1.5°C Pathways for the EU27:

accelerating climate action to deliver the Paris Agreement

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Supplementary material

A digital copy of this report is available at: www.climateanalytics.org/publications.

Citation and acknowledgments

This report was updated in March 2023 to improve the region mapping used to downscale data from global 1.5°C compatible pathways to the EU27 member states and improve the treatment of non-energy demand for oil and gas in the industrial sector.

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About Climate Analytics

Climate Analytics is a non-profit institute leading research on climate science and policy in relation to the 1.5°C limit in the Paris Agreement. It has offices in Germany, the United States, Togo, Australia, Nepal and Trinidad and Tobago.

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Executive summary

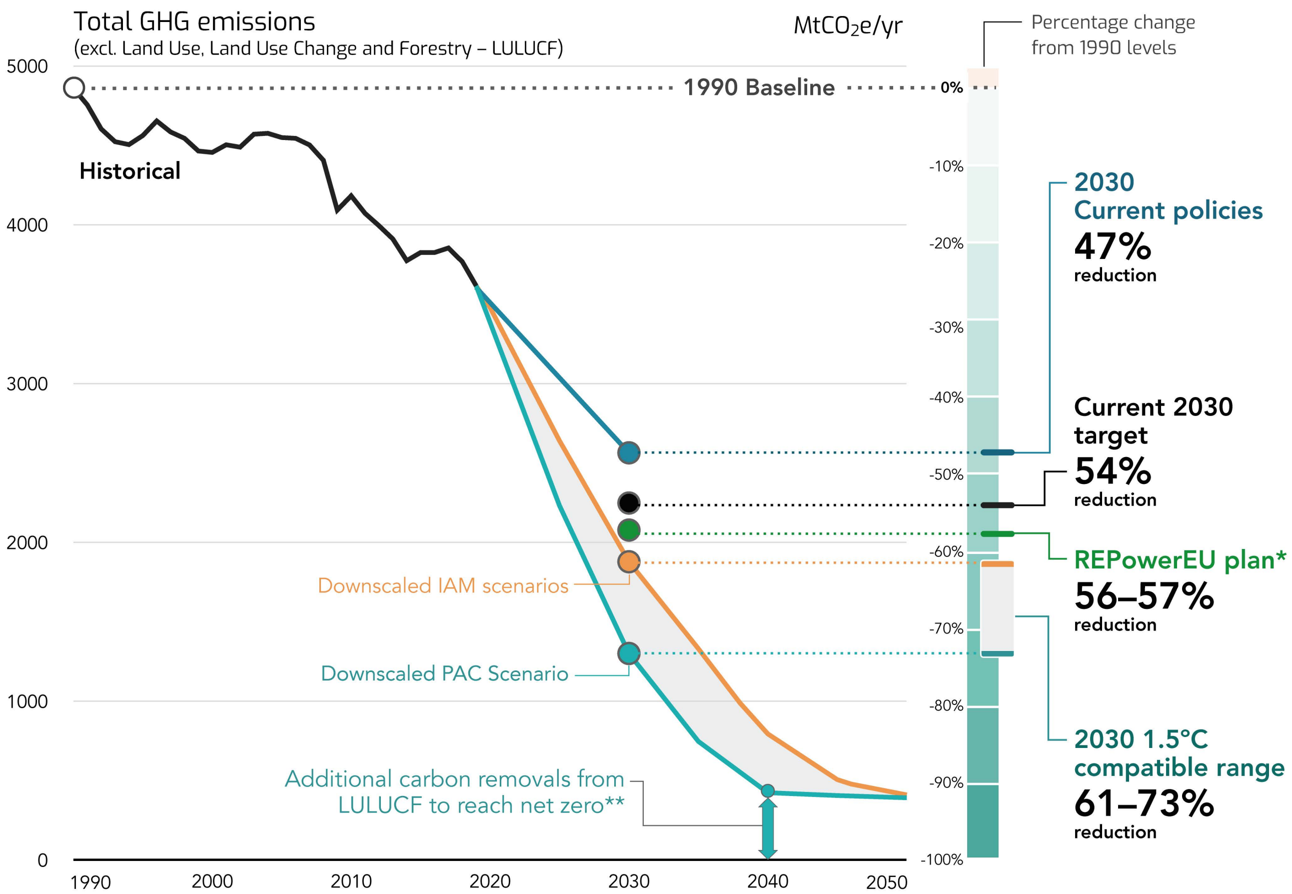
Global action remains insufficient to meet the Paris Agreement's long-term temperature goal. Increasing the ambition of 2030 climate targets and accelerating emissions reductions in this decade are essential. This report presents technically feasible 1.5°C compatible energy and emissions pathways for the EU27 and assesses whether the EU's current 2030 climate targets are aligned with limiting warming to 1.5°C.

The report finds that, to be 1.5°C compatible, the EU27 would need to cut its domestic emissions faster than currently planned. 1.5°C compatible pathways assessed in this report, and filtered to meet sustainability constraints, show that the EU27 can feasibly:

- Reduce its greenhouse gas (GHG) emissions between **61-73% below 1990 levels** excl. land use, land use change and forestry (LULUCF). Accounting for LULUCF, this corresponds to a **64-77% reduction by 2030, relative to 1990 levels**
- Reach net zero GHG emissions between **2040-2047**
- Limit the EU27's total cumulative CO_2 emissions to **12-23GtCO_2** from 2020 until mid-century (incl. LULUCF)

The analysis therefore suggests that the EU27's current Nationally Determined Contribution (NDC), which aims to cut emissions by 55% below 1990 levels by 2030 (incl. LULUCF), cannot be seen as compatible with 1.5°C.

The EU is accelerating its energy transition, but remains off-track for 1.5°C



* In light of Russia's illegal invasion of Ukraine, the EU27 is accelerating its energy transition via the REPowerEU plan, which further accelerates renewables deployment and efficiency improvements.

** To achieve the net zero emission target, emissions from LULUCF need to be reduced while increasing the capacity of forests, wetlands, grasslands and farmlands to remove carbon. These carbon removals are not equal to emissions in other sectors and the two cannot simply be considered fungible.

This figure shows domestic 1.5°C compatible GHG emissions for the EU27, compared to current policies and targets proposed by the bloc. The EU's current policies and targets do not align with 1.5°C, as assessed in this report. All targets and plans are converted to exclude LULUCF and international aviation and shipping within the EU27. Historical data is taken from PRIMAP (Gütschow et al 2021).

The report also demonstrates how the EU27 could achieve these 1.5°C compatible benchmarks through a rapid transition to an efficient energy system powered by renewable energy sources. It focuses on two illustrative pathways, the HighRE scenario and the PAC scenario. The HighRE scenario is a downscaled version of an integrated assessment model pathway which relies on low-cost renewables to limit warming to 1.5°C while reducing reliance on bioenergy and carbon dioxide removal. The PAC scenario provides a bottom-up perspective on how the EU27+UK can reach absolute zero CO_2 emissions by 2040. These pathways are produced by different methodologies, which gives a more robust assessment of 1.5°C compatible action for the EU27.

In these pathways, electricity provides **67-70%** of final energy in 2050. There are also strong and sustained reductions in final energy demand, which means that by 2050, total energy demand in the EU27 can be up to **56%** lower than in 2019. Overall, renewables provide **52-54%** of final energy demand in 2030, rising to **95-100%** of final energy by 2050.

Fossil fuels are rapidly displaced from the energy system in 1.5°C compatible pathways for the EU27. In the most ambitious pathways, coal is phased out of the energy system by the **2030**, and oil/gas by **2040** at the latest**.** There is a particularly strong action in the power sector, where rapid deployment of wind and solar is the cornerstone of the energy transition. Key milestones for the power sector in these illustrative pathways include:

- Coal phased out of power generation **by 2030** and fossil gas by the **mid-2030s**
- A transition to **100% fossil-free electricity** by the mid-2030s
- Electricity generation **more than doubling** by 2050

It is clear that the EU27 can and must do more to align with the Paris Agreement's 1.5°C target and provide global leadership on the climate crisis. By providing an updated NDC which aims to cut emissions by at least 64% (incl. LULUCF) by 2030, by committing to 100% fossil-free electricity by the mid-2030s, and by bringing forward the date of net zero GHG emissions by up to a decade, the EU27 can drive ambitious climate action and help keep 1.5°C alive.

Contents

1 Introduction

Achieving the Paris Agreement's long-term temperature goal requires rapid, large-scale, and sustained reductions in global greenhouse gas (GHG) emissions. The latest report from the Intergovernmental Panel on Climate Change (IPCC) found that global GHG emissions need to fall 43% by 2030 relative to 2019, and CO_2 emissions reach net zero around mid-century, in pathways which limit warming to 1.5°C with no or low overshoot (IPCC 2022b). Achieving such transformative change requires ambitious leadership from every country in the world.

To date, this leadership is still lacking at a global level. The world is not on track to limit warming to the Paris Agreement's long-term temperature goal. Current 2030 targets, or Nationally Determined Contributions (NDCs), put the world on a path to approximately 2.4°C of warming by 2100, if fully implemented (Climate Action Tracker 2021). This is almost a full degree above the 1.5°C limit. It is essential that governments substantially strengthen their NDCs and take action to achieve greater emissions reductions by 2030. At COP26 in Glasgow, the parties to the Paris Agreement acknowledged this, and agreed to 'revisit and strengthen' their pledges in advance of COP27 in Egypt (UNFCCC 2021). At the same time, Russia's invasion of Ukraine has further highlighted the benefits of energy independence and the need to rapidly reduce fossil fuel consumption.

In this context, every country should re-assess their climate targets in the run-up to COP27, considering whether their current action is aligned with 1.5°C, and if not, taking steps to close the ambition gap. This report provides such information for the EU27. It assesses whether the EU27 could improve its most recently submitted NDC, which aims to cut the bloc's emissions by 55% below 1990 levels by 2030.

Industrialised economies such as the EU27 have a critical role to play in the transition to a zero-carbon future. The EU should be a leader in the global efforts to address climate change, considering its historical responsibility for climate change and its economic and regulatory capacity to do so. The EU must therefore reduce domestic emissions in line with the highest plausible ambition, while also supporting decarbonisation in developing countries by providing climate finance. This report focuses on the EU's own emissions target. However, for the EU to contribute its "fair share" to climate action, it also needs to substantially increase its support for climate action in developing nations (Climate Action Tracker 2022).

The report uses the latest evidence from the IPCC (Byers *et al* 2022), as well as other lines of scientific evidence, to explore 1.5°C compatible action for the EU27. The analysis focuses on the level of emissions reduction by 2030, the date of net zero GHG emissions, the transition in final energy demand, and the transition to a decarbonised electricity sector. A range of 1.5°C compatible benchmarks can be derived for the EU27.

This report shows that the EU27 can considerably increase the ambition contained in its 2030 NDC. In pathways consistent with the highest plausible ambition for the EU27, emissions fall 63-73% below 1990 levels by 2030 (excl. LULUCF). The current 'Fit for 55' target falls short of 1.5°C compatible pathways by 500-1000MtCO_2e in 2030. While actions contained in the RePowerEU plan go some way to closing this gap, there remain technically feasible routes to higher near-term action. Our analysis also shows that, by rapidly reducing fossil fuels while preserving and expanding the LULUCF sink, net zero GHG emissions could be reached by 2040 in the EU27, a full decade ahead of the current target.

The pathways assessed in this report involve a rapid upscaling of renewable energy over the coming decades, with wind and solar the cornerstone of the energy transition. The EU27 achieves close to 100% fossil-free power generation by 2035 in these pathways. The transition to a more electrified and efficient energy system, coupled with behavioural and societal change, leads to strong reductions in final energy demand. This enables the rapid phase-out of fossil fuels from the energy system. This demonstrates that the EU27 can still align itself with the 1.5°C target, but only by drastically increasing the action taken in this decade.

2 Latest mitigation pathways consistent with the 1.5°C temperature limit

2.1 The goal of the Paris Agreement

In 2015, countries adopted the Paris Agreement. Article 2.1 of the Paris Agreement commits signatories to "[…] strengthen the global response to the threat of climate change […], including by holding the increase in the global average temperature to well below 2°C […] and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC 2015).

The Glasgow COP in 2021 reinforced the 1.5°C limit in the Paris Agreement and recognized "that limiting global warming to 1.5 °C requires rapid, deep and sustained reductions in global greenhouse gas emissions, including reducing global carbon dioxide emissions by 45 per cent by 2030 relative to the 2010 level and to net zero around mid-century as well as deep reductions in other greenhouse gases" (UNFCCC 2022).

Article 4.1 of the Paris Agreement outlines key elements that would operationalize the achievement of this long-term temperature goal (LTTG), including:

- To "reach global peaking of greenhouse gas emissions as soon as possible"
- To "undertake rapid reductions thereafter in accordance with best available science"
- To "achieve a balance between anthropogenic emissions by sources and removals by sinks in the second half of this century"

The Agreement establishes a mandatory requirement for all parties to take action to contribute to the reduction of global greenhouse gas emissions. It further affirms that action taken for implementation should "reflect equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR)".

Therefore, in order to make a fair contribution to meeting the Paris Agreement's goals, developed countries need to both undertake domestic emissions reductions and assist developing countries to reduce their emissions through both financial and technological transfers. A developed country's total "fair share" action range is the total sum of domestic reductions plus support for emission reductions overseas (Climate Action Tracker, 2018).

2.2 Highest plausible ambition

A variety of equity principles can be used to distribute global climate effort across different countries and regions. The pathways considered in this report do not align with a particular equity principle but instead use the concept of "highest plausible ambition". For the EU27, we define this as 1.5°C compatible pathways that are technically and economically feasible, that demonstrate the steepest near-term GHG emissions reductions and that do not violate sustainability criteria as laid out in section 2.3. Where these pathways are not aligned with the EU27's "fair share" climate action, as outlined in assessments such as that from the Climate Action Tracker, then the EU27 would need to either outperform these pathways (by taking further action that has not been considered in the pathways), or increase the provision of finance to support emissions reductions in less wealthy countries (Climate Action Tracker 2022).

2.3 How are the EU27 1.5°C compatible pathways derived?

2.3.1 Selecting scenarios

This project uses four 1.5°C compatible pathways to assess the EU27's role in addressing climate change. These include three scenarios produced by the integrated assessment modelling framework REMIND, and the Paris Agreement Compatible (PAC) scenario. These pathways are briefly summarised in Table 1.

Table 1: 1.5°C compatible scenarios selected for analysis

Model	Scenario	Report Abbreviation	Description	Source
PAC Model	Paris Agreement Compatible (PAC)	PAC	A bottom-up energy system scenario for the EU27+UK. This achieves absolute zero CO_2 emissions in the EU27+UK energy sector by 2040.	(Mühlenhoff and Bonadio 2020)
REMIND 2.1	R2p1_SSP1-PkBudg900	SSP1	A global scenario that limits warming to 1.5°C with no/low overshoot. This scenario uses the SSP1 socio-economic pathway, representing a more sustainable future in which there is reduced consumption, greater equity, and continued progress in low-carbon technologies.	(Baumstark *et al* 2021)
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000	SusDev	A global scenario that limits warming to 1.5°C with no/low overshoot. This scenario has an explicit focus on achieving the SDGs via sufficient and healthy nutrition, improved access to modern energy in the developing world, and ambitious lifestyle shifts in industrialised countries.	(Soergel *et al* 2021)
REMIND-MAgPIE 2.1-4.2	DeepElec_SSP2 HighRE_Budg900	HighRE	A global scenario that limits warming to 1.5°C with no/low overshoot. This scenario displays highly ambitious near-term emissions reductions, underpinned by high renewable deployment.	(Luderer *et al* 2021)

Integrated Assessment Model scenarios

The three integrated assessment model (IAM) scenarios are selected from the latest evidence on pathways compatible with the 1.5°C temperature goal, as assessed by the IPCC in the contribution to the 6th Assessment Report (AR6) from Working Group 3 (WGIII) (IPCC 2022a). The AR6 report provides the most comprehensive assessment to-date of GHG emissions pathways which rapidly reduce emissions in line with the Paris Agreement (Riahi *et al* 2022). It provides the results from numerous different modelled scenarios, presenting a diversity of possible low-carbon futures.

The IPCC SR1.5 defined 1.5°C compatible pathways as those that limit warming to 1.5°C with *no or low overshoot* (<0.1°C.) The AR6 WGIII report assessed 97 pathways that limit warming to 1.5°C with *no or low overshoot*. This means they have:

- More than a 33% chance of limiting warming to below 1.5°C throughout the 21st century, and;
- At least a 50% chance of limiting warming to below 1.5°C in 2100.

The majority of these pathways are simultaneously very likely (>90% chance) to limit warming to 2°C, which means they are compatible with holding warming to "well below" 2°C. They are therefore consistent with the long-term temperature goal as set out in Article 2.1 of the Paris Agreement (Schleussner *et al* 2022). Each pathway reflects a unique set of economic and technological developments that achieves this temperature goal.

As well as the Paris Agreement's long term temperature goal of "holding warming well below 2°C and pursuing efforts to limit warming to 1.5°C", Article 4.1 of the Paris Agreement sets out an objective to achieve a balance between anthropogenic emissions by sources and sinks in the second half of the century. This represents a commitment to achieving net-zero GHG emissions at a global level before 2100, in line with the best available science. We apply this filter to give a set of 49 pathways for analysis, which are consistent with both Article 2.1 and Article 4.1 of the Paris Agreement (Schleussner *et al* 2022).

Of these "Paris compatible" pathways, we further filter to select pathways which limit the use of carbon dioxide removal (CDR) to sustainable levels, using sustainability thresholds from the literature (Fuss *et al* 2018) and that were identified in the IPCC SR1.5. This means they deploy less than 5GtCO_2/y of bioenergy with carbon capture and storage (BECCS) in 2050, and under 3.6GtCO_2/y of afforestation/reforestation in the second half of the century.

Finally, to identify the EU27's "highest plausible ambition", we then filter to select pathways in which the emissions of the European macro region (a larger model region which includes non-EU27 countries such as Norway) fall by at least 62% in 2030, relative to 1990. This represents the upper quartile of the distribution in terms of emissions reductions by 2030, and ensures that selected pathways show a transformative pathway towards a decarbonised energy system and identify what could be described as the highest plausible domestic ambition for the EU27.

This filtering provides two pathways which are compatible with the Paris Agreement, use sustainable levels of CDR, and which demonstrate the highest plausible ambition for Europe[1]. These are:

1 The scenario filtering actually provides three scenarios. However, of these, one was identified as a duplicate and was dropped, leaving two pathways for analysis.

R2p1_SSP1-PkBudg900 (termed "SSP1" in the rest of the report), **SusDev_SDP-PkBudg1000** (described as "SusDev" in this report).

We complement these two pathways with the REMIND-MAgPIE scenario **DeepElec_SSP2_HighRE_Budg900** (described as "HighRE" in this report). While this scenario does not reach net-zero GHG emissions globally, it remains a valuable scenario for the following reasons:

- It still undertakes ambitious emissions reductions compatible with limiting warming to 1.5°C and holding warming to 'well below' 2°C.
- Until the mid-2040s, this scenario is more ambitious than either of the SSP1 and SusDev scenarios, at both a global and European level. It is post-2050 that the HighRE scenario displays slower emissions reductions, which prevent it from reaching net zero GHG emissions at a global level.

The HighRE scenario demonstrates the feasibility of rapidly reducing emissions by relying on renewables. While it does not reach net zero GHG emissions by 2100, the rapid decarbonisation of the energy system by 2050 means this scenario would be well-placed to achieve net zero GHG emissions, if so desired. For example, it could achieve this while still deploying *less* CDR than the SSP1 scenario, or by achieving comparable non-CO_2 emissions reductions as observed in the SusDev scenario. It remains a valuable scenario for analysis, particularly when the timescale of analysis is focused on the pre-2050 period.

Paris Agreement Compatible (PAC) scenario

These three IAM scenarios (SSP1, SusDev and HighRE) are complemented by the Paris Agreement Compatible (PAC) scenario. This scenario was created by Climate Action Network (CAN) Europe and the European Environmental Bureau (EEB), with the aim of identifying a Paris Agreement compatible energy system transition for Europe. The PAC scenario was produced by a mixture of desk research and expert engagement. CAN Europe and EEB reviewed a wide range of existing studies and models, to identify core elements of the 1.5°C compatible energy system transition in Europe. In addition, around 150 expert stakeholders were involved in the scenario building process, via a range of workshops, webinars, surveys and bilateral engagement (Mühlenhoff and Bonadio 2020). The combination of literature review and expert engagement was used to collaboratively build the qualitative narrative and quantitative underpinning of the PAC scenario. The scenario is not the output of a single modelling framework, although elements of the PAC scenario were tested and informed by systems modelling (e.g., modelling European electricity markets with the PowerFlex model and assessing system adequacy via the PyPSA-Eur-Sec open-source energy model).

The combination of IAM pathways and the PAC scenario represents a methodologically diverse set of low-carbon pathways for Europe. This diversity of methodology is valuable, as it can improve the robustness of the resulting 1.5°C compatible benchmarks, and provide insights that a single approach in isolation could miss. It also demonstrates that high ambition pathways for Europe are not contingent on the use of one particular approach. For further illustration of the scenario selection process, see Appendix A.

2.3.2 Scenario downscaling

These pathways do not provide energy and emissions data at the EU27 level, but for a larger geographical region. In the case of the PAC and REMIND scenarios, data is provided for the

EU27+United Kingdom as an aggregate. It was therefore necessary to downscale the results to obtain EU27 energy and emissions pathways.

A downscaling process disaggregates coarse resolution data to a finer spatial scale. In this case, the IAM and PAC outputs are converted from the European level to the EU27 level. This is performed using the SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) tool (Sferra *et al* 2019a). SIAMESE allocates energy consumption to individual countries within the European region by equating marginal fuel prices across all countries. This is equivalent to maximizing welfare in the macro region as a whole, providing a cost-effective allocation of energy demand and emissions across the underlying countries. For more details, see Appendix B.

2.3.3 Emissions from the land use, land use change, and forestry (LULUCF) sector

The PAC scenario is an energy system scenario, and therefore does not report emissions from the LULUCF sector. To ensure comparability across scenarios, the IAM emissions pathways are also shown excluding LULUCF emissions. Separate assumptions can then be made about future LULUCF emissions.

This report uses a set of seven different projections to create estimates for the future EU27 LULUCF sink (European Commission 2020a, Umweltbundesamt 2019, CLIMACT 2018, Nabuurs *et al* 2017, European Commission 2020b, EUCalc 2020) as assessed in a recent literature review (Böttcher *et al* 2021). From the literature review, an average and a maximum future LULUCF sink is calculated. These average and maximum LULUCF sinks are used in the report to convert emissions (excluding LULUCF) into emissions data that covers all sources and sinks.

2.3.4 Introduction to the four selected scenarios

REMIND scenarios

The REMIND (REgional Model of INvestment and Development) model is an integrated assessment model with a special focus on the development of the energy sector and its climate implications (Luderer *et al* 2020). REMIND can be coupled with the global land-use model MAgPIE (Model of Agricultural Production and its Impact on the Environment) (Dietrich *et al* 2018), or run as a standalone energy-economy model.

The goal of REMIND is to find the optimal mix of investments in the economy and energy sectors of each modelled region given a set of population, technology, policy, and climate constraints. REMIND is an energy-economy general equilibrium model that links a macro-economic growth model with a bottom-up engineering-based energy system model. The macro-economic growth model projects growth, savings and investments, factor incomes, energy, and material demand, while a nested production function with constant elasticity of substitution determines the final energy demand. For a full discussion of the model, see Baumstark et al. (2021). REMIND disaggregates the world into eleven "macro regions", including the Europe region, from which the EU27 pathways for this project are derived.

The three IAM scenarios used in this report are all derived from the REMIND modelling framework. Each scenario provides a different perspective on how the world could limit warming to 1.5°C. This diversity of possible low-carbon futures highlights the multiple possible actions the global community could take to reduce emissions.

The **SSP1** scenario (Baumstark *et al* 2021) uses the underlying shared socio-economic pathway SSP1, which represents a shift to a more sustainable society (Riahi *et al* 2017, van Vuuren *et al* 2017b). In this scenario, there is moderate progress towards the Sustainable Development Goals (SDGs). Greater access to education, healthcare and modern energy leads to improved equality within and between regions. As well as development progress, there are some shifts which help enable stronger climate action in this scenario. These include changes in consumption patterns towards low material growth, and greater progress in resource and energy efficiency. This therefore represents a future in which climate action occurs alongside broader progress towards sustainable development.

The **SusDev** scenario (Soergel *et al* 2021) builds on the SSP1 scenario, envisaging further changes which help achieve the SDGs. As well as an SSP1 socio-economic set-up, there is a global shift to the EAT-Lancet diet (Willett *et al* 2019), which reduces pressure on land and enables zero malnutrition to be achieved by 2050. High-income countries further reduce their energy demand, while in lower-income countries there is rapid growth in energy demand to enable decent living standards to be achieved by all. The SusDev scenario demonstrates particularly large cuts in non-CO_2 emissions, as the shift to sufficient, healthy and sustainable diets leads to reduced CH_4 and N_2O emissions. As a result, the scenario cuts CO_2 emissions at a slightly slower pace.

The **HighRE** scenario (Luderer *et al* 2021) uses the shared socio-economic pathway SSP2, which is a middle-of-the-road scenario (Fricko *et al* 2017). In this scenario, social, economic and technological trends do not shift markedly from historical trends. This leads to higher overall energy demand, and therefore the scale of the decarbonisation challenge is greater. The HighRE scenario explores the potential for a highly electrified future energy system. In this scenario, the rapidly declining cost of wind and solar, coupled with progress on battery storage, flexible hydrogen generation and demand response leads to large-scale deployment of renewables and electrification of end-use sectors.

Paris Agreement Compatible (PAC) scenario

We complement these three IAM scenarios with the Paris Agreement Compatible (PAC) scenario, which uses a different methodology to produce a European-wide energy scenario that aligns with the Paris Agreement's objective to limit global warming to 1.5°C, and which embodies the demands of civil society (PAC Consortium 2020). The combination of these two distinct methodologies for scenario production improves the robustness of the resultant 1.5°C compatible benchmarks, and provides additional insights that either approach in isolation would miss.

The PAC scenario envisages a trajectory with:

- At least 65% GHG emissions reductions by the year 2030
- 100% renewable energy supply by 2040
- Absolute zero CO_2 emissions from the energy system by 2040

These benchmarks are all for the EU27+UK. Key elements of the PAC scenario are:

1. **A mobilisation of energy savings potentials** through accelerating deep renovation of buildings and a modernisation of industrial production processes. The increase of energy efficiency in transport is also a main contributor. The EU's final energy demand halves between 2015 and 2050.
2. **A swift ramping up of domestic renewables**, particularly solar PV and wind energy for electricity production. Renewable electricity generation more than quadruples between 2015 and 2030.

3. **An electrification of industrial processes, heating and transport,** based on renewable electricity.
4. **A quick phase-out of fossil fuels,** with coal mostly disappearing from the energy mix by 2030, fossil gas by 2035 and fossil oil products by 2040. Most nuclear power plants also are closed by 2040.
5. **A limited role for non-fossil gases and fuels** which are based exclusively on renewable hydrogen. These synthetic gases and fuels produced through electrolysis are essential for decarbonising industry and aviation, besides a smaller and declining contribution of sustainably sourced biogas and biomethane.

The PAC scenario is an energy systems scenario and only provides data for energy-related CO_2 emissions. It was therefore necessary to complement this scenario with data for non-CO_2 emissions and process-based CO_2 emissions. These are taken from the HighRE scenario, which is the IAM scenario whose internal logic and narrative best matches that of the PAC scenario.

3 1.5°C compatible mitigation pathways for the EU27

3.1 Current targets and policy context

The EU27's greenhouse gas (GHG) emissions have been declining gently since 1990, when measured on a territorial basis (this excludes the emissions associated with the EU27's consumption of imported goods). In 2019, total GHG emissions (excl. LULUCF) were 26% below 1990 levels at 3,610MtCO_2e (EEA 2021a). Emissions fell 10% in 2020 as the Covid-19 pandemic reduced energy demand and associated emissions (EEA 2021b), reaching 31% below 1990 levels. However, it appears highly likely that emissions rebounded in 2021 (Friedlingstein *et al* 2021), and there are substantial opportunities to further align Covid-19 recovery packages with ambitious climate action.

Under current policies, total EU27 GHG emissions are projected to reach 47% below 1990 levels excluding LULUCF, achieving the union's original emissions target of at least a 40% reduction below 1990 levels (Climate Action Tracker 2022).

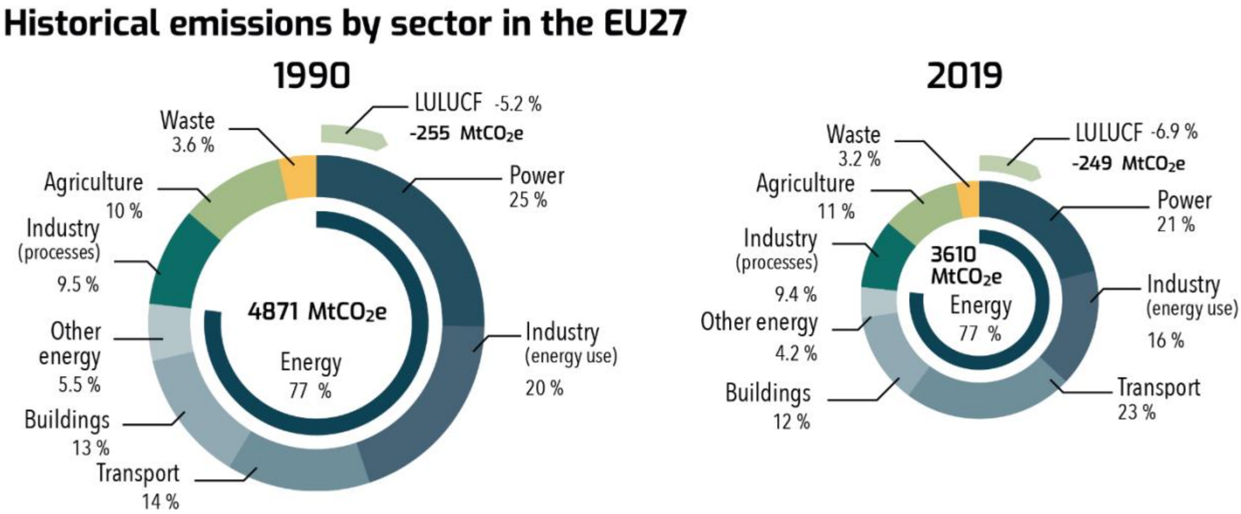


Figure 1: Historical EU27 emissions by sector Source: (EEA 2020)

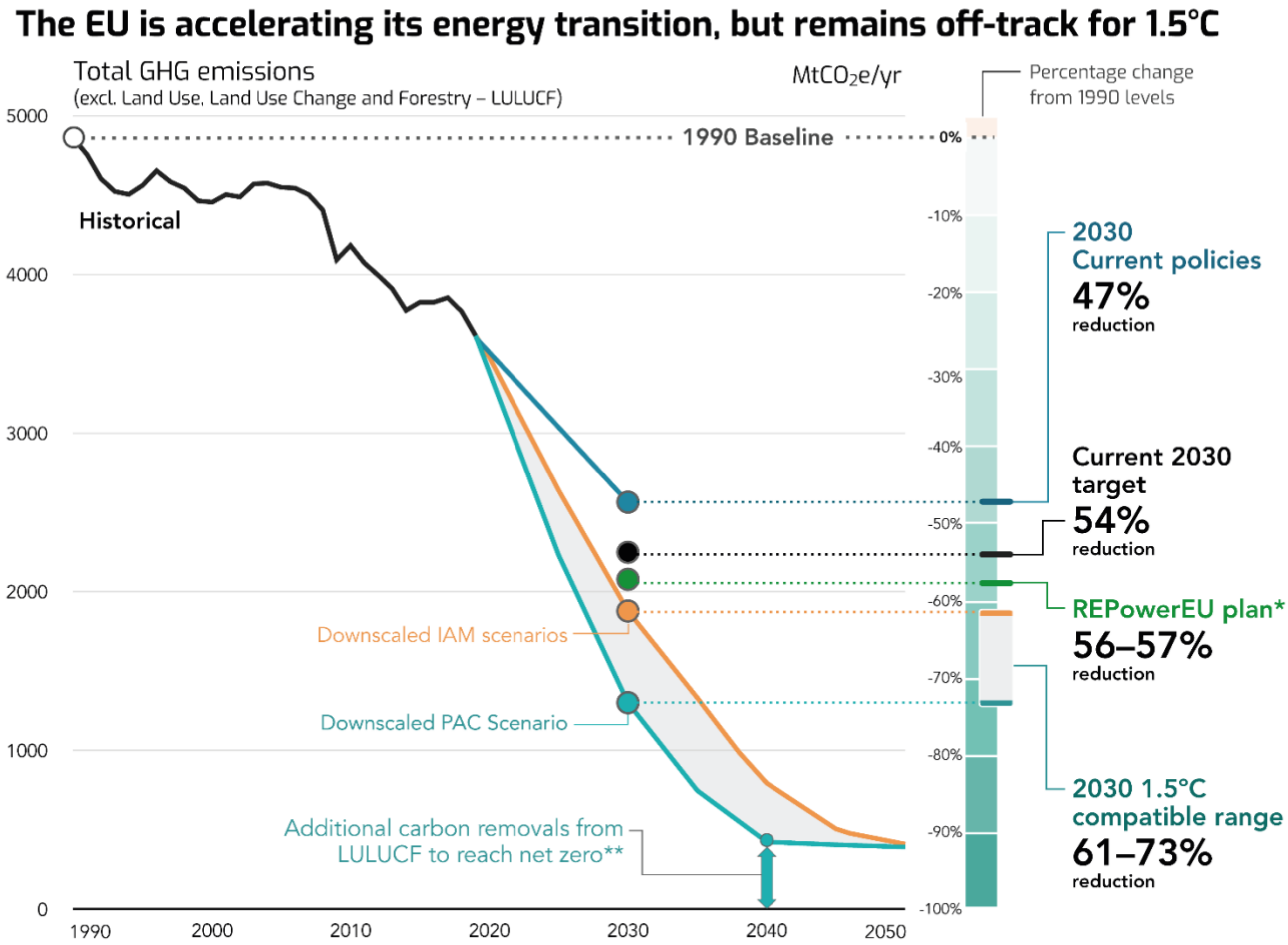
In late 2020, EU leaders agreed to enhance the EU27's 2030 GHG emissions reduction target from at least a 40% reduction below 1990 levels (excl. LULUCF), to at least 55% by 2030 (incl. LULUCF). If the LULUCF sector in 2030 contributes at most 225MtCO_2 towards this goal (the maximum amount allowed in the European Climate Law), then 2030 emissions excluding LULUCF would be 54% below 1990 levels. The EU Commission has since adopted a package of revisions and additional regulations under the moniker of 'Fit for 55', for the purpose of achieving this higher revised target (European Commission, 2021b). This package includes increasing the share of renewables in final energy to 40% by 2030, and reducing final energy demand by 36% in 2030, relative to the 2007 reference scenario (European Commission 2021). This equates to a reduction in final energy demand of 11% relative to 2019. The 'Fit for 55' package is currently being discussed in the European Parliament and the Council representing the EU member states before it will be formally adopted as EU legislation.

A key pillar to the EU's policy is the implementation of the EU Emissions Trading System (EU ETS). This EU regulation sets an EU-wide cap for the power, industry and intra-EU aviation sectors. The remaining sectors are covered by the Effort Sharing Regulation (ESR), which distributes emission reduction goals between EU member states, mainly according to their GDP per capita. In its 'Fit for 55' package of proposals, the Commission suggested more stringent emissions reduction targets for the EU ETS and non-EU ETS sectors covered. These targets still need to be approved by the European Parliament and the Council.

Russia's invasion of Ukraine has highlighted the additional energy security benefits of rapidly reducing fossil fuel consumption. In light of this, in May 2022 the European Commission released the REPowerEU plan, which aims to further accelerate the energy transition and reduce Europe's dependence on Russian oil and gas. The REPowerEU plan proposes that renewables should provide 45% of the bloc's final energy in 2030, up from 40% as included in Fit for 55. In addition, the REPowerEU plan strengthens ambition on energy efficiency, targeting a 13% reduction in final energy demand in 2030 relative to demand in 2019, compared to 11% as included in Fit for 55 (the EU expresses its targets as % reductions relative to a baseline scenario – which we have converted into % reductions relative to 2019 demand levels). This represents a welcome increase in ambition. Depending on the exact implementation of the REPowerEU plan, and the relative role of coal and gas, this would likely lead to EU27 emissions in 2030 reaching 56-57% below 1990 levels, excluding LULUCF (Climate Action Tracker 2022). Including LULUCF, the ambition in the REPowerEU plan potentially constitutes a 2030 emissions level of 58-60% below 1990 levels. This ambition has not yet been codified in the EU's NDC to the UNFCCC.

3.2 Emissions pathways and the adequacy of the EU27's climate targets

In 1.5°C compatible scenarios assessed in this analysis, total GHG emissions reach 61-73% below 1990 levels in 2030 (excl. LULUCF). The EU27's current NDC, cutting total GHG emissions in 2030 by at least 55% relative to 1990 levels (at least 54% when excluding LULUCF) therefore falls considerably short of this range. There is an emissions gap of between 370 and 950MtCO_2e in 2030 between the EU27's current NDC and the 1.5°C compatible scenarios assessed in this report. Importantly, while the actions contained in the REPowerEU plan go some way to closing this gap, there remains a substantial ambition gap of 200 to 780MtCO_2e that would need to be addressed for the EU's targets to be deemed 1.5°C compatible.



* In light of Russia's illegal invasion of Ukraine, the EU27 is accelerating its energy transition via the REPowerEU plan, which further accelerates renewables deployment and efficiency improvements.

** To achieve the net zero emission target, emissions from LULUCF need to be reduced while increasing the capacity of forests, wetlands, grasslands and farmlands to remove carbon. These carbon removals are not equal to emissions in other sectors and the two cannot simply be considered fungible.

Figure 2: Economy-wide domestic 1.5°C compatible GHG emissions pathways for the EU27

This figure shows domestic 1.5°C compatible GHG emissions for the EU27, compared to current policies and targets proposed by the bloc. The EU's current policies and targets do not align with 1.5°C, as assessed in this report. All targets and plans are converted to exclude LULUCF and international aviation and shipping within the EU27. Historical data is taken from PRIMAP (Gütschow et al 2021).

There are technically feasible routes for the EU27 to cut emissions much faster than current targets or recent proposals. To be 1.5°C compatible, as assessed by these scenarios, the EU27 would need to update its 2030 target to be considerably more ambitious. Table 2 highlights what a 2030 NDC aligned with the 1.5°C compatible pathways selected here would entail for the EU27 and compares this to the EU's current targets and plans.

Table 2: 2030 emissions reductions for assessed 1.5°C compatible scenarios in comparison to the EU's current targets and proposals

Scenario	2030 emissions reduction below 1990 levels (excluding LULUCF)
Current policies	47%
Fit for 55	54%
REPowerEU	56-57%
PAC	73%
HighRE	66%
SusDev	62%
SSP1	61%

1.5°C compatible action requires not only rapid reduction in emissions out to 2030 but also continued strong reductions post-2030. In the scenarios assessed here, total GHG emissions reach 84-91% below 1990 levels by 2040 and fall 91-94% below 1990 levels in 2050, excluding LULUCF. If the EU27 cut emissions at this rate, while also expanding the LULUCF sink, it could reach net zero GHG emissions before 2050.

The scale of the future LULUCF sink is uncertain, but a range of scenarios suggest that it could be increased significantly from its current levels of around -250MtCO_2/y (Böttcher *et al* 2021). In seven scenarios that explore how the LULUCF sink could be expanded, the average sink size reaches -400MtCO_2/y in 2030, growing further to -480MtCO_2/y in 2050. If this average sink is applied to the selected 1.5°C compatible scenarios, they reach net zero GHG emissions between 2040 and 2047. The maximum sink in the literature reaches -570MtCO_2/y in 2030 and grows to more than -780MtCO_2/y by 2050. If this maximum sink is achieved, then the date of net zero can be brought forwards further by three to six years, to 2037-2042. Expanding the EU27's LULUCF sink to -600MtCO_2/y and beyond can help the EU27 cut emissions faster, reach net zero GHG emissions sooner, and further limit the EU27's contribution to global warming. Table 3 shows the date of net zero GHG emissions by scenario, depending on the size of the LULUCF sink.

Table 3: Date of net zero GHG emissions for the EU27 by scenario for different LULUCF projections

Scenario	Date of net-zero GHG emissions	
	Average LULUCF sink	Maximum LULUCF sink
PAC	2040	2037
HighRE	2047	2041
SusDev	2047	2042
SSP1	2046	2042

There is a finite carbon budget remaining if warming is to be limited to 1.5°C. To do so with a 50% likelihood, global emissions from 2020 onwards need to be limited to 500 billion tonnes (IPCC 2021).

In the 1.5°C compatible pathways assessed here, cumulative CO_2 emissions from 2020 to 2050 (excluding LULUCF) are 23-35GtCO_2. If the average LULUCF sink from the above sources is included, then the EU27's cumulative CO_2 emissions from 2020–2050 would be 12-23GtCO_2. This represents about 2.2-4.6% of the global 1.5°C compatible carbon budget. For comparison, the EU27's fraction of global population is around 5.6%, and one would expect that as a developed region its carbon budget would be substantially less than its population share.

These cumulative CO_2 emissions calculations assume that the EU27 takes 1.5°C compatible action from 2020 onwards. In reality, this has not occurred, and even if a more ambitious 2030 target was agreed, it would take time for policies to be developed and emissions to be reduced in the real economy. As immediate alignment with 1.5°C compatible emissions pathways is not possible, the EU27's cumulative CO_2 emissions will likely exceed these numbers to some limited extent. However, the EU27's current proposals would lead to 39GtCO_2 being emitted between 2020 and 2050 (AirClim 2022). This is far beyond the cumulative CO_2 emissions of the pathways assessed in this report, and is not compatible with limiting warming to 1.5°C. The EU would need to reduce cumulative emissions much further to align with the Paris Agreement.

3.3 Final energy transitions for the EU27

In all 1.5°C compatible pathways assessed here, final energy demand in the EU27 falls out to 2050 due to a combination of efficiency gains and reduced demand. At the same time, renewable energy is rapidly deployed to displace fossil fuels from the energy system.

This section focuses on two illustrative pathways – the PAC scenario and the HighRE IAM scenario – as they show the most rapid transition in the energy sector of the four scenarios considered. However, it brings in insights from the other two IAM scenarios where relevant. Figure 3 shows the transition in final energy out to 2050 for these two illustrative pathways. We highlight a range of key results below.

The central importance of electrification

In all pathways, electrifying energy demand is a key step on the road to net zero emissions. Electric vehicles, heat pumps and other electric technologies are highly efficient applications that can save energy, cut energy bills, reduce fossil fuel use, and avoid air pollution. In the PAC and HighRE pathways, electricity meets 37-40% of final energy in 2030, rising to 67-70% by 2050, up from 23% today (IEA 2021). The consumption of electricity in the end-use sectors grows 22-45% by 2030, and 31-128% by 2050 (relative to 2019 levels). The PAC scenario sees a smaller scale-up of direct electricity consumption due to greater progress on energy efficiency and greater indirect electrification via hydrogen and synthetic fuels.

The role of other low-carbon fuels

In addition to electricity, a range of other low-carbon fuels can help cut emissions. Three possible fuels are sustainable biomass, renewable hydrogen and renewable-based synthetic fuels. Both the PAC and HighRE pathways use hydrogen to provide high-temperature heat in industry, to help decarbonise long-distance transport (such as shipping), and to provide long-duration storage for electricity systems with large amounts of wind and solar power on the grid. Hydrogen provides 5-11% of final energy demand by 2050 in these illustrative pathways. Neither scenario uses hydrogen in the buildings sector, which is instead decarbonised by the widespread roll-out of heat pumps and greater use of district heating.

Both scenarios also use biomass in the end-use sectors. The PAC scenario shows a small and declining contribution of sustainably sourced biomass, which provides 4% of final energy demand in 2050, down from 9% in 2019. This is predominantly solid biomass consumed in the industrial sector. In the HighRE scenario, total biomass consumption grows 36% over the time horizon, and the share of biomass in final energy reaches 16% by 2050. The main reason for this difference is demand for biomass in the transport sector. The HighRE scenario does not consider the use of renewable synthetic hydrocarbon fuels as a mitigation option. In the absence of renewable-based synthetic fuels, biomass represents a valuable energy dense fuel for long-distance transportation. The PAC scenario avoids large-scale reliance on biofuels by explicitly representing synthetic hydrocarbon fuels to decarbonise long-distance transport, as well as greater deployment of hydrogen.

It is critically important to ensure any biomass used in a future energy system is sustainably sourced, avoiding upstream emissions from land-use change, competition with food crops, negative biodiversity impacts, and respecting the rights of indigenous peoples who may be the traditional users of the land (Energy Transitions Committee 2021). The HighRE scenario assumes that the global potential for biomass is 100EJ/y, approximately double today's levels (Luderer *et al* 2021). While such a potential is at the low end of global 1.5°C compatible scenarios, it still represents a considerable growth in biomass supply. Further reductions in biomass consumption, via further fuel switching to hydrogen, electricity and synthetic fuels, or reduction in overall transport demand, could help avoid some of the negative side effects of biomass production.

Unlike the three IAM scenarios considered in the report, the PAC scenario explicitly models synthetic fuels. These are produced using renewable electricity, green hydrogen and atmospheric CO_2 captured by direct air capture, as well as by upgrading biogas to biomethane. These rapidly scale up in the PAC scenario to provide 20% of final energy demand in the transport sector and 4% of final energy demand in the industrial sector by 2050. Together, synthetic fuels provide 8.5% of total final energy demand by 2050. The use of synthetic fuels not only enables the PAC scenario to use less biofuels in the transport sector, but also to entirely phase out oil consumption by 2040. In the HighRE and other IAM scenarios, the lack of representation of synthetic kerosene means that there is some residual oil demand in 2050, which is likely concentrated in the aviation sector. This oil consumption could be further reduced if synthetic fuels were explicitly considered in the IAM scenarios.

Rapid reductions in fossil fuel demand

Fossil fuel demand falls rapidly in both the PAC and HighRE scenarios. The remaining coal consumption in the EU27 (which is concentrated in the industrial sector) is phased out by 2029 at the latest. Oil and fossil gas demand also falls rapidly in both the PAC and HighRE scenarios. Oil provides 24-28% of final energy in 2030 (down from 37% in 2019), and fossil gas provides 15-16% of final energy in 2030 (down from 22% in 2019). The PAC scenario shows the fastest reductions, with both fuels phased out entirely by 2040.

The difference in the speed of reductions in gas consumption between the two scenarios is largely due to different assumptions in the deployment of efficiency and demand reduction measures. In the HighRE scenario, gas consumption in 2040 provides less than 5% of final energy, with most of this demand concentrated in the buildings sector. Some gas demand remains because this scenario does not explicitly account for the potential to reduce heating demand via deep retrofits and societal change. Absent these strategies, final energy demand in the buildings sector only falls by 9% by 2040, and low-carbon heating systems such as heat pumps cannot scale sufficiently quickly to totally eliminate gas use by 2040. On the other hand, the PAC scenario explicitly assumes that a combination of widespread building renovation, as well as societal trends such as urbanisation and demand reduction, can reduce buildings final energy demand by 65% in 2040. As such, it is able to eliminate gas demand entirely after 2035.

Electrification and improved efficiency can help phase out fossil fuels and align the EU with 1.5°C

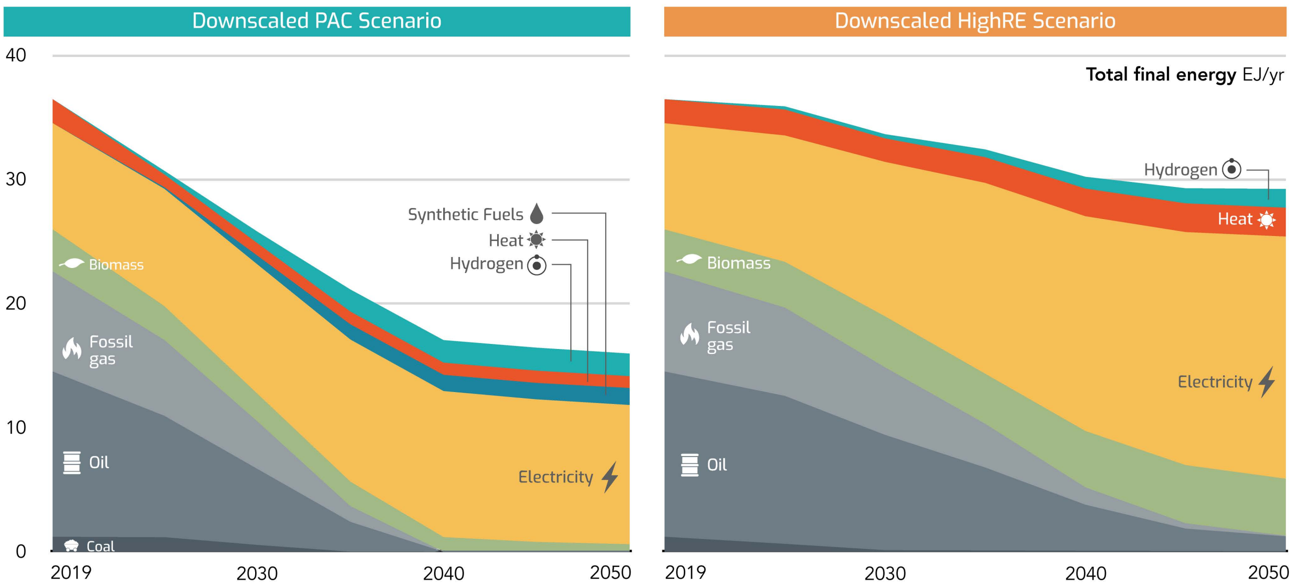


Figure 3: 1.5°C compatible final energy demand pathways in the EU27

This figure shows 1.5°C compatible final energy demand in the EU27 between 2019-2050. The EU27 can rapidly reduce consumption of fossil fuels by transitioning to a more efficient and electrified energy system.

Oil consumption also falls fastest in the PAC because of the availability of alternatives, particularly synthetic liquid fuels, in this scenario. In the HighRE scenario, oil still provides around 4% of final energy in 2050. Remaining consumption is concentrated in the transport sector (likely in aviation). The PAC scenario does not explicitly consider non-energy use, but assumes that non-energy demand for oil can be eliminated by 2050 via a combination of bio-based feedstocks and transition towards a more circular economy (Material Economics 2019). In the HighRE scenario, greater deployment of hydrogen and explicit modelling of synthetic fuels could reduce oil demand further in the transport sector, while modelling synthetic feedstocks and circular economy measures could reduce demand for oil in the non-energy sector.

A growing share of renewables in final energy

Renewables provide an increasing share of final energy in 1.5°C compatible trajectories (Figure 4). This is driven by a rise in the use of renewable electricity, renewable hydrogen/heat, biomass and synthetic fuels. By 2030, renewables provide 52 to 55% of final energy in the PAC and HighRE scenarios, respectively - above the 45% target proposed by the European Commission in the REPowerEU plan. This shows that while the ambition in the REPowerEU plan is to be welcomed, there are technically feasible routes to achieve an even greater share of final energy from renewables by 2030. By 2040, the PAC scenario reaches 100% renewables across the energy system. In the HighRE scenario, the slower phase-out of fossil fuels and in particular the remaining oil consumption in transport means that renewables provide 82% of final energy in 2040 and 95% in 2050. Table 4 provides further information on the 1.5°C compatible final energy mix in 2030 and 2050.

The EU27 must strengthen its renewable energy target to align with 1.5°C

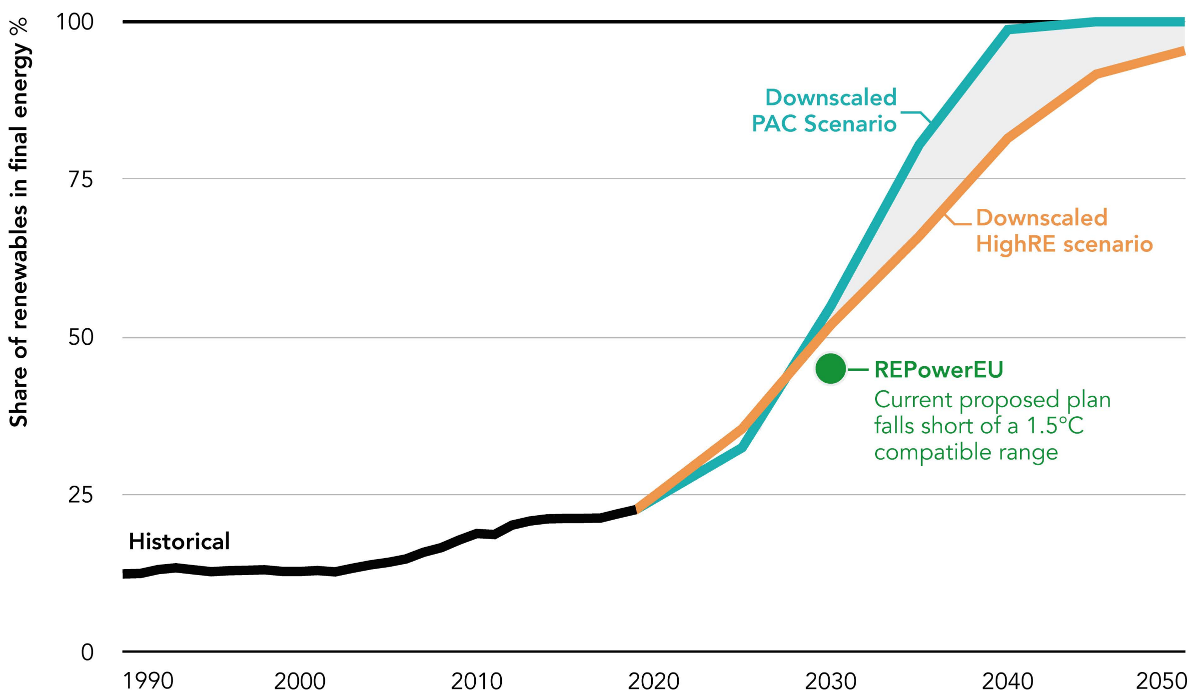


Figure 4: Share of renewables in final energy in the EU27 for the two illustrative pathways selected

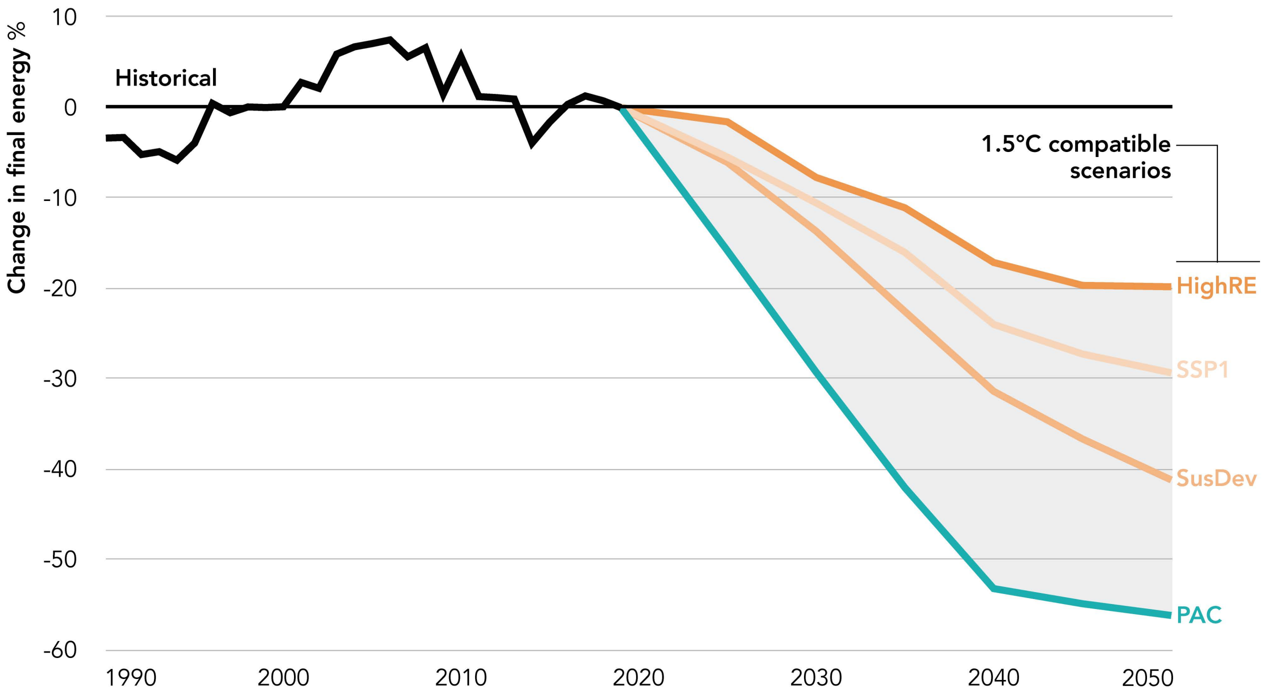
This figure shows the share of renewable energy in final energy demand (EU27) until 2050. The PAC and HighRE scenario demonstrate that the EU27 can achieve a higher share of renewables in 2030 than currently included in the RePowerEU plan. Historical data is taken from the IEA World Energy Balances (IEA 2021)

Table 4: 1.5°C compatible final energy mix in 2030 and 2050 in the EU27

Year	Scenario	Electricity	Biomass	Renewable heat	Renewable hydrogen	Coal	Fossil gas	Oil	Synthetic fuels
2019	Historical	23%	9%	2%	0%	3%	22%	37%	0%
2030	PAC	40%	9%	4%	4%	2%	15%	24%	3%
	HighRE	37%	12%	6%	1%	0%	16%	28%	0%
2050	PAC	70%	4%	6%	11%	0%	0%	0%	8.5%
	HighRE	67%	16%	8%	5%	0%	0%	4%	0%

Reducing final energy demand is an often overlooked, but key, strategy in reducing emissions. Reducing energy demand can speed up the pace of fossil fuel phase-outs (Barrett et al 2022), reduce the need for large-scale carbon dioxide removal (Grubler et al 2018), and have substantial wellbeing benefits (Creutzig et al 2022). Demand can be reduced by a combination of improved energy efficiency and reduced consumption of goods and services by households and businesses.

With electrification and efficiency improvements, the EU27 can significantly reduce final energy demand



All 1.5°C compatible scenarios assessed in this report see the EU27's final energy demand decline across the time horizon (Figure 5).

Figure 5: Percentage change in final energy demand for selected 1.5°C compatible scenarios

This figure shows the change in final energy demand in the EU27, relative to the historical base year of 2019. It demonstrates that the EU27 can strongly reduce final energy demand, through a combination of efficiency improvements, electrification and reduction in overconsumption. Historical data is taken from the IEA World Energy Balances (IEA 2021)

In the PAC scenario, final energy demand falls 29% from 2019 to 2030, and by 2050 final energy demand is 56% lower than in 2019. The 1.5°C compatible IAM scenarios taken from AR6 generally display smaller, although non-negligible, levels of demand reduction. Final energy demand falls by 8-14% in 2030, and up to 41% in 2050. The SusDev scenario displays particularly large reductions in energy demand out to 2050. This further highlights the feasibility of significantly reducing final energy demand. In the SusDev scenario, shifting consumption towards healthier and more sustainable diets and a reduction in energy demand in industrialised economies ensures that global emissions fall rapidly even while access to modern energy is expanded to cover all developing countries (Soergel *et al* 2021). Reduced demand therefore helps achieve both the Paris Agreement and the sustainable development goals.

3.4 Power sector decarbonisation

Renewable energy capacity has been growing rapidly in the EU27 over the past decade, with wind capacity doubling and installed solar capacity more than tripling since 2010 (IRENA 2022). The cost of wind and solar has also fallen dramatically since 2010 (IRENA 2021), with renewables becoming cheaper than fossil fuels in the majority of the world (Figure 6). 1.5°C compatible pathways take advantage of this fact and accelerate the transition, with rapid deployment of wind and solar key to cutting the EU27's emissions. These pathways were developed before the ongoing energy crisis, and Russian invasion of Ukraine. These crises have led to substantial increases in the price of fossil fuels (particularly gas) and underscored the volatility of fossil-based energy systems. In the current context, the cost advantage of renewables is even greater than assumed in these pathways, and the rationale for rapid deployment even stronger.

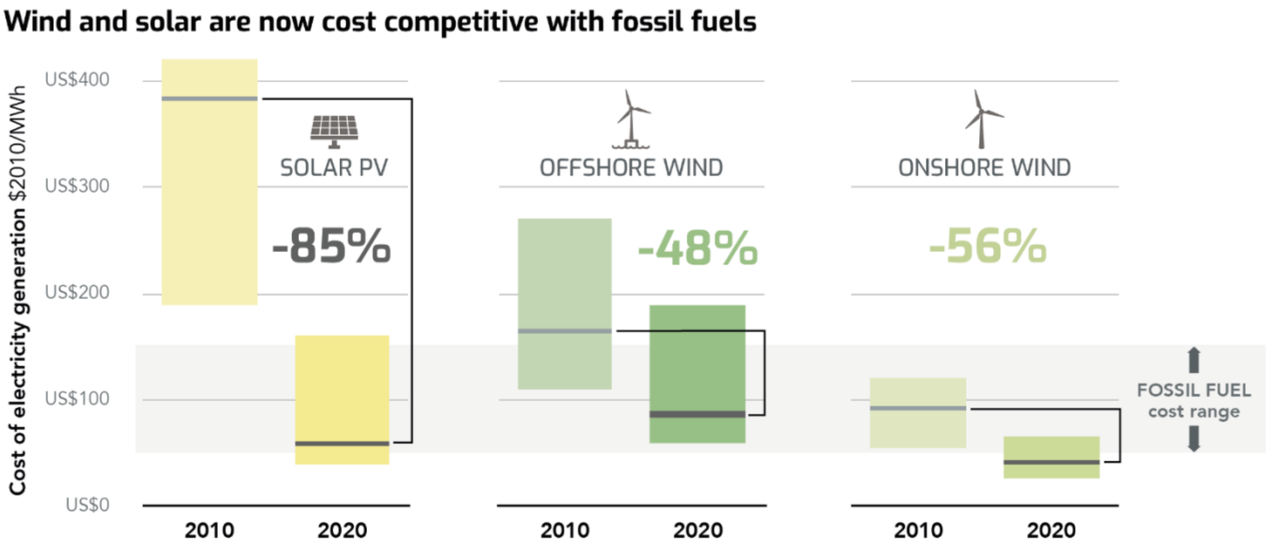


Figure 6: Cost reduction in renewables over the past decade

This figure shows the cost reductions in electricity from wind and solar over 2010–2020. The bars represent the 5th and 95th percentile of all projects, while the yellow diamonds give the global median. The grey bar shows the cost of generating electricity from fossil fuels. The cost of electricity from solar PV fell 85% over the decade, while the cost of wind fell by 48-56%. Data is taken from IRENA (IRENA 2021).

In the HighRE and PAC scenarios, total electricity generation more than doubles out to 2050. The share of renewable electricity increases from around 35% in 2019 to 89% by 2030, with both scenarios achieving 100% renewables in the power sector by 2050. Non-biomass renewables such

On the path to 100% renewables, the EU27 must phase out fossil fuels by 2035

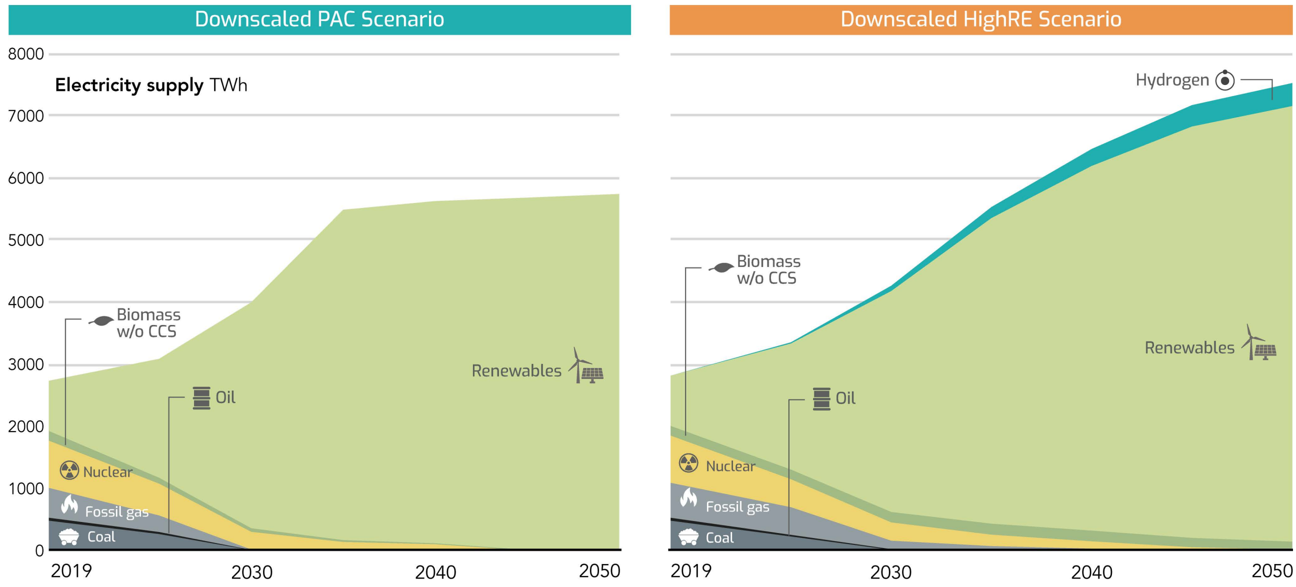


Figure 7: Power sector transition with 1.5°C compatible emissions pathways

This figure shows 1.5°C compatible electricity generation in the EU27 between 2019-2050. There is rapid expansion of renewables such as wind and solar. Coal is phased out by 2029, and fossil gas is effectively phased out before 2035. Large-scale biomass and nuclear deployment are not needed to align with 1.5°C. The PAC scenario does not model hydrogen deployment within the power sector.

Large-scale biomass and nuclear electricity generation are not required components of 1.5°C compatible action. Both scenarios display a diminishing role for nuclear in the future power mix, with phase-out by 2050. In the PAC scenario, biomass is also phased out of electricity production, while in the HighRE scenario there is a relatively constant but limited level of bio-electricity production, with no real growth in the sector.

Rapid deployment of wind and solar, coupled with a limited and declining role for biomass and nuclear, mean that in 2035, 99% of the EU27's electricity production is generated from zero-carbon sources. This represents a transition to a carbon-free power sector in just over a decade's time.

Fossil fuels are rapidly displaced from the power sector. To align with 1.5°C compatible pathways, coal would need to be phased out of the power sector by 2029. Gas is effectively phased out of the power sector around 2033 in the PAC and HighRE scenarios[2]. Table 5 shows the share of electricity produced by different sources out to 2050.

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2 Phase-out dates are defined by the year in which gas provides <2.5% of total electricity generation. We term this the 'effective phase-out" year. At this low level, fossil gas will be playing the role of a "peaking technology", providing electricity at limited times in the year, or acting as a back-up during disruptions to VRE systems. At this low level, gas plants will struggle to recover their investment costs and will effectively be phased out as alternatives (for example, hydrogen for long-term energy storage) diffuse into the energy system. For more details see Climate Analytics (2022).

Table 5: 1.5°C compatible power sector fuel mix in 2030 and 2050 in the EU27

Year	Scenario	Renewables	Coal	Gas	Nuclear
2019	Historical	35%	16%	20%	27%
2030	PAC	89%	0%	4%	7%
	HighRE	89%	0%	3%	7%
2050	PAC	100%	0%	0%	0%
	HighRE	100%	0%	0%	0%

To realise an energy system with such a high penetration of renewable energy, renewables deployment will need to be complemented with other infrastructure, as well as structural changes in energy markets. As with any highly renewable energy system, variability in solar and wind will need to be smoothed using a combination of transmission, storage, and demand-side flexibility. However, it has been shown that additional electricity transmission infrastructure in Europe, to help balance the grid at a continental scale, could realise a zero-carbon power system at substantially lower costs (Schlachtberger *et al* 2017). In fact, most of these benefits can be achieved with only around 25% more transmission capacity than what is installed currently (Horsch and Brown 2017).

Demand-side flexibility, the ability within a system to shift peak demands, also offers considerable untapped potential in Europe to integrate higher proportions of renewables at lower cost. Estimates show around 15–30% of the peak load can be shifted (Söder *et al* 2018), and unlocking this potential could not only reduce the total capacity needed, but also help to stabilise the variability in renewable supplies. Fortunately, the technological barriers to rolling out demand-side flexibility at scale are limited given that solutions already exist, such as smart metering and grids. The main barriers to greater adoption of the technology are the roll-out of infrastructure, as well as the structure of energy markets, which for the moment does not sufficiently incentivise consumers to participate in flexibility programmes or change their behaviour (Cardoso *et al* 2020)).

3.5 Key characteristics of the EU27's 1.5°C compatible pathways

Table 6 provides a summary of key derived 1.5°C compatible economy-wide and power sector benchmarks for the EU27 in 2030 and 2050, compared against recent historical values. All four scenarios are used to derive benchmarks for total emissions and reductions in final energy demand. Other benchmarks are based on the HighRE and PAC scenarios.

Table 6: Key characteristics of the EU27's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		EU27 targets	
	2019*	**2030**	**2050**	**2030****	**2050****
Total GHG excl. LULUCF	3621 $MtCO_2e/yr$	1305-1665 $MtCO_2e/yr$	286-415 $MtCO_2e/yr$	2299 $MtCO_2e/yr$	271 $MtCO_2e/yr$
	26% below 1990	61-73% below 1990	91-94% below 1990	54% below 1990	90-94% below 1990
Reduction in final energy demand (relative to 2019)	0%	8 to 27%	20 to 55%	11%	
Share of renewables in final energy	21%	52 to 55%	95 to 100%	45% (REpowerEU target)	
Emissions intensity of power generation* **	248 gCO_2/kWh	17-21 gCO_2/kWh	-1 to 0 gCO_2/kWh		
Share of renewables in electricity production	35%	89%	100%	65%	
Share of unabated fossil fuel in power	36%	4%	0%		
Share of nuclear power	27%	7%	0%		

* Historical data comes from PRIMAP for emissions, and the IEA World Energy Balances for energy consumption

** 2030 target assumes that at most a -225$MtCO_2$ LULUCF sink can be used to meet the 2030 target, in line with European Climate Law. The 2050 target excluding LULUCF is calculated using LULUCF projections from the European Commission's own analysis of scenarios which meet net zero GHG emissions in 2050 (European Commission 2018). The target here represents the EU27's formal NDC, rather than the REPowerEU plan

*** Does not include upstream emissions

4 Conclusion

The EU is at a pivotal moment in its energy transition. The evidence continues to build around the urgency, feasibility and desirability of tackling climate change, as the impacts of a warming planet continue to escalate, and the cost of low-carbon technologies continues to fall. The Russian invasion of Ukraine has further emphasised the risks of our addiction to fossil fuels, and the benefits of rapidly transitioning to renewables. In addition, the global community has agreed to return to COP27 with more ambitious climate targets for 2030, to address the alarming discrepancy between current NDCs and 1.5°C compatible pathways. In this context, we must ask: what can the EU do to help drive climate action at home and abroad, and keep the 1.5°C goal alive?

This report finds that the EU can, and should, do more to reduce its own emissions by 2030. To align with the derived 1.5°C compatible pathways assessed in this report, the EU27 should submit a revised NDC which aims to reduce emissions by between 61-73% in 2030, relative to 1990 levels (excl. LULUCF). Incorporating the -225MtCO_2 LULUCF sink that the EU27 can use to meet its 2030 climate targets, this would correspond to an NDC of 64-77%, including LULUCF. This would represent a feasible target in line with the principle of highest plausible ambition for the bloc. The EU's current NDC, which aims to reduce emissions to 55% below 1990 levels in 2030 (54% excl. LULUCF) is not aligned with the 1.5°C goal. While the steps taken as part of the RePowerEU strategy are welcome, they still leave a considerable ambition gap of 200 to 780MtCO_2e in 2030 that the EU must address urgently.

The report highlights a range of measures that could help the EU27 align its energy transition with the Paris Agreement. The rapid roll-out of wind and solar is a cornerstone of the transition, with the EU27 achieving a carbon neutral power system by 2035 in the most ambitious pathways. At the same time, the widespread electrification of energy demand through EVs, heat pumps and industrial electrification will be crucial for displacing fossil fuels from the wider energy system. The report finds that energy efficiency improvements and behavioural change can lead to strong and sustained reductions in final energy demand, which can help accelerate the phase-out of fossil fuels and reduce the need for engineered CO_2 removal, all while benefitting health and wellbeing.

The actions set out in this report require a step-change in ambition but are technically feasible and economically cost-effective. Taking these actions, alongside strong efforts to preserve and expand the EU's LULUCF sink, could enable the EU27 to reach net zero GHG emissions by 2040, a full decade earlier than currently planned.

If the EU27 was to commit to these more ambitious near-term and long-term targets, this would represent a substantial increase in the bloc's climate ambition. Such a stance would send a clear message to businesses and consumers about the direction of travel for the EU. It could also encourage and inspire other countries to reassess their climate targets, catalysing global climate action in the run-up to COP27. A rapid, well managed transition to a renewable future would improve Europe's energy security, reduce premature deaths from air pollution, and create millions of jobs in key growth sectors.

In addition to setting stronger emission reduction targets and adopting more stringent policies to achieve them, the EU27 also has an obligation, under the fair share and equity considerations embedded in the Paris Agreement, to assist less wealthy countries to rapidly reduce their own emissions. Without such assistance, the global effort required to limit warming to 1.5°C will be distributed unfairly and will be unlikely to be met in time.

The urgency of rapid emissions reductions has never been greater, as the impacts of climate change continue to escalate. At the same time, the desirability and feasibility of deep decarbonisation is clearer than ever. Shifting away from fossil fuels will bring huge benefits, not only to the climate, but in the areas of health, economic productivity and energy security. The EU27 therefore faces a historic choice – will it use this critical decade to act decisively as a global leader on climate action, or maintain its current target and relinquish this role?

Appendix A: Scenario selection process

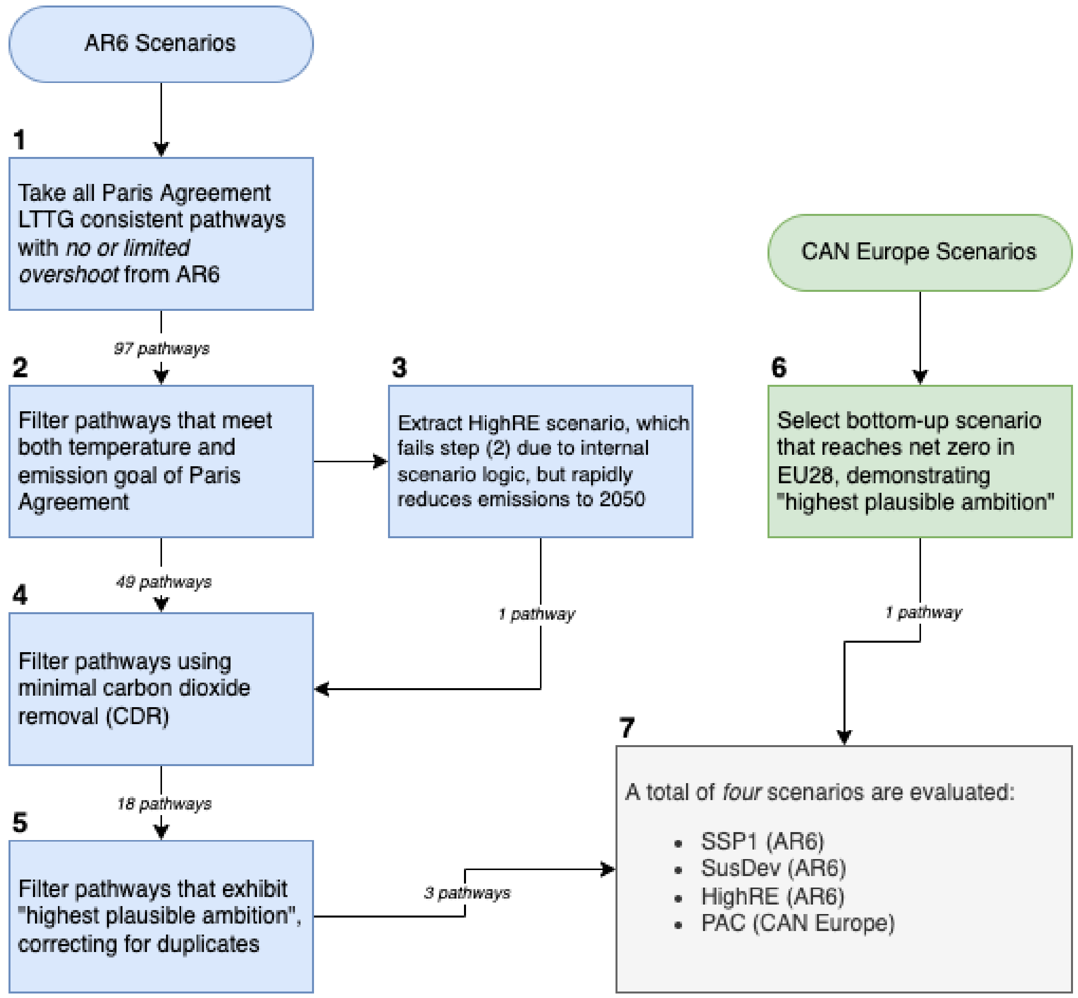

Figure A1: Scenario selection process.

Appendix B: Downscaling methodology description

B1: Energy sector downscaling: SIAMESE

The Simplified Integrated Assessment Model with Energy System Emulator (SIAMESE) is a reduced complexity IAM. SIAMESE is used to downscale the energy system transitions produced by global/regional IAMs (Sferra *et al* 2019b). These models provide cost-effective energy and emissions pathways for a given *macro region*, but often do not provide results at the national or sub-national level. For example, the PAC and REMIND scenarios provide data for a European region which comprises the EU27+UK.

SIAMESE can be used to downscale these aggregated results to the required spatial resolution, accounting for the relationship between economic growth, energy consumption and associated emissions. SIAMESE provides downscaled energy consumption pathways for the country of interest, as well as a CO_2 emissions pathway for the energy sector. This can be combined with non-energy CO_2 and non-CO_2 emissions pathways to give an economy-wide emissions pathway covering all relevant gases.

When downscaling results from a given model (e.g. REMIND, IMAGE, AIM etc.), SIAMESE uses population and GDP projections from the Shared Socioeconomic Pathway (SSP) associated with the scenario being assessed (van Vuuren *et al* 2017a). SIAMESE then takes the energy consumption in the wider macro region and allocates it across the underlying countries that constitute this larger region. It does so by equating marginal fuel prices across all countries. This gives a distribution of energy consumption across the underlying countries which maximises the total welfare of the IAM macro region. Therefore, energy consumption and associated emissions are downscaled to the country level on a cost-effective basis, minimising total costs at the macro region level. This mirrors the internal logic of IAMs and ensures consistency between the downscaled results and the initial model pathway used as an input.

In this project, final energy demand in the industry, buildings and transport sectors, and electricity production in the power sector are downscaled.

The downscaling process itself can be broken down into several sub-steps:

1. **The macro region containing the EU27 is defined**. In the case of the PAC scenario, this is the EU27+UK. In the case of the REMIND scenarios, this is a wider European region containing 45 different countries.
2. **Historical emissions and energy consumptions** are determined for all countries in the macro region for the base year (2019).
3. **Future emissions and energy consumption for the macro region** are obtained from to-be-downscaled 1.5°C compatible pathway.
4. **The macro region's scenario data is adapted to match historical data** in the base year. This process is called *harmonisation*. Harmonisation is required to update the pathways to the latest available historical data.
5. **The macro region's energy consumption is downscaled to the underlying countries using SIAMESE.** It is distributed to the countries in an internally consistent way, which preserves total consumption in the macro region and matches historical consumption in

each country in the base year. To optimise computational performance, SIAMESE does not downscale countries which represent <1% of the macro region's GDP.

6. **Once the consumptions are downscaled, then energy sector CO_2 emissions can be determined.** A calibration process is run which calculates emissions factors for coal, oil, gas and biomass in each sector. The calibration process aims to ensure that the sum of downscaled emissions equals the emissions pathway of the macro region as a whole.

B2: Non-energy CO_2 emissions, and non-CO_2 emissions

SIAMESE is used to provide energy consumption and energy sector CO_2 pathways for the EU27. This then needs to be combined with data on non-energy CO_2 emissions and non-CO_2 emissions to give a complete emissions pathway. The following sections explain how this is undertaken in the analysis. This downscaling only takes place for REMIND scenarios, as the PAC scenario does not report non-CO_2 and non-energy CO_2 emissions.

Agricultural emissions

The emissions on the macro region level for the agriculture sector are collected from the REMIND scenario data and harmonised to historical data. The emissions for individual countries are determined by assuming their shares in the base year (2019) are constant over the whole scenario period, a simple downscaling methodology called *base-year pattern*.

Remaining energy system emissions

The emissions for industrial processes, waste and non-CO_2 emissions in the energy sector are collected from the REMIND scenario data and harmonised to historical data in 2019. To perform the downscaling from the macro region to the individual country level, a methodology based on *intensity convergence* is used; more specifically the Impact, Population, Affluence, and Technology (IPAT) method developed by van Vuuren et al (2007) and extended by Gidden et al (2019).

This assumes that emission intensities (the ratio of emissions to GDP) will converge from their values in the historical base year to the macro region intensity in the last year of the scenario data (here 2100). This is made possible by an exponential interpolation of emission intensities from the base-year to the convergence year. These emissions intensity trajectories in emissions/GDP are then combined with country-level GDP trajectories for the given SSP, to give country-level emissions pathways for industrial processes, waste and non-CO_2 energy sector emissions.

Use in the PAC scenario

In each of the REMIND scenarios, this downscaling process gives an emissions pathway for non-energy CO_2 and non-CO_2 emissions. This can then be combined with the energy sector CO_2 pathway trajectory produced by SIAMESE to give an economy-wide GHG emissions pathway. This pathway still excludes LULUCF emissions, as discrepancies between the reporting of LULUCF emissions in IAMs and the reporting of LULUCF emissions in national GHG inventories (Reference) remain which need to be addressed. Further work will enable the downscaling of LULUCF emissions.

To create an economy-wide GHG pathway for the PAC scenario, non-CO_2 and non-energy CO_2 data from the HighRE scenario was used, as the HighRE scenario is the IAM pathway which is most closely aligned to the internal narrative of the PAC scenario.

B3: Global Warming Potentials

All historical and projected emissions series use global warming potentials from the IPCC's Fourth Assessment Report (AR4).

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About the author

Supporting science-based policy to prevent dangerous climate change, enabling sustainable development.

Climate Analytics is a non-profit climate science and policy institute based in Berlin, Germany with offices in New York, USA, Lomé, Togo and Perth, Australia, which brings together interdisciplinary expertise in the scientific and policy aspects of climate change. Climate Analytics aims to synthesise and advance scientific knowledge in the area of climate, and by linking scientific and policy analysis provide state-of-the-art solutions to global and national climate change policy challenges.

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