demand and supply structures over time.

In addition, **Aalto-EU-TIMES**, a recently developed variant of JRC-EU-TIMES [16], is also used. JRC-EU-TIMES is a technology-rich, bottom-up optimisation model developed by the European Commission's Joint Research Centre (JRC) to represent the EU's energy system from resource extraction through end-use sectors. Built on the TIMES platform [17], the model characterises supply, conversion, and demand technologies across power generation, industry, buildings, and transport, and determines the least-cost investment and operational pathways under defined policy, resource, and technology cost assumptions. The model operates at the country level for the EU-27 plus the UK, Norway, Iceland, and Switzerland, with medium- to long-term time horizons (in five-year steps from 2010 to 2050), capturing interactions between fuel markets, infrastructure constraints, and emissions reduction targets. JRC-EU-TIMES provides policymakers with detailed insights into how technology choices, energy flows, and costs evolve over time. Aalto-EU-TIMES uses the updated datasets for the costs of power generation, hydrogen production, and carbon capture, storage, and utilisation technologies [18]. In this variant, the recent updates related to the ETS, the Effort Sharing Regulation (ESR), the share of renewables in final energy, the energy efficiency, and the Land Use, Land-Use Change, and Forestry (LULUCF) targets have been implemented [19].

In this analysis, PROMETHEUS provides Aalto-EU-TIMES with the information on global fuel prices and costs of power generation technologies. For the model harmonisation, the cost assumptions for electric vehicles and heat pumps in Aalto-EU-TIMES are also updated to match the dataset used in PROMETHEUS [18]. We also harmonise the two models based on their final energy consumption in the buildings sector. To do so, since the demand assumptions of Aalto-EU-TIMES significantly differ from those of PROMETHEUS, we constrain the primary energy consumption from 2030 to 2050 for Aalto-EU-TIMES, based on the corresponding values in the results from PROMETHEUS, using a linear interpolation. This constraint, along with the use of demand elasticity in Aalto-EU-TIMES, helps us to change the demands automatically and, consequently, harmonise final energy consumption. As a result, a deviation of below 10% in the results about the final energy consumption is observed. We also ensure a high degree of consistency across historical emissions.

To evaluate energy transition pathways in the EU's residential sector based on current trends and policies in place, the "*Current Policy (CP)*" scenario is assessed. The CP scenario builds on the existing suite of emission-reduction measures and credible policy targets in place through 2030 across both EU and non-EU countries [19], assuming that, after 2030, climate policy ambition remains at its current level without further strengthening. Specifically, the annual rate of decline in CO_2 emissions per unit of gross domestic product (GDP) observed between 2020 and 2030 is projected to continue unchanged beyond 2030, in line with Sognnaes et al. [20]. To prevent any backsliding on progress achieved, all policy targets established for 2030 are retained as binding floors after 2030, ensuring that improvements in emissions' intensity realised during the period 2020-2030 remain the baseline for subsequent decades. The "CP" scenario has been implemented in both PROMETHEUS and Aalto-EU-TIMES, and the necessary data has been exchanged between the models. In this policy brief, we analyse results from Aalto-EU-TIMES, as the model provides a granular, country-level representation of the residential sector in EU-27 plus the UK, capturing a wide range of heating, cooling, and other service technologies across different housing types.

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3 Results

3.1 Regional level

Simulation results confirm more than a doubling in the share of electricity in the final energy consumption in the residential sector across EU-27 plus the UK from 2016 to 2050 (**Fig. 1a**). The share grows from 24.6% in 2016 to 55% in 2050, with the largest increase taking place during the decade 2030-2040. This increase is driven by the EU's climate policies and targets, including electrification of heating and cooking, growing use of electric appliances, and the shift to cleaner electricity while fossil fuels are being phased out.

Electrification leads to a corresponding decline in households' use of fossil fuels, which by mid-century accounts for only a minor share of the final energy consumption in most countries' residential sector. In 2016, natural gas, heating oil, liquified petroleum gas (LPG), and coal cover 37.5%, 7.2%, 5.2%, and 3.2% of the residential fuel basket, respectively. Coal is phased out before 2035, heating oil is phased out before 2040, LPG is phased out by 2050, while natural gas covers 6.5% of households' energy mix by 2050.

Key finding: By 2050, nearly half (13 out of 28) of the European countries under study (EU-27 plus the UK) surpass the 50% electrification threshold in their households' fuel basket, while biomass emerges as the second most consumed fuel across the region, accounting for 30.4% of the residential energy mix.

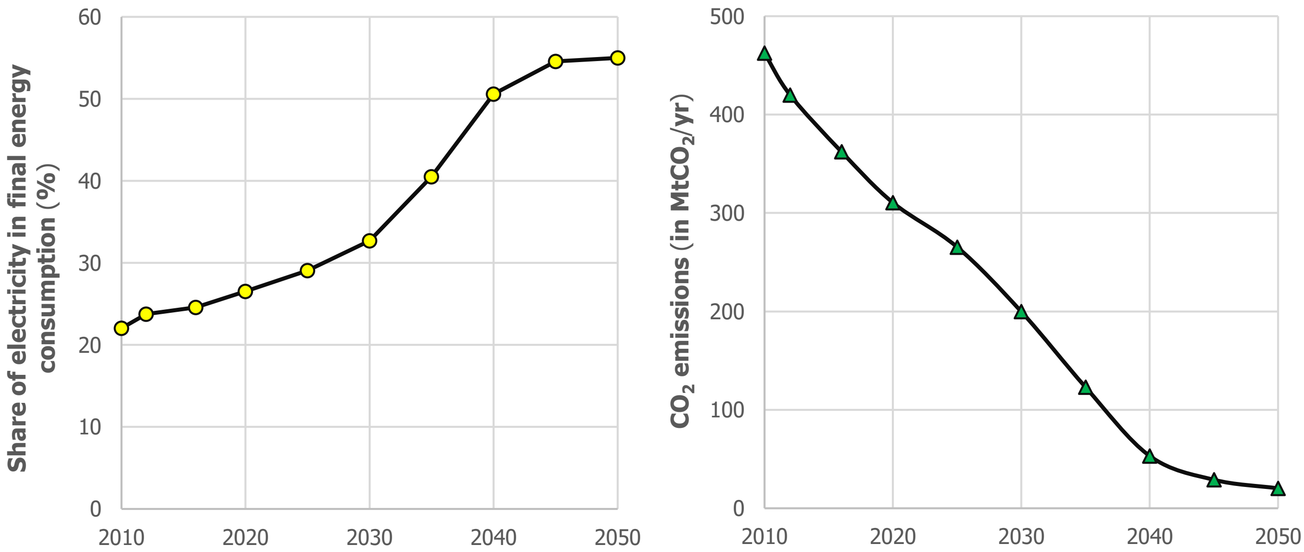

Fig. 1. (**a**). Share of electricity in the residential sector's final energy consumption (%) in the EU-27 plus the UK, under the "Current Policy (CP)" scenario[2]. (**b**). CO_2 emissions (in $MtCO_2$/yr) in the residential sector in the EU-27 plus the UK, under the "Current Policy (CP)" scenario[3].

Residential sector's CO_2 emissions fall sharply in parallel with electrification and the phase-out of fossil fuels (**Fig. 1b**). From 2016 to 2050, households' emissions decrease by 94.4%, also reflecting the lower overall energy use due to significant gain from energy-efficiency measures, i.e., the total final energy consumption is reduced by 50.5% from 2016 (11.2 PJ) to 2050 (5.5 PJ)[4]. The latter highlights that sectoral emissions reduction is not only a function of switching fuels but also of achieving energy savings through improving the EU buildings' performance.

[2] According to the results of the Impact Assessment on the 2040 climate target, the share of electricity in the residential sector is projected to grow from one fourth today to just above 40% in 2030, 53-56% in 2040, and up to 60% in 2050 [34].
[3] Direct CO_2 emissions from buildings in the residential sector experience a rapid decrease already in this decade, from about 320 $MtCO_2$ in 2015 to 135 $MtCO_2$ in 2030, i.e., -57%. Then, CO_2 emissions further reduce to about 35-65 $MtCO_2$ in 2040 and reach almost zero emissions in 2050 [34].
[4] Moreover, residential buildings' consumption is expected to decrease by 44% in 2050 compared to 2015 levels [35].

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3.2 National level

Russia's invasion of Ukraine accelerated the adoption of heat pumps across the EU, as surging natural gas and electricity prices prompted consumers to shift towards more energy-efficient heating technologies. In response to the energy crisis, the EC announced in 2022 its intention to double the deployment rate of heat pumps [10]. As a result, nearly 3 million heat pumps were sold across Europe that year, an increase of almost 40% compared to 2021 [21]. The EU market grew by approximately 35%, with countries such as **Poland**, **the Netherlands**, **Italy**, and **Austria** recording sales in the first half of 2022 that were roughly double those of the same period in the previous year [22]. Emerging markets like **Poland** and **the Czech Republic** saw their markets double in size, while **Italy**, **France**, and **Germany** together accounted for nearly half of all the European heat pump sales. In the **Nordic countries**, where heat pumps are an already well-established heating solution, nearly five times as many units were sold per household compared to the rest of the Europe [21].

Strong sales growth continued into the first half of 2023, with heat pump sales rising by 75% in **Germany**, **the Netherlands**, and **Sweden** combined. However, a slowdown took place in other markets, including **Italy**, **Finland**, and **Poland**, where sales declined in 2023 [23]. In light of this mixed outlook, the European Heat Pump Association (EHPA) has called for stable and consistent policy frameworks to provide clarity for investors and consumers and to accelerate a green transition in the European residential sector [13]. Several European countries have either implemented or announced bans on the installation of boilers powered exclusively by fossil fuels [21]. As of 2022, **the UK**, **Norway**, and seven EU countries, together responsible for 80% of Europe's residential gas use, had introduced or planned such bans for new or existing buildings [24]. In 2023, several governments clarified their phase-out timelines and minimum energy performance standards (MEPS) for heating systems, though others postponed their plans due to concerns over public acceptance and implementation challenges [13].

Overall, our analysis shows that despite the shared regional climate targets, the European countries under study (EU-27 plus the UK) follow distinct transition pathways due to differences in economic conditions, starting points in the energy transition, and policy ambition levels.

3.2.1 Electrification rates by country

Because of these boundary conditions, the transition to electrification in the European residential sector follows different trajectories (**Figure 2**). *Electrification leaders* like **France**, **Portugal**, **Spain**, and **Sweden** attain a relatively high share of electricity in their households' fuel basket by 2030 (44%, 48%, 53%, and 58%, respectively). This increasing trend is further strengthened by 2050 for France, Portugal, and Spain (64%, 75%, and 69%, respectively), while the electrification trend in Sweden stabilises at around 58% between 2030 and 2050, due to increased gains from energy efficiency, which reduce total heating demand while electrification trends remain high. These countries benefit from established electric and biomass heating systems, or district heating systems in the case of **Sweden**. In **France**, the installation of gas boilers in new buildings has been banned since 2022, and the government has considered extending this ban to existing buildings from 2026 [25]. However, in September 2023, the French President ruled out such a ban for existing properties [26]. Additionally, France prohibits the full-time rental of buildings with very low energy performance (above 450 kWh/m²), with stricter regulations to follow: rentals will be banned for properties rated an Energy Performance Certificate (EPC) class G from 2025, class F from 2028, and class E from 2034 [13]. In 2022, for the first time, heat pump sales in France surpassed those of fossil-fuel boilers, a milestone that coincided with the first year of the gas boiler ban in new buildings.

Despite declining demand for fossil-fuel boilers across other major European markets, these systems continue to hold a larger market share than heat pumps [21]. These countries' leadership in electrification is further underpinned by a combination of favourable policy environments, strong investment in renewable electricity infrastructure, and government incentives for clean heating technologies, such as heat pumps. In **Portugal** and **Spain**, the relatively mild climate significantly supports this transition: electric heating systems, particularly heat pumps, operate more efficiently and economically in warmer regions, where peak heating demand is lower and seasonal temperature fluctuations are less severe. Meanwhile, France leverages its low-carbon electricity mix, largely supplied by nuclear power, to advance clean heating, and Sweden builds on its mature district heating

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and biomass sectors as well as high energy-efficiency standards.

Fast adopters such as **the Netherlands**, **Germany**, **the UK**, and **Ireland** begin with lower electrification rates than the *electrification leaders* but are projected to make substantial gains, reaching 25%, 30%, 34%, and 37% in 2030, and 65%, 65%, 67%, 77% in 2050, respectively (**Figure 2**). Despite their lower baseline levels, stemming from an entrenched reliance on fossil fuels, such as natural gas, heating oil, LPG, and coal, which are all prevalent in the residential fuel baskets of **Germany**, **the UK**, and **Ireland**, *fast adopters* are making rapid progress, supported by a mix of regulatory reforms and targets. **The Netherlands** has emerged as a frontrunner in buildings' decarbonisation by banning gas boiler installations in new buildings since 2018 and introducing municipal-level heat transition plans. In 2022, the government also set a new standard requiring hybrid heat pumps to replace existing gas boilers from 2026 [13].

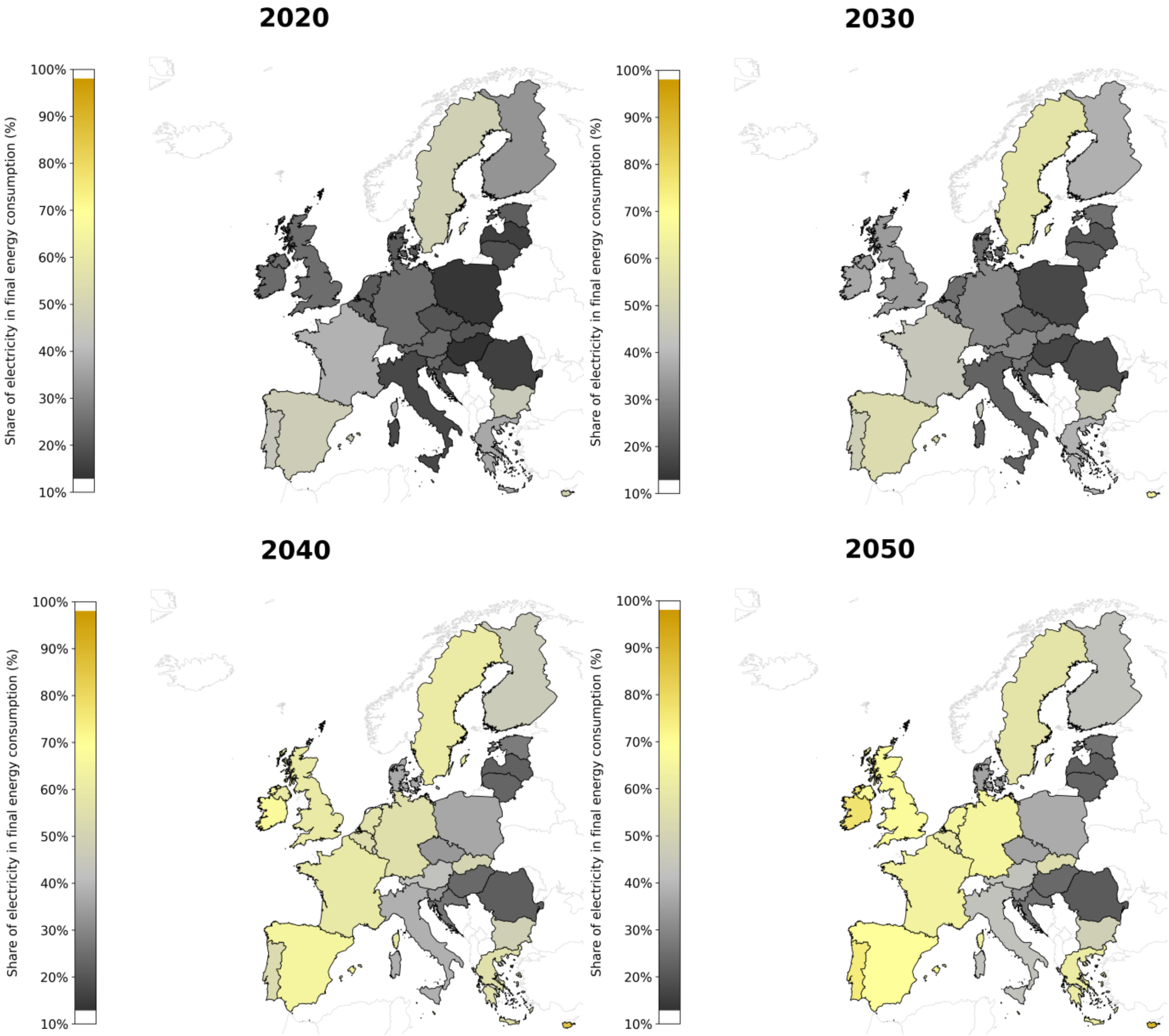

Figure 2. Share of electricity in the residential sector's final energy consumption (%) across the EU-27 plus the UK in 2020, 2030, 2040, and 2050, under the "Current Policy (CP)" scenario.

Germany's "Building Energy Act" mandated that new heating systems must source at least 65% of their energy from renewables, a requirement that was originally intended to apply to all new installations in both newly built and existing buildings starting in 2024, supported by federal initiatives for local heat planning [27]. However, following extensive parliamentary negotiations, an amendment was passed stipulating that the 2024 deadline will apply only to buildings in newly developed areas. For all other new and existing buildings, the requirement has been postponed to 2026 in larger cities and to 2028 in other regions [28]. Despite this policy shift, the market remains dominated by fossil-fuel technologies: in 2022, the sales of fossil-fuel boilers in Germany were double those of heat pumps. Nevertheless, proposals are under discussion to phase out the most polluting heating technologies and fuels.

The **UK** has set a target to install 600,000 heat pumps annually by 2028 and to phase out the sale of most new fossil-fuel boilers by 2035. Originally, the government planned to ban the installation of new oil, LPG, and gas boilers in newly built homes from 2026, and to prohibit new gas boilers in existing buildings from 2035. However, these timelines have since been revised: the full phase-out is now set for 2035, with an exemption for 20% of households [29]. To drive the transition towards low-carbon heating, the government has introduced the "Boiler Upgrade Scheme", a financial incentive programme aimed at supporting the replacement of fossil-fuel heating systems with heat pumps or biomass boilers. Similarly, **Ireland** is providing policy support to replace fossil fuels in buildings, with a ban on the installation of new fossil-fuel heating systems set to take effect after 2035. While colder climates in these countries present additional challenges, such as higher peak heating demand and longer heating seasons, these are being addressed through expanding renewable electricity capacity, increased heat pump installations and improvements in their efficiency, and financial incentives to support household adoption. These efforts demonstrate a swift transition away from fossil-based heating, even in regions starting from a more carbon-intensive baseline.

Conversely, *slow adopters* including the **Baltic states** (**Estonia**, **Latvia**, and **Lithuania**), and **Romania** remain heavily reliant on biomass, district heating, and natural gas, with electricity comprising less than 26% of their residential energy use even by 2050 (**Figure 2**). This slower transition is largely due to worse economic conditions compared to the rest of the countries under study that limit investment in new technologies and infrastructure with high upfront investment costs, such as heat pumps. Moreover, these countries remain dependent on existing fossil-fuel infrastructure, such as extensive natural gas networks, which are costly and complex to replace. The latter creates a form of lock-in, making the shift to electrification more difficult and costly.

It is worth noting that **Denmark**, which banned the installation of gas and oil boilers in new buildings as early as 2013 and aims to phase out all remaining fossil-fuel boilers by 2029 through the expansion of district heating and heat pumps [13], continues to rely primarily on district heating for residential energy demand until 2035. After this point, the energy mix shifts further, with biomass and electricity accounting for the largest shares by 2050.

3.2.2 CO_2 emissions reduction across countries

Emissions reduction trajectories in the residential sector also vary significantly across the countries under study, reflecting underlying differences in starting points, energy system structures, policy ambition, and the pace of electrification (**Figure 3**). *Decarbonisation frontrunners* include the **Nordic countries** (**Finland** and **Sweden**), which are projected to reduce residential emissions by 87% and 97%, respectively, until 2035, compared to the 2016 levels. Both countries achieve deep reductions between 2030 and 2035; this is largely the result of an already low-carbon energy mix, the widespread use of district heating and biomass, high energy-efficiency standards, and the rapid deployment of electric heating systems. The rapid adoption of electric heating technologies, particularly heat pumps, has also played a central role; over 40% of residential buildings in both Finland [30] and Sweden [31] are equipped with heat pumps, demonstrating their suitability even in cold climates. Nevertheless, the two countries accounted for only 0.4% of the total CO_2 emissions in the European of the EU-27 plus the UK region's residential sector in 2016, so their impact on the overall EU's targets is relatively limited despite their ambitious trajectories.

Major emitters (i.e., **Belgium**, **Germany**, **France**, **Italy**, **the Netherlands**, **Poland**, **Spain**, and **the UK**) achieve gradual yet substantial drops, reaching over an 80% of CO_2 emissions reduction in the residential sector by 2040, following more incremental improvements over time (**Figure 3**). These countries begin with higher levels of fossil-fuel use in residential heating, which makes their transition more complex. However, their decarbonisation targets are mainly driven by a combination of long-term climate targets, increasing carbon prices associated with the recent ETS updates, and robust policy packages to support electrification. As a result, these countries are making strong progress in shifting their residential energy mix towards electricity, primarily through the expansion of renewable energy and the further deployment of heat pumps.

Conversely, *lagging countries*, like **Luxembourg** and **Romania,** are projected to reach only 67% and 86% reductions by 2050, respectively (**Figure 3**). These outcomes show limited ambition, suggesting structural and policy-related barriers. In Romania, for instance, slower electrification reflects lower income levels, limited access to clean heating alternatives, and reliance on heating systems that are difficult to modernise, while Luxembourg's slow progress is partly driven by its higher energy consumption per capita compared to the average levels in the EU-27 plus the UK region. Although Luxembourg has announced a phase-out of fossil-fuel heating when replacing existing boilers, this measure initially remains voluntary, limiting its immediate impact [32].

It is important to note that some countries, such as **Portugal**, start with lower total CO_2 emissions compared to the region's average, which means their potential for further reductions is naturally more limited. However, this does not imply a lack of progress; rather, it reflects a slower pace of reduction while maintaining a strong overall position in terms of decarbonisation.

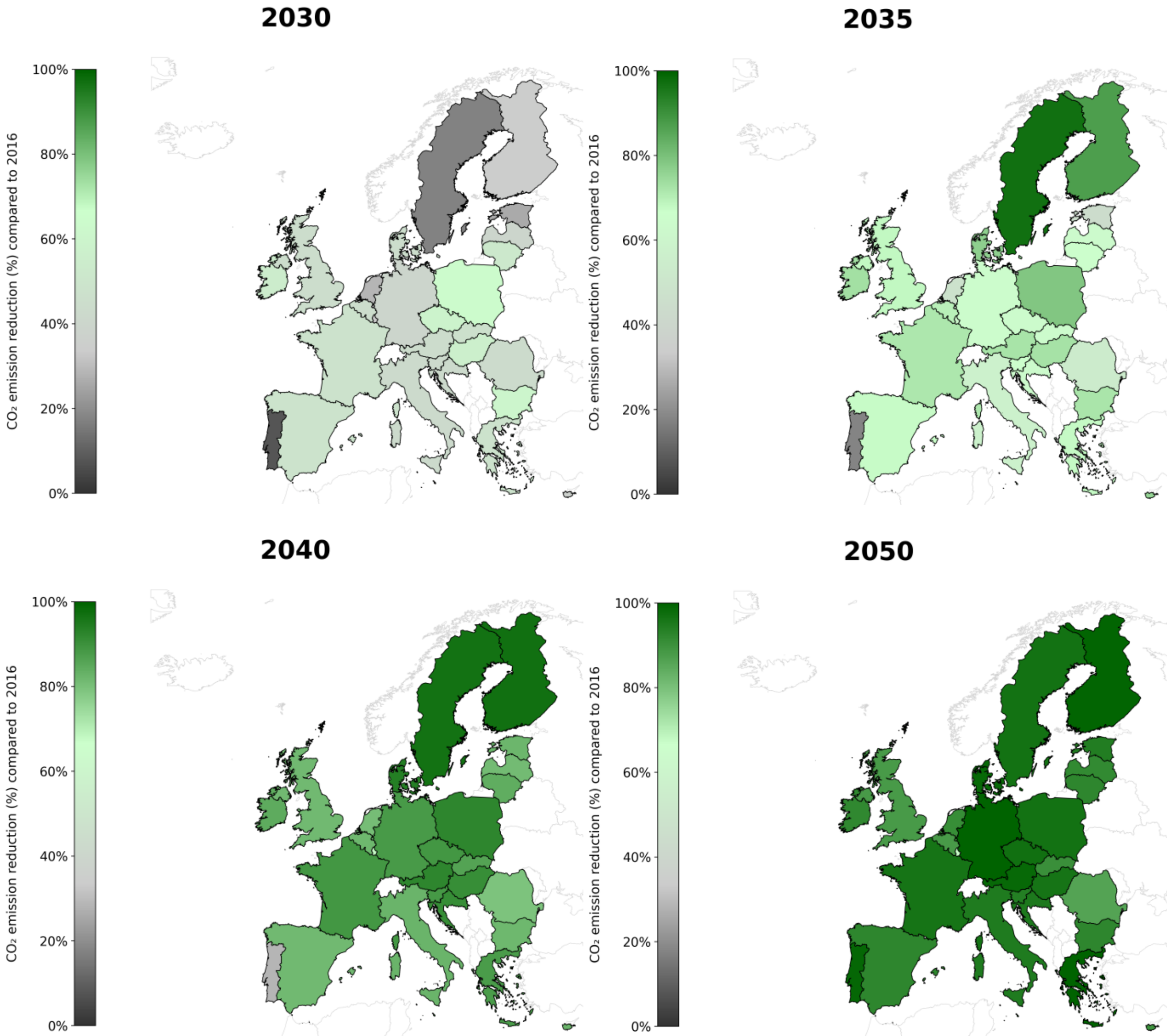

Figure 3. CO_2 emissions reduction in the residential sector across the EU-27 plus the UK region in 2030, 2035, 2040, and 2050, under the "Current Policy" scenario (compared to the 2016 levels).

Overall, the variation in emissions reduction levels is closely tied to the speed and the scale of electrification in each country. *Fast adopters* expect better progress, while countries with greater fossil-fuel dependency, infrastructure inertia, or limited financial capacity are expected to progress more slowly. These differences stem from a mix of climatic, structural, and socioeconomic factors. For example, the design and the condition of national housing stocks affect their retrofit potential, while climate variability affects the attractiveness of technologies like heat pumps. Cultural habits and attitudes towards energy use also shape adoption rates. Policy coherence is crucial, yet fragmented governance often hinders progress. Disparities in fiscal and institutional capacity limit the ability of less affluent Member States to finance public investments, or support household upgrades, slowing their progress. These combined factors lead to uneven progress and underscore the importance of context-sensitive policies to enable all countries to contribute effectively to the European residential sector's transition.

4 Implications for policy and practice

This policy brief highlights that, while deep decarbonisation in the European residential sector through electrification is technically feasible and already underway in many parts of Europe, achieving equitable and timely progress requires a well-targeted and multi-level policy response. Our modelling underscores both regional successes and disparities that demand nuanced action.

I1. Plan for a fair and regionally/ nationally tailored energy transition
Southern and Eastern European countries face unique challenges that shape their electrification potential, including climatic differences (e.g., *higher seasonal variations due to heating and cooling needs*), economic barriers (e.g., *high upfront investment costs*), and structural constraints (e.g., *availability of skilled installation companies*). The stark contrast in electrification and emission reduction trajectories between frontrunner and lagging countries highlights that a "one-size-fits-all" approach is insufficient.

Recommendation: Electrification strategies must be tailored to regional and national differences through flexible, context-sensitive policy instruments that ensure a fair and inclusive transition across all the European countries. EU funding mechanisms should be more responsive to these national contexts by prioritising support and allocating greater resources to countries facing limited fiscal capacity and higher transition costs. These mechanisms could go beyond current subsidiarity by introducing dedicated flexibility windows, rapid reallocation tools, and targeted technical assistance facilities that respond in real time to local electrification bottlenecks identified through standardised EU-wide diagnostics. This would allow Cohesion Fund, Recovery and Resilience Facility, and InvestEU resources to be dynamically adjusted to regional realities, such as grid constraints or climate-driven heating and cooling needs, rather than being locked into pre-programmed allocations.

I2. Accelerate electrification by strengthening infrastructure and energy renovations
Electrification requires not just cleaner electricity but also the physical and institutional capacity to deliver it.

Recommendation: In light of the preparation of the European Grids Package, upgrading the distribution grid is essential to accommodate rising household electricity demand. However, national governments should also significantly increase investments in self-consumption, storage, and smart-home technologies (e.g., smart heat pumps) to provide grid operators with additional demand flexibility, while ensuring that the energy transition does not rely excessively on grid expansion alone.

I3. Enable a diversified and accelerated renewable-based heating transition
Achieving decarbonisation in the European heating sector requires both a rapid scale-up of renewable energy and district heating solutions and a decisive phase-out of fossil-fuel boilers.

Recommendation: Member States should implement integrated, technology-neutral support schemes that encourage the adoption of a wider range of renewable-based heating and cooling solutions, including heat pumps and geothermal energy, to reduce reliance on bioenergy. They should also upgrade district heating and cooling systems into smart thermal networks to enhance flexibility in power grids. In parallel, they should also set binding national deadlines for phasing out fossil-fuel boilers in existing buildings well before 2040. Coordinating these efforts will accelerate the transition to low-carbon heating systems across Europe.

I4. Mobilise and scale up investments for an inclusive "Renovation Wave"
Achieving a zero-emission building stock requires a rapid scale-up of deep and staged renovation efforts, supported by the ambitious and timely implementation of the EPBD and the EED, which establish the regulatory framework for improving building energy performance and driving energy savings across Europe [33].

Recommendation: In line with the Energy Efficiency First principle, support should prioritise energy efficiency measures on an equal footing with renewable energy solutions. Member States should align higher levels of financial support with ambitious (staged) deep renovation projects that exceed minimum energy performance standard (MEPS) requirements, with a particular focus on Worst Performing Buildings (WPBs). Prioritising WPBs helps ensure compliance with the EPBD's MEPS, achieves the deepest renovation and greatest energy savings compared to other buildings, and addresses social equity since vulnerable populations often reside in these buildings. Member States must also ensure that public financial resources are used efficiently and distributed equitably, envisioning support for vulnerable and low-income households, to guarantee an inclusive "Renovation Wave" that leaves "no one behind" and accelerates the shift toward zero-emission buildings.

I_5. Build local delivery capacity and empower households

Implementation success depends on local actors and households' willingness to engage in the transition, both of which are shaped by barriers, such as *access to information about investments* and *cultural preferences*, e.g., attitudes towards heat pumps and small-scale solar photovoltaic (PV) systems.

Recommendation: EU and national programmes should invest in training local authorities, offer subsidies, or low-interest loans for households, and launch information campaigns at the local level to boost technology uptake. They should also support the establishment and strengthening of one-stop shops pursuant to Article 22 of the EED and Article 18 of the EPBD, which can provide citizens with streamlined access to renovation services, advice, and financing options.

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IAM COMPACT

Policy Brief

Energy transition trends in the European residential sector: Outlook for the EU-27 plus the UK by 2030 and 2050

In a nutshell

IAM COMPACT supports the assessment of global climate goals, progress, and feasibility space, and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030 for major emitters and non-high-income countries. It uses a diverse ensemble of models, tools, and insights from social and political sciences and operations research, integrating bodies of knowledge to co-create the research process and enhance transparency, robustness, and policy relevance. It explores the role of structural changes in major emitting sectors and of political, behaviour, and social aspects in mitigation, quantifies factors promoting or hindering climate neutrality, and accounts for extreme scenarios, to deliver a range of global and national pathways that are environmentally effective, viable, feasible, and desirable. In doing so, it aligns climate action with broader sustainability goals, while developing technical capacity and promoting ownership in non-high-income countries.

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