1.5°C Pathways for Europe: Achieving the highest plausible climate ambition

EU27, Denmark, France, Germany, Italy, Poland, Portugal, Romania, Spain, Sweden

October 2021

1.5°C Pathways for Europe: Achieving the highest plausible climate ambition

EU27, Denmark, France, Germany, Italy, Poland, Portugal, Romania, Spain, Sweden

AUTHORS

Ryan Wilson
Lara Welder
Alexandre Delfosse
Jonas Hörsch
Deborah Ramalope
Matthew Gidden
Bill Hare

Design Designers For Climate Studios

We would like to thank the REMIND research team who have made available the underlying data from global least cost pathways used in this analysis.

SUPPLEMENTARY MATERIAL

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

CITATION AND ACKNOWLEDGMENTS

This document may be cited as:
Climate Analytics (2021). 1.5°C Pathways for Europe: Achieving the highest plausible climate ambition.

This report has been prepared under the "1.5°C Pathways for Europe Project" supported by the Swedish Postcode Foundation.

CLIMATE ANALYTICS

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

www.climateanalytics.org

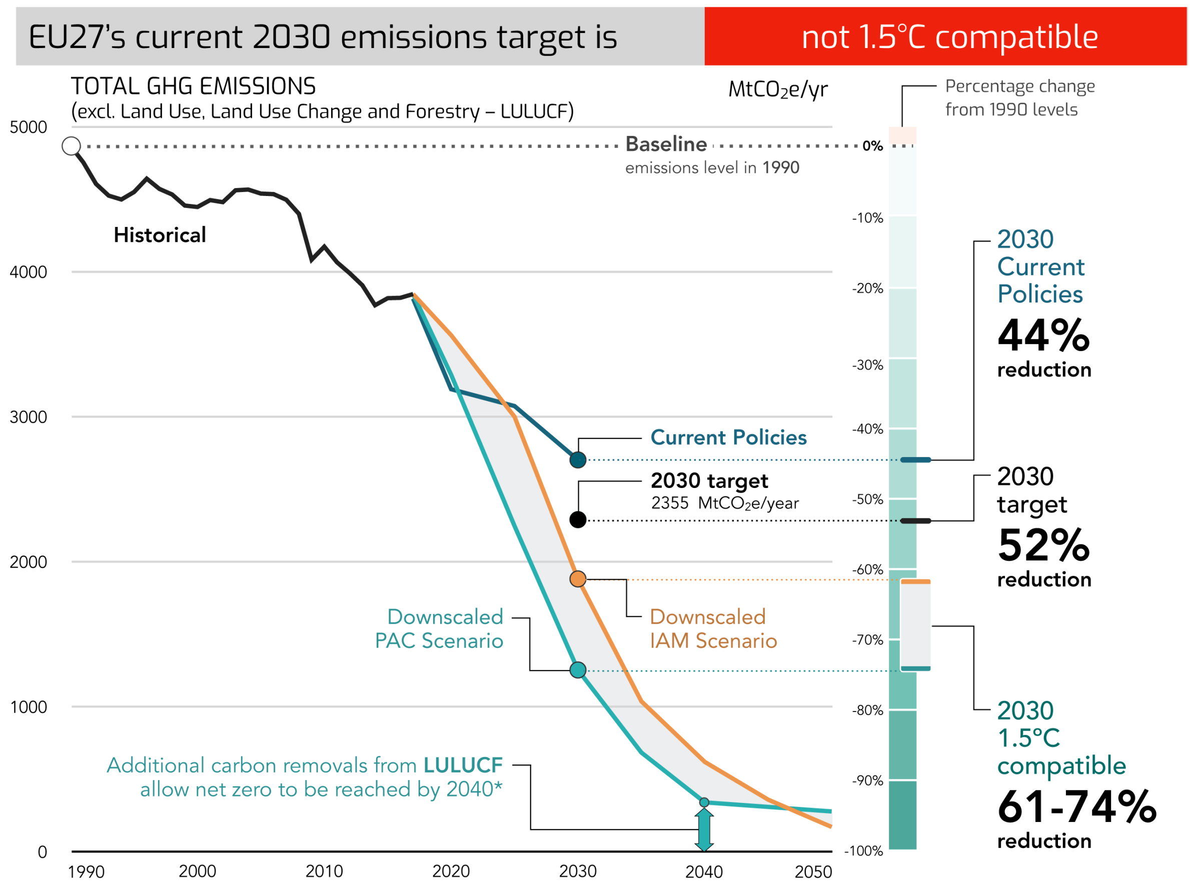
Executive Summary

To date, governments have submitted inadequate and unambitious national climate targets that are not sufficient to meet the Paris Agreement long-term temperature goal according to the latest available science.

This report presents domestic emissions and energy mix pathways required to meet the Paris Agreement's 1.5°C goal for the EU27 and nine Member States: Denmark, France, Germany, Italy, Poland, Portugal, Romania, Spain, and Sweden, and assesses if their current 2030 climate targets are in line with these pathways. Pathways are derived from the REMIND model, in particular a scenario that meets the necessary sustainability criteria and achieves the greatest regional emissions reduction to 2030 found in the IPCC Special Report 1.5°C, and the Paris Agreement Compatible (PAC) Scenario, a bottom-up derived scenario compiled by the Climate Action Network Europe and European Environmental Bureau. Key decarbonisation benchmarks for the power and industry sectors consistent with 1.5°C emissions and energy mix pathways are also provided.

For the EU27, the two assessed scenarios outline the following 1.5°C compatible ranges:

- 2030 GHG emissions reduction target of between **61-74% below 1990 levels** (excl. LULUCF)
- Share of renewable power generation in 2030 of between **76-90%**
- Share of unabated fossil gas in the power sector of between just **3-8% by 2030**, with **coal phased out by 2030**
- Achieving **net zero emissions between 2040 and 2050**



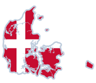
*To achieve the net zero emission target, emissions from LULUCF need to be reduced while increasing the capacity of forests, wetlands, grasslands and farmlands to remove carbon. These carbon removals are not equal to emissions in other sectors and the two cannot simply be considered fungible.

ES Figure 1: Domestic 1.5°C compatible GHG emissions pathways for the EU27

The EU is currently discussing the proposed 'Fit for 55' package of climate-related regulation amendments and updates. However, none of these proposals, including the 55% headline emissions reduction target align with the pathways derived in this report that represent the highest plausible ambition level for Europe.

Among the countries analysed here, all except for Romania are designated as Annex II countries by the United Nations Framework Convention on Climate Change (UNFCCC), meaning they are developed countries. Applying equity principles implies that all Annex II countries need to provide support to developing countries' emissions reduction efforts above and beyond their cost-effective 1.5°C-consistent domestic emissions reductions.

Country key messages



Denmark's 2030 and 2050 domestic emission reduction targets are within the range created by the two downscaled 1.5°C compatible pathways. Focus should now be on implementing strong and effective policies to phase out remaining fossil fuel use in the power sector by 2030, and the industry and transport sectors by 2040.

While **France's** 2050 net zero emissions target aligns with the downscaled 1.5°C emissions pathways, its 2030 emissions reduction and renewable generation targets do not. Improving its 2030 emissions target to between 48-66% below 1990 levels (excl. LULUCF), phasing out the limited remaining fossil fuel power generation by around 2030, and ratcheting up its 2030 renewable generation target to between 57-74% would all align with the 1.5°C compatible national results derived for France.

Recent updates to **Germany's** 2030 and net zero emissions targets are a welcome sign of progress, but the 1.5°C aligned emissions reduction pathways produced in this report show a further strengthening of its 2030 target to between 72-79% below 1990 levels (excl. LULUCF) is needed. This could be accompanied by a significant ratcheting up of its 65% 2030 renewable generation target to between 93-97%.

An indication in early 2021 by **Italy's** Minister for the Ecological transition that Italy would set a 60% emissions reduction target for 2030 has yet to lead to a concrete commitment. While discussions on the target remain ongoing, Italy has the ideal opportunity to ratchet it up to reach the 1.5°C range derived in this report of 67-73% below 1990 levels (excl. LULUCF).

Poland's stated intention to continue burning coal well into the 2040s is far from aligned with the Paris Agreement's 1.5°C long-term temperature goal. In this report's 1.5°C downscaled emissions and fuel mix pathways, Poland's current 2030 emissions reduction target would need to more than double in ambition to between a 65-69% reduction below 1990 levels (excl. LULUCF), while the 2030 share of renewable generation reaches at least 90%.

A 2023 phase-out of coal from the power sector and 2030 renewable generation target of 80% are commendable policy measures adopted by **Portugal**, but a projected continued reliance on natural gas in its energy sector beyond 2030 is problematic. Increasing its current 2030 renewable generation and emissions reduction targets to at least 88% and 43% below 1990 levels (excl. LULUCF) respectively would align with the 1.5°C pathways derived in this analysis.

A recent announcement by the **Romanian** government of a 2032 coal phase-out is a positive development, but still missing are commitments to phase out gas generation and address the stalled growth in generation from renewables, both critical to achieving a 1.5°C aligned trajectory. Benchmarks for Romania derived in this analysis include at least an 88% share of renewables in power generation by 2030 and a 2030 emissions reduction target of at least 79% below 1990 levels (excl. LULUCF).

Spain's commitments to phase out coal use by 2030 and achieve net zero emissions by 2050 are examples of 1.5°C compatible climate policies, but some insufficient 2030 targets remain. The derived 1.5°C compatible mix pathways for Spain set 2030 emissions reductions of 41-62% below 1990 levels compared to the current target of 23% below 1990 levels, and between an 82-95% share of renewables in power generation by 2030 compared to the current 74% target.

Sweden has so far failed to set an economy-wide GHG emissions reduction target, instead targeting sector-specific emissions like transport and those not covered by the EU emissions trading system. According to the two downscaled 1.5°C compatible pathways, the last remaining fossil fuel in Sweden's power sector should be phased out by 2030, while a targeted emissions reduction of 72-78% below 1990 levels by the same date is needed.

Table of Contents

1 Introduction

As part of the Paris Agreement, 184 governments have put forward targets (Nationally Determined Contributions, or NDCs) to limit the global average temperature increase to 1.5ºC with the aim to '*significantly reduce the risks and impacts of climate change*'. To date, their combined effect is not sufficient to achieve this limit. At the moment, they put the world on a path to approximately 2.4-2.7°C of warming – at risk of almost doubling the agreed limit (Climate Action Tracker, 2020; UNFCCC, 2021b).

In their successive NDCs, governments are required to put forward more ambitious emissions reduction targets that should align with the Paris Agreement. The Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C showed not only why governments must act urgently to prevent higher levels of warming, but also how global emissions need to, and can be reduced, by at least 45% by 2030 compared to 2010 (Rogelj et al., 2018). By mid-century emissions will need to be brought to net zero to limit global warming to 1.5°C.

To meet the urgent need to translate these global trajectories to action in line with the Paris Agreement, developing countries will require support. It is expected that developed countries provide such support in the form of climate finance and other measures, and to lead in the mobilisation of finance.

Developed countries such as those in the EU27 have a critical role in leading the rapid transition to decarbonised economies, and it is important for such countries to understand the extent to which their current emissions reduction targets need to be strengthened. This analysis aims to be a resource to empower a broad range of national stakeholders, including public institutions, business, and civil society, in understanding decarbonisation pathways in line with the 1.5°C limit.

These pathways, assessed with other lines of scientific evidence, show how a selection of nine EU countries can update their 2030 emissions reduction targets and develop long-term low carbon development strategies in line with the Paris Agreement, living up to their pledges to limit temperature rise to 1.5°C. The scenarios chosen for this analysis represent the highest plausible ambition for Europe and embody two methodologically distinct approaches to deriving 1.5°C compatible emissions and energy pathways for the EU27 and its Member States.

The analysis is framed around two timelines: the medium term (by 2030), and the long term (by mid-century). Sectoral benchmarks consistent with the analysed emissions pathways are provided for the power and industry sectors that outline a range of fuel mixes and necessary emissions reductions to ensure sectoral alignment with the 1.5°C limit.

For the EU27 and all nine Member States covered in this report, both scenarios outline a steep reduction in emissions in the current decade and ramping up of renewable energy technologies to replace fossil fuel combustion, which is subsequently eliminated between 2030 and 2040. This reflects the reality that we are now in the critical decade, where the 1.5°C long-term temperature goal of the Paris Agreement remains within reach, but only if global action drastically ramps up to 2030. The EU27 and its Member States now have an opportunity to light a path forward for the rest of the world to follow, but it will require political courage to embrace the highest plausible climate ambition. This report seeks to illustrate what such climate ambition for Europe could look like.

2 Mitigation pathways consistent with the 1.5°C temperature limit

2.1 Domestic action and equity considerations

In 2015, countries adopted the Paris Agreement, and agreed 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, 2021a).

Article 4.1 of the Paris Agreement outlines key elements that would enable the achievement of the long-term temperature goal:

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

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

This implies that in order to make a fair contribution to meeting the Paris Agreement's goals, developed countries need to both take domestic emissions reduction action and assist developing countries to reduce their emissions through both financial and technological transfers. This means that a developed country's total NDC "fair share" action range is the total sum of domestic reductions plus support for emission reductions action overseas. This can be in the form of climate finance, or other support for mitigation consistent with the Paris agreement (Climate Action Tracker, 2018).

For developing countries, the 1.5°C compatible pathways go beyond their needed domestic emission reduction targets and require additional support to be achieved. The fair share and equity considerations embedded in the Paris Agreement imply that without support a developing country would only reduce its emissions to its "fair share" range, and the gap between this fair share range and the 1.5°C compatible domestic pathway could only likely be bridged with support from developed countries. If a developing country's current policy emissions pathway lies above its fair share range, then it should take further action domestically to bring its emissions to at least this range.

2.2 Highest plausible ambition

While there are several equity principles, pathways considered here are not aligned with a given equity principle, but are aligned with the notion of "highest plausible ambition": defined here as pathways that are technically and economically feasible, but with the steep medium-term emissions reductions. These pathways take into account present day characteristics, such as the current infrastructure (e.g., emissions intensity of the economy), of individual countries.

To characterise this notion of "highest plausible ambition", the choice was made to present two scenarios reflecting disparate methodological approaches to deriving ambitious 1.5°C compatible pathways for the EU27. Incorporating such methodologically divergent approaches reflects an attempt to increase the robustness of the resulting 1.5°C compatible ranges, as it ameliorates the potential for systematic errors or errant assumptions underpinning scenarios derived when using the same methodology. It also shows that deriving results that demonstrate high levels of ambition are not dependent on utilising one particular approach.

The choice to present scenarios embodying the highest plausible ambition of a specific region (EU27) differs from other approaches that have been utilised to illustrate 1.5°C compatible energy and emissions pathways. A similar project that sought to portray country-level 1.5°C compatible emissions and energy pathways utilised a large subset of the "no or low overshoot" integrated assessment model (IAM) pathways collated in the IPCC Special Report on 1.5°C (SR1.5) (see section 2.3.1) (Climate Analytics, 2021). This approach was chosen to give a broad representation of the existing IAM literature on achieving the Paris Agreement's 1.5°C long-term temperature goal, without a specific focus on the highest plausible ambition embodied by individual scenarios for any specific region.

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

The two scenarios chosen for this project are the REMIND 1.7 CEMICS-1.5-CDR8 IAM scenario, and the Paris Agreement Compatible (PAC) scenario, a bottom-up collective research exercise involving energy and climate experts and incorporating findings from relevant scientific literature. These scenarios are downscaled to both the EU27 and country level using the SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) tool.

An explanation of the significance of the IAM scenarios included in the IPCC's Special Report on 1.5°C (SR1.5) and how the REMIND CEMICS-1.5-CDR8 scenario was chosen and the specific characteristics of each scenario (REMIND and PAC) are outlined in the following sections (for a description of the SIAMESE tool and the general methodology for deriving EU27 and national energy mix and emissions projections, see Annex).

2.3.1 SR1.5 IAM scenarios

The IPCC Special Report on Global Warming of 1.5°C (SR1.5) authored by more than 91 scientists and policy experts drawn from 44 nationalities, provides the most comprehensive assessment to date of greenhouse gas emission pathways that would meet the long-term temperature goal (LTTG) of the Paris Agreement (Rogelj et al., 2018). Emissions pathways contained in this report are derived from numerous modelled scenarios reflecting different evolutions of global energy demand and consumption and non-energy emissions.

The only emissions pathways from the IPCC SR1.5 report that are in line with the Paris Agreement LTTG are those categorised as:

- no or low overshoot 1.5°C pathways;
- with a probability of more than 33% of limiting warming to below 1.5°C throughout the 21st century, and;
- with at least a 50% chance of limiting warming to below 1.5°C in 2100.

There are 42 such emissions pathways that are classified as "low or no overshoot 1.5°C pathways", with each pathway reflecting a unique set of economic and technological developments that achieves this goal.

The existence of such a diverse set of global 1.5°C compatible pathways shows not only that there are many different approaches possible to achieve the Paris Agreement's 1.5°C temperature goal, but that this goal is still very much achievable. All of these pathways, however, entail steep emissions reductions between 2020 and 2030, reflecting the fact that we have entered the critical decade, during which action to reduce emissions must be drastically scaled up.

Of these "no or low overshoot 1.5°C pathways", we filter out scenarios that exceed global land-use sustainability constraints as assessed by Fuss et al. (2018). From the remaining scenarios, we singled out the scenario with the largest overall drop in emissions by 2030, which we take as signifying the highest plausible level of ambition for Europe in the IAM literature.

The scenario that meets these criteria is the REMIND 1.7 CEMICS-1.5-CDR8, and hence this scenario was chosen to represent the IAM approach to deriving a 1.5°C compatible energy mix and economy-wide emissions trajectory.

2.3.2 REMIND model and the 1.7 CEMICS-1.5-CDR8 scenario

The REMIND (REgional Model of INvestment and Development) model is an integrated assessment model (IAM) with a special focus on the development of the energy sector and its climate implications. 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 (Potsdam Institute of Climate Impact Research, 2016).

Specifically, REMIND is an energy-economy general equilibrium model linking a macro-economic growth model with a bottom-up engineering-based energy system model. It covers twelve world regions including the Europe region, from which the EU27 and country level results for this project are derived. 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.

The REMIND Europe region consists of the EU28 and several small semi-autonomous regions from the UK and Nordic countries. The SIAMESE tool is used to derive EU27 results from this slightly larger defined region used by the REMIND model (see Annex). SIAMESE is also used to derive national level results for the nine Member States covered in this project.

A misalignment of the scope of industry sector energy demand data in the REMIND scenario exists compared to the IEA World Energy Balances dataset that is used to provide historical data and the PAC scenario historical demand data. Due to this energy data misalignment it was not possible to provide downscaled industry sector energy and emissions pathways from the REMIND scenario.

The REMIND 1.7 CEMICS-1.5-CDR8 scenario chosen for use in this project envisages some natural gas and biomass combustion with carbon capture and storage.

2.3.3 Paris Agreement Compatible (PAC) scenario

The PAC scenario is a European-wide energy scenario aligned 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). In doing this, it suggests a trajectory with:

- 100% renewable energy supply by 2040
- At least 65% greenhouse gas emissions (GHGs) reductions by the year 2030
- Net zero emissions by 2040

The scenario was developed through a process of desk research, comparing and adopting elements of a multitude of existing studies and models, and feedback on key assumptions gathered through a comprehensive stakeholder engagement process. This process entailed a series of workshops and webinars and an online survey and involved around 150 individuals from science, industry, and member organisations of the Climate Action Network (CAN) Europe and the European Environment Bureau (EEB).

The resultant scenario provides an ambitious blueprint for building a 1.5°C aligned energy system for the EU28. Key elements of this 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 contribution. This leads to halving the EU's energy demand between 2015 and 2050.
2. **A swift ramping up of domestic renewable energy use**, in particular of solar PV and wind energy for electricity production. Renewable electricity generation more than triples during the decade from 2020 to 2030. This leads to renewables covering 50% of gross final energy consumption in 2030 and 100% in 2040.
3. **An electrification of industrial processes, heating and transport,** based on renewable electricity.
4. **A quick phase-out of fossil fuels,** starting with coal mostly disappearing from the mix by 2030, fossil gas by 2035 and fossil oil products by 2040. Most nuclear power plants also will be 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.

These elements and the overall scenario provide the starting point from which the EU27 and national level results are derived using SIAMESE. Consequently, while the dynamics of national results can differ in the relative composition of various fuels, they are bound by these general features of the overall scenario.

The PAC scenario is an energy system model, meaning that it does not include a sophisticated estimation of non-energy-related GHG emissions. As part of this project, a methodology was therefore derived to estimate these emissions for the PAC scenario to create robust economy-wide GHG emissions pathways for the EU27 and nine Member States analysed in this project (see Annex).

A key assumption underpinning the PAC scenario is that carbon capture and storage will not be required to achieve net zero emissions for the European Union.

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

The scenarios chosen for analysis in this project do not include a capacity for modelling emissions from the LULUCF sector. As a result, the economy-wide emissions pathways generated for the EU27 and nine Member States are all excluding LULUCF emissions.

As the PAC scenario assumes the achievement of net zero GHG emissions in 2040, the remaining non-energy related emissions for each country in 2040 shown in this analysis are assumed to be abated by a LULUCF sink of at least the size of these remaining emissions.

Crucially, the level of EU27 residual emissions in 2040 under the PAC scenario that represents the size of the LULUCF sink needed to achieve net zero emissions by this date (345 $MtCO_2e$) is below the nearly 400 $MtCO_2e$ LULUCF sink in 2040 projected by the European Commission under its LULUCF+ scenario (European Commission, 2020). In this scenario, initiatives at EU, Member State or regional level have been developed that enable action at the local level and can include optimisation of forest management, afforestation projects and improving soil management including through rewetting and restoration of carbon-rich ecosystems.

The size of the implied 2040 LULUCF sink for the EU27 under the PAC scenario is also well below the projected potential sink in numerous analyses in the scientific literature, which range from 430 to 570 in 2030, and 488 to 787 $MtCO_2e$ in 2050 (Build Up, 2019; Fraunhofer ISI & Öko-Institut, 2019; PIK, 2020; Welle et al., 2020). This provides strong evidence that the 2040 net zero target of the PAC scenario is achievable with enhanced efforts to maximise the size of the EU's LULUCF sink.

For the REMIND scenario, the implied size of the LULUCF sink required for the EU27 to reach net zero GHG emissions reaches those found in the aforementioned literature between 2040 and 2043. This declines further to just 175 $MtCO_2e$ in 2050, well below even the European Commission's BAU scenario in 2050 of 271 $MtCO_2e$ (European Commission, 2021a).

2.4 Limitations and outlook towards updated global pathways

While global emissions pathways assessed in IPCC reports are essential for the broad scientific setting and underpinning of the guidance on long-term energy system transformation, these pathways were published in the scientific literature well ahead of the release of the IPCC SR1.5, and were therefore often developed in 2017, or before. They do not necessarily keep track of current developments in energy markets, disruptive technological developments, consumer choices and policy trajectories. Furthermore, sustainability constraints identified by the IPCC and others and the plausibility of future large-scale deployment of key technologies, such as BECCS, nuclear power plants, fossil fuel with CCS and land-use options are often not captured in these pathways.

A parallel workstream to this analysis, together with the global energy-economic modelling community, aims at developing an additional illustrative set of 1.5°C compatible pathway variants, taking into account both the IPCC assessments and the latest data and analyses on policies and technology markets and costs. This will allow the addition of further models and other lines of evidence to empower stakeholders in understanding and making informed choices about the necessary transformative changes. A future version of this report is planned to incorporate these more up to date adjusted pathways that will be added to the two scenarios analysed here.

3 1.5°C compatible mitigation pathways for the EU27

3.1 Current targets and policy context

Since 1990, total EU27 GHG emissions (excl. LULUCF) have fallen by 26%, reaching 3,610 $MtCO_2e$ in 2019, with much of this decline occurring since 2007, when they were just 8% below 1990 levels (EEA, 2021). Under current policies,[1] total EU27 GHG emissions are projected to reach 48% below 1990 levels including LULUCF (44% excl. LULUCF), achieving its original emissions target of at least a 40% reduction below 1990 levels (incl. LULUCF) (European Commission, 2021a).

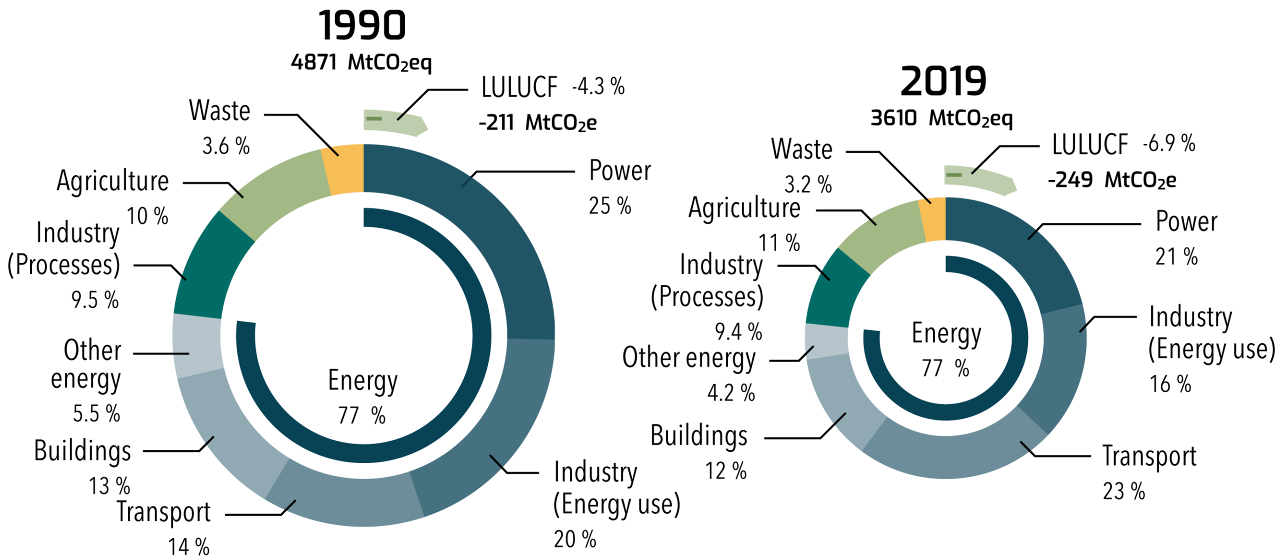


Figure 1: Historical EU27 emissions by sector. Source: (EEA 2020)

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, to at least 55% by 2030 (incl. LULUCF). 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). The 'Fit for 55' package must still be reviewed and approved by the European Parliament and Council when it will be formally adopted as EU legislation.

As the EU27 includes countries at various stages of development, the emissions reduction burden to achieve the EU-wide 2030 target is not distributed evenly.

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 electricity, industry and intra-EU aviation sectors, while 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 levels. In its 'Fit for 55' package of proposals, the Commission suggested more stringent emissions reduction

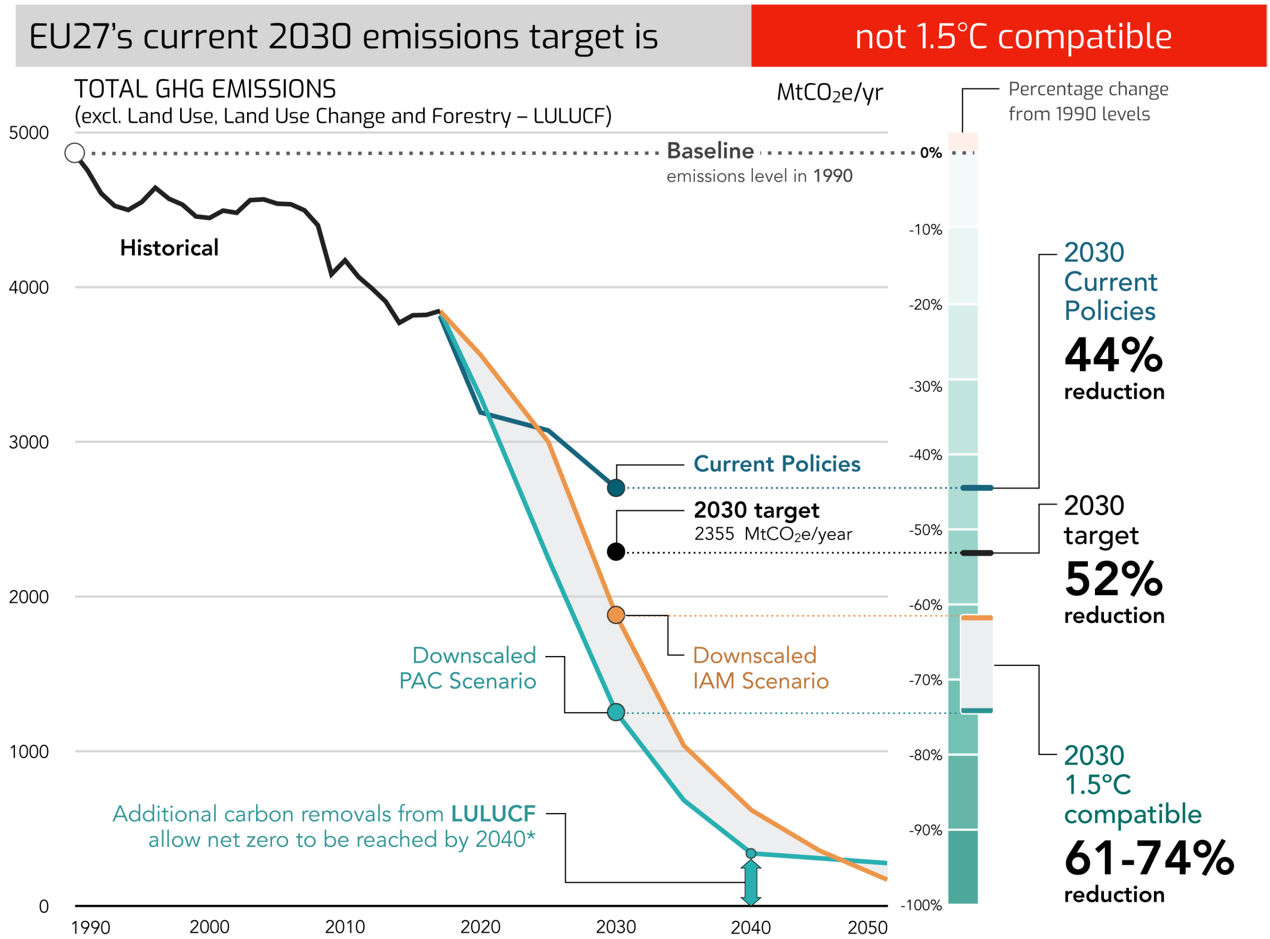
[1] EU27 emissions under current policies are taken from the EU Reference Scenario 2020. Non-CO_2 emissions are converted from global warming potentials (GWP) from the Fifth Assessment Report (AR5) into AR4 GWP to maintain comparability with emissions data in the remainder of this report.

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.

The EU27's total energy supply peaked in 2006 and in 2019 was only marginally below 1990 levels, falling in recent years due to plummeting coal demand and a steady decline in demand for oil and petroleum products (IEA, 2020). Renewables have to date displaced considerable amounts of fossil fuel consumption, with total renewable supply in the EU27 increasing fourfold since 1990, primarily due to increasing solar and wind generation and biomass consumption.

3.2 Emissions and energy pathways and adequacy of targets

The EU27's recently updated 2030 NDC of at least a 55% reduction in total GHG emissions below 1990 levels including LULUCF (at least 52% excl. LULUCF[2]) falls short of the 1.5°C compatible range derived from the difference between the 2030 emissions levels of the downscaled IAM and PAC scenarios used in this analysis. For the EU27, that range is determined as 61-74% (excl. LULUCF), which is taken to represent the highest plausible ambition level for Europe.



*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: Domestic 1.5°C compatible GHG emissions pathways for the EU27

2 The EU27's 2030 emissions reduction target excluding LULUCF emissions is calculated by assuming LULUCF emissions in 2030 will reach the level projected under the EU's Reference Scenario 2020 (-258 $MtCO_2e$).

Assuming the European Commission's conservative business-as-usual scenario for the size of the EU27 LULUCF sink in 2030 (-258 $MtCO_2e$), this equates to a 2030 emissions reduction target including LULUCF of 65% below 1990 levels for the downscaled IAM scenario and a 79% reduction below 1990 levels for the downscaled PAC scenario (European Commission, 2021a).

The current target of a 55% reduction below 1990 levels (incl. LULUCF) is not 1.5°C compatible according to these downscaled pathways, and therefore cannot reasonably be promoted as a world-leading contribution to global climate mitigation efforts.

Under the downscaled PAC scenario, total energy use for the EU27 declines steeply to 2030 whereby coal use is mostly phased out, then continues falling to 2040 as the remaining fossil gas and oil consumption is eliminated. Much of the decline in fossil fuel demand is displaced by renewable power generation which eliminates combustion-related losses, though energy savings, efficiency gains, and behavioural change in the residential, tertiary, and transport sectors contribute strongly (PAC Consortium, 2020). Ongoing efficiency gains prevent total energy demand from rising after 2040, with 2050 demand, consisting of 100% renewable energy, near 2040 levels.

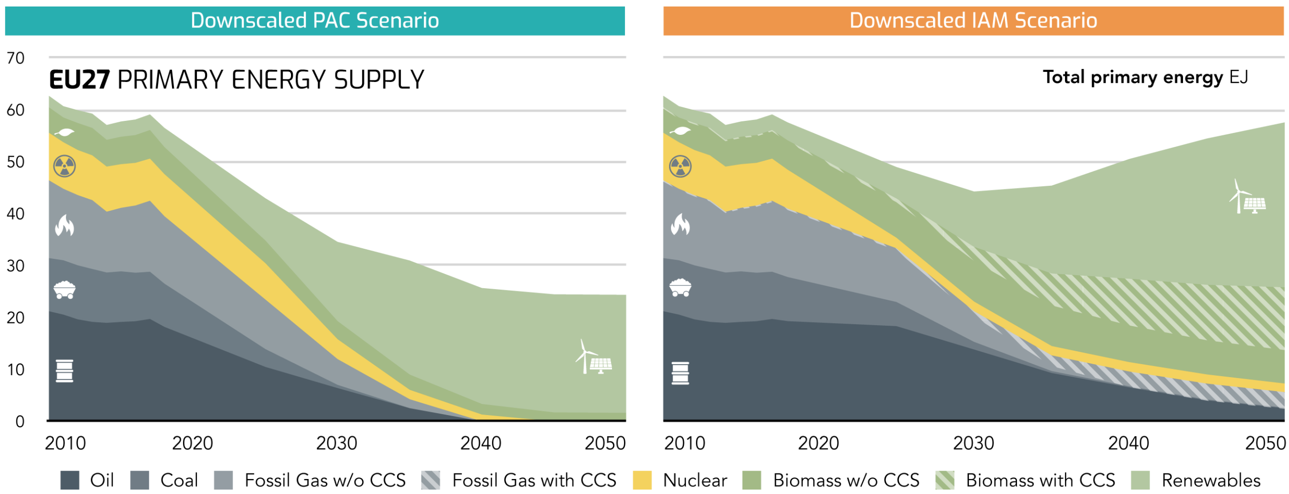


Figure 3: 1.5°C compatible primary energy supply pathways by fuel

In the downscaled IAM scenario, total energy demand is in large part driven by GDP and population growth assumptions, that are taken from the shared socioeconomic pathway 2 (SSP2), which is a middle-of-the-road scenario (Luderer et al., 2015). This assumption of moderate GDP growth and convergence of per capita energy demand across regions beyond 2100 leads to an overall increase in primary energy demand after 2030 once inefficient coal combustion has been mostly phased out. Further efficiency gains resulting from ongoing displacement of oil and fossil gas combustion with renewable generation is outweighed by increasing demand, leading total demand in the EU27 to reach near current levels by 2050. Unabated fossil gas is mostly phased out by 2035, with over 95% of remaining fossil gas in 2040 utilising carbon capture and storage (CCS).

3.3 Power sector decarbonisation

Electricity generation in the EU27 has undergone a profound transformation over the last decade, notably after EU ETS free allocation of allowances were phased out, with supply from coal and oil roughly halving since 2007, while generation from renewables almost doubled over the same period (IEA, 2020). This shift occurred while total electricity demand fell slightly, though still well above 1990 levels.

Table 1: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	31%	23%	18%	26%
2030	76–90% (IAM PAC)	0–2% (IAM PAC)	3–8% (PAC IAM)	7–14% (IAM PAC)

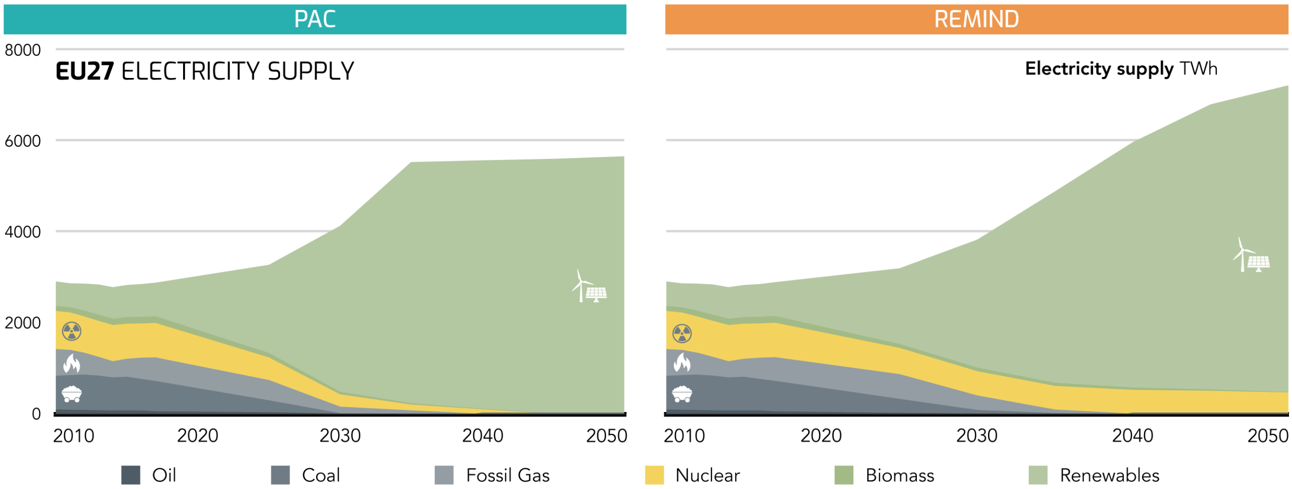


Figure 4: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

In 2019, renewable energy generation made up 34% of the total EU27 power supply, up from just 20% ten years earlier (IEA, 2020). To ensure the power sector is aligned with the derived 1.5°C compatible energy mix pathways, this would need to more than double to at least 76% by 2030; above the recently projected 2030 level of 64-67%. Coal would need to be phased out by 2030, while fossil gas should be mostly removed from the system by 2035, with the last remaining fossil-based generation gone by 2040.

Emissions from the power sector in the EU27 would need to decline by 84-95% below 1990 levels by 2030 to align with the two downscaled 1.5°C compatible emissions pathways, with total emissions reaching zero by 2040.

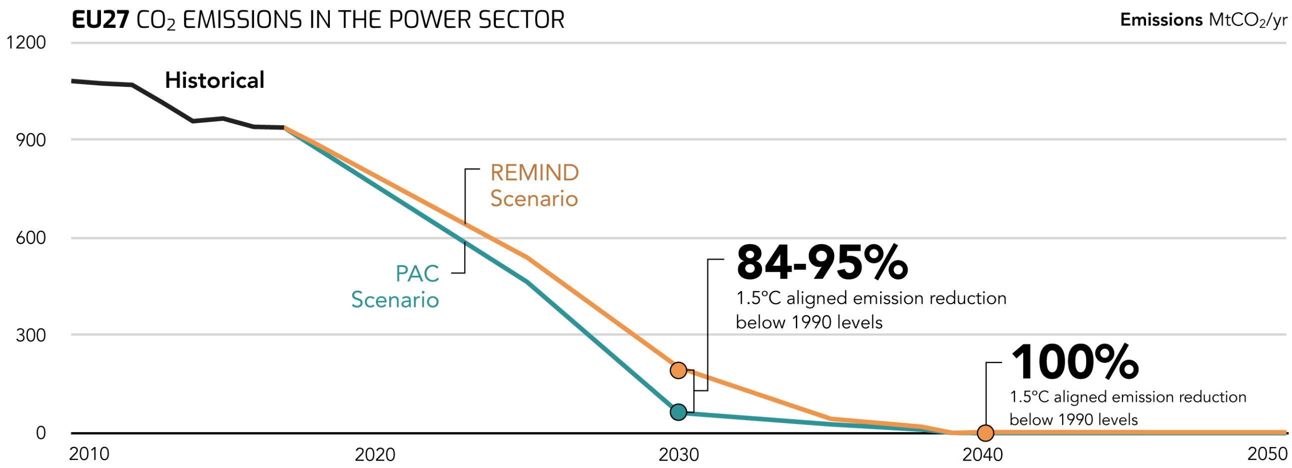


Figure 5: 1.5°C compatible power sector emissions for the EU27

3.4 Industry sector decarbonisation

The sectoral composition of the EU27's multitude of economies varies considerably, including the size and nature of each member state's industry sector. Countries with extensive heavy industry activity like steel or cement production, or fossil fuel or mineral processing generally see higher shares of industry sector emissions as a proportion of total emissions. This variation should be considered in the formulation of EU-wide policy proposals to achieve industry sector decarbonisation, but the existence of extensive industrial output in the EU means setting ambitious overarching policies and targets is crucial to its realisation.

Variation in GDP per capita across Member States is also substantial and EU-wide policy proposals must accommodate this to ensure the mitigation burden is spread equitably. One measure that seeks to address this in the 'Fit for 55' package's proposed revisions to the EU ETS is an increase in the percentage of the cap auctioned to fund the transition in Member States with below average GDP per capita through the Modernisation Fund. These funds are allocated to help modernise these Member States' energy systems and improve energy efficiency (European Commission, 2021c).

While assisting those Member States with fewer resources to make the necessary rapid transition to a decarbonised industry sector is important, having overarching targets to guide the development of policies that reflect the necessary level of urgency to achieve the 1.5°C temperature limit is crucial. The derived 1.5°C compatible industry energy mix and emissions pathway for the EU27 seeks to guide the development of such targets, particularly to spur action in the current critical decade.

Due to the misalignment of industrial energy consumption data from the REMIND model's Europe region with historical data used for this project, it was not possible to derive downscaled 1.5°C compatible energy mix and emissions pathways from the chosen REMIND scenario. As a result, industry sector results are only provided from the downscaled PAC scenario pathways.

Table 2: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	34%	10%	31%	0%
2030	**47%**	**5%**	**18%**	**6%**

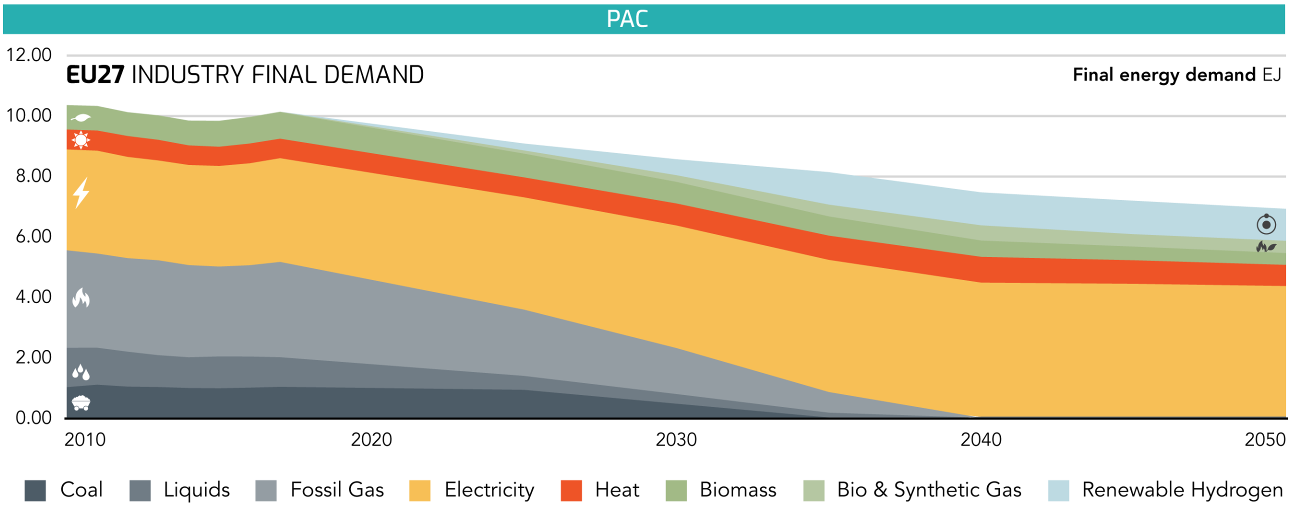


Figure 6: 1.5°C compatible share of technologies in the industry energy mix

According to industry energy mix and emissions pathways downscaled from the PAC scenario, the EU27 should eliminate fossil fuel combustion by around 2035. Significant energy efficiency gains are combined with declining overall energy and resource consumption, while electrification and renewable hydrogen contribute an increasingly significant share over the coming decades. Total emissions should decline by 68% and 89% below 1990 levels by 2030 and 2050 respectively, with energy-related emissions reaching zero by 2040.

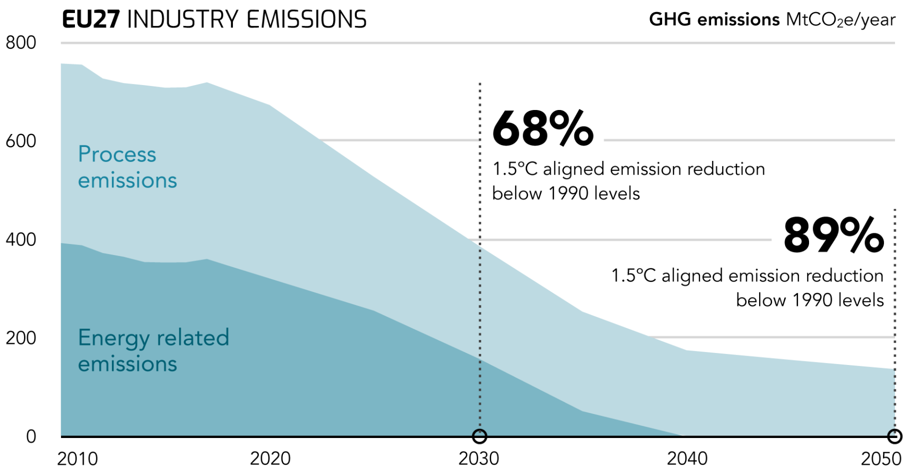


Figure 7: 1.5°C compatible industry sector emissions for the EU27

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

Table 3 below provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for the EU27 in 2030 and 2050, compared against recent historical values.

Table 3: Key characteristics of the EU27's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		EU27 targets	
	2017	**2030**	**2050**	**2030***	**2050***
Total GHG excl. LULUCF	3850 $MtCO_2e/yr$	1257–1885 $MtCO_2e$ /yr	175–282 $MtCO_2e$ /yr	2355 $MtCO_2e$ /yr	271 $MtCO_2e$ /yr
	21 % below 1990	61–74 % below 1990	94–96 % below 1990	52 % below 1990	94% below 1990
Emissions intensity of power generation**	325 gCO_2/kWh	15–53 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	31 %	76–90 %	94-100 %	65 %	
Share of unabated fossil fuel in power	43 %	4–10 %	0 %		
Share of nuclear power	26 %	7–14 %	0–6 %	16 %	
Industry electrification rate	32 %	47 %	63 %		

* 2030 and 2050 targets excluding LULUCF calculated using the EU Reference Scenario 2020 projections

** Does not include upstream emissions

4 National mitigation pathways consistent with the 1.5°C temperature limit

The following sections will provide country level results for the nine member countries selected to be assessed in this project (Denmark, France, Germany, Italy, Poland, Portugal, Romania, Spain, Sweden). Included in each section is a brief discussion of the current situation and recent trajectory of each country, including existing targets and key policies. A set of 1.5°C compatible economy-wide energy and emissions pathways and benchmarks are derived by downscaling the chosen IAM and PAC scenarios, as well as pathways and benchmarks for the power and industry sectors.

4.1 Denmark's domestic transition pathways

4.1.1 National context and current targets

Though a small country with just 5.8 million inhabitants, Denmark is a global front-runner in its commitments and contributions towards climate mitigation. Total Danish GHG emissions in 2019 were 50% below their peak in 1996 (36% below 1990 levels), with the majority of these emission reductions coming from the power sector which registered an 85% reduction below 1996 levels in 2019 (Government of Denmark, 2021b).

This has been achieved primarily through an ambitious scaling up of renewable energy, particularly wind energy, with the renewable share of Denmark's electricity supply in 2019 averaging 50% (IEA, 2020). Transport sector emissions have risen, however, reaching 23% above 1990 levels in 2019 due to increasing road traffic over this time (Government of Denmark, 2021b).

The agriculture sector in Denmark is a significant emitter, constituting 24% of total emissions in 2019, with livestock production making up the bulk of emissions. Emissions from agriculture in 2019 were 17% below 1990 levels though, primarily from a reduction in N_2O emissions. Non-combustion emissions from industry processes and product use made up roughly 4% of total emissions in 2019, mainly from cement production and F-gases used in refrigeration and air conditioning.

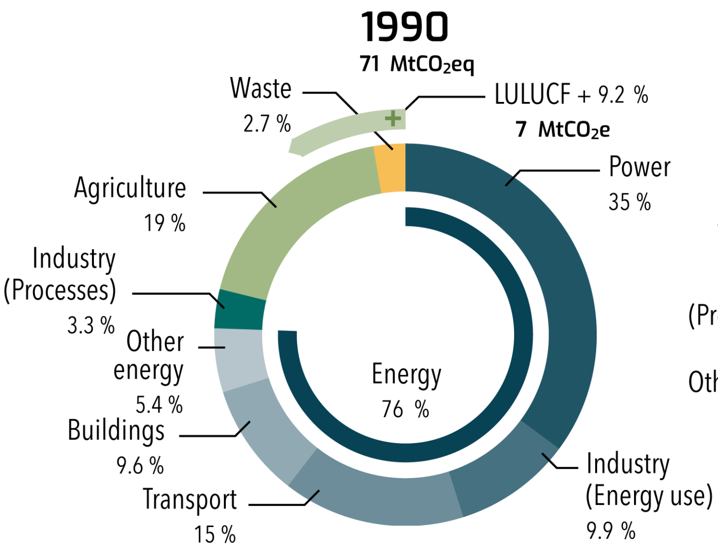


Figure 8: Historical emissions by sector. Source: (Government of Denmark, 2021a)

In 2019, Denmark passed its Climate Act, which targets a 70% reduction in GHG emissions below 1990 levels by 2030 including LULUCF (73% excl. LULUCF), and net zero emissions by 2050. This is one of the strongest domestic emissions reduction targets in the world given the steep reduction in emissions required by 2030 (Government of Denmark, 2019).

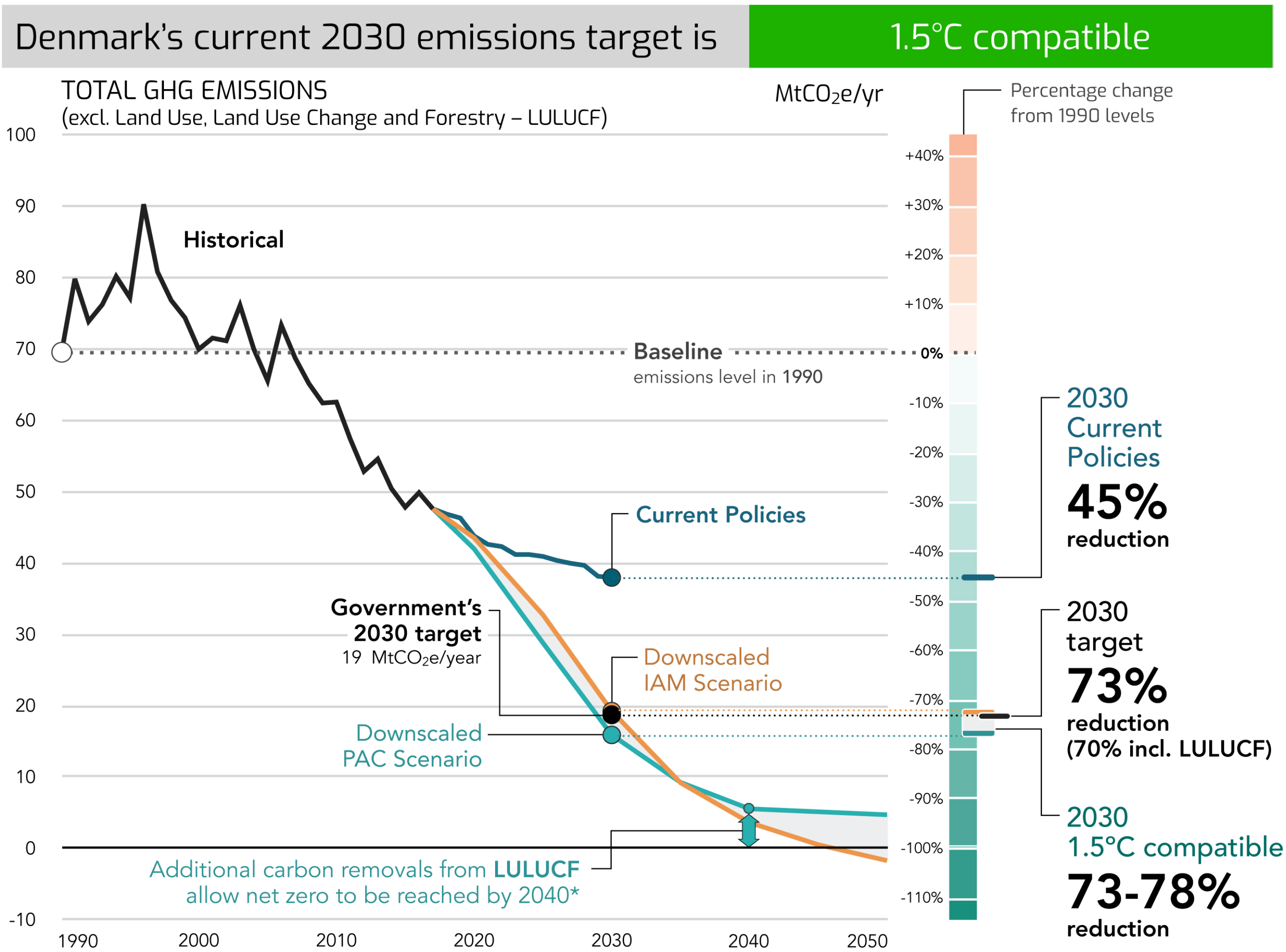
To achieve these targets, Denmark has put in place a number of ambitious medium-term policies, including: phasing out coal from its electricity system by 2030, reaching a 55% renewable share of gross final energy consumption and 100% of electricity generation by 2030, a 90% share of district heating based on energy sources other than coal, oil, and gas by 2030, and phasing out the sale of new petrol and diesel cars by 2030.

Further and more ambitious policies are needed, however, as under current policies, Denmark is projected to fall considerably short of its 2030 target, instead reaching just 45% below 1990 levels excluding LULUCF (Government of Denmark, 2020).

4.1.2 Emissions and energy pathways and adequacy of domestic targets

A reduction of 73-78% below 1990 levels (excl. LULUCF) is determined to be a 1.5°C compatible range for a 2030 domestic emissions target, making Denmark's 73% (excl. LULUCF) target aligned with the Paris Agreement's 1.5°C temperature goal. Denmark's current suite of climate policies as outlined in its National Energy and Climate Plan will, however, fail to achieve this target, reflecting the need for greater urgency across all sectors of the economy (Government of Denmark, 2020).

In particular, policies are lacking to encourage the necessary rapid decarbonisation of the transport, industry, and buildings sectors. After falling from their record high in 2018, transport emissions need to continue to decline. Investments to achieve modal shift from cars to public transport and walking or cycling are crucial moving forward, as are incentives to encourage house owners to install low carbon heating options.



*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 9: Domestic 1.5°C compatible GHG emissions pathways for Denmark

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand is reduced to between 25-32% by 2030, whereas the renewable energy share reaches between 68-75% by the same date. The transport and industry sectors constitute a combined 42%

of total GHG emissions in Denmark, illustrating the need for strong policies to reduce the oil and natural gas demand that produce these sectoral emissions.

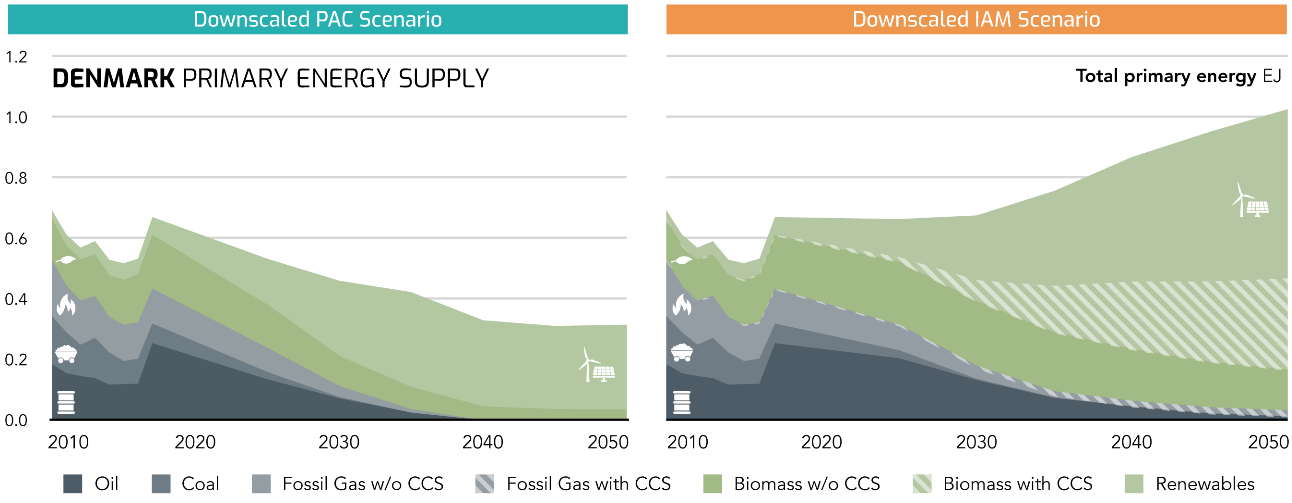


Figure 10: 1.5°C compatible primary energy supply pathways by fuel

4.1.3 Decarbonising the power sector and policy implications

Denmark's power sector has undergone a transformation over the last decade, marked by rapidly declining coal and gas use and rising generation from renewables and biomass. The government's 2030 coal phase-out is 1.5°C compatible, and should now be accompanied by a commitment to phase out gas use by around the same date.

Table 4: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	72%	20%	7%	0%
2030	**98–99%** IAM PAC	**0%**	**1–2%** PAC IAM	**0%**

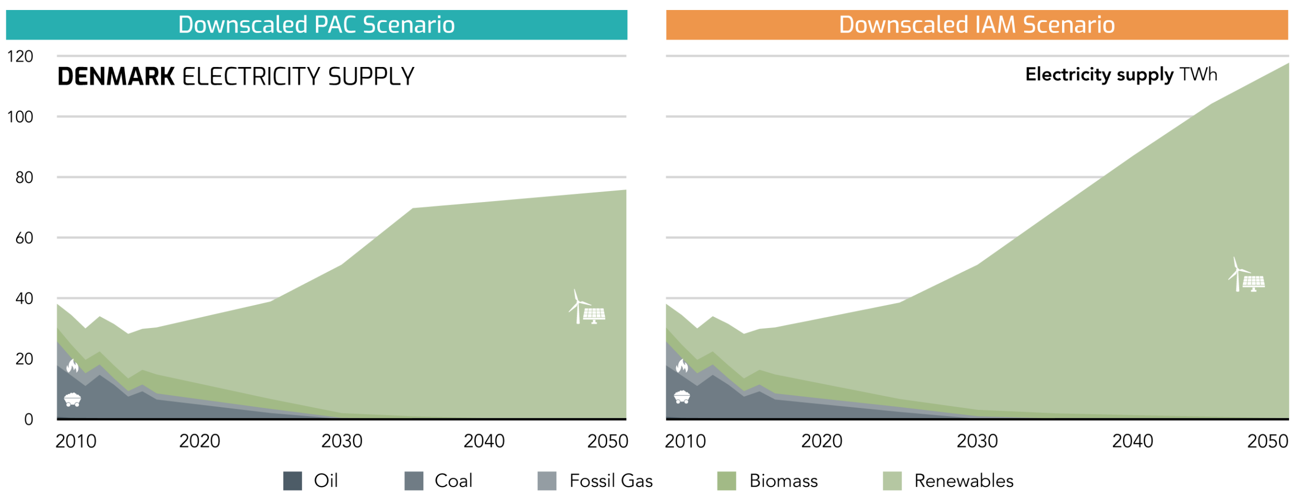


Figure 11: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in the Danish power sector should reach close to zero by 2030 as the last remaining coal and natural gas is phased out by this date.

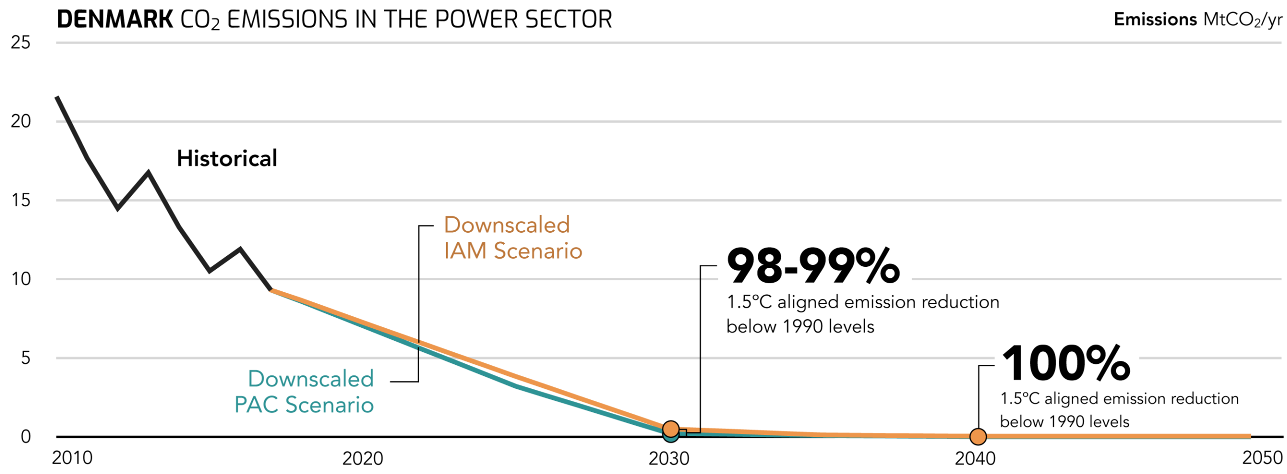


Figure 12: 1.5°C compatible power sector emissions for Denmark

4.1.4 Decarbonising the industry sector and policy implications

Emissions from Denmark's industry sector have fallen at more than double the rate (-31%) at which energy demand has declined (-15%) over the period 1990-2019 (IEA 2020; Government of Denmark 2021a). This is primarily due to fuel switching from coal and oil, which have seen demand decline by 71% and 41% respectively, to fossil gas and biomass, the consumption of which are 15% and 133% higher in 2019 than in 1990. To align with the 1.5°C compatible fuel mix pathway downscaled from the PAC scenario, the remaining coal use should be phased out by 2035 at the latest, while oil and gas demand should be eliminated between 2035 and 2040.

Table 5: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	32%	6%	30%	0%
2030	47%	4%	21%	6%

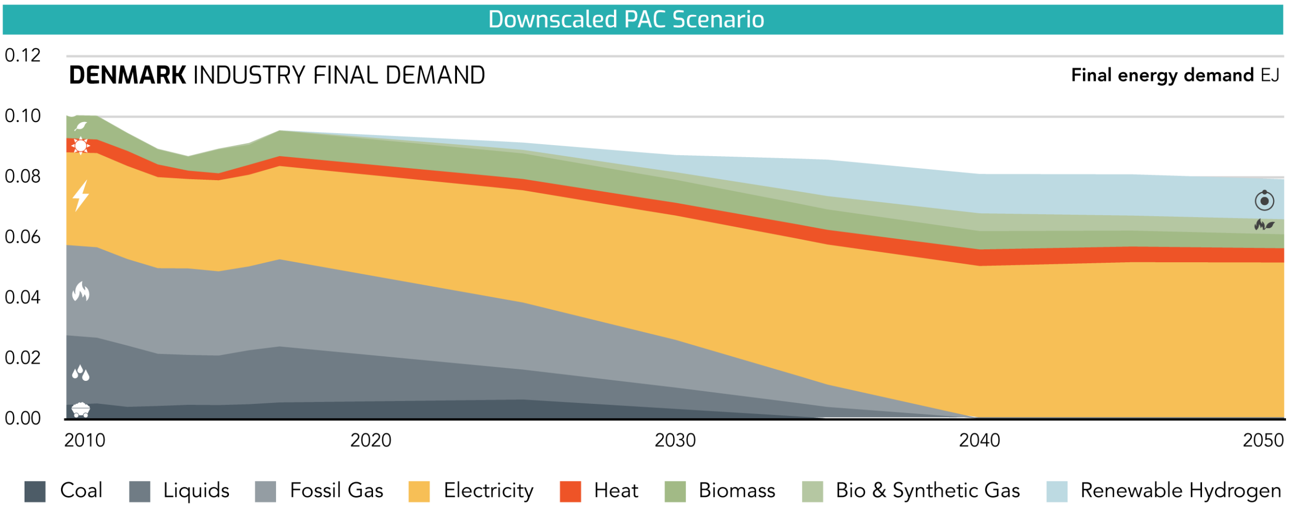


Figure 13: 1.5°C compatible share of technologies in the industry energy mix

The share of electricity in industry final demand increases from its 2017 level of 32% to reach 47% by 2030, and 65% by 2050. This would help achieve the total emission reductions necessary to align with the derived 1.5°C targets of 50% and 82% by 2030 and 2050 respectively. Energy-related emissions reach zero by 2040.

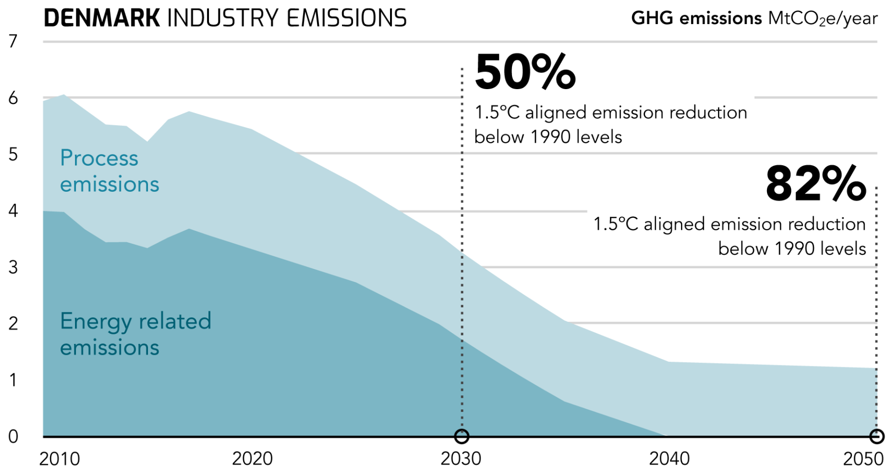


Figure 14: 1.5°C compatible industry sector emissions for Denmark

4.1.5 Key characteristics of Denmark's 1.5°C compatible pathways and other analyses

Table 6 below provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Denmark in 2030 and 2050, compared against recent historical values.

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

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030***	**2050** incl. LULUCF**
Total GHG excl. LULUCF	48 $MtCO_2e/yr$	16–19 $MtCO_2e$ /yr	-2–5 $MtCO_2e$ /yr	19 $MtCO_2e$ /yr	0 $MtCO_2e$ /yr
	31% below 1990	73–78 % below 1990	93–103 % below 1990	73 % below 1990	100% below 1990
Emissions intensity of power generation***	307 gCO_2/kWh	4–10 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	72%	98–99 %	100 %	100%	
Share of unabated fossil fuel in power	28%	1–2 %	0 %	0 %	
Share of nuclear power	0%	0 %	0 %		
Industry electrification rate	32 %	47 %	65%		

* 2030 target excluding LULUCF calculated using the government's 'with existing measures' emissions projections from NECP 2020
** 2050 target is shown including LULUCF emissions due to the absence of government projections for these emissions to 2050
*** Does not include upstream emissions

An analysis by INFORSE-Europe and Vedvarende Energi demonstrated that a 100% renewable energy target for 2030 is feasible and aligns with both the benchmark in this report and with the government's current 2030 target (Olesen, 2010).

4.2 France's domestic transition pathways

4.2.1 National context and current targets

Despite France being one of the largest economies in Europe, it is one of Europe's least carbon intensive, primarily due to the high share of nuclear generation in its power sector, which was 72% in 2018 (IEA, 2020). The share of fossil fuels was just 7% in the same year, while renewables made up 21%.

The transport sector is France's largest emitter, constituting 30% of total GHG emissions in 2019, with industry making up 25% and the buildings sector 14%; all well above the power sector (7%) (Government of France, 2021b).

Though its power sector has relatively low emissions intensity compared to other major European economies, economy-wide GHG emissions in France have also not fallen as quickly as in other major economies since 1990, falling to just 20% below 1990 levels in 2019. However, total N_2O emissions in France have fallen by almost double this amount due to a 94% reduction from industrial processes; the result of both improved processes and a loss of manufacturing sites.

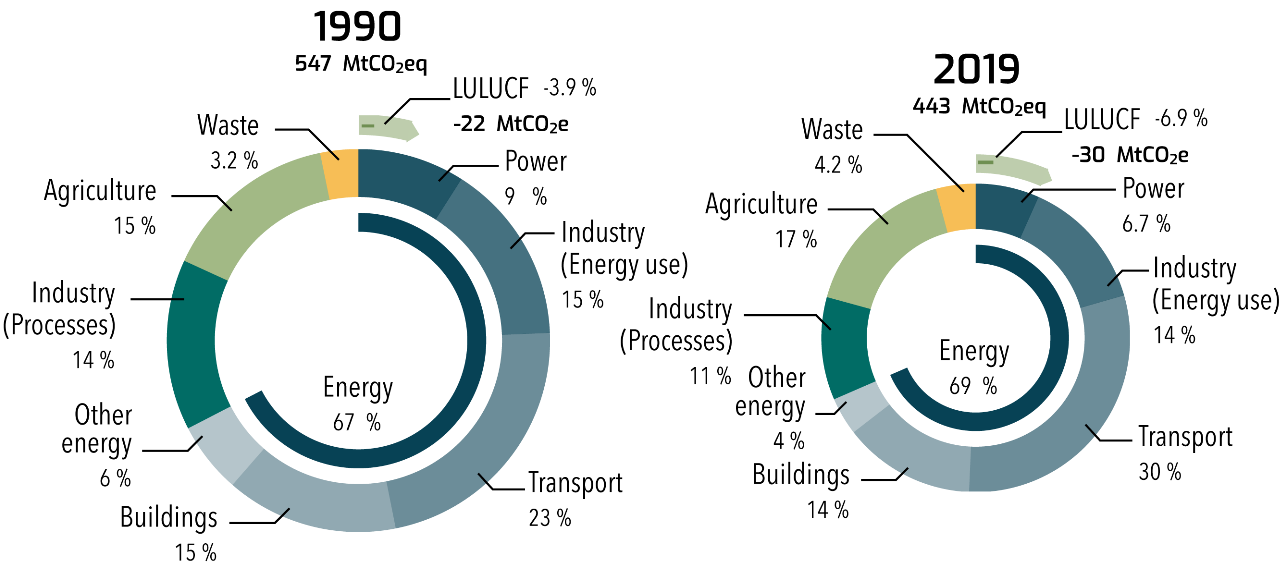
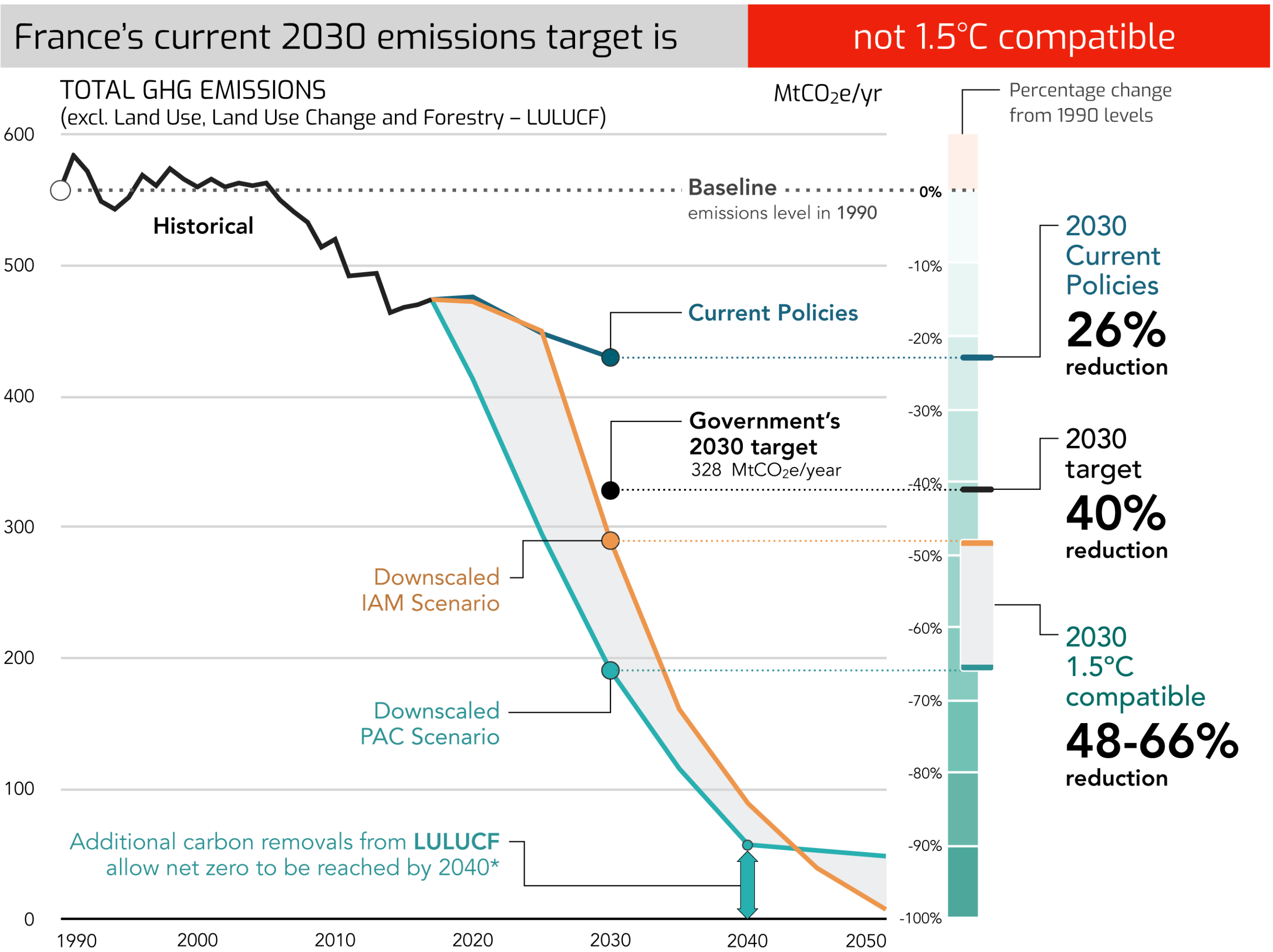


Figure 15: Historical emissions by sector. Source: (Government of France, 2021a)

In 2017, France passed its Climate Plan, which committed the country to achieving net zero emissions by 2050. In addition to this, France has a target to reduce total GHG emissions by 40% below 1990 levels by 2030 (Government of France, 2020a).

4.2.2 Emissions and energy pathways and adequacy of domestic targets

Achieving a 1.5°C compatible economy for France as determined by this project requires a 48-66% reduction in total GHG emissions below 1990 levels by 2030 (excl. LULUCF) and reaching net zero emissions between 2040 and 2050. France's current suite of climate policies as outlined in its National Energy and Climate Plan will fail to achieve even its insufficient 2030 target, reflecting the need for greater urgency across all sectors of the economy and a more ambitious target that guides such action (Government of France, 2020b).



*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 16: Domestic 1.5°C compatible GHG emissions pathways for France

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand is reduced to between 30-42% by 2030, whereas the share of renewables climbs to between 36-44% by the same date. The transport and building sectors constitute a combined 44% of total GHG emissions in France, illustrating the need for strong policies to reduce the oil and natural gas demand that produce these sectoral emissions.

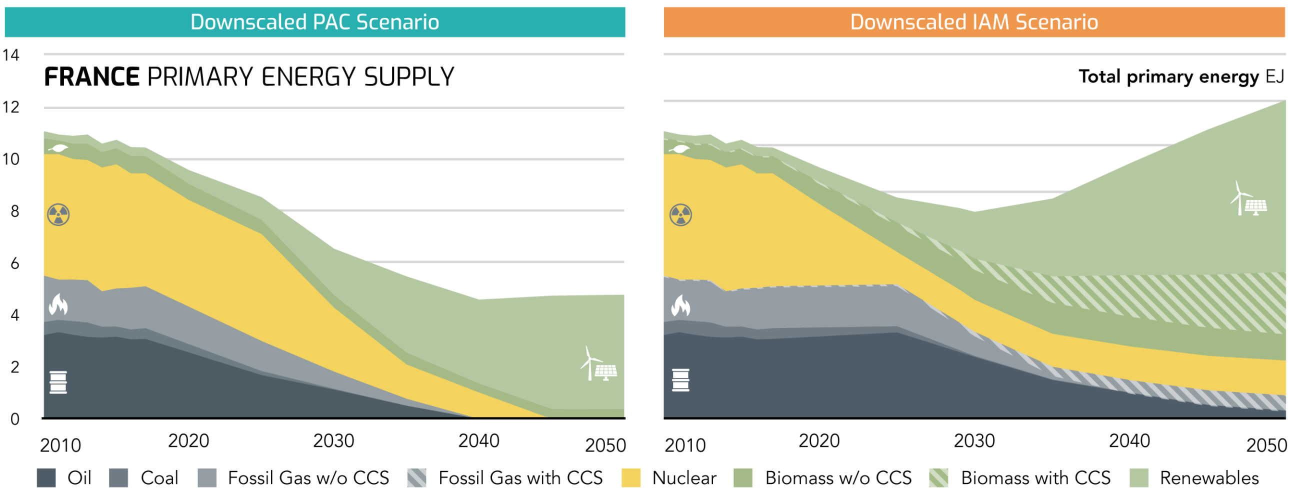


Figure 17: 1.5°C compatible primary energy supply pathways by fuel

4.2.3 Decarbonising the power sector and policy implications

France's power sector is largely fossil-free, with significant nuclear generation, and rising levels of renewables. However, the remaining fossil gas consumption in the power sector would need to be phased out shortly after 2030 in order to be consistent with the derived 1.5°C compatible pathways, and no new plants should be constructed.

With a large uptick in total electricity demand projected due to widespread electrification throughout the economy, a steep increase in renewable energy capacity is required over the next two decades. The downscaled PAC scenario demonstrates that the French power sector can be decarbonised while also phasing out nuclear, with recently published literature also supporting this finding (négaWatt, 2017).

Table 7: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	17%	3%	7%	72%
2030	57–74% (IAM – PAC)	0%	2–4% (PAC – IAM)	24–39% (PAC – IAM)

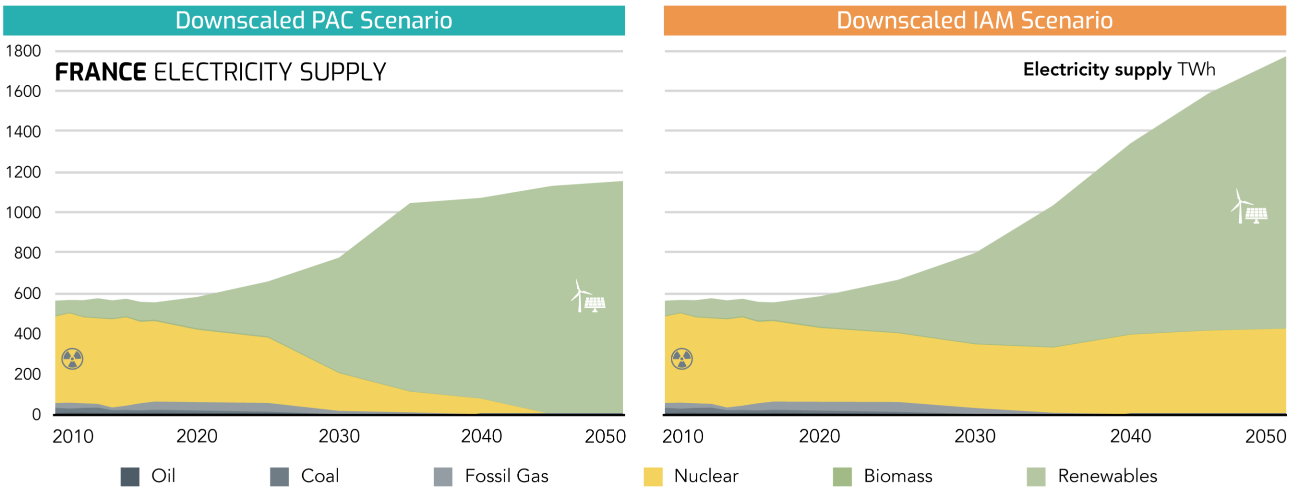


Figure 18: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in the French power sector should decline by between 72-86% below 1990 levels by 2030 with the last remaining coal generation phased out by this date.

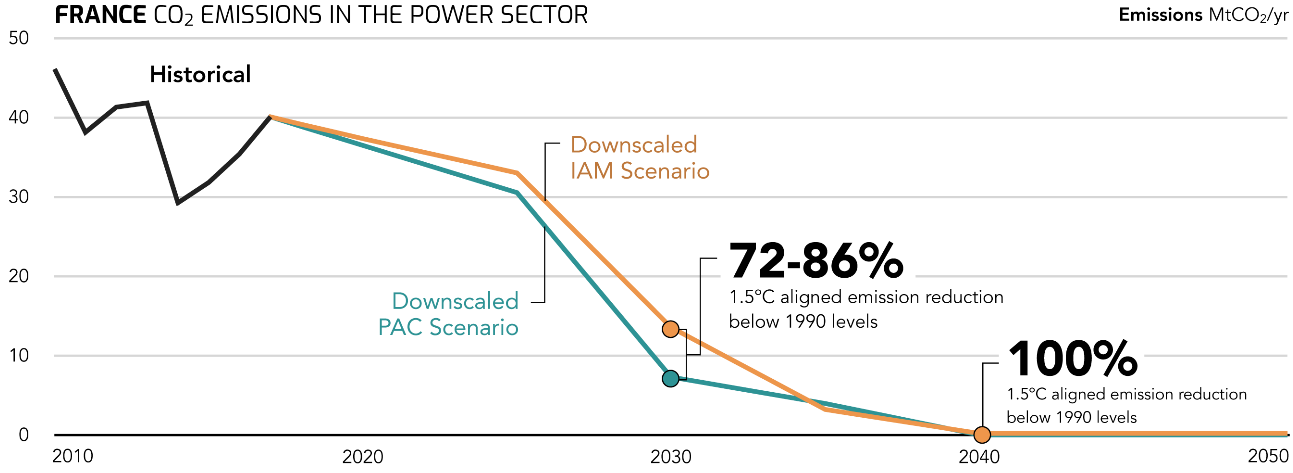


Figure 19: 1.5°C compatible power sector emissions for France

4.2.4 Decarbonising the industry sector and policy implications

While some French industries are already far more efficient than the G20 average, including cement and steel production, considerable coal and fossil gas demand remains (Climate Transparency, 2020). To align with the 1.5°C pathway for France downscaled from the PAC scenario, the use of these fuels in the French industry sector would need to decline steadily, with coal phased out by 2035, and fossil gas by 2040.

Table 8: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	38%	9%	34%	0%
2030	**52%**	**6%**	**21%**	**6%**

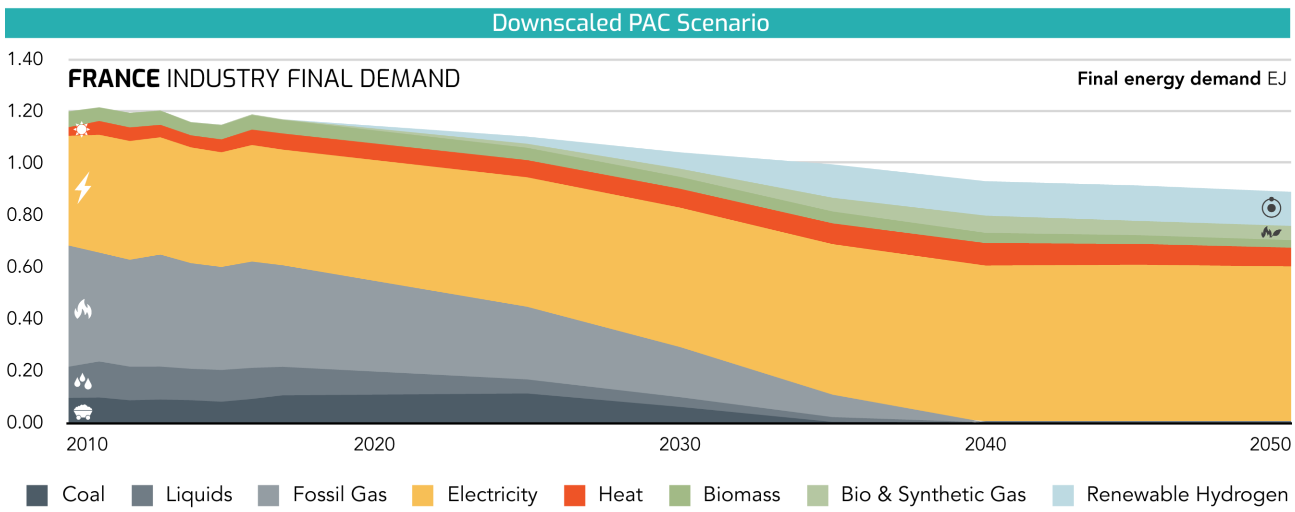


Figure 20: 1.5°C compatible share of technologies in the industry energy mix

Electricity's share in industry final energy demand would need to increase from 38% (2017) to 52% in 2030 and 68% by 2050. Renewable hydrogen begins to play a significant role in industry beyond 2030. Total emissions decline by 62% and 83% below 1990 levels by 2030 and 2050 respectively, with energy-related emissions reaching zero by 2040.

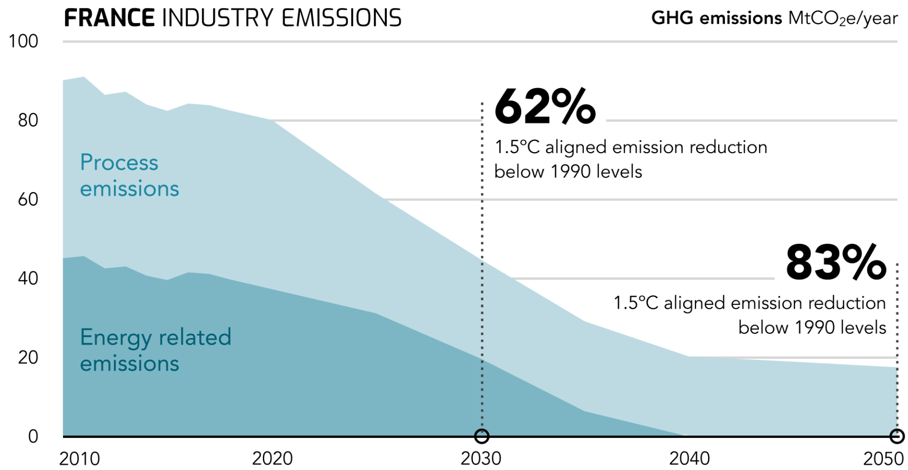


Figure 21: 1.5°C compatible industry sector emissions for France

4.2.5 Key characteristics of France's 1.5°C compatible pathways and other analyses

Table 9 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for France in 2030 and 2050, compared against recent historical values.

Table 9: Key characteristics of France's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030**	**2050** incl. LULUCF*
Total GHG excl. LULUCF	474 $MtCO_2e$/yr	191–290 $MtCO_2e$ /yr	8–49 $MtCO_2e$ /yr	328 $MtCO_2e$ /yr	0 $MtCO_2e$ /yr
	15% below 1990	48–66 % below 1990	92–99 % below 1990	40 % below 1990	100% below 1990
Emissions intensity of power generation**	72 gCO_2/kWh	9–17 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	17 %	59–76 %	81–100 %	40 %	
Share of unabated fossil fuel in power	11 %	2–4 %	0 %		
Share of nuclear power	72 %	22–37 %	0–19 %		
Industry electrification rate	38 %	52 %	68 %		

* 2050 target is shown including LULUCF emissions due to the absence of government projections for these emissions to 2050
** Does not include upstream emissions

In the existing literature on energy system transformation, the scenario derived by Association négaWatt (2017) outlines the following benchmarks for France:

- Net zero GHG emissions in 2050 with a LULUCF sink of up to 75 $MtCO_2e$
- 100% renewable power generation by 2050
- Nuclear power phased out by 2035

The size of the modelled 2050 LULUCF sink in this scenario would be more than sufficient to achieve net zero in 2050 in both downscaled emissions pathways, and in 2040 in the downscaled PAC scenario pathway. In addition, the 2050 renewable share of power generation is in line with the upper bound of the derived 1.5°C compatible range.

4.3 Germany's domestic transition pathway

4.3.1 National context and current targets

Germany is the largest EU country by population, and its economy is the largest in Europe. As a result, its GHG emissions are substantial, however in 2019 they had decreased by 35% compared to 1990 levels (German federal bureau of environment (Umweltbundesamt 2021). Emissions are expected to rebound strongly in 2021, though, due to heightened economic activity following the 2020 COVID-19-related downturn (Agora Energiewende, 2021).

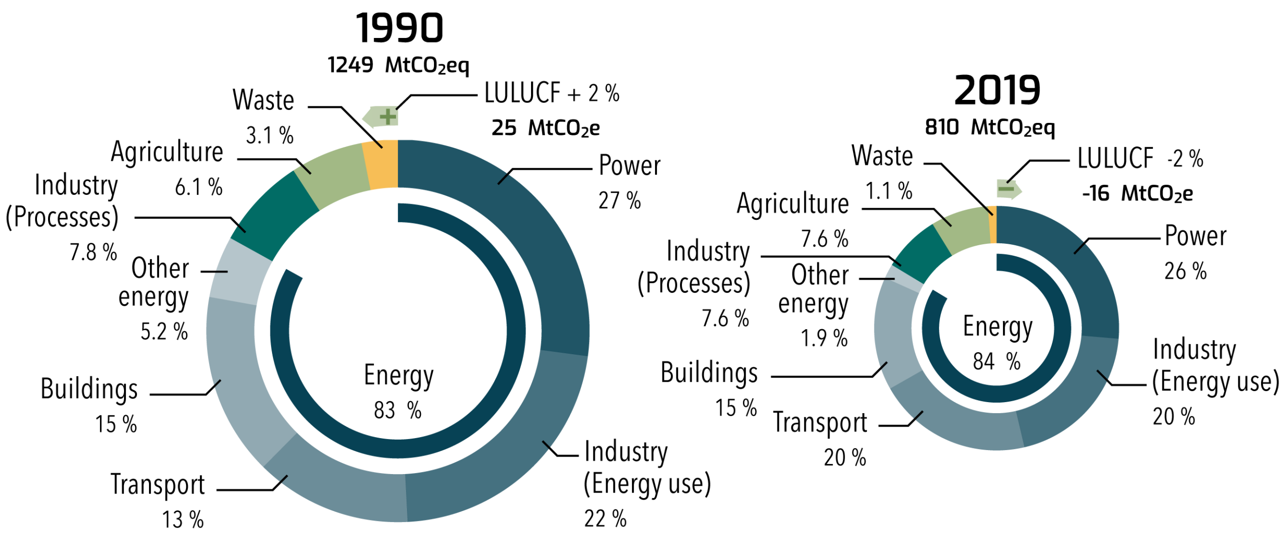


Figure 22: Historical emissions by sector. Source: (Government of Germany, 2021)

Germany's economy continues to rely heavily on fossil fuels; in 2018, petroleum, gas and coal accounted for around 80% of primary energy supply (Government of Germany, 2019). The remaining shares were held by renewables (14%) and nuclear energy (6%). However, the country has committed to reducing its primary energy consumption by 30% by 2030 compared to 2008 levels (Eriksen, 2019).

Germany pledged to phase out coal by 2038 in its Coal Phase Out Act (Gesley, 2020), and in 2019 set a 65% renewable electricity generation target for 2030 (Government of Germany, 2019). This increase in renewables will mainly come from offshore wind and photovoltaic capacities, but meeting this target will require the implementation of additional policies.

In 2021 Germany's constitutional court ruled that it must update its climate law to set out how it will bring net GHG emissions to zero by 2050 (Bodle & Sina, 2021). In June 2021, the German government formally increased its 2030 emissions target to a 65% reduction below 1990 levels (excl. LULUCF), and 88% by 2040, reaching net zero by 2045, five years earlier than the previous target (Appunn et al., 2021).

Under current policies (including those outlined in the Climate Protection Programme 2030), emissions in 2030 are projected to reach just 51% below 1990 levels (without LULUCF) (Umwelt Bundesamt, 2020).

4.3.2 Emissions and energy pathways and adequacy of domestic targets

Achieving a 1.5°C compatible economy for Germany as determined by this project requires a 72-79% reduction in total GHG emissions by 2030 (excluding LULUCF), and reaching net zero emissions between 2040 and 2050. There are numerous different pathways to reaching net zero emissions in this timeframe. In the scenarios analysed, a LULUCF sink of between 0-42 $MtCO_2e$ would achieve net zero by 2050, while under the PAC scenario, a LULUCF sink of 50 $MtCO_2e$ would achieve net zero emissions in 2040.

Germany's recently updated 2030 target of a 65% reduction below 1990 levels (excl. LULUCF) falls short of this 1.5°C compatible range. Ratcheting up its target to fall within this range and align with its 2045 net zero target should be a priority, as should adopting a 2030 coal phase-out, and raising its 2030 renewable generation target to at least 93%. Reaching net zero emissions by 2045 will require a rapid decarbonisation across all sectors including transport and buildings.

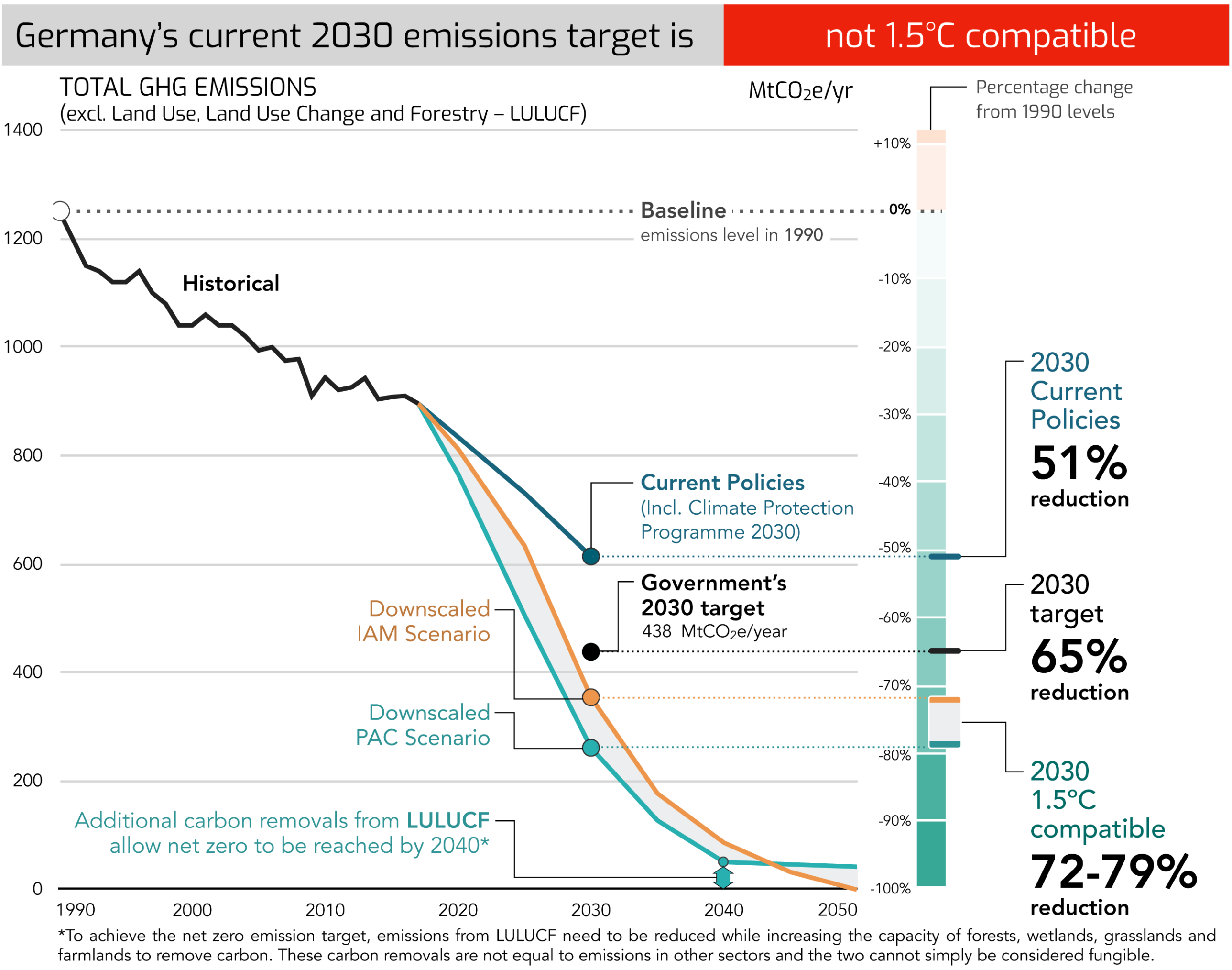


Figure 23: National 1.5°C compatible GHG emissions pathways for Germany

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand falls to between 42-47% by 2030, whereas the share of renewables including biomass reaches 53-58% by the same year. The transport and building sectors constitute a combined 47% of total GHG emissions in Germany, illustrating the need for strong policies to reduce the oil and natural gas demand that produce these sectoral emissions (Government of Germany, 2021).

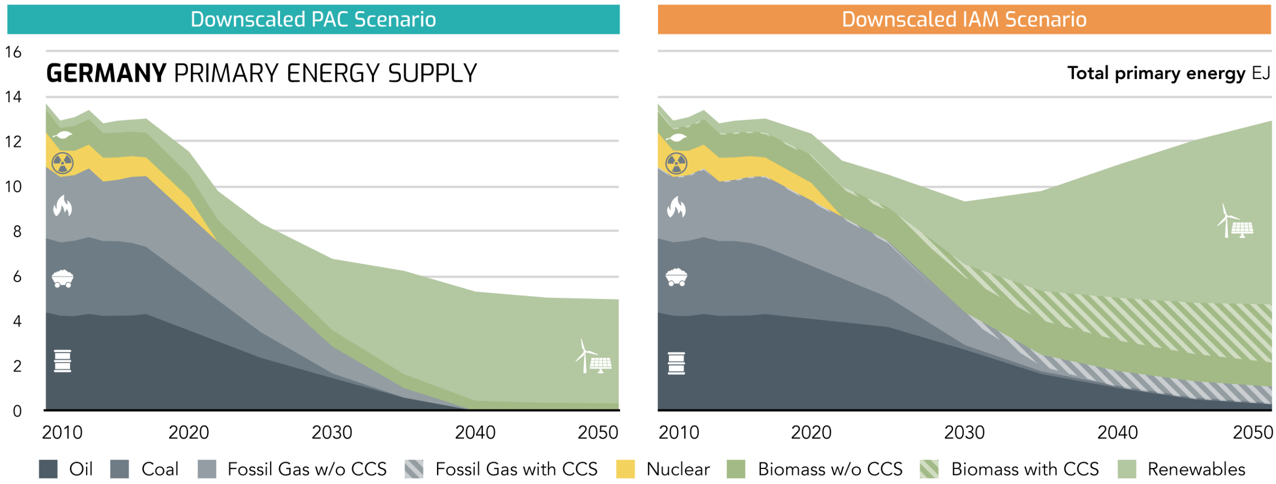


Figure 24: 1.5°C compatible primary energy supply pathways by fuel

4.3.3 Decarbonising the power sector and policy implications

Germany has adopted a 2038 coal phase-out date, but this is well after the commitments of many of its European peers, with the UK, a historically highly coal reliant nation committing to a 2024 phase-out (UK Government, 2021). This would need to be brought forward to 2030 at the latest to ensure it aligned with the derived 1.5°C compatible pathways. An earlier coal phase-out should be accompanied by a commitment to phase out unabated fossil gas use by around 2035.

Table 10: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	34%	40%	14%	11%
2030	**93-97%** IAM PAC	**0–1%** PAC IAM	**3–6%** PAC IAM	**0%**

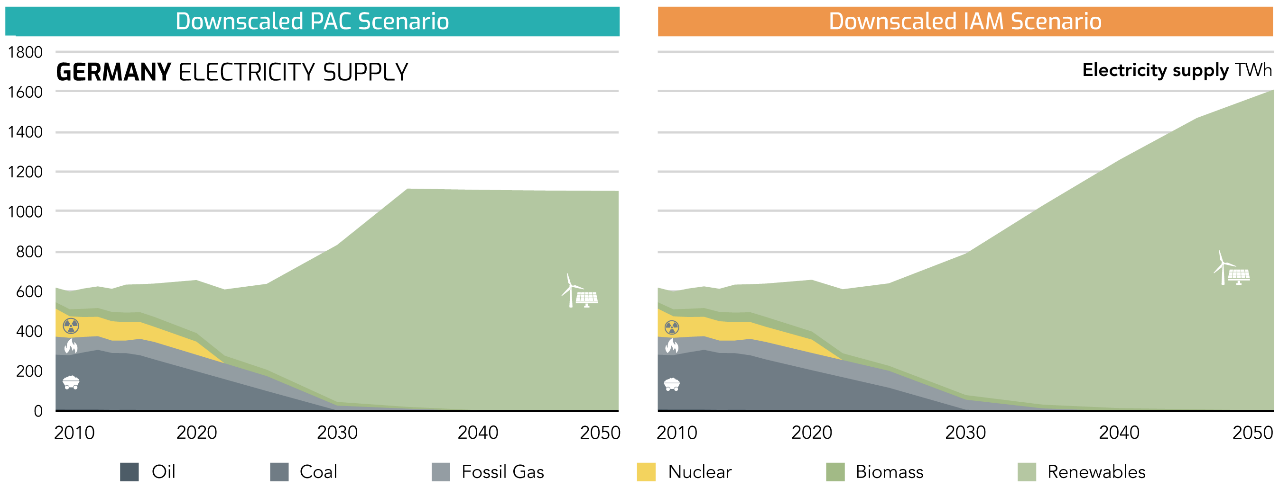


Figure 25: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in the German power sector under the derived 1.5°C compatible pathways decline by between 92-96% below 1990 levels by 2030. Current investments being made in fossil gas infrastructure risk becoming stranded assets, as a 1.5°C power system for Germany contains little to no fossil gas by 2035.

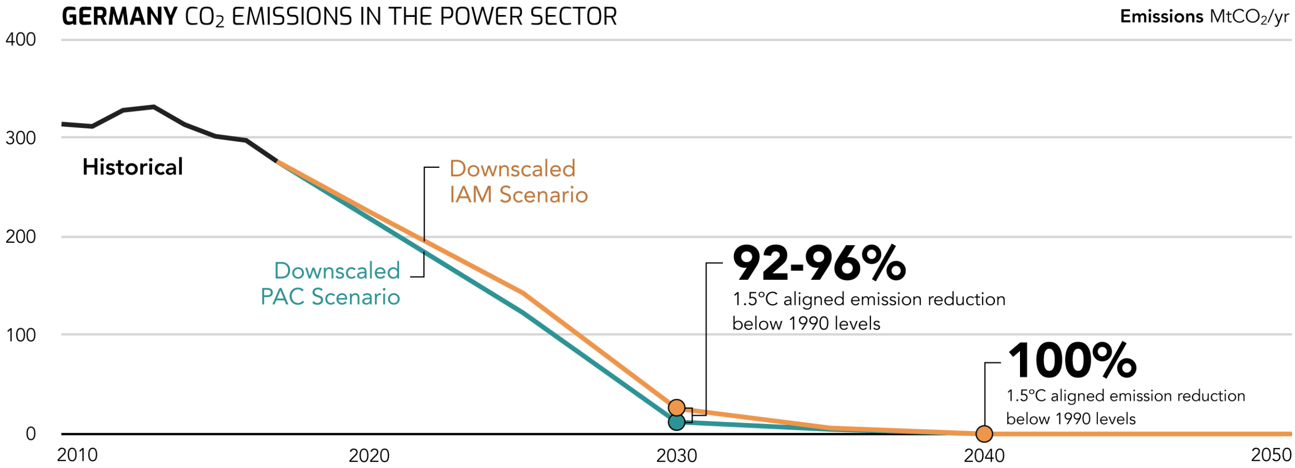


Figure 26: 1.5°C compatible power sector emissions for Germany

4.3.4 Decarbonising the industry sector and policy implications

Between 1990 and 2005, Germany achieved a significant reduction in coal demand in its industry sector, but since then consumption has remained relatively stable (IEA 2020). To be aligned with the 1.5°C compatible pathway downscaled from the PAC scenario, this will need to change, with coal needing to be phased out of German industry by 2035. Roughly 50% of industry energy demand should be met by electricity by 2030, compared to the current 36%.

Table 11: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	36%	11%	37%	0%
2030	**48%**	**7%**	**24%**	**6%**

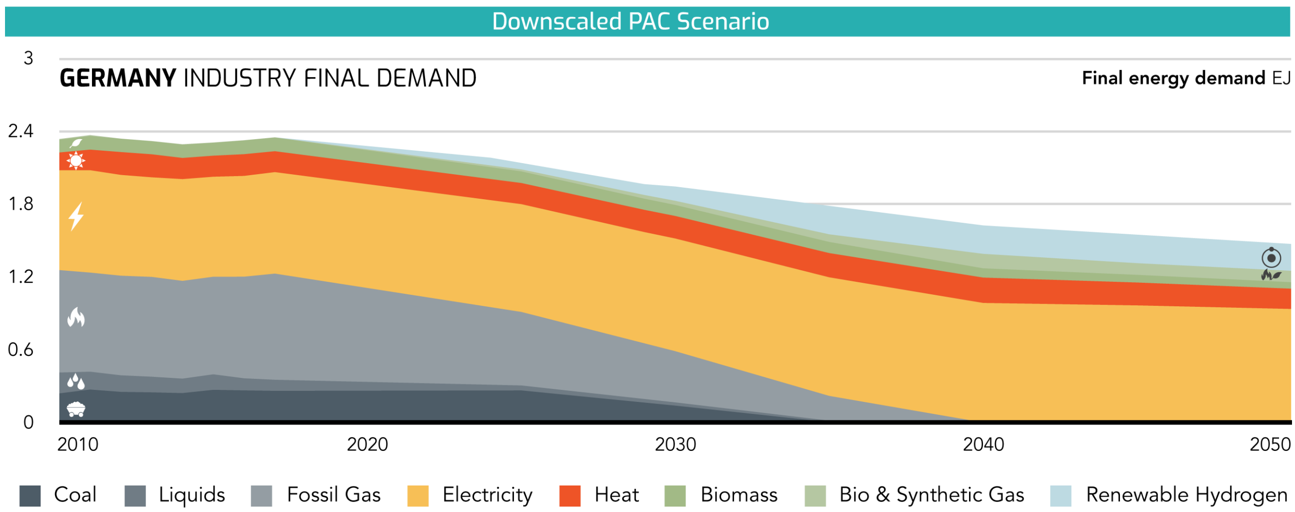


Figure 27: 1.5°C compatible share of technologies in the industry energy mix

Total industry emissions fall by 68% and 89% by 2030 and 2050 respectively under the downscaled PAC scenario for Germany, with energy-related emissions reaching zero by 2040.

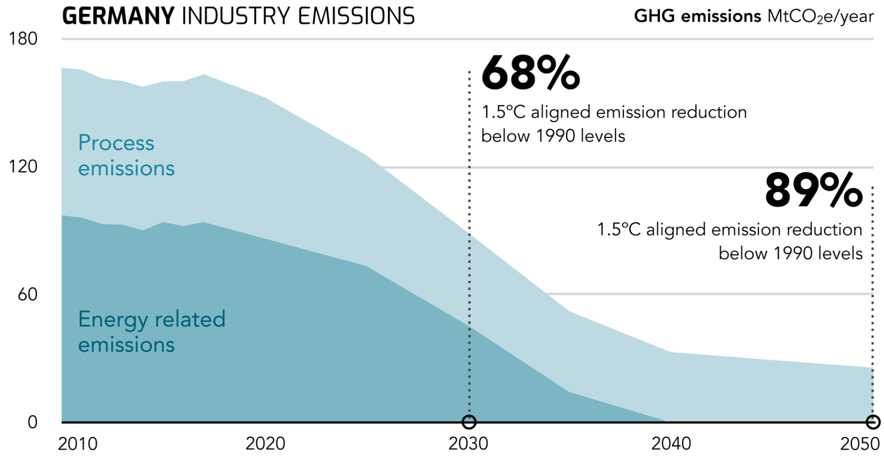


Figure 28: 1.5°C compatible industry sector emissions for Germany

4.3.5 Key characteristics of 1.5°C compatible pathways and other analyses

Table 12 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Germany in 2030 and 2050, compared against recent historical values.

Table 12: Key characteristics of Germany's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	2030	2050	2030	2050 incl. LULUCF*
Total GHG excl. LULUCF	896 $MtCO_2e/yr$	261–354 $MtCO_2e$ /yr	-1–42 $MtCO_2e$ /yr	438 $MtCO_2e$ /yr	0 $MtCO_2e$ /yr
	28% below 1990	72–79 % below 1990	97–100 % below 1990	65 % below 1990	100% below 1990
Emissions intensity of power generation**	433 gCO_2/kWh	15–33 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	34 %	93–97 %	100 %	65 %	
Share of unabated fossil fuel in power	55 %	3–7 %	0 %		
Share of nuclear power	12 %	0 %	0 %		
Industry electrification rate	32 %	48 %	63 %		

* 2050 target is shown including LULUCF emissions due to the absence of government projections for these emissions to 2050

** Does not include upstream emissions

Various existing studies analysing energy system transformation and emissions reductions for Germany have derived benchmarks that are mostly less ambitious than those in this report that aim to reflect the highest plausible ambition. They are summarised below:

Agora Energiewende: Towards a Climate-Neutral Germany (2020)

- 65% GHG emissions reduction below 1990 by 2030, net zero by 2050
- Coal phase out and 70% share of renewable energy sources in electricity generation by 2030, 100% by 2050
- 50% reduction in primary energy demand below 2018 levels by 2050, 38% share of renewable energy sources in primary energy demand by 2030

Fraunhofer ISE: Paths to a climate neutral energy system (2020)

- Wind and solar provide 50-60% of primary energy demand by 2050
- Primary energy demand falls by 26-49% below current levels by 2050
- 100% renewable energy in power sector by 2050

Boston Consulting Group/Prognos: Climate Paths for Germany (95% Path) (2018)

- 57% GHG emissions reduction below 1990 by 2030, 95% by 2050
- 64% reduction in power sector emissions below 1990 by 2030, 48% reduction in industry emissions by 2030
- 100% renewable energy in power sector by 2050

Ensure Project: Transformation of the Energy System by 2030 (2020)

- 78% 2030 emissions reduction target, net zero by 2050
- Coal phase out and 83% renewable energy sources in power system by 2030
- <15% natural gas power generation of 2030 levels by 2050

The exception is the Ensure Project's Transformation of the Energy System by 2030, which contains an 'Ambitious climate protection' scenario that partially aligns with the benchmarks derived in this report. These aligned benchmarks include a sufficiently strong 2030 GHG emissions target and a 2030 coal phase-out.

4.4 Italy's domestic transition pathway

4.4.1 National context and current targets

Total Italian GHG emissions in 2019 were 29% below their peak in 2005, and 19% below 1990 levels (excl. LULUCF) (Government of Italy, 2021). The power, transport, and industry sectors all emit similar levels of emissions and combined make up roughly two thirds of total emissions. Transport has overtaken both the power and industry sectors, however, and is now the largest single emitting sector (IEA 2020; Government of Italy 2019a).

Italy has achieved significant reductions in power sector emissions, with renewables representing 40% of total power generation in 2019 (IEA, 2020). Emissions from industry and agriculture have also decreased, while emissions from the transport and buildings sectors have increased since 1990.

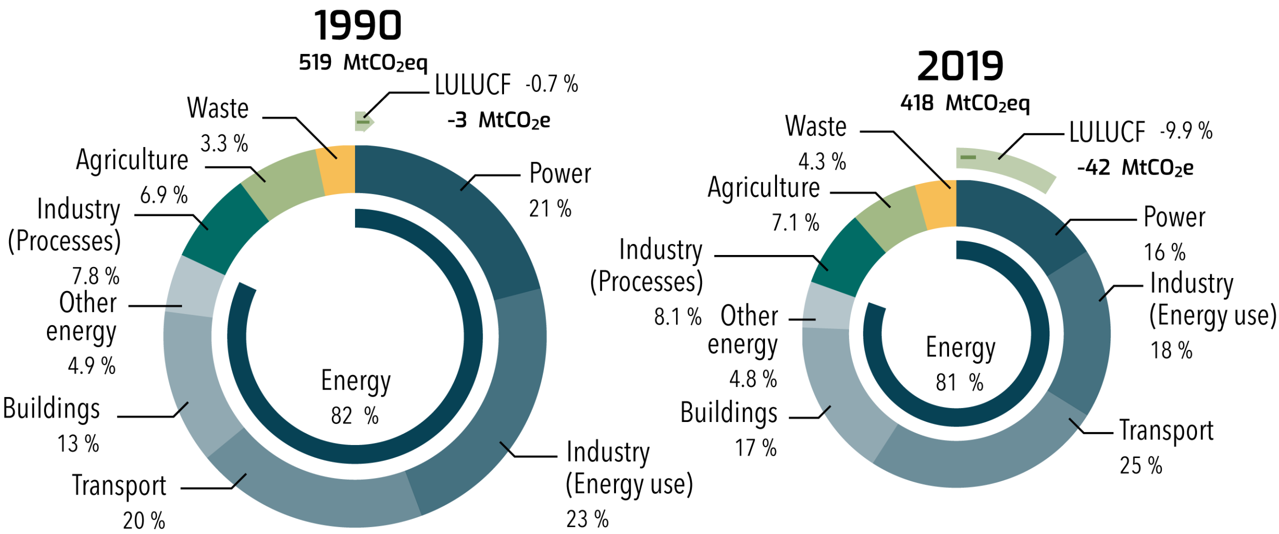


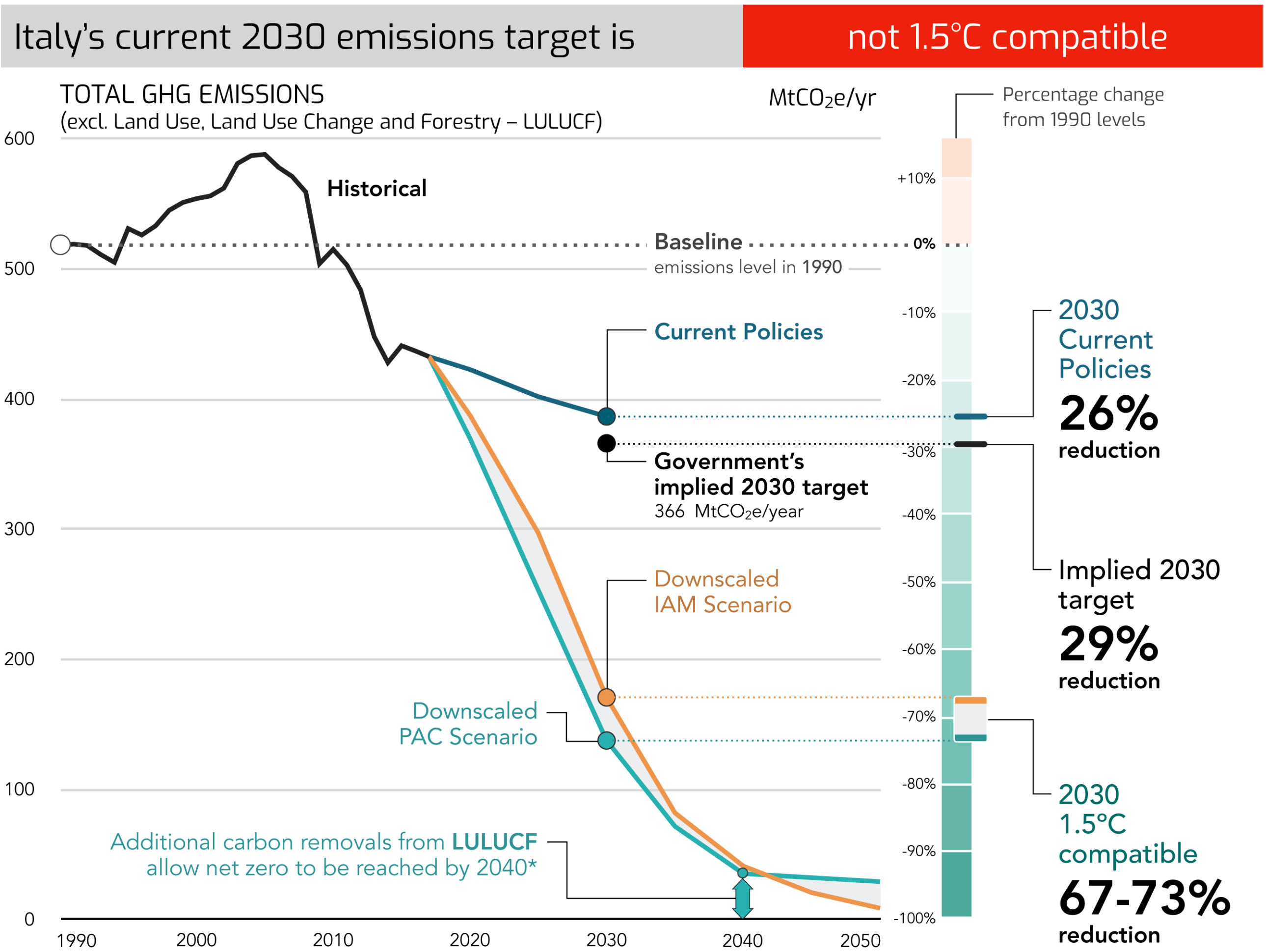
Figure 29: Historical emissions by sector. Source: (Government of Italy, 2021)

Italy has achieved a steep reduction in total coal demand in recent years, reaching 71% below 2005 levels in 2019 while total energy use fell just 26% over the same period. Oil demand fell more rapidly than the overall drop in energy use between 2005 and 2019, primarily due to a decline in the industry sector and its use in the power sector being phased out. Italy has very significant solar resources that it is seeking to tap with its 55% 2030 renewable generation target. There is as yet, no policy to phase out natural gas consumption in the Italian economy.

4.4.2 Emissions and energy pathways and adequacy of domestic targets

Europe's fourth largest economy, Italy has so far failed to formalise an economy-wide target, having proposed a 60% reduction below 1990 levels by 2030, but not yet adopted it (Reuters, 2021a). Instead, it currently relies on the minimum emissions reductions required under the EU's previous 2030 target (Government of Italy, 2019b). Under this framework, there is one target for emissions covered by the EU ETS, and one that covers the remaining emissions. If these targets are combined, an economy-wide target of 29% below 1990 levels can be derived (excl. LULUCF). Italy has also set a target of 30% of renewables in gross final energy consumption and a 55% renewable share of power generation by 2030, but current policies are not sufficient to achieve them or its obligations under the previous EU target (Government of Italy, 2019b).

A 1.5°C aligned 2030 emissions reduction target for Italy as determined by this project would be within the range of 67-73% below 1990 levels (excl. LULUCF), more than twice as ambitious as its current obligations under the previous EU target. The EU's decision to strengthen its 2030 target gives Italy the chance to set an economy-wide target of its own, and one that is Paris Agreement compatible.



*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 30: Domestic 1.5°C compatible GHG emissions pathways for Italy

Based on current policies, fossil fuels' share in primary energy demand is projected to reach 68-71% by 2030, while total emissions are projected to decrease by 26% compared to 1990 levels (Government of Italy 2019a). In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand falls to between 37-43% by 2030, whereas renewables reach between 57-63% by the same date. Policies to rapidly reduce oil and gas consumption further are needed in particular for the transport and buildings sector respectively, which made up 39% of total emissions in 2019.

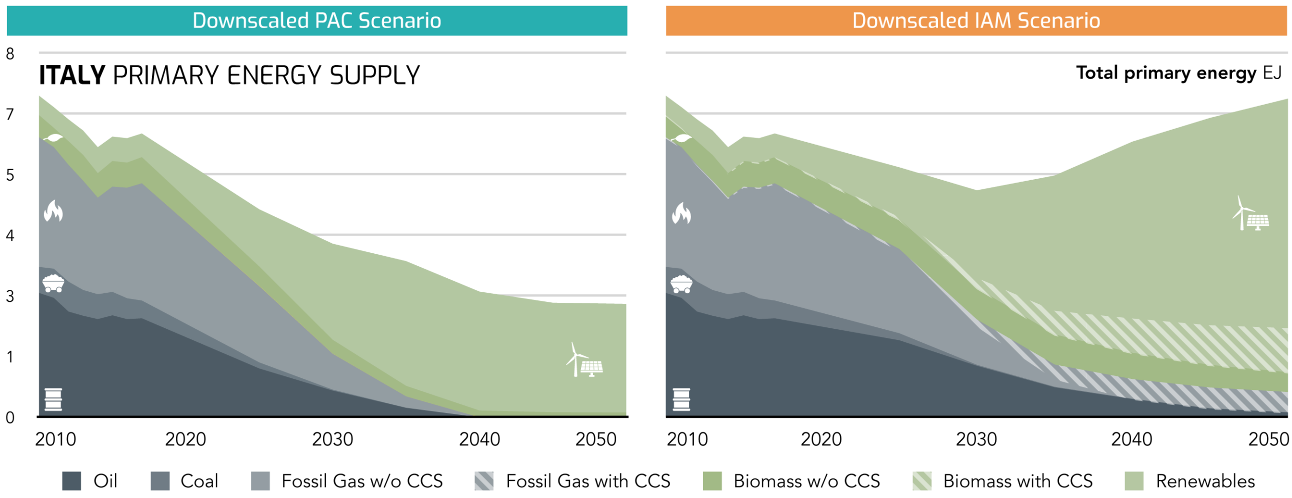


Figure 31: 1.5°C compatible primary energy supply pathways by fuel

4.4.3 Decarbonising the power sector and policy implications

Following Italy's commendable decision to phase out coal use by 2025, a fossil gas phase-out date of between 2035 and 2040 is needed to ensure the power sector is aligned with derived 1.5°C compatible trajectories. Steep increases in renewable energy generation will be needed, beyond the 55% renewable power generation target for 2030, and beyond even the 70-72% renewable generation target suggested by the Italian Minister for the Ecological Transition in 2021 that would be needed to meet the EU's new emission reduction target of net 55% below 1990 levels by 2030 (Reuters, 2021b). A minimum 82% share of renewable generation would be required according to the derived 1.5°C compatible pathways.

Table 13: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	36%	12%	48%	0%
2030	82–91% (IAM PAC)	0%	9–18% (PAC IAM)	0%

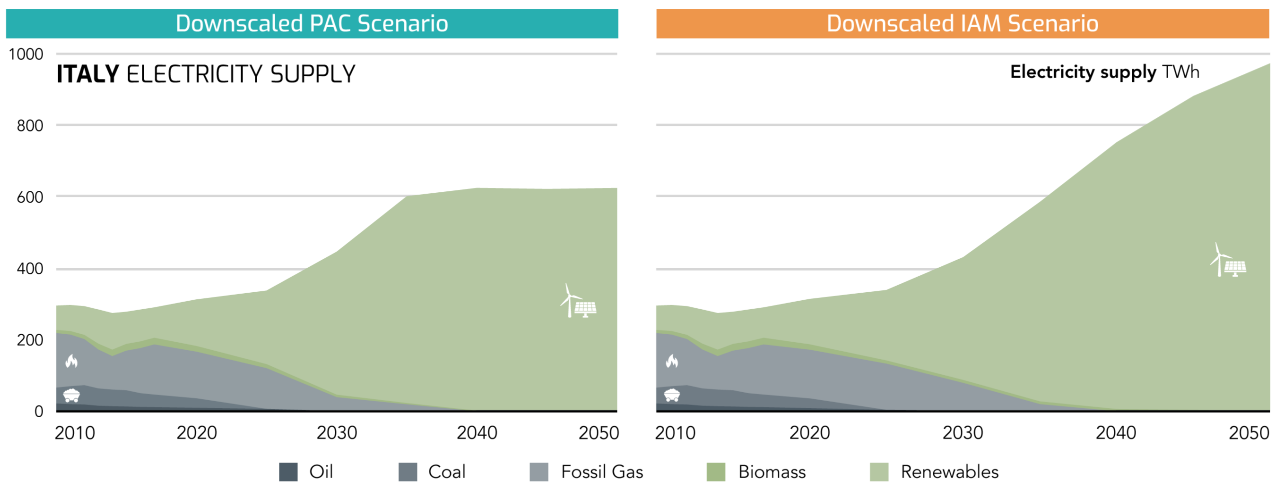


Figure 32: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in the Italian power sector decline by between 76-88% below 1990 levels by 2030, reaching zero by 2040.

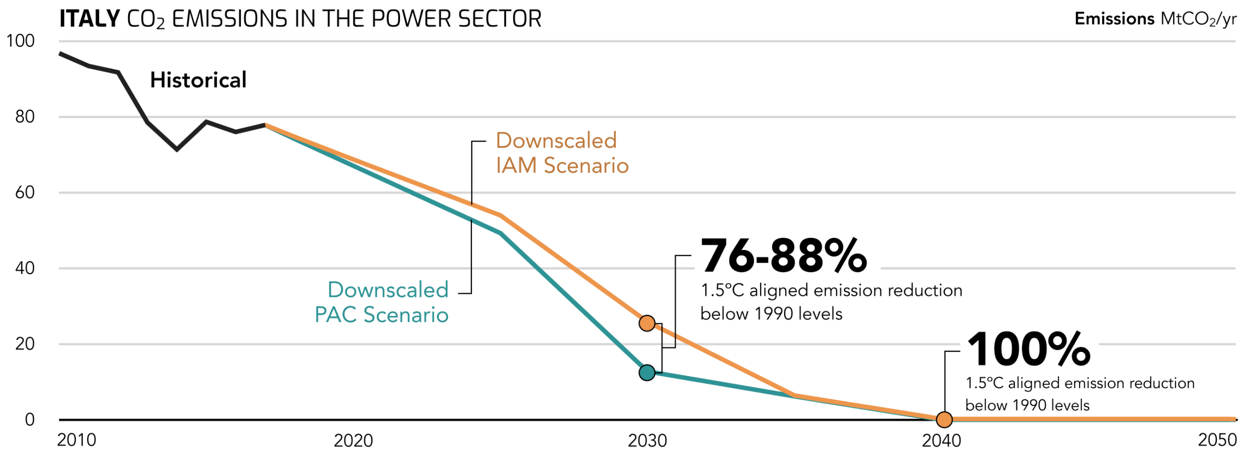


Figure 33: 1.5°C compatible power sector emissions for Italy

4.4.4 Decarbonising the industry sector and policy implications

Coal use in the Italian industry sector fell twice as fast as total industrial energy demand between 2005 and 2019, outpacing the sector's decline (IEA, 2020). In 2019, coal made up just 3% of total energy demand, down from 10% in 1990. Oil demand in industry also fell dramatically over recent years, making up just 7% of total demand in 2019, compared with 24% in 1990.

Coal demand should be phased out by 2030, with oil eliminated by 2035 to ensure Italy's industry sector is aligned with the 1.5°C compatible pathway downscaled from the PAC scenario. Fossil gas consumption should be eliminated by 2040 and begin declining immediately.

Table 14: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	40%	3%	36%	0%
2030	**52%**	**2%**	**22%**	**6%**

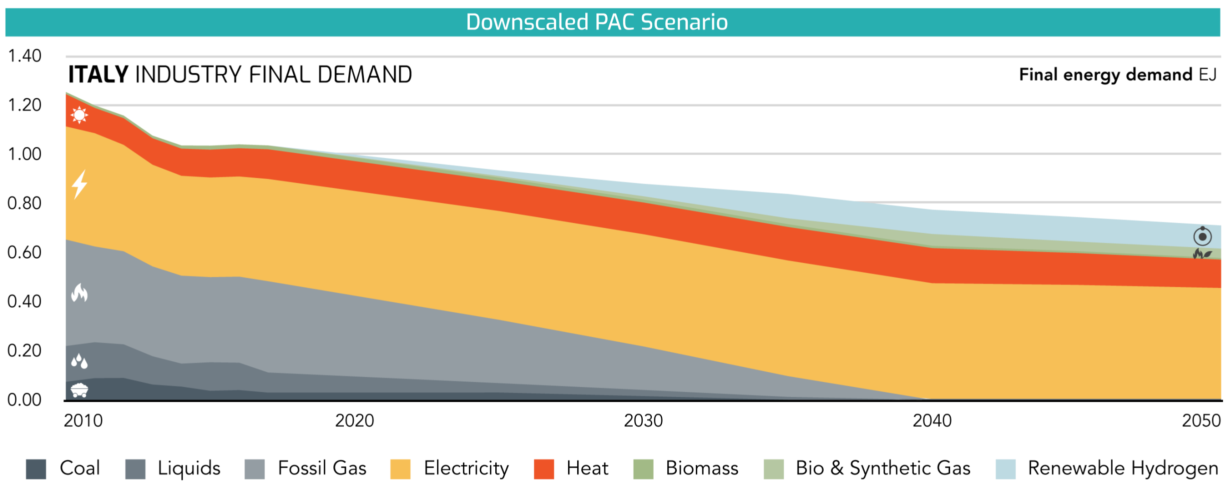


Figure 34: 1.5°C compatible share of technologies in the industry energy mix

Total industry emissions fall by 64% and 87% by 2030 and 2050 respectively, with energy-related emissions reaching zero by 2040.

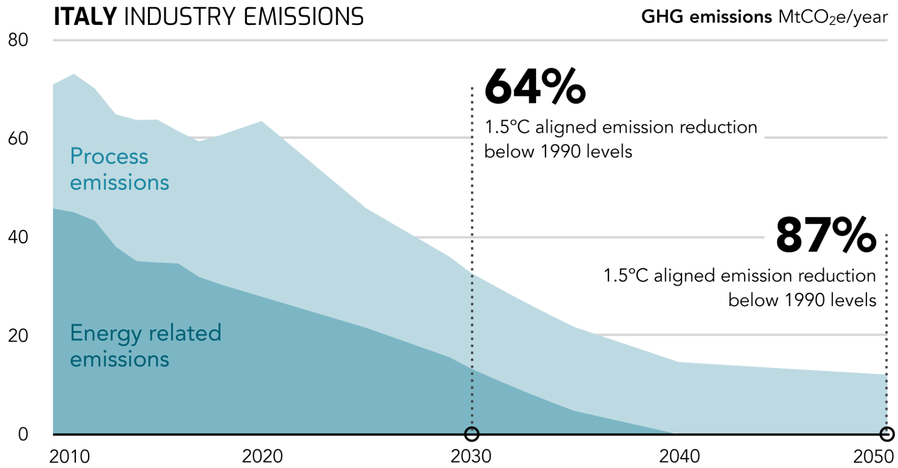


Figure 35: 1.5°C compatible industry sector emissions for Italy

4.4.5 Key characteristics of 1.5°C compatible pathways and other analyses

Table 15 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Italy in 2030 and 2050, compared against recent historical values.

Table 15: Key characteristics of Italy's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030** (implied)	**2050**
Total GHG excl. LULUCF	433 $MtCO_2e$/yr	138–171 $MtCO_2e$ /yr	9–29 $MtCO_2e$ /yr	366 $MtCO_2e$ /yr	
	16 % below 1990	67–73 % below 1990	94–98 % below 1990	29 % below 1990	
Emissions intensity of power generation*	268 gCO_2/kWh	29–60 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	36 %	82–91 %	100 %	55 %	
Share of unabated fossil fuel in power	64 %	9–18 %	0 %		
Share of nuclear power	0 %	0 %	0 %		
Industry electrification rate	40 %	52 %	64 %		

* Does not include upstream emissions

Several analyses in existing literature produce less ambitious results for Italy's emissions and energy mix, though higher than existing government targets. These include the following 2030 targets:

- 55% total GHG emissions reduction
- 63-75% renewable power generation
- 33% renewable share of primary energy

(Elemens, 2016; University of Technology Sydney, 2020)

Targets for 2050 can also be found in the existing literature, including:

- 95% total GHG emissions reduction
- 96% renewable share of primary energy
- 100% renewable energy share in final energy consumption
  (Economia e Sostenibilità, 2020; Elemens, 2016; University of Technology Sydney, 2020)

4.5 Poland's domestic transition pathway

4.5.1 National context and current targets

Due to an economic transformation since the end of the 1980s, Poland's GHG emissions fell steeply in the early 1990's from 580 $MtCO_2e$ in 1988 to reach 396 $MtCO_2e$ in 2000 (Government of Poland 2021b). Emissions have remained relatively stable since then, and are projected to still be above 2000 levels in 2030 under current policies in its National Energy and Climate Plan (Government of Poland, 2019).

Poland, with a large coal mining industry, remains highly dependent on coal for its energy supply, though the share of coal in total primary energy supply has fallen from 76% in 1990 to 43% in 2019 (IEA, 2020). This has partly been replaced by renewables, that now contribute a 9% share, while oil consumption has risen from a 13% share in 1990 to 29% in 2019.

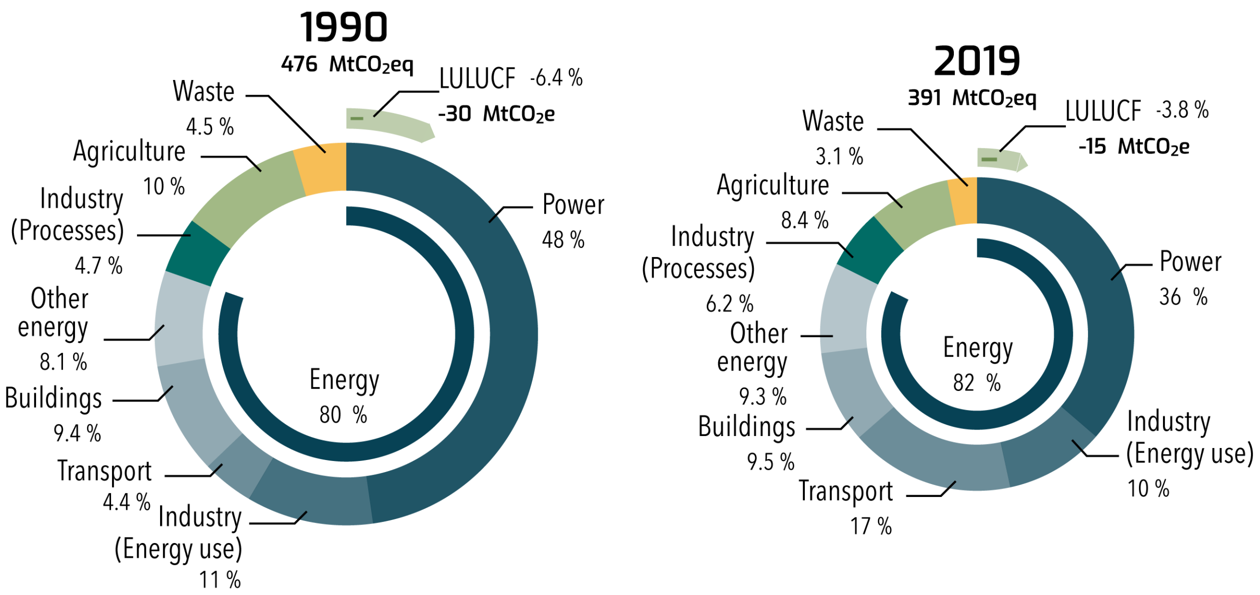


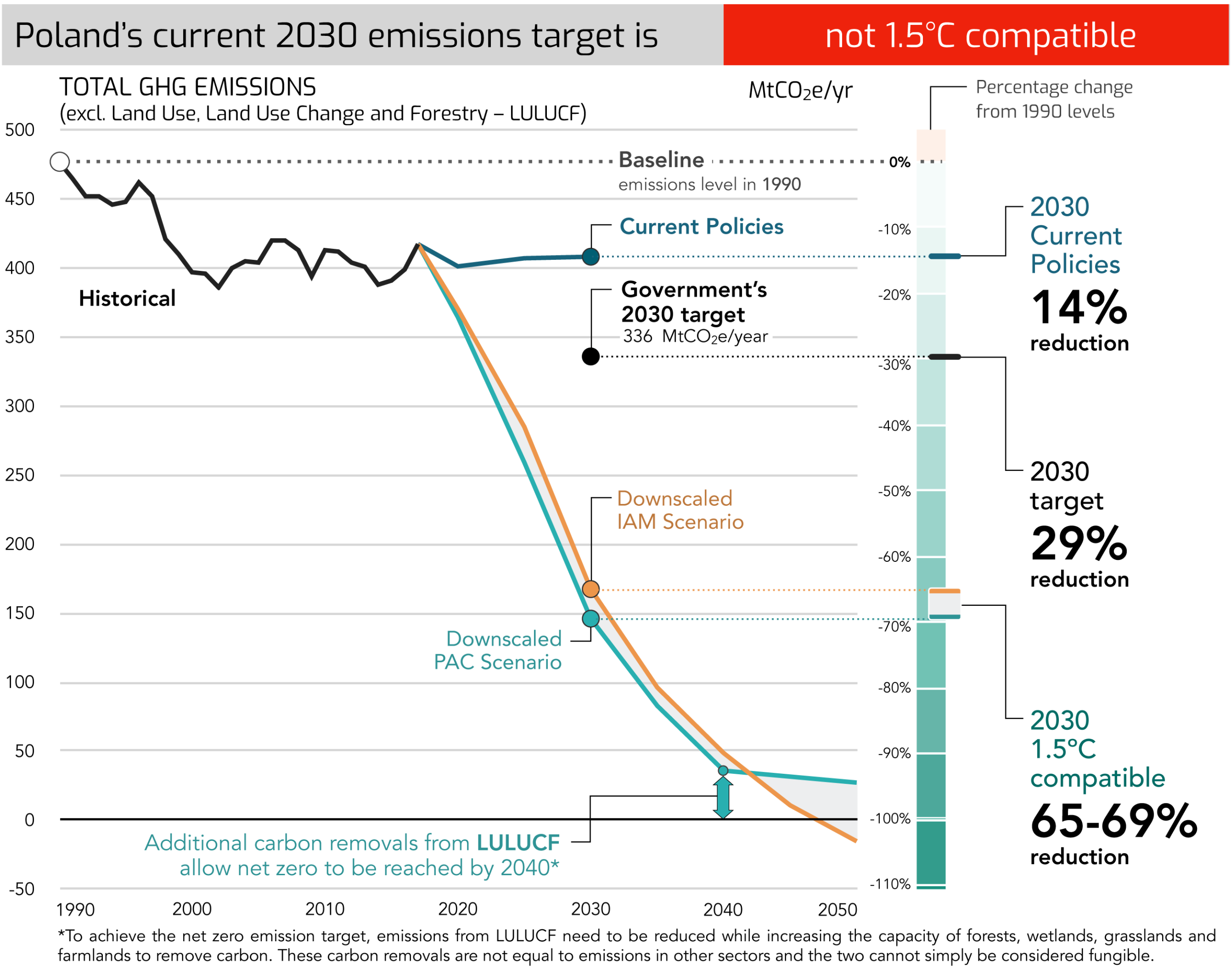
Figure 36: Historical emissions by sector. Source: (Government of Poland, 2021c)

Transport emissions made up 17% of 2019 emissions, however they have tripled since 1990, and continue to head in the wrong direction (Government of Poland 2021b). While buildings' emissions made up just 10% of total emissions, a high proportion of this was from the burning of coal for heat, a highly polluting method of heating.

Poland's current 2030 target outlined in its energy policy to 2040 is a 30% reduction below 1990 levels including LULUCF emissions (29% excluding LULUCF).

4.5.2 Emissions and energy pathways and adequacy of domestic targets

The emissions level implied by Poland's current 2030 target is more than double that of the 1.5°C compatible emissions range determined by this project of 65-69% below 1990 levels (excl. LULUCF), demonstrating the urgent need to ratchet up its ambition. Coal is currently projected to remain in the Polish energy system until well into the 2040s under the current 2049 phase-out date despite the need for developed countries to phase out coal power by 2030 to remain 1.5°C compatible (Climate Analytics 2019; Government of Poland 2021a). Reaching net zero emissions in 2050 will require a rapid decarbonisation across all sectors including transport and buildings.



*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 37: Domestic 1.5°C compatible GHG emissions pathways for Poland

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand is reduced to between 57-59% by 2030, whereas the share of renewables reaches between 41-43% by the same date. Roughly two thirds of emissions from fuel combustion in homes and roughly half in the industry sector in Poland comes from burning coal, demonstrating that measures to eliminate these emissions are urgently needed.

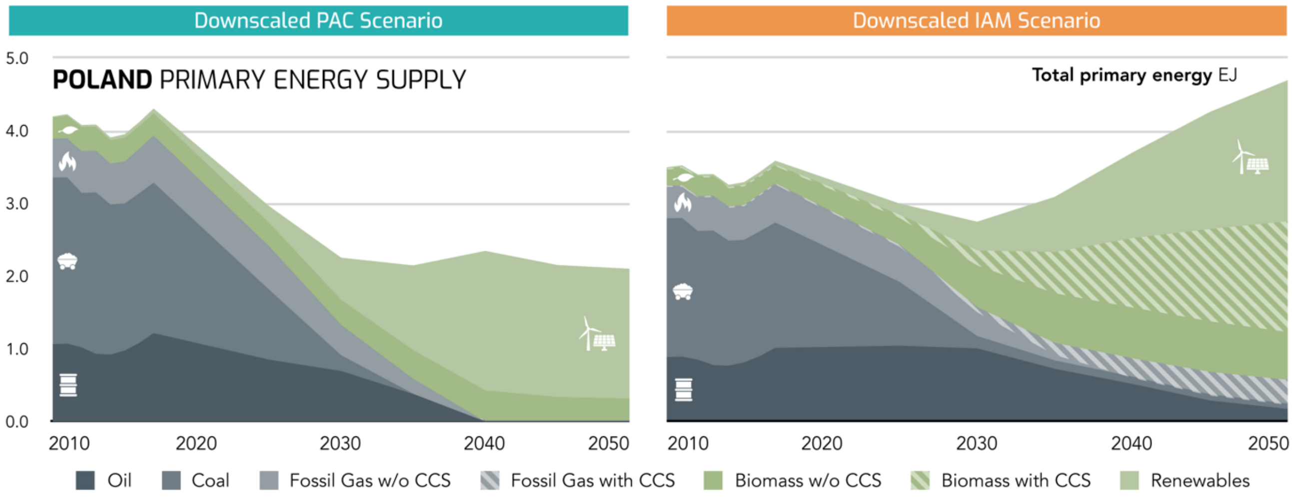


Figure 38: 1.5°C compatible primary energy supply pathways by fuel

4.5.3 Decarbonising the power sector and policy implications

Coal's share in Poland's power generation remains high (74% in 2019), while renewables only accounted for 16% in 2019 (IEA, 2020). National policies have set the target for the share of renewables in electricity generation at 32% in 2030 – however projections under current policies show it reaching only 19%. Coal's share in electricity generation is targeted at 56-60% for 2030.

A coal phase-out date that was recently set at 2049 is far behind all others already set by EU countries, and leaves coal in the system well beyond what is compatible with the 1.5°C temperature goal. In 2040, 11% of power generation is targeted to still come from coal (Climate Analytics, 2019).

Coal and gas are phased out between 2030 and 2035 in the derived 1.5°C aligned power sector pathways, with coal demand falling particularly rapidly after 2025. The expected increase in total electricity demand due to widespread electrification across the economy is met exclusively with renewable sources, with at least a doubling in total electricity demand by 2035 in both scenarios. Biomass demand does not rise above the current low levels in either scenario.

Table 16: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	24%	79%	6%	0%
2030	90–96% (IAM PAC)	1–3% (PAC IAM)	3–7% (PAC IAM)	0%

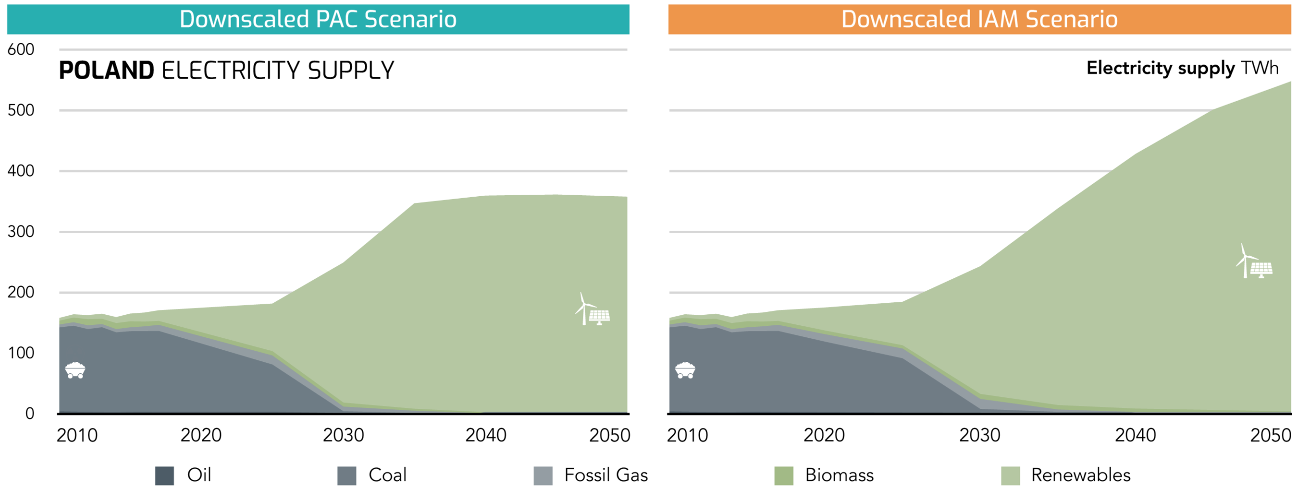


Figure 39: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in Poland's power sector decline by between 93-97% below 1990 levels by 2030, reaching zero by 2040.

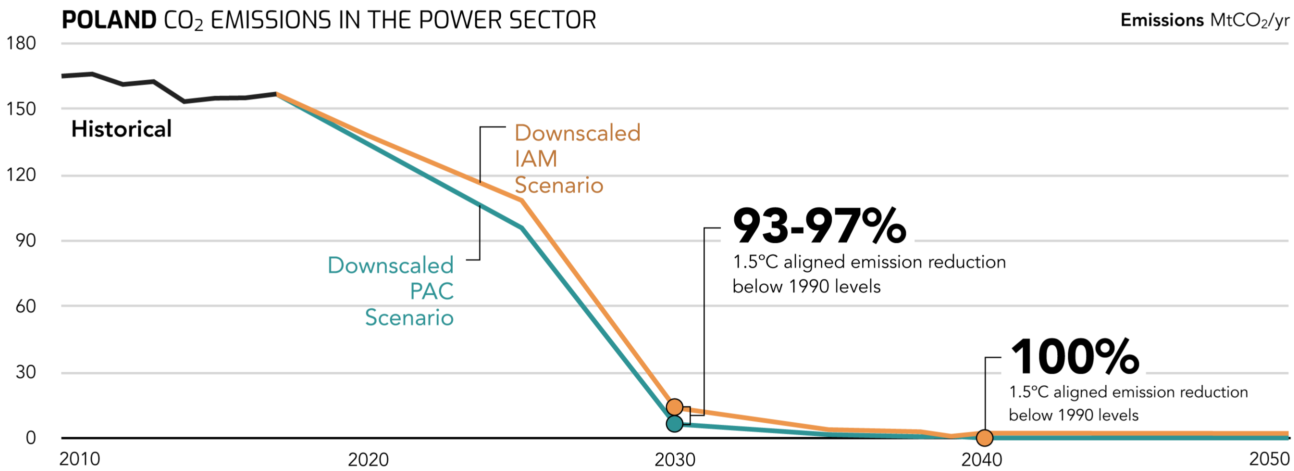


Figure 40: 1.5°C compatible power sector emissions for Poland

4.5.4 Decarbonising the industry sector and policy implications

Poland's industry sector declined markedly due to the economic transformation that began at the end of the 1980s, causing emissions in this sector to drop by 75% between 1990 and 2000 (Government of Poland 2021b). Emissions have since stabilised, and under current policies, are not projected to decline significantly below current levels by 2030 (Government of Poland, 2019). Roughly half of Poland's industrial energy-related emissions come from coal consumption, reflecting the need to prioritise electrification of this sector.

A 50% reduction in total industrial GHG emissions by 2030 and 82% by 2050 would make Poland's industry sector 1.5°C compatible. This could be achieved with a 43% electrification of final energy demand by 2030, reaching 61% by 2050, with renewable hydrogen making up 17% by 2050.

Table 17: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	31%	24%	24%	0%
2030	**43%**	**15%**	**16%**	**6%**

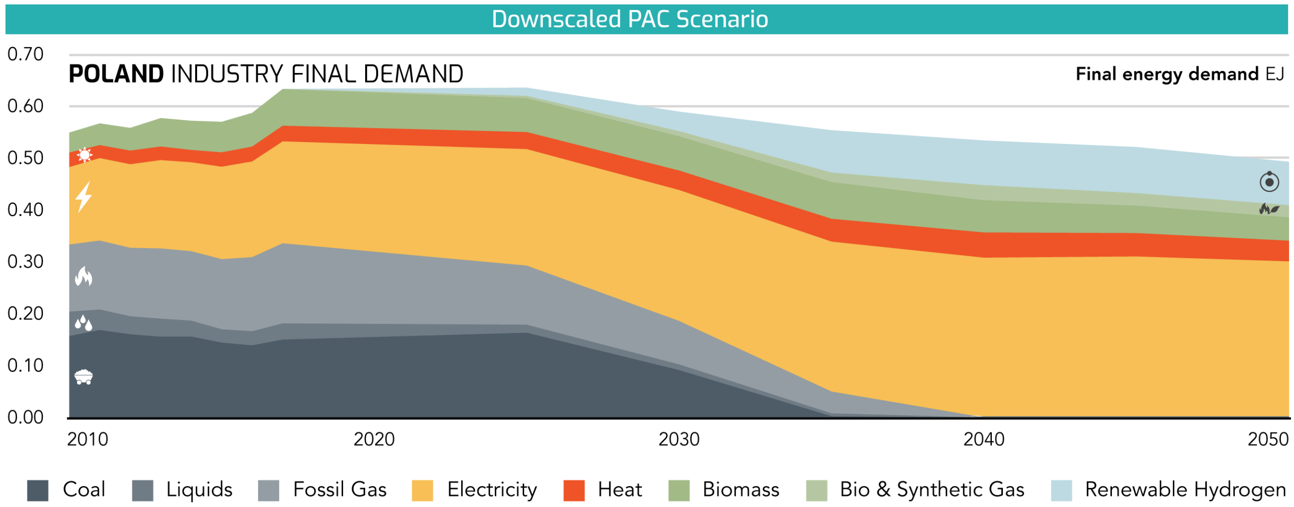


Figure 41: 1.5°C compatible share of technologies in the industry energy mix

Total industrial emissions fall by 50% and 82% by 2030 and 2050 respectively in the industry sector pathway derived from the PAC scenario, with energy-related emissions reaching zero by 2040.

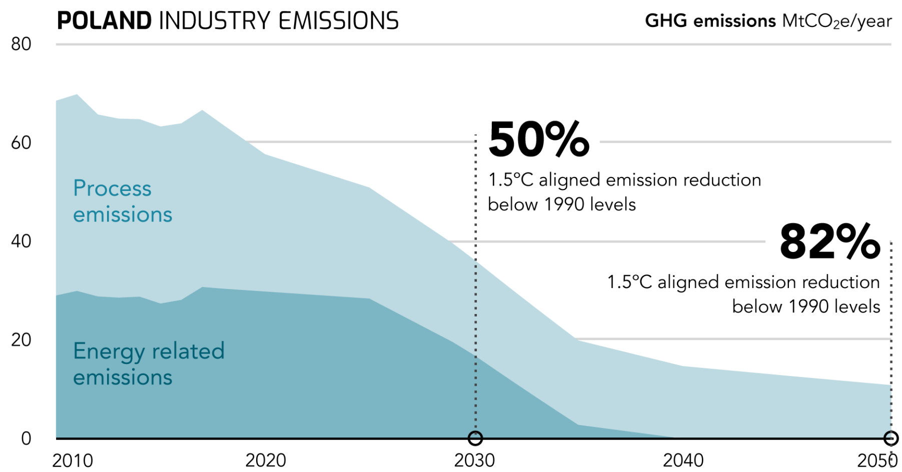


Figure 42: 1.5°C compatible industry sector emissions for Portugal

4.5.5 Key characteristics of 1.5°C compatible trajectories and other analyses

Table 18 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Poland in 2030 and 2050, compared against recent historical values.

Table 18: Key characteristics of Poland's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030***	**2050**
Total GHG excl. LULUCF	417 $MtCO_2e/yr$	146–168 $MtCO_2e$ /yr	-15–27 $MtCO_2e$ /yr	336 $MtCO_2e$ /yr	
	12 % below 1990	65–69 % below 1990	94–100 % below 1990	29 % below 1990	
Emissions intensity of power generation**	925 gCO_2/kWh	26–57 gCO_2/kWh	0-4 gCO_2/kWh	533 gCO_2/kWh	
Share of renewable power	14 %	90–96 %	100 %	32 %	
Share of unabated fossil fuel in power	86 %	4–9 %	0 %	68 %	
Share of nuclear power	0 %	0 %	0 %	0 %	
Industry electrification rate	31 %	43 %	61 %		

* 2030 target excluding LULUCF calculated using the government's 'with existing measures' emissions projections submitted to the UNFCCC
** Does not include upstream emissions

Other analyses bolster the case for a rapid coal phase-out in Poland. A report from the World Wildlife Fund calls for a 2030 phase-out, while an analysis of coal under 'business as usual' conditions by Greenpeace demonstrates results in a 2035 phase-out date (Greenpeace, 2020; World Wildlife Fund (WWF), 2020). A study by Forum Energii, however, derives less ambitious results including a coal phase-out between 2040-2050 and renewable shares of power generation in 2030 and 2050 of 39% and 73% respectively (Forum Energii, 2017).

4.6 Portugal's domestic transition pathway

4.6.1 National context and current targets

After peaking in 2005, Portuguese emissions fell rapidly until 2014 to reach 24% below the peak of ten years earlier (Government of Portugal, 2021a). Emissions have since risen to be 8% higher than 1990 levels in 2019, one of only a handful of European countries where emissions have not fallen relative to 1990 levels.

Compared to 2005 levels, emissions from all sectors have fallen considerably except for those from transport, which declined by just 11% (Government of Portugal, 2021a). Transport sector emissions overtook those from the power sector in 2006 to become the largest source of emissions, and have seen a 64% increase since 1990.

Portugal's National Energy and Climate Plan set a 2030 GHG emissions reduction target of a 45-55% reduction below 2005 levels (21-35% below 1990) (Government of Portugal 2019a). A long-term target to reach carbon neutrality by 2050 was also set in 2019, while a 2023 coal phase-out target has been in place since 2019, but in the meantime was brought forward to the end of 2021 (Government of Portugal 2019b).

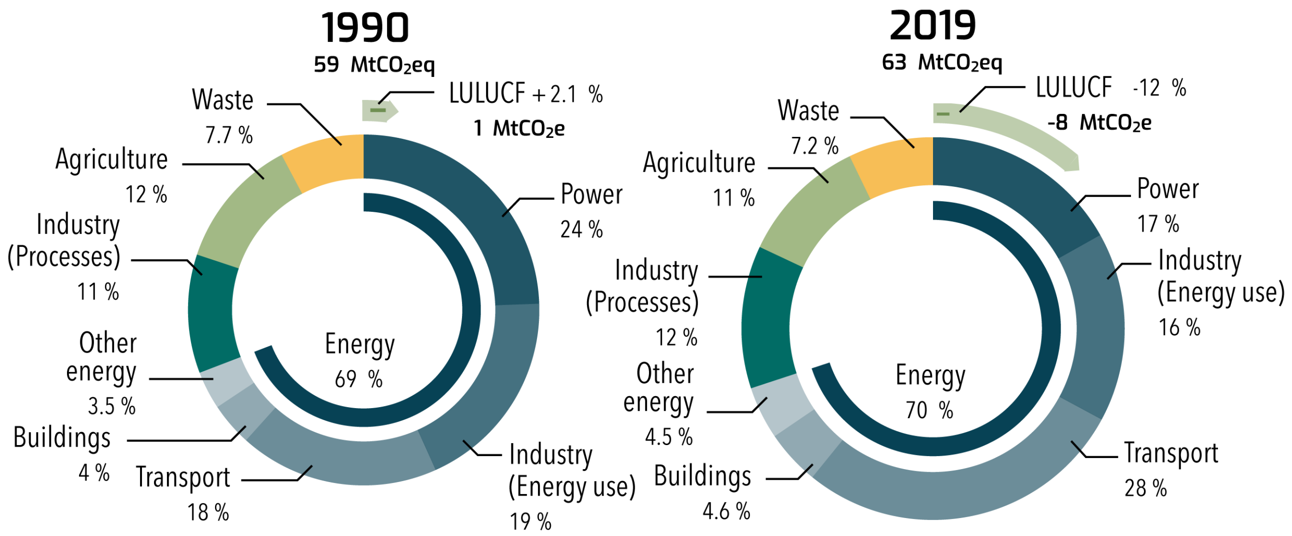


Figure 43: Historical emissions by sector. Source: (Government of Portugal, 2021b)

4.6.2 Emissions and energy pathways and adequacy of domestic targets

Portugal's current 2030 target fails to align with the 1.5°C aligned emissions reduction pathways determined by this project. Emissions excluding LULUCF in 2030 would instead need to reach 43-58% below 1990 levels, showing that a moderate increase in ambition is required to reach the lower bound of Portugal's 1.5°C compatible range. Portugal's own emissions projections show it meeting its current 2030 target under current policies (Government of Portugal, 2019a). Given Portugal's excellent solar and wind resources, achieving a higher level of ambition that is 1.5°C aligned is within reach.

Similarly, the targeted 80% renewable electricity generation target for 2030 is only 8 percentage points below the lower bound of the 1.5°C range of 88-94%. Portugal is in a unique position to set an example for the rest of the EU27 Member States, given the relative proximity of their current emissions and renewable energy targets to being 1.5°C compatible.

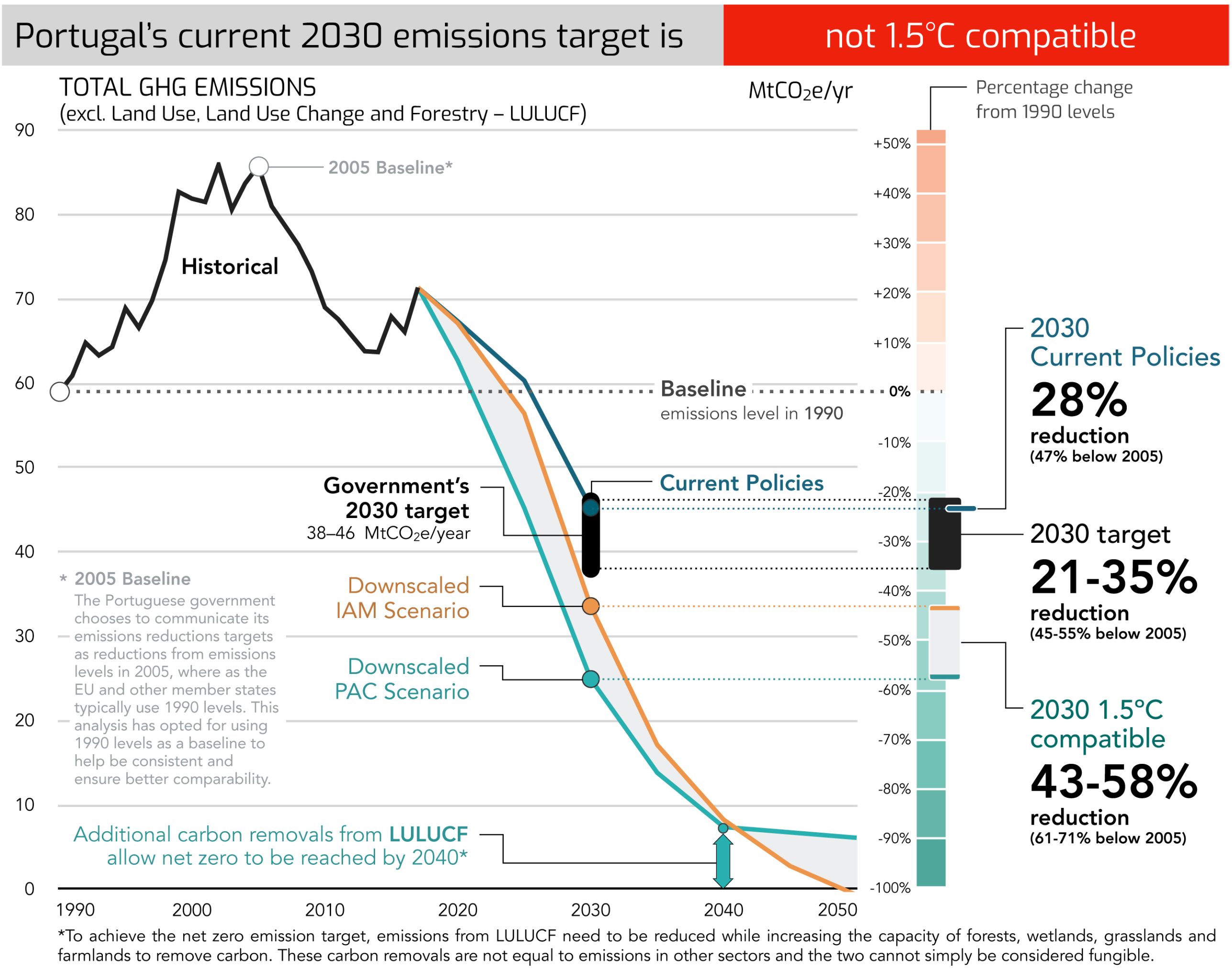


Figure 44: Domestic 1.5°C compatible GHG emissions pathways for Portugal

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand is reduced to between 30-38% by 2030, whereas renewables reach between 62-68% of primary energy by the same date. This compares with the NECP target values for 2030, where renewables have a weight of about 42% and fossil energy 58%. The transport and industry sectors constitute a combined 51% of total GHG emissions in Portugal, illustrating the need for strong policies to reduce the oil and natural gas demand that produce these sectoral emissions.

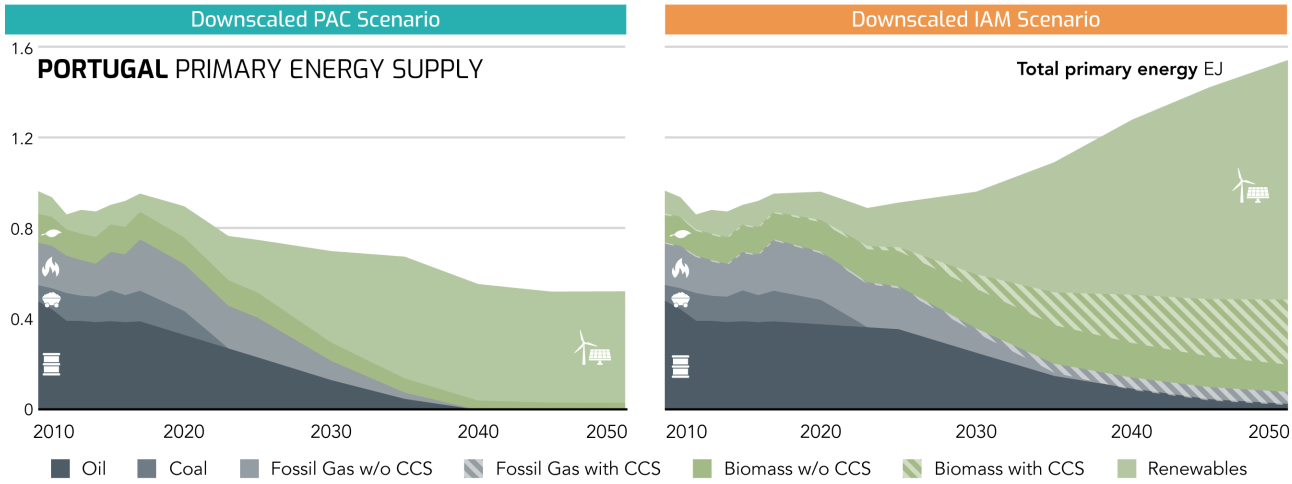


Figure 45: 1.5°C compatible primary energy supply pathways by fuel

Due to the significant levels of biomass consumption in the IAM scenario used to downscale primary energy to the national level in Portugal, the model has allocated an increasing share of biomass demand over time. With a limited domestic supply of biomass likely to be exacerbated by climate change, this modelled demand may need to be displaced by energy efficiency gains as envisaged under the downscaled PAC scenario

4.6.3 Decarbonising the power sector and policy implications

Portugal's power sector has undergone a transformation since 1990, when fuel combustion in the power sector was roughly half from coal and half from oil (IEA, 2020). Power sector oil and coal demand since then has fallen by 89% and 40% respectively, with fossil gas in 2019 making up 35% of total generation, while renewables contributed over half, increasing threefold since 1990. With a 2021 coal phase-out policy in place, focus should now turn to replacing fossil gas consumption with a steep increase in renewable energy generation.

Total electricity generation in 2019 is almost double 1990 levels, but due to the precipitous falls in oil and coal combustion, power sector emissions are 26% lower (Government of Portugal, 2021a; IEA, 2020). Renewables reached a 53% share in 2019 and are projected to contribute to at least 80% of electricity generation by 2030, mainly thanks to wind and solar power (Government of Portugal, 2019a; IEA, 2020). A continuation of this steep trajectory is projected to enable Portugal to reduce its power sector emissions by more than 90% by 2030 compared to 2005.

Table 19: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	39%	26%	33%	0%
2030	89–95% (IAM PAC)	0%	5–11% (PAC IAM)	0%

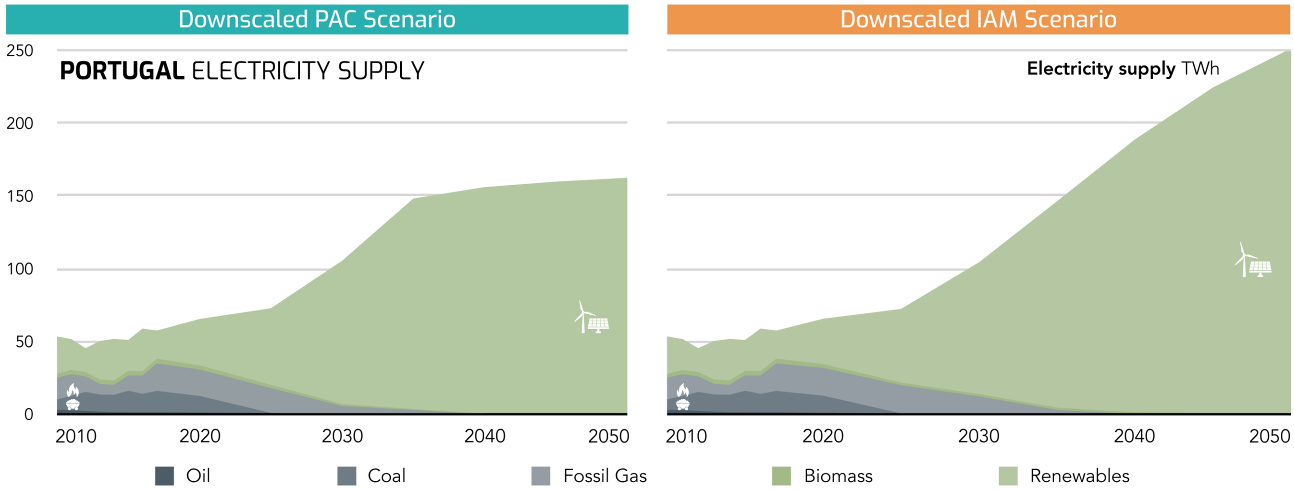


Figure 46: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in Portugal's power sector decline by between 72-87% below 1990 levels by 2030 in derived 1.5°C aligned pathways, reaching zero by 2040 whereby the last fossil gas is eliminated.

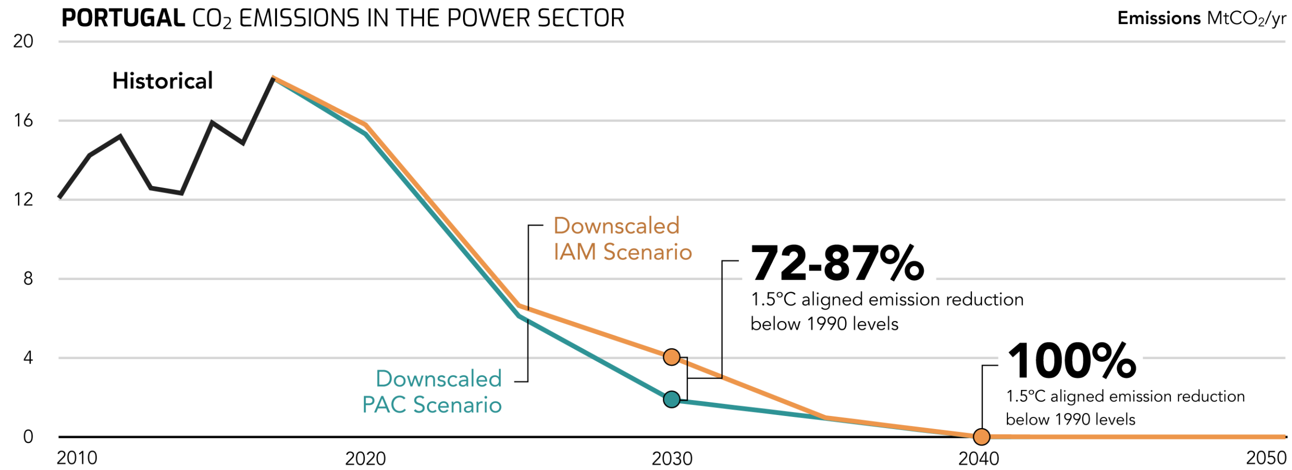


Figure 47: 1.5°C compatible power sector emissions for Portugal

4.6.4 Decarbonising the industry sector and policy implications

Portugal's industry sector consumes very little coal, making up less than 1% of total sectoral demand (IEA, 2020). Industrial coal consumption has fallen by 98% since 1990, when it made up 13% of demand. In 2019, fossil gas made up 27% of industrial energy demand, standing in stark contrast to its total absence from industry in 1990.

Table 20: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	31%	0%	28%	0%
2030	44%	0%	18%	6%

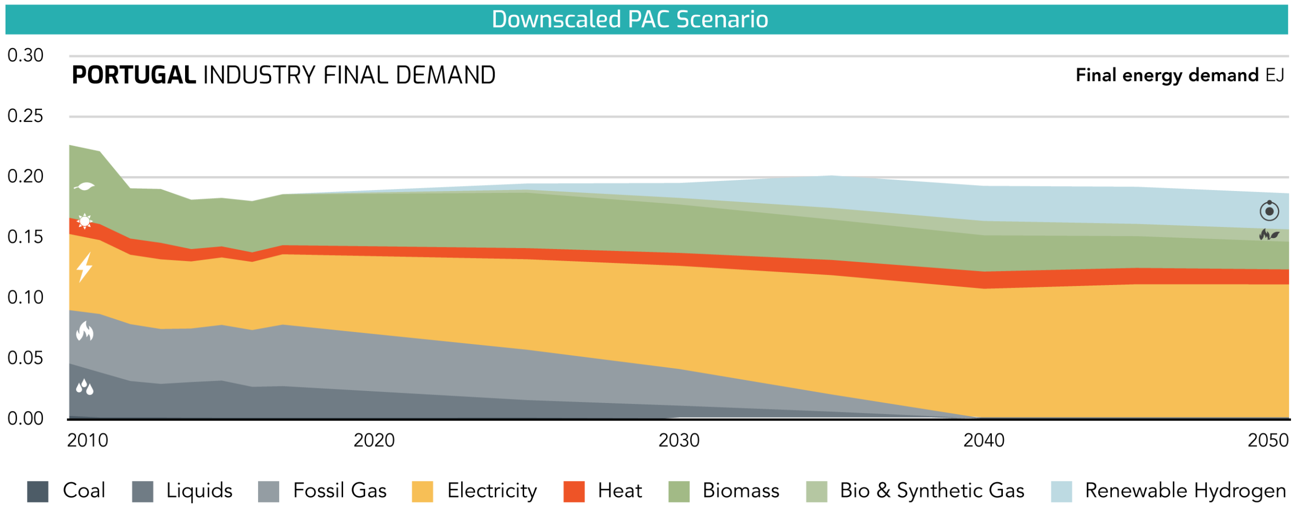


Figure 48: 1.5°C compatible share of technologies in the industry energy mix

The replacement of oil and coal demand since 1990 with fossil gas along with rising supply from renewables has meant that energy-related emissions from this sector are lower than in 1990 despite total demand being roughly the same. Focus should now be on electrifying industry energy demand and deriving methods for dealing with process emissions, which are harder to bring to zero than energy-related emissions.

Electrification rates of 44% and 60% by 2030 and 2050 respectively would align with the 1.5°C compatible industry sector pathway for Portugal downscaled from the PAC scenario, as would overall emissions reductions of 50% and 82% below 1990 levels by 2030 and 2050 respectively.

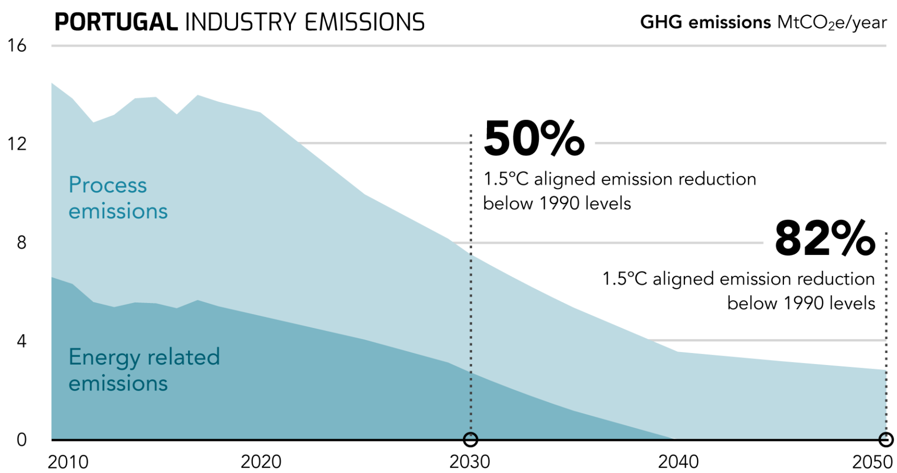


Figure 49: 1.5°C compatible industry sector emissions for Portugal

4.6.5 Key characteristics of 1.5°C compatible pathways

Table 21 below provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Portugal in 2030 and 2050, compared against recent historical values.

Table 21: Key characteristics of Portugal's 1.5°C compatible pathways

	Historical	**1.5°C compatible benchmarks**		**Country targets**	
	2017	**2030**	**2050**	**2030**	**2050** incl. LULUCF*
Total GHG excl. LULUCF	71 $MtCO_2e/yr$	25–34 $MtCO_2e$ /yr	-1–6 $MtCO_2e$ /yr	38–46 $MtCO_2e$ /yr	0 $MtCO_2e$ /yr
	20% below 1990	43–58 % below 1990	90–101 % below 1990	21-35 % below 1990	100% below 1990
	17% below 2005	61–71 % below 2005	93–101 % below 2005	45-55 % below 2005	100% below 2005
Emissions intensity of power generation**	316 gCO_2/kWh	18–39 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	39 %	88–94 %	100 %	80 %	
Share of unabated fossil fuel in power	61 %	5–11 %	0 %		
Share of nuclear power	0 %	0 %	0 %		
Industry electrification rate	31 %	44 %	60 %		

* 2050 target is shown including LULUCF emissions due to the absence of government projections for these emissions to 2050

** Does not include upstream emissions

4.7 Romania's domestic transition pathway

4.7.1 National context and current targets

Romania's emissions fell precipitously due to a structural change to Romania's economy beginning in the late 1980s and the subsequent decline in emissions-intensive heavy industry, experiencing a 42% decline in total emissions (excl. LULUCF) over just four years between 1989-1993 (Government of Romania, 2021a). Emissions have continued to fall since, reaching 64% below their 1989 peak by 2019 (55% below 1990 levels).

Since the more commonly used reference year of 1990, the industry and the power sectors have seen steep emissions reductions to 2019; 68% and 72% respectively. In contrast, buildings' emissions were roughly at 1990 levels, while transport emissions (17% of total) have risen by 67%, outpacing a 55% increase in fuel combustion. This is primarily due to a switch from gasoline to diesel fuel in road transportation, with demand for the latter increasing 244%, while gasoline consumption fell 41% (IEA, 2020).

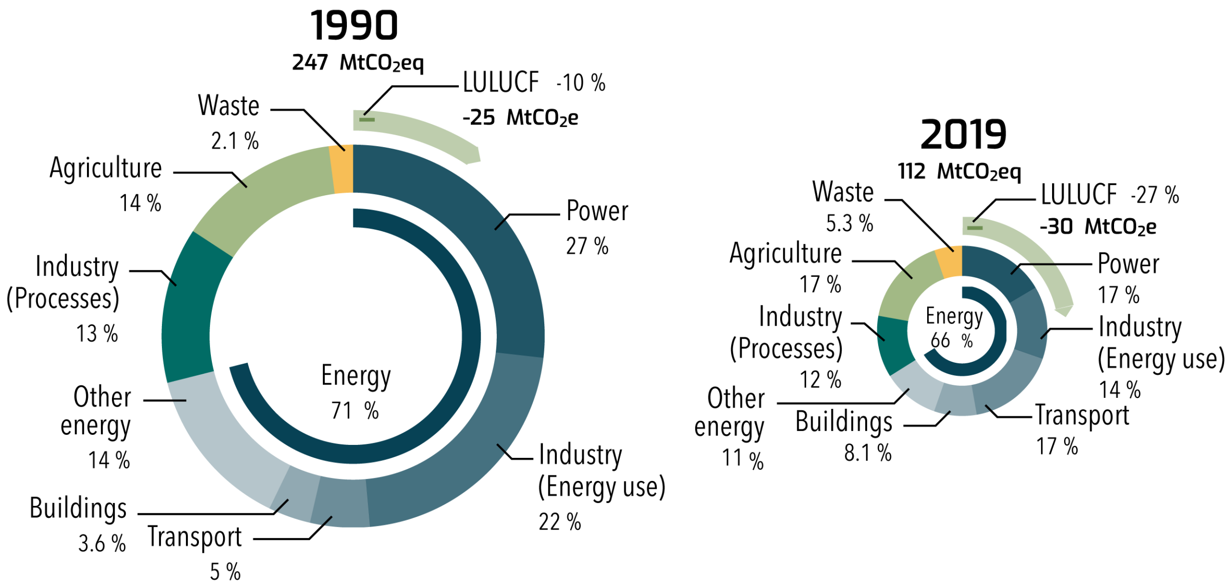


Figure 50: Historical emissions by sector. Source: (Government of Romania, 2021b)

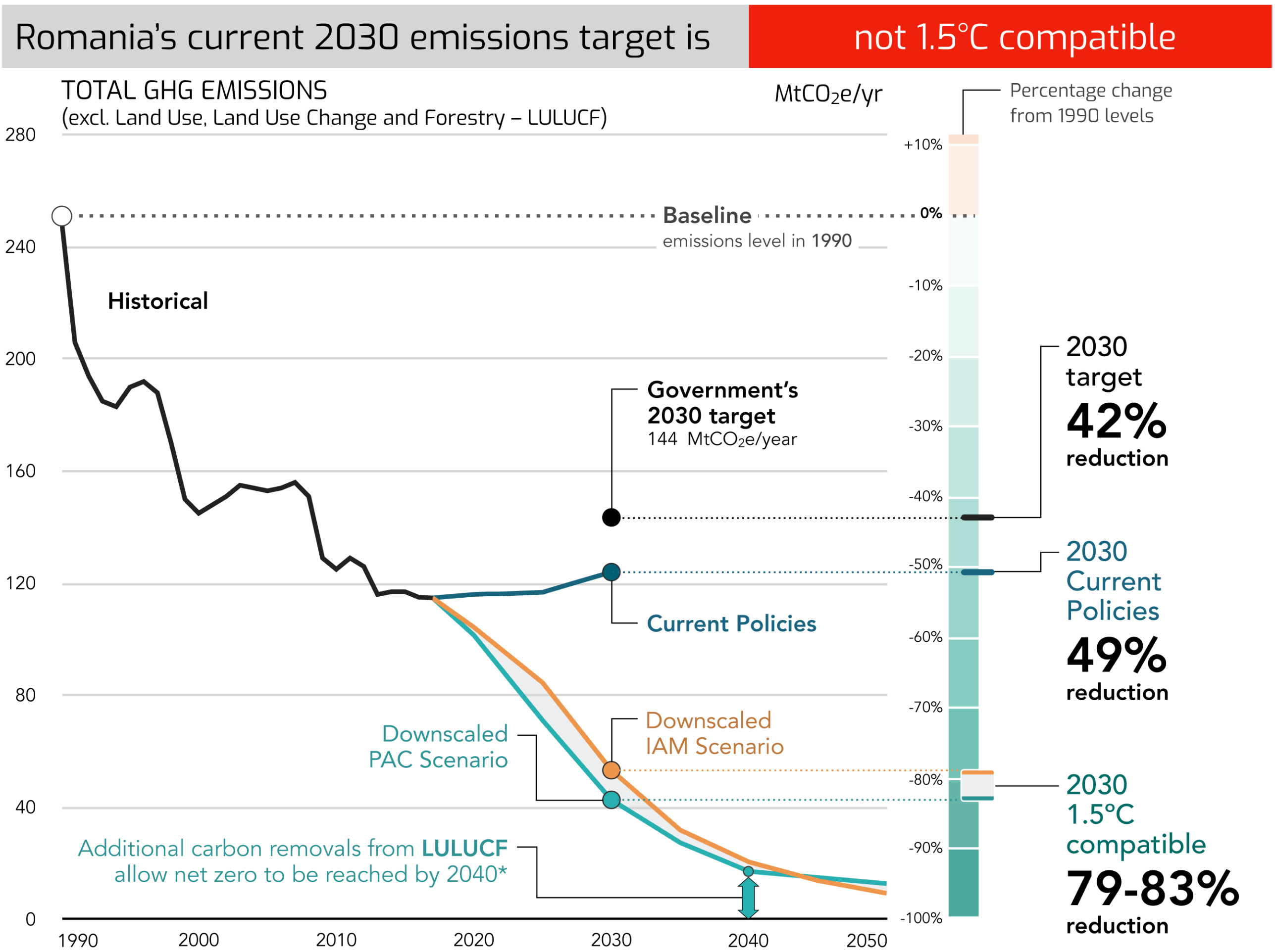
Total primary energy supply in Romania was 47% lower in 2019 than in 1990, with especially steep declines seen in coal and fossil gas demand (both -68%) (IEA, 2020). This was partially displaced by the introduction of nuclear power in 1996, which in 2019 made up 9% of total supply, while supply from renewable sources, particularly biomass (+573%), increased substantially, to make up 18% compared to just 3% in 1990.

The decline of Romania's industry sector, which saw a 74% reduction in energy demand, is the primary cause of the overall drop in fossil gas consumption, as it fell 87% in industry between 1990 and 2019. Declining gas demand also occurred in the power sector over this time (-60%), while oil use has almost been phased out by 2019 after being 18% of supply in 1990. Steep increases in wind and solar generation from almost nothing in 2010 to 14% of electricity supply in 2015 have since stalled. Effective policy intervention could help to spur investment and see a return of such strong growth.

Romania's current 2030 emissions reduction target of 42% below 1990 levels (excl. LULUCF) allows emissions to rise over the next ten years. No country in Europe should see rising emissions, as any such rises would require even steeper reductions in other countries. The Romanian government announced in June 2021 that coal in the power sector would be phased out by 2032 (Neagu & Taylor, 2021).

4.7.2 Emissions and energy pathways and adequacy of domestic targets

While Romania's emissions have already fallen further than many other European countries, this is primarily due to structural changes that occurred at the end of the 1980s rather than the implementation of climate policies. The current 2030 target allows emissions to rise from their present levels and is even above where emissions are projected to be under current policies (EEA 2020). A much stronger target, in the range of 79-83% below 1990 levels would be needed for compatibility with the 1.5°C range determined by this project, together with a suite of policies affecting all sectors of the economy. The power and industry sectors are the top two emitting sectors, but policies targeting these and transport and buildings' emissions are urgently needed to ensure Romania's emissions continue to fall.



*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 51: Domestic 1.5°C compatible GHG emissions pathways for Romania

In the derived 1.5°C compatible pathways, the share of unabated fossil fuels in primary energy demand is reduced to between 33-38% by 2030, whereas the share of renewables reaches 60% by the same date. The transport and industry sectors constitute a combined 40% of total GHG emissions in Romania, illustrating the need for strong policies to reduce the oil and natural gas demand that produce these sectoral emissions.

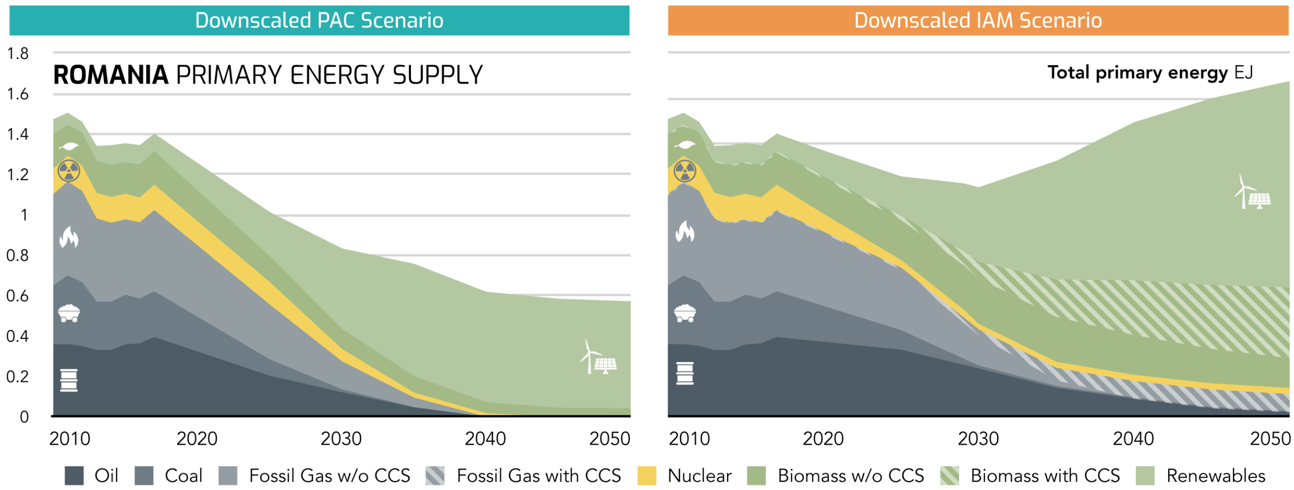


Figure 52: 1.5°C compatible primary energy supply pathways by fuel

4.7.3 Decarbonising the power sector and policy implications

Total electricity supply from Romania's power sector has only declined slightly since 1990 (-8% in 2019), though the composition of this supply has changed dramatically (IEA, 2020). Generation from renewables has more than doubled since 1990, while coal and fossil gas consumption has fallen by 26% and 60% respectively. Oil use for power generation has almost ceased, declining 95% since 1990, and been replaced almost entirely by nuclear generation, which has grown to a 19% share in 2019. Growth in renewables has stalled since 2014, a development that requires urgent action to ensure Romania's power sector is mostly decarbonised by 2030.

For Romania's power sector to be aligned with the 1.5°C compatible pathways derived in this project, coal would need to be phased out by 2030, two years earlier than the government's recently announced date, with gas shortly afterwards.

Table 22: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	38%	26%	17%	18%
2030	88–94% IAM PAC	0%	2–5% PAC IAM	4–7% PAC IAM

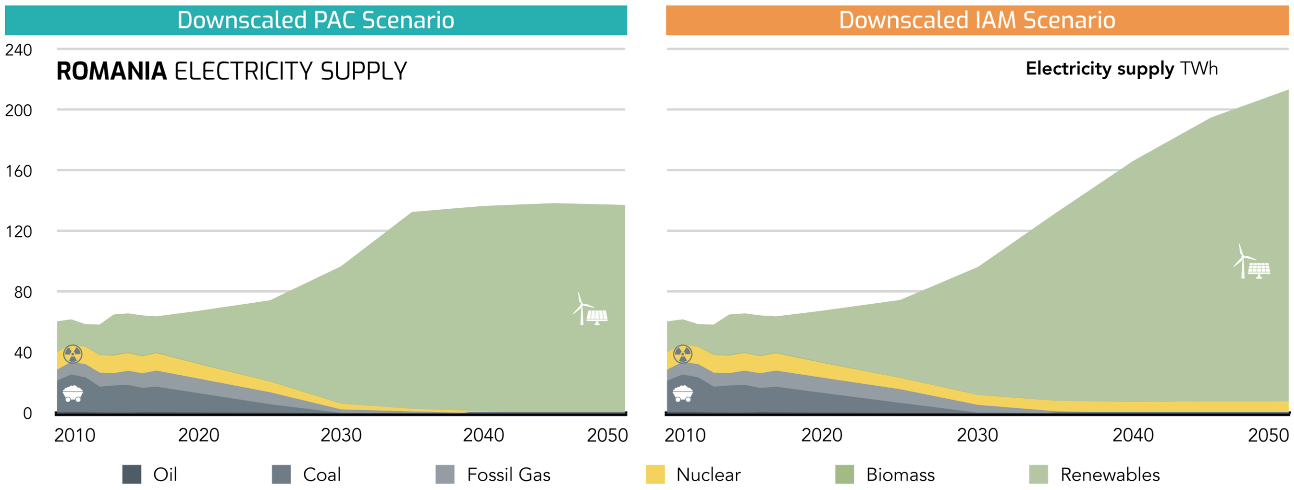


Figure 53: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Total CO_2 emissions in Romania's power sector decline by between 97-98% below 1990 levels by 2030 under the derived 1.5°C aligned power sector pathways, reaching zero by around 2035.

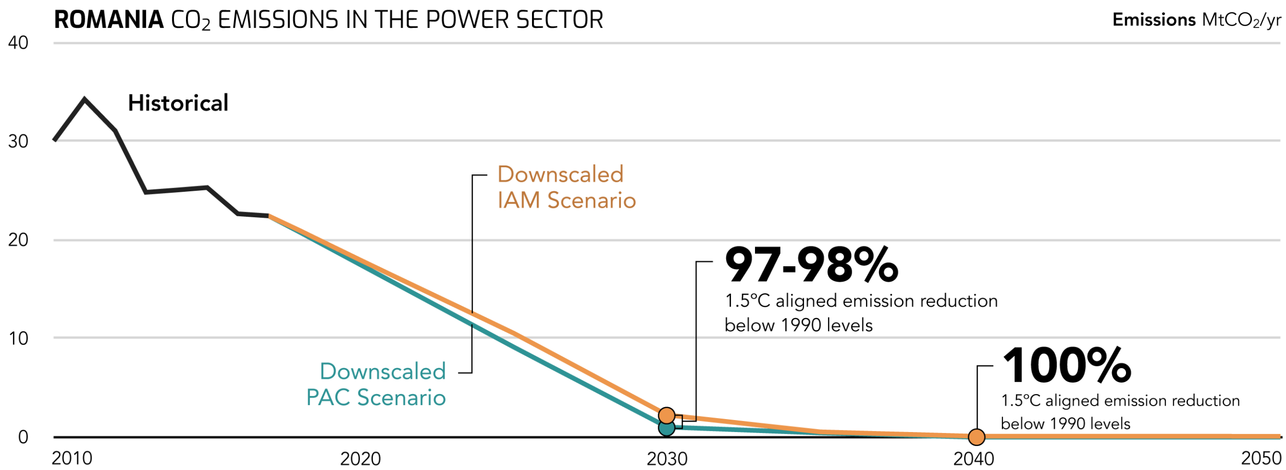


Figure 54: 1.5°C compatible power sector emissions for Romania

4.7.4 Decarbonising the industry sector and policy implications

Total industrial energy demand in Romania plummeted due to a structural shift to Romania's economy beginning in the late 1980s when a large percentage of factories shut down. It levelled out around 2009 after falling 75% from 1990 levels, staying relatively consistent for the following decade. The composition of this demand, though, has changed markedly, with fossil fuels falling to a 60% share in 2019 from 86% in 1990 (IEA, 2020). Electricity's share more than doubled to 29% over this time, while biomass which was not used at all in 1990, made up a 4% share in 2019. Policies targeting energy efficiency gains and electrification are urgently needed to ensure the remaining fossil fuel use is phased out between 2035 and 2040.

Table 23: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	39%	9%	36%	0%
2030	45%	6%	25%	6%

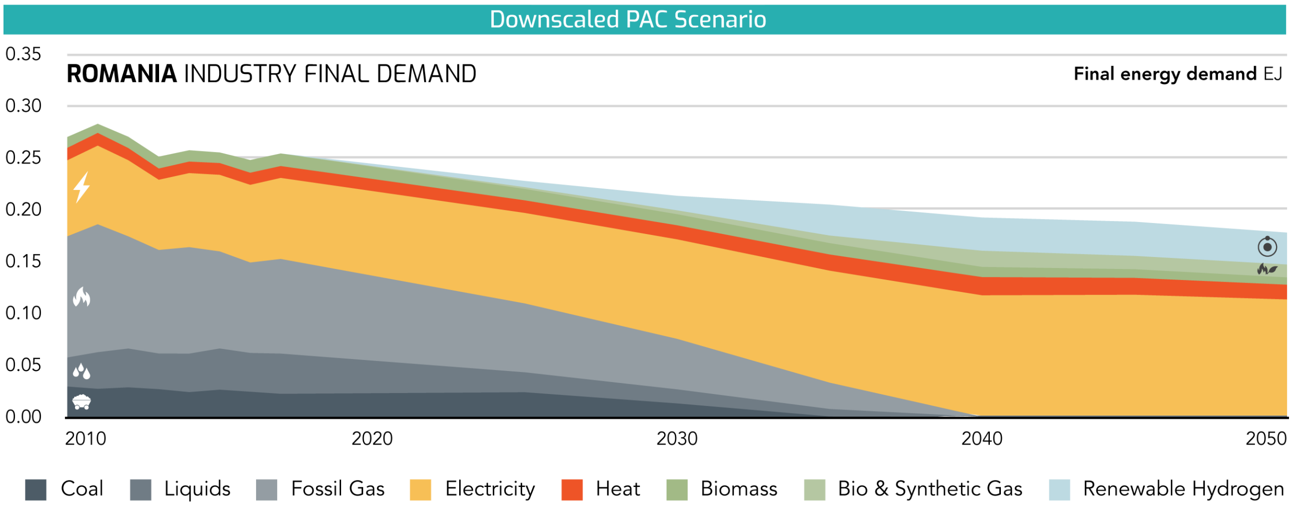


Figure 55: 1.5°C compatible share of technologies in the industry energy mix

Increasing the electrification of industry final energy demand to 45% by 2030 and 64% by 2050, while achieving emissions reductions of 50% and 82% by 2030 and 2050 respectively would align Romania's industry sector with the 1.5°C compatible trajectory downscaled from the PAC scenario.

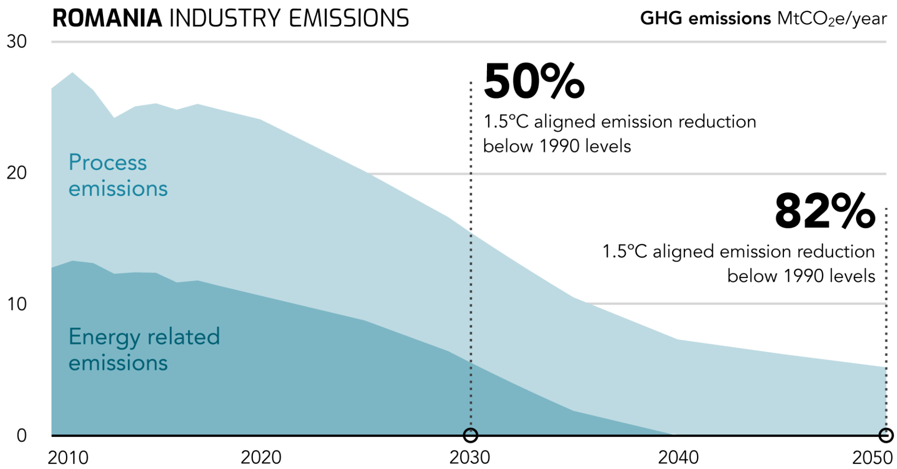


Figure 56: 1.5°C compatible industry sector emissions for Romania

4.7.5 Key characteristics of 1.5°C compatible pathways and other analyses

Table 24 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Romania in 2030 and 2050, compared against recent historical values.

Table 24: Key characteristics of Romania's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030***	**2050**
Total GHG excl. LULUCF	115 $MtCO_2e/yr$	43–53 $MtCO_2e$ /yr	9–13 $MtCO_2e$ /yr	146 $MtCO_2e$ /yr	
	54 % below 1990	79–83 % below 1990	95–96 % below 1990	42 % below 1990	
Emissions intensity of power generation**	351 gCO_2/kWh	11–23 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	38 %	88–94 %	100 %		
Share of unabated fossil fuel in power	44 %	2–5 %	0 %		
Share of nuclear power	18 %	4–7 %	0–3 %		
Industry electrification rate	39 %	45 %	63 %		

* 2030 target excluding LULUCF calculated using the government's 'with existing measures' emissions projections submitted to the UNFCC
** Does not include upstream emissions

A 2019 analysis by the REKK Foundation derives benchmarks for the power system of Southeast Europe that include a 50% renewable generation target for 2030 and for coal to generate less than 25% of power in the region by the same date (REKK Foundation, 2019).

4.8 Spain's domestic transition pathway

4.8.1 National context and current targets

Spain's emissions peaked in 2007, well above 1990 levels, and fell rapidly afterwards due to the global financial crisis and associated economic slowdown (Government of Spain, 2021a). Emissions have been rising again, however, since their 2013 low. Power sector emissions have fallen from a 24% share of total emissions at their peak in 2007, to just 14% in 2019. Coal demand fell 81% over this period, well above the 52% fall in total power sector fuel combustion (IEA, 2020).

Emissions in the industry sector fell by 34% between 2007 and 2019, while total industrial energy demand declined by only 26%, suggesting efficiency gains and the use of cleaner fuels (Government of Spain, 2021a; IEA, 2020). The share of fossil gas in industry energy demand increased five percentage points between 2007-2019, rising to 43% from 38%. The transport and buildings sectors have seen much more moderate emissions declines, falling just 15% and 18% respectively over this time, with transport emissions trending higher since 2013.

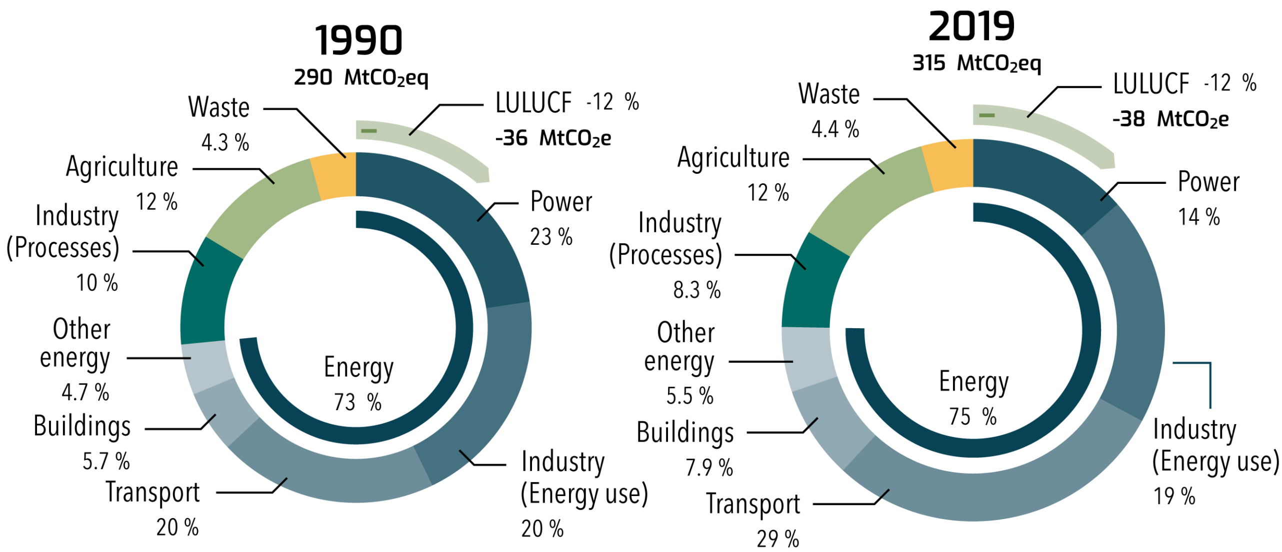


Figure 57: Spanish historical emissions by sector. Source: (Government of Spain, 2021c)

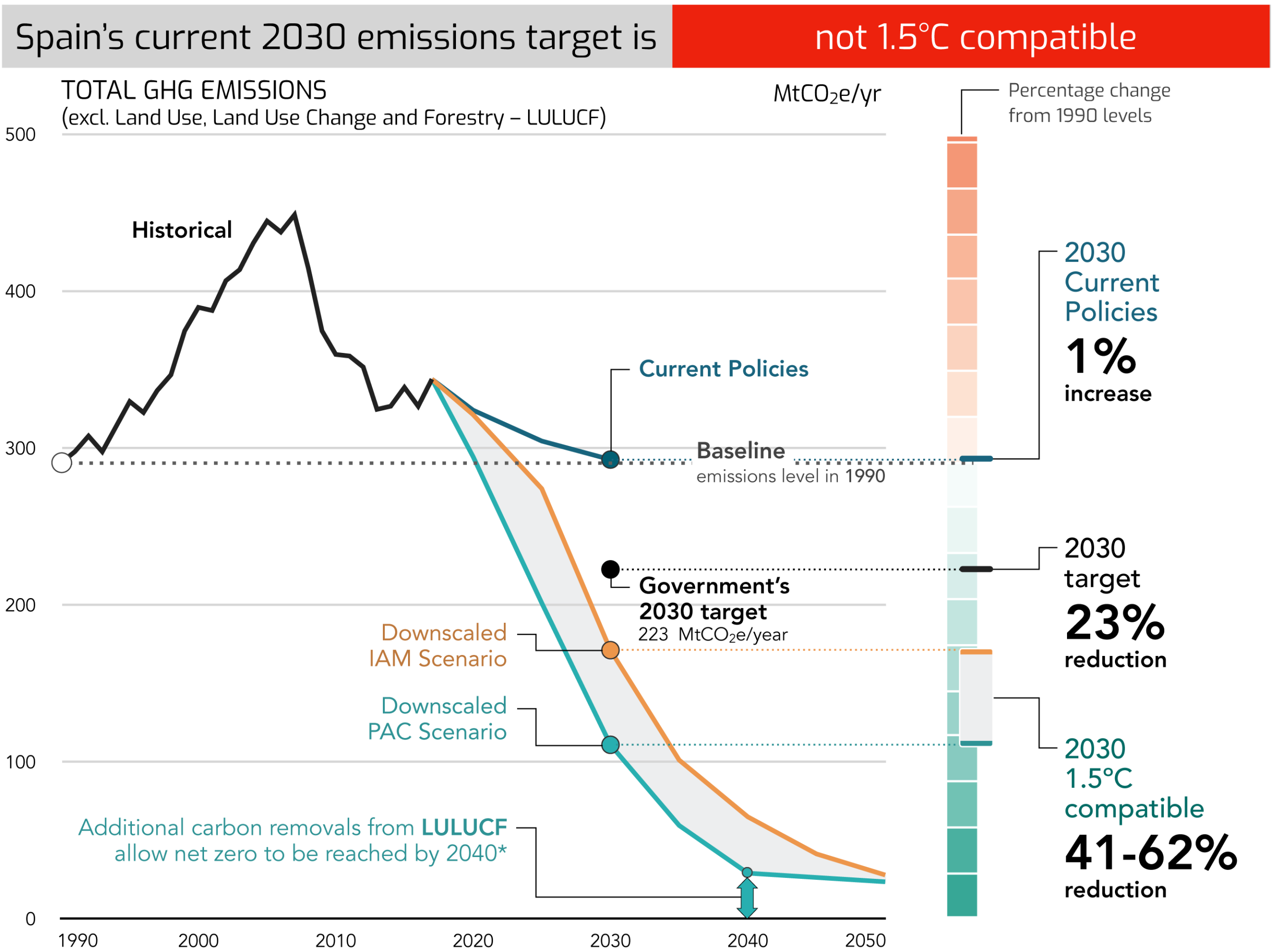
Spain has achieved a steep reduction in total coal demand in recent years, reaching 78% below 2007 levels in 2019 while total energy use fell just 24% over the same period (Government of Spain, 2020b). A 2030 coal phase-out policy was announced in 2020, which is aligned with the 1.5°C temperature goal, but is yet to be formally adopted (Climate Analytics, 2019; Government of Spain, 2020b). Similarly, it is intended that all nuclear power stations will be closed by 2035. Oil demand fell roughly in line with the overall decline in energy use, while fossil gas consumption fell just 3% between 2007 and 2019. Policies to rapidly reduce oil and gas consumption are needed in particular for the buildings and transport sectors, and while some such measures have been included in the recently released Recovery and Resilience Plan, a continued focus on these sectors will be needed to ensure their necessary rapid decarbonisation (Government of Spain, 2021b).

Spain has very significant solar resources that it is seeking to tap with its recently adopted 74% 2030 renewable generation target (Government of Spain, 2020b). This is a welcome turnaround from the stifling measures implemented between 2009 and 2015 including a cap on the operating hours of renewable installations, a moratorium on new projects, and a tax on solar prosumers which together led to a sharp decline in new renewable energy capacity. A new national prosumerism strategy is due to be published by the end of 2021 as part of the reforms of Spain's National Recovery Plan.

4.8.2 Emissions and energy pathways and adequacy of domestic targets

Spain is currently not on track to achieve its modest 2030 emissions reduction target; under current policies, as outlined in its National Energy and Climate Plan (NECP) of 2020, total Spanish GHG emissions in 2030 are projected to remain above 1990 levels (Government of Spain, 2020b).

A recent change of direction on climate policy, with the adoption of ambitious 2030 and 2050 renewable energy targets and a commitment to reach net zero emissions by 2050, is a welcome development. However, the current target, which is far from being aligned with the 1.5°C compatible derived pathways, is only projected to be achieved under planned policies as outlined in Spain's National Energy and Climate Plan (2020), demonstrating the need for a significant increase in the ambition of Spain's climate policies.



*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 58: Domestic 1.5°C compatible GHG emissions pathways for Spain

Achieving a 1.5°C compatible economy for Spain as determined by this project requires a 41-62% reduction in total GHG emissions by 2030 (excluding LULUCF), and reaching net zero emissions between 2040 and 2050. There are numerous different pathways to achieving net zero emissions in this timeframe. In the two scenarios analysed, a LULUCF sink of 24-28 $MtCO_2e$ achieves net zero emissions by 2050, while under the PAC scenario, a LULUCF sink of 29 $MtCO_2e$ achieves net zero emissions in 2040. This is less than the negative emissions in 2050 projected in the LULUCF sector under Spain's long-term climate strategy of 37 $MtCO_2e$ (Government of Spain, 2020a).

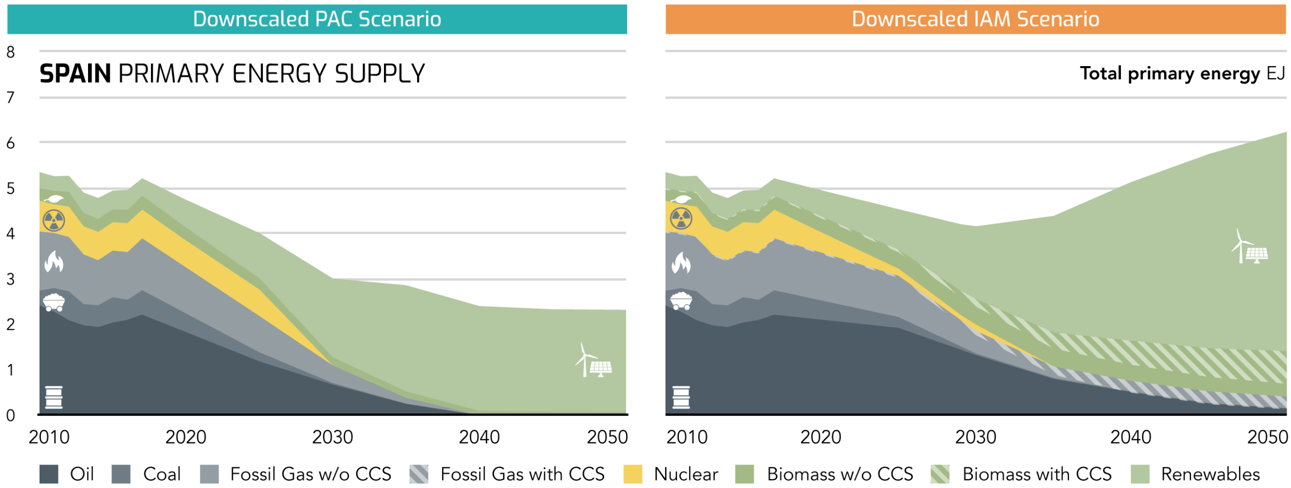


Figure 59: 1.5°C compatible primary energy supply pathways by fuel

4.8.3 Decarbonising the power sector and policy implications

In both downscaled 1.5°C compatible scenarios, remaining coal consumption in Spain's power sector steadily declines and is phased out by 2030, in line with the government's current 2030 phase out date (Government of Spain, 2020b). There is no increase in gas generation in either scenario and it is phased out of the system by around 2035, when the system is fully decarbonised.

The expected increase in total electricity demand due to widespread electrification across the economy is met exclusively with renewable sources, with a doubling in total electricity demand by 2035 in both scenarios. The government's current 2030 renewable energy target of a 74% share of total power generation would need to be strengthened to at least 82% to ensure alignment with the downscaled pathways. Nuclear power is phased out between 2030-2035, in line with the government's 2035 phase out date.

Table 25: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	32%	17%	23%	21%
2030	82–95% IAM PAC	0%	5–9% PAC IAM	0–9% PAC IAM

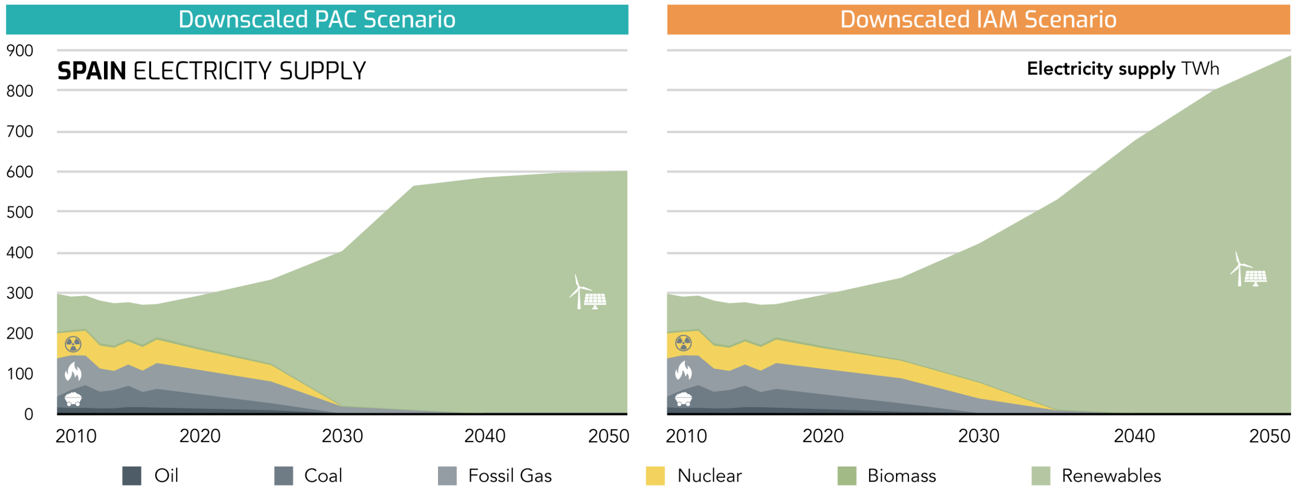


Figure 60: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

Power sector CO_2 emissions fall rapidly in both scenarios, especially between 2025 and 2030, to between 80-91% below 1990 levels by 2030, and reach zero by 2040.

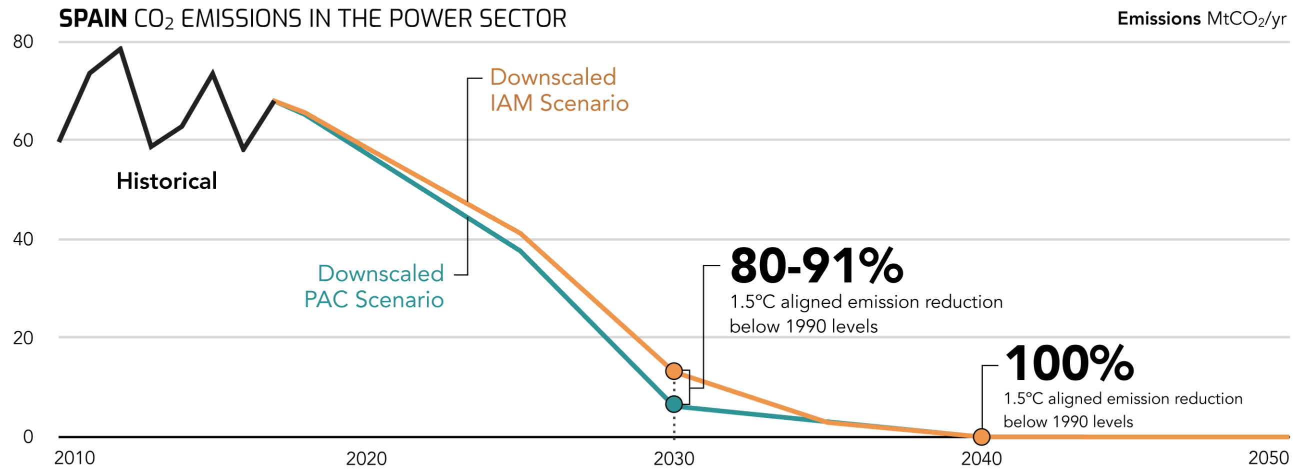


Figure 61: 1.5°C compatible power sector emissions for Spain

4.8.4 Decarbonising the industry sector and policy implications

A halving of industry coal demand in Spain between 1990 and 2000 was followed by a steady decline, with mostly fossil gas and oil combustion remaining in 2019, making up 57% of total industry energy use (IEA, 2020). The remaining coal demand should be phased out between 2030 and 2035, while oil and fossil gas consumption would need to be eliminated by 2040 to ensure Spain's industry sector aligns with the 1.5°C compatible trajectory downscaled from the PAC scenario.

Table 26: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	36%	4%	39%	0%
2030	52%	3%	25%	6%

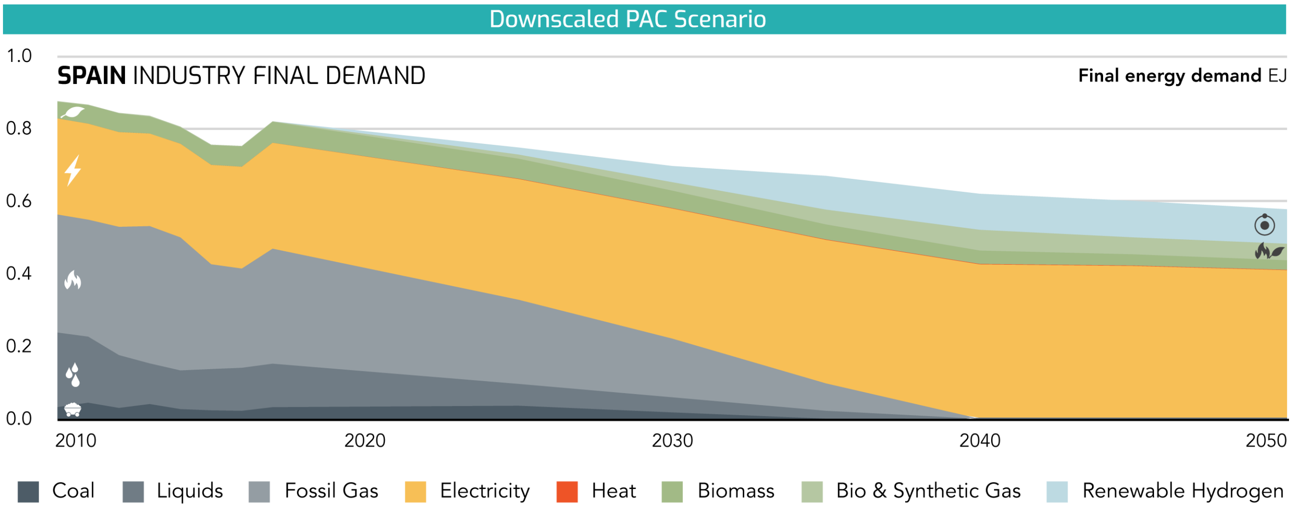


Figure 62: 1.5°C compatible share of technologies in the industry energy mix

The associated emissions pathway for this downscaled industry energy pathway from the PAC scenario shown below stipulates a 55% reduction in total industry GHG emissions by 2030, an 85% reduction in total GHG emissions by 2050, and energy-related CO_2 emissions reaching zero by 2040.

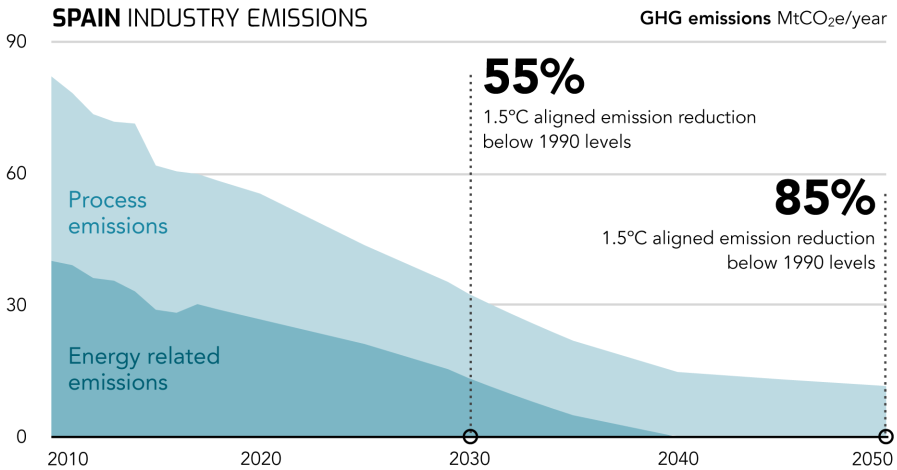


Figure 63: 1.5°C compatible industry sector emissions for Spain

4.8.5 Key characteristics of 1.5°C compatible pathways and other analyses

Table 27 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Spain in 2030 and 2050, compared against recent historical values.

Table 27: Key characteristics of Spain's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030**	**2050**
Total GHG excl. LULUCF	344 $MtCO_2e/yr$	111–173 $MtCO_2e$ /yr	24–28 $MtCO_2e$ /yr	223 $MtCO_2e$ /yr	29 $MtCO_2e$ /yr
	18 % below 1990	41–62 % below 1990	90–92 % below 1990	23 % below 1990	90 % below 1990
Emissions intensity of power generation*	250 gCO_2/kWh	15–31 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	32 %	82–95 %	100 %	74 %	100 %
Share of unabated fossil fuel in power	47 %	5–9 %	0 %		
Share of nuclear power	21 %	0–9 %	0 %		
Industry electrification rate	36 %	52 %	71 %		

* Does not include upstream emissions

In the existing literature on energy system transformation, the scenario derived by Ecologistas en Acción (2015) outlines the following benchmarks for Spain:

- 65% reduction in total final energy consumption below 2015 level by 2050
- Nuclear phase-out by 2030
- Coal phased out of the power sector by 2030

These metrics broadly align with the downscaled PAC and IAM scenarios for Spain, which stipulate a 2030 coal phase out and a nuclear phase out between 2030 and 2035.

4.9 Sweden's domestic transition pathway

4.9.1 National context and current targets

Sweden's emissions excluding LULUCF peaked in 1970 and have been trending down since. Between 1990 and 2019, emissions have fallen by 23%, led by the buildings sector, which saw an 87% drop in emissions over this time (Government of Sweden, 2021a). All sectors have seen emissions decline, though the transport and industry sectors underperformed compared to the economy-wide drop, falling just 14% and 19% since 1990 respectively.

Emissions reductions in the industry sector were achieved through lower total energy demand and fuel switching between coal and oil to biomass, with coal consumption falling 42% between 1990 and 2019 (IEA, 2020). Though transport emissions are on the decline, they produce more than twice as many emissions as the next largest emitting sector (32% of total emissions in 2019), highlighting the need for ambitious and effective policies targeting this sector.

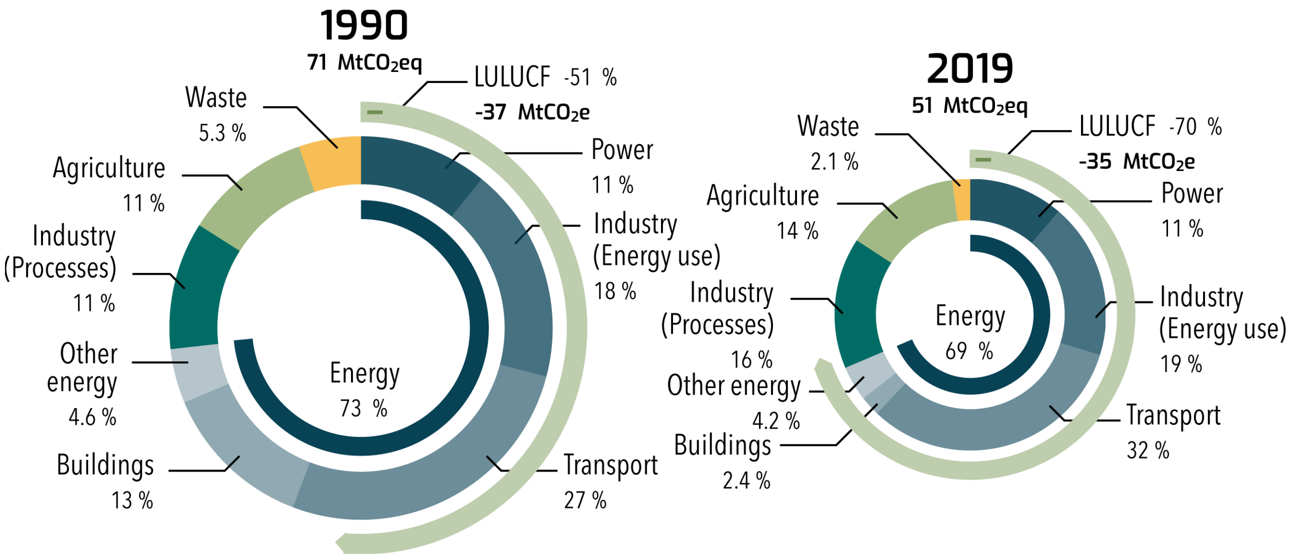


Figure 64: Historical emissions by sector. Source: (Government of Sweden, 2021b)

Sweden's total energy supply has stayed relatively stable since 1990, though the composition of this energy supply has changed dramatically. Coal consumption fell 47% and now makes up just 4% of total energy, while oil consumption has fallen 31% and makes up a 20% share compared to 30% in 1990 (IEA, 2020). Renewables now make up 40% of total energy supply, with nuclear contributing a further 35% in 2019.

Sweden has pledged to reduce its net GHG emissions to zero by 2045, and then achieve negative emissions (Government of Sweden, 2020). This means that GHG emissions must be at least 85% lower in 2045 than they were in 1990.

4.9.2 Emissions and energy pathways and adequacy of domestic targets

While Sweden has committed to an ambitious 2045 net zero emissions target, it has yet failed to set an economy-wide 2030 GHG emissions target in contrast to most European countries. Instead, it has committed to a 63% reduction in emissions not covered by the EU Emissions Trading System (ETS) below 1990 levels by 2030, and a 70% reduction in transport emissions below 2010 levels by

2030 (Government of Sweden, 2020). Neither of these are sufficient in ambition to meet the range of 1.5°C compatible economy-wide 2030 targets derived in this analysis of a 72-78% reduction below 1990 levels. To allow for full comparability and transparency, Sweden should adopt an economy-wide 2030 emissions target within this range.

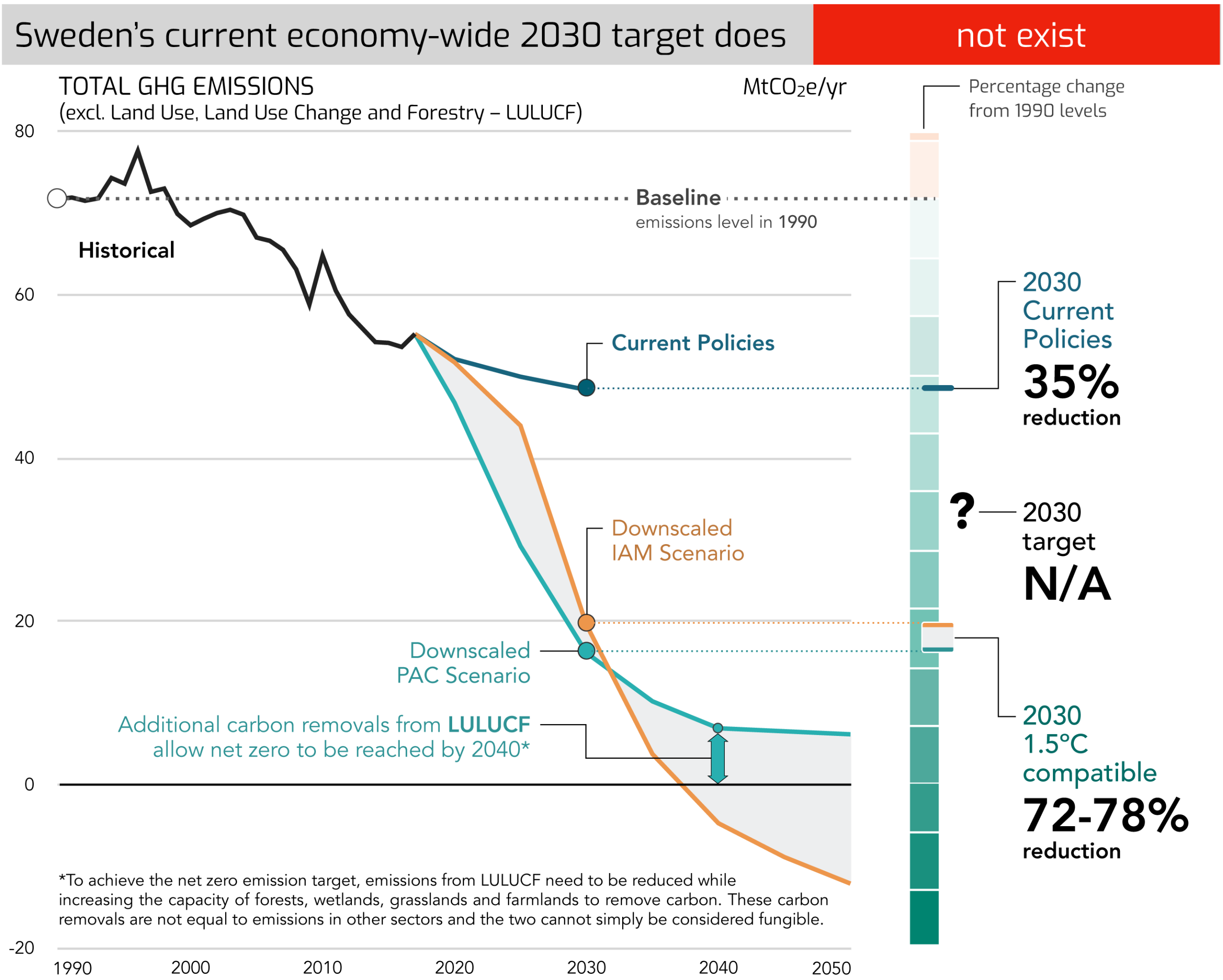


Figure 65: Domestic 1.5°C compatible GHG emissions pathways for Sweden

Sweden has a high proportion of renewable and low carbon energy use, but a large amount of fossil fuel consumption (primarily oil and petroleum products) remains in the transport and industry sectors. To achieve its 2030 target of a 70% reduction in transport emissions, a suite of strong and effective policies beyond what is currently in place will be needed. Such policies need to both reduce reliance on personal vehicle use, through incentives and infrastructure for cycling, walking and using public transport, as well as ramp up vehicle electrification.

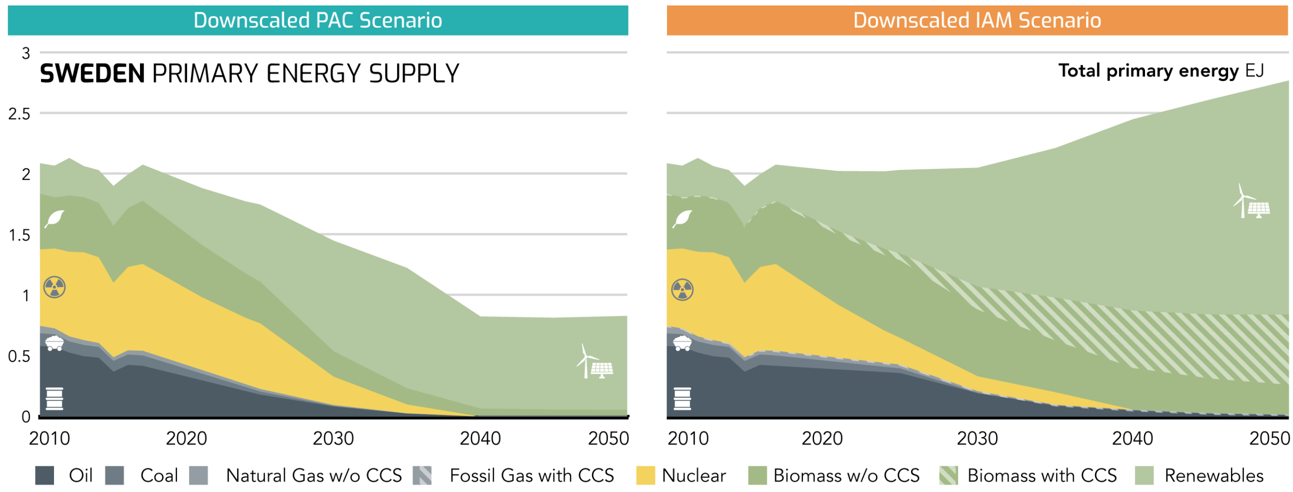


Figure 66: 1.5°C compatible primary energy supply pathways by fuel

4.9.3 Decarbonising the power sector and policy implications

Sweden's power sector is largely decarbonised, with only a very small degree of fossil fuel-based generation remaining. Phasing this out as rapidly as possible should be a priority. Due to the need to electrify the economy, total electricity demand under the analysed scenarios increases considerably over the coming decades, rising between 3-4 times above current levels by 2050. Achieving the government's 100% renewable energy target by 2040 will require the phasing out of nuclear power by this date.

Table 28: 1.5°C compatible 2030 power sector fuel mix

	Renewables incl. biomass	Coal	Fossil gas	Nuclear
2017	58%	1%	0%	40%
2030	90–95% (IAM PAC)	0%	0%	5–10% (PAC IAM)

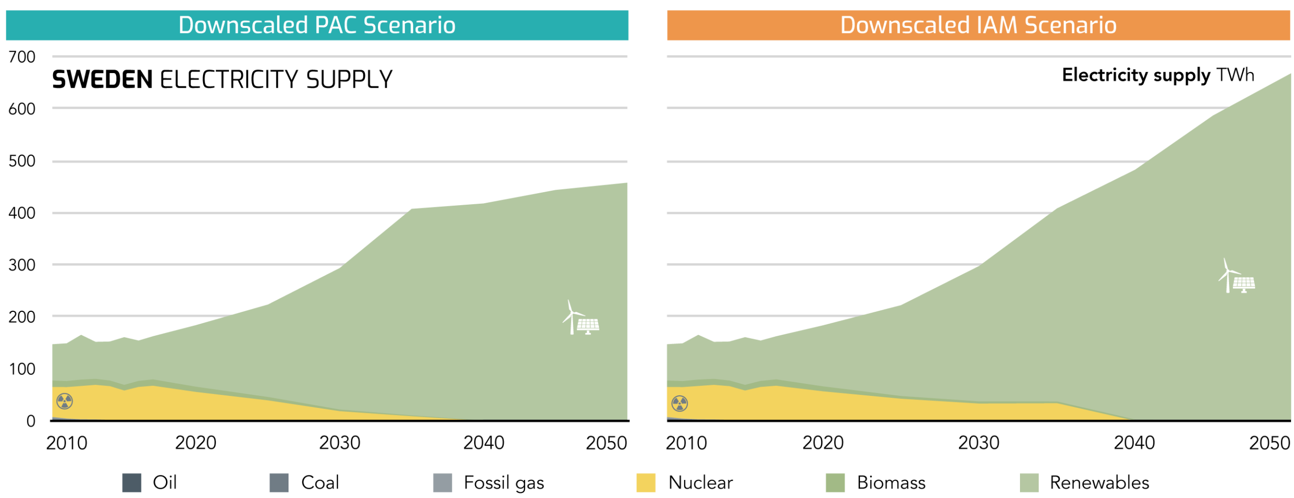


Figure 67: Share of technologies in the power mix consistent with 1.5°C compatible emissions pathways

The limited remaining emissions in Sweden's power sector should be brought down to zero by 2030, by phasing out the sector's remaining coal consumption by this date.

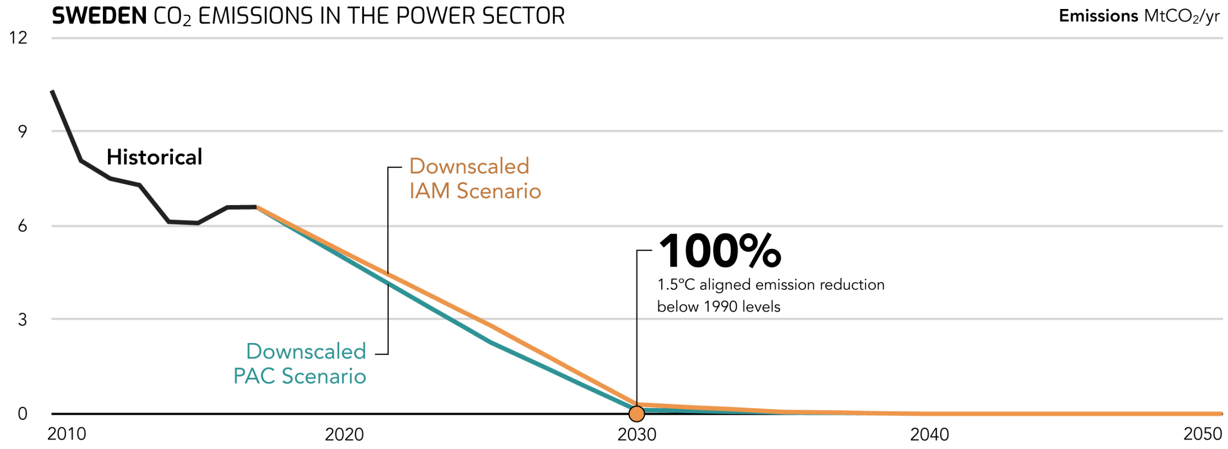


Figure 68: 1.5°C compatible power sector emissions for Sweden

4.9.4 Decarbonising the industry sector and policy implications

Sweden's industry sector is comparatively non-carbon intensive, with only small levels of fossil fuel consumption remaining (IEA, 2020). Coal and oil demand has been replaced mostly with biomass, which is likely to form a large part of future demand in a decarbonised industry sector. Remaining fossil fuel use should be mostly phased out between 2030 and 2035 to ensure Sweden's industry sector is aligned with a 1.5°C compatible trajectory downscaled from the PAC scenario.

Table 29: 1.5°C compatible 2030 industry sector final energy mix

	Electricity	Coal	Fossil gas	Renewable Hydrogen
2017	39%	6%	3%	0%
2030	**50%**	**3%**	**2%**	**6%**

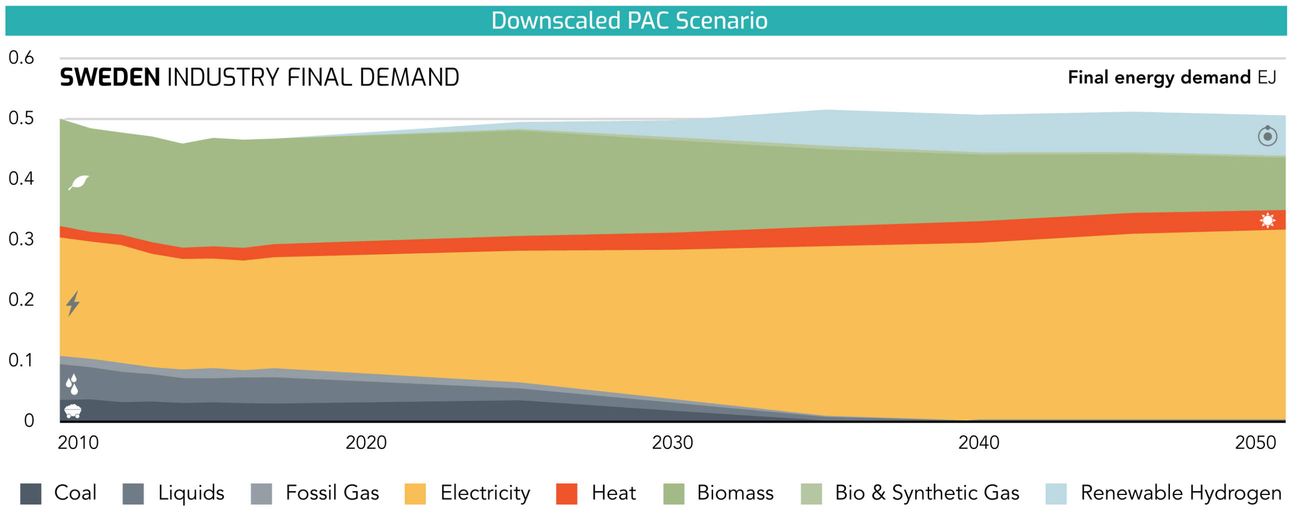


Figure 69: 1.5°C compatible share of technologies in the industry energy mix

Aligning Sweden's industry sector emissions over time with the downscaled 1.5°C compatible pathway will require a 49% reduction in total GHG emissions by 2030, and a 76% reduction by 2050. In addition, energy related emissions will need to be brought down to zero by 2040.

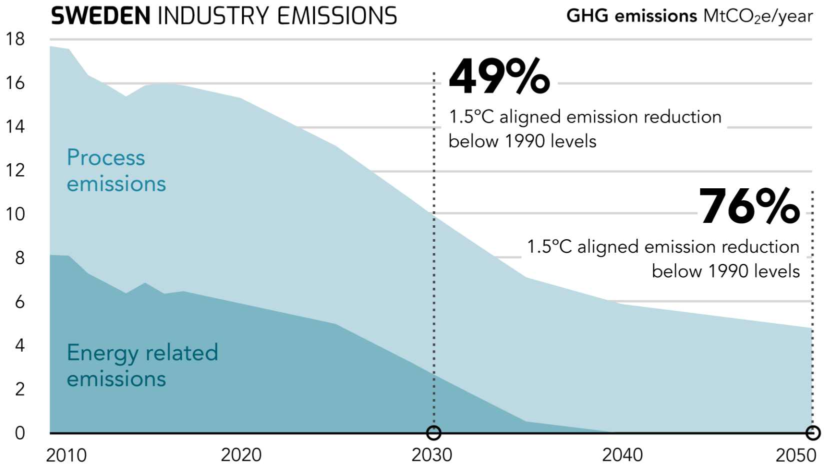


Figure 70: 1.5°C compatible industry sector emissions for Spain

4.9.5 Key characteristics of 1.5°C compatible pathways and other analyses

Table 30 provides a summary of key derived 1.5°C compatible economy-wide and sectoral benchmarks for Sweden in 2030 and 2050, compared against recent historical values.

Table 30: Key characteristics of Sweden's 1.5°C compatible pathways

	Historical	1.5°C compatible benchmarks		Country targets	
	2017	**2030**	**2050**	**2030**	**2050** incl. LULUCF*
Total GHG excl. LULUCF	55 $MtCO_2e/yr$	16–20 $MtCO_2e$ /yr	-5–7 $MtCO_2e$ /yr	N/A	0 $MtCO_2e$ /yr
	23% below 1990	72–78 % below 1990	92–117 % below 1990	N/A	100% below 1990
Emissions intensity of power generation**	7 gCO_2/kWh	0 gCO_2/kWh	0 gCO_2/kWh		
Share of renewable power	58 %	90–95 %	100 %		100 % (2040)
Share of unabated fossil fuel in power	1 %	0 %	0 %		
Share of nuclear power	40 %	5-10 %	0 %		
Industry electrification rate	39 %	50 %	71 %		

* 2050 target is shown including LULUCF emissions due to the absence of government projections for these emissions to 2050
** Does not include upstream emissions

An analysis by Naturskyddsföreningen (2019) also finds that a 2030 phase-out of fossil fuels and a 100% share of renewable power generation by 2040 is possible in Sweden, bolstering the case for the government's own 2040 target. In addition, the report finds that a 37% reduction in total primary energy demand is possible by 2040.

5 Conclusion

The European Union and its 27 Member states currently find themselves in a defining moment in the global effort to prevent the most dire predicted consequences of global warming and associated climate change. Debate is ongoing over the EU's 'Fit for 55' package of regulation amendments and updates, that has the stated aim of achieving a net 55% reduction in EU27 GHG emissions below 1990 levels by 2030 (53% excl. LULUCF). This report seeks to demonstrate that such a target is not aligned with the Paris Agreement's 1.5°C long-term temperature goal, and is far from what could be considered the highest plausible level of ambition for Europe.

To align with the derived 1.5°C compatible pathways in this project, the EU27 must change course and strengthen its 2030 target and the proposed policies to achieve it. A 2030 GHG emissions reduction target of between 61-74% below 1990 levels (excl. LULUCF) would embody this highest plausible ambition according to the two scenarios chosen for assessment in this report.

The 1.5°C goal is still alive, but only if countries commit to steep emissions reductions during this critical decade until 2030 and bring global emissions to net zero by mid-century. While the EU27 and many Member States have committed to a net zero target by 2050 or earlier, targets and policies to 2030 across the EU fall short of the level of effort required.

The two scenarios chosen for assessment in this report not only outline very deep emission reductions to 2030 for the Europe region, which we have taken to represent the EU27's highest plausible ambition, but reflect two distinct methodological approaches to deriving 1.5°C compatible energy and emissions pathways. These methodological differences also result in considerable qualitative variation between the two scenarios, with a key difference being the very high levels of energy efficiency gains and reduction in total energy use assumed by the PAC scenario.

Such steep energy efficiency gains and reduction in energy use help to facilitate an EU-wide phasing out of fossil fuel combustion by 2040 and a 2045 nuclear phase-out, while CCS technology is deemed to be unnecessary. Conversely, the higher total EU energy demand in the chosen REMIND scenario does entail the use of CCS and nuclear energy beyond 2050. Achieving high levels of energy efficiency across all sectors of the economy may lessen or eliminate the need to rely on such commercially unproven technologies like CCS and therefore reduce overall system risk if these technologies do not ultimately prove to be broadly viable in the future.

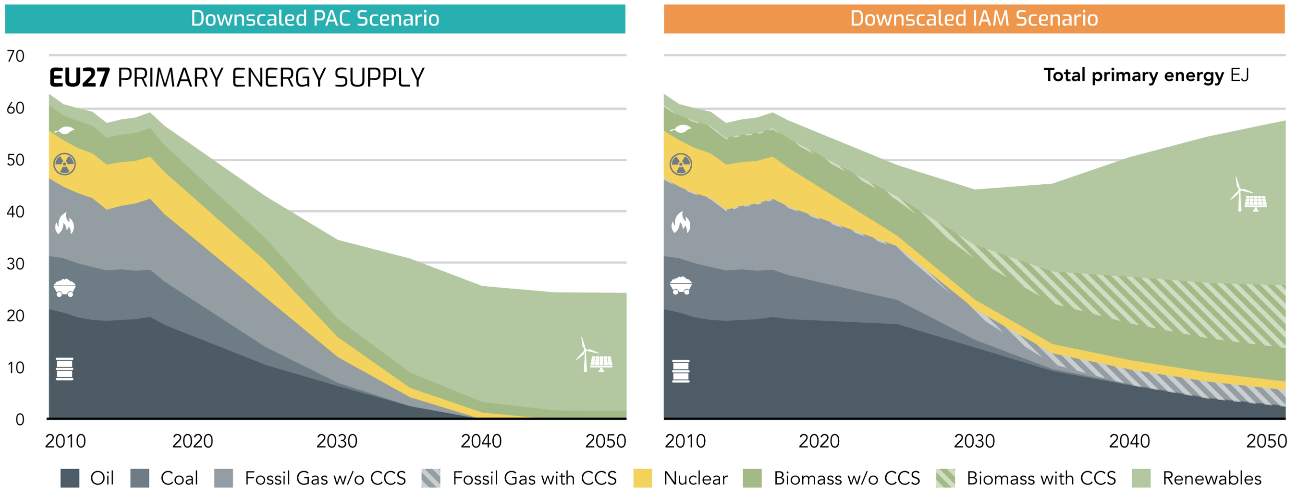


Figure 71: 1.5°C compatible primary energy supply pathways by fuel

Of the nine EU Member States assessed in this report, only Denmark's 2030 domestic emissions reduction target is determined to fall within the derived 1.5°C compatible range, but its policies remain insufficient to achieve it. All eight other Member States assessed have both insufficient domestic 2030 targets, and policies to achieve them. Ratcheting up these targets and adopting much stronger policies targeting emissions in all sectors of the economy should be a top priority and would demonstrate to the EU that it could, and should, aim higher with its own targets and policies still under consideration.

In addition to setting stronger emission reduction targets and adopting more stringent policies to achieve them, wealthy countries like most in the EU have 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 climate mitigation burden required to limit warming to 1.5°C will be distributed unfairly and will be unlikely to be met in time.

The EU27 faces a historic choice; aim for the highest plausible climate ambition that keeps the Paris Agreement's 1.5°C long-term temperature goal alive, or keep the current insufficient 2030 target and proposed policies in place and relinquish its role as a global leader on climate action. The critical decade for climate action is upon us, strong global leadership from the European Union has perhaps never been so sorely needed.

Annex: Downscaling methodology description

The Simplified Integrated Assessment Model with Energy System Emulator (SIAMESE) is a reduced complexity IAM, which provides cost-effective energy mix and emissions pathways at the country, or state level, taking into account the complex interaction between economic growth, energy consumption and climate change. For example, higher economic growth entails higher energy consumption leading to higher emissions (also depending on low carbon technology developments, costs and climate change targets).

While downscaling results from a given model (e.g. REMIND, IMAGE, AIM etc.), SIAMESE takes into account a coherent set of assumptions in line with a Shared Socioeconomic Pathway (SSP) associated with the scenario being assessed (Fricko, Havlik, Rogelj, Klimont, & Gusti, 2017; Riahi et al., 2017). At the same time, SIAMESE has a cost optimisation perspective when allocating how much a country or a region would need to contribute to global emissions reductions in line with the Paris Agreement long term temperature goal.

The SIAMESE approach can be applied to the overall economy (e.g. scaling down the overall primary energy consumption and emissions), or adapted to individual sectors. For this project, both primary energy demand and the power and industry sectors' energy demand are downscaled. SIAMESE takes as its input the original IAM or energy scenario pathways (e.g. REMIND Europe region and PAC EU28) and the observed energy consumption of a specific country.

Based on the SIAMESE simulation we calculate the Paris compatible energy projection for the EU27 and nine Member States. In terms of the equations underpinning the model, SIAMESE mimics the structure of IAMs, where the economic output (GDP) is a function of capital, labour and energy consumption by using a CES (Constant Elasticity of Substitution) production function.

The data underlying 1.5°C compatible pathways such as the REMIND 1.7 CEMICS-1.5-CDR8 scenario specifies how future energy consumptions and emissions should be composed in different regions of the world. Typically, this data is only available for regional aggregates called *macro regions*. For the REMIND integrated assessment model and the PAC scenario, the Europe region comprises the EU27+UK. This means that to derive EU27 results, the UK energy mix projection must be downscaled from the macro region and then subsequently removed. National level results are downscaled from the original EU27+UK macro region.

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

1. **Defining the macro region(s)** in which the country of interest is located.
2. **Countries' historical emissions and energy consumption** are determined for all countries in the macro region(s).
3. **Future emissions and energy consumption** are obtained from the scenario data underlying the to-be-downscaled 1.5°C compatible pathway.
4. **The macro region's scenario data is adapted to match the country's historical data** in a 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 its countries.** It is distributed to the countries in an internally consistent way, which preserves total values and matches the historical value of each country.

i Illustrative Pathways

i.1.1 Energy - CO_2 emissions

Energy consumption in the energy sector in general and the power sector specifically are downscaled with the Simplified Integrated Assessment Model with Energy System Emulator (SIAMESE) method as described in Sferra et al. (2019). Through this method, energy emissions pathways are derived directly from the downscaled energy consumption at national levels brought back to emissions by applying emissions factors, providing national emissions pathways directly consistent from the related energy system (Sferra et al., 2018).

The method is wrapped in the general downscaling process as follows:

Downscaling energy consumptions:

- **Historical primary and secondary energy consumptions** are obtained from the International Energy Agency (IEA) World Energy Balances (WEB) (IEA, 2020).

Consumption by fuel	Determination method
Non-biomass renewable	The sum over the consumption of wind, solar, geothermal and hydro energy.
Biomass	The difference between renewable energy consumption and the aforementioned non-bio renewable energy consumption.
Coal	The sum over peat and coal.
Oil	The sum over oil, oil products and natural gas liquids.
Gas and Nuclear	Directly obtained from the database.

It has to be noted that in the IEA database, secondary energy consumptions are assigned to both electricity and heat generation. For downscaling purposes, the assumption is made that a majority of the consumption is dedicated to the power sector, with heat generation being a by-product of centralised electricity generation.

- **The consumption projections for the Europe macro region** are obtained from the REMIND integrated assessment model.
- During the **harmonisation process**, the historical energy consumptions in the macro region(s) are set equal to the determined historical energy consumptions in the subregions. The energy consumption projections are not altered.
- The **energy consumptions are downscaled from Macro-Region(s)** to countries by applying the method SIAMESE described by Sferra et al. (2019). Conceptually, the model allocates energy consumption to the country level by maximising welfare in all countries belonging to the same macro-region under a common set of assumptions (e.g. technological availability, expected GDP and population growths at the country level, common SSP storylines).
- To **reduce the computational load of the method,** the countries are aggregated into two regions before the downscaling. The first region holds the country of interest and the second region holds all other countries.

Once the consumptions are downscaled, the emissions can be determined:

- Historical emissions are obtained from the PRIMAP dataset for economy-wide GHG emissions excluding LULUCF, and from an IEA dataset for the power and industry sector energy demand, again with the caveat of including combustion related CO_2 emissions from both electricity and heat.
- Emissions intensities are derived from the macro-region(s) model's emissions datasets and their respective energy consumptions. A calibration is run to match national emission projections to the downscaled energy consumptions
- For the power and industry sectors, emissions are obtained by applying respective emissions intensities to the downscaled energy consumptions.

It has to be noted that for the emissions in the energy sector, this process is done with the full primary energy consumption set due to data availability rather than more accurately only with the primary energy consumptions specifically allocated to the energy sector.

i.1.2 Agriculture sector

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

i.1.3 Industrial processes, waste and energy non-CO_2 emissions

The macro region emissions for industrial processes, waste and non-CO_2 emissions in the energy sector are taken from variables in the REMIND scenario data and harmonised to historical data in a base year, as described in the previous section. To perform the downscaling from macro regions to the subregions a methodology based on *intensity convergence* is used; more specifically the Impact, Population, Affluence, and Technology (IPAT) method that was developed by Van Vuuren et al. (2007) and extended by Gidden et al. (2019).

It 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, in the year 2100. This is made possible by an exponential interpolation of emission intensities from the base-year to the convergence year. Together with the yearly GDP by the given scenario, this interpolation defines how the emissions of the macro region are shared amongst the countries.

The downscaled industrial process emissions pathways for each subregion from the REMIND 1.7 CEMICS-1.5-CDR8 scenario are used to create total industry sector GHG emissions pathways for the downscaled PAC scenario results. This is achieved by adding these pathways to the downscaled energy related CO_2 emissions pathways derived from the PAC scenario.

For determining the 1.5°C compatible economy-wide GHG emissions range (excl. LULUCF) introduced in section 3.2, the IPAT emissions intensity convergence method is also used to downscale the energy CO_2 emissions of the PAC and REMIND scenarios. In the REMIND scenario, these emissions become negative long before 2100. To account for the shift from positive to negative emissions in the downscaling routine, the exponential model is pulled into negative emission intensity space with an affine transform.

i.1.4 Global Warming Potentials

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

Bibliography

Agora Energiewende. (2020). *Towards a Climate-Neutral Germany*. https://www.agora-energiewende.de/en/publications/towards-a-climate-neutral-germany-executive-summary/

Agora Energiewende. (2021). *Deutschland steht 2021 vor dem höchsten Anstieg der Treibhausgasemissionen seit 1990*. https://www.agora-energiewende.de/presse/neuigkeiten-archiv/deutschland-steht-2021-vor-dem-hoechsten-anstieg-der-treibhausgasemissionen-seit-1990/

Appunn, K., Eriksen, F., & Wettengel, J. (2021). *Germany's greenhouse gas emissions and energy transition targets*. Clean Energy Wire. https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets

Bodle, R., & Sina, S. (2021). *The German Federal Constitutional Court's decision on the Climate Change Act*. https://www.ecologic.eu/sites/default/files/publication/2021/bodle-21-Ecologic-Institut-policy-brief-constitutional-court-climate-change-act.pdf

Boston Consulting Group. (2018). *Klimapfade für Deutschland*. https://image-src.bcg.com/Images/Klimapfade-fuer-Deutschland_tcm108-181356.pdf

Build Up. (2019). *The CTI 2050 Roadmap Tool*. buildup.eu/en/learn/tools/cti-2050-roadmap-tool

Bundesministerium für Bildung and Forschung. (2020). *Transformation des Energiesystems bis zum Jahr 2030*. https://www.oeko.de/publikationen/p-details/transformation-des-energiesystems-bis-zum-jahr-2030

Climate Action Tracker. (2018). *Fair Share, Climate Action Tracker*. Climate Analytics. https://climateactiontracker.org/countries/australia/fair-share/

Climate Action Tracker. (2020). *Paris Agreement turning point: Wave of net zero targets reduces warming estimate to 2.1˚C in 2100, all eyes on 2030 targets* (Issue December 2020).

Climate Analytics. (2019). *Global and regional coal phase-out requirements of the Paris Agreement: Insights from the IPCC Special Report on 1.5°C*. https://climateanalytics.org/media/report_coal_phase_out_2019.pdf

Climate Analytics. (2021). *1.5°C National Pathway Explorer*. 1.5°C National Pathway Explorer. http://1p5ndc-pathways.climateanalytics.org/

Climate Transparency. (2020). *France - Climate Transparency Report*. https://www.climate-transparency.org/wp-content/uploads/2020/11/France-CT-2020-WEB.pdf

Ecologistas en acción. (2015). *Hacia un escenario energético justo y sostenible en 2050*. https://www.ecologistasenaccion.org/31234/hacia-un-escenario-energetico-justo-y-sostenible-en-2050-2/

Economia e Sostenibilità. (2020). *Il Green Deal conviene - Benefici per economia e lavoro in Italia al 2030*.

EEA. (2021). *EEA greenhouse gas data viewer*. European Environmental Agency Data Viewer. https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

Elemens. (2016). *Decarbonisation Roadmap by 2030 and beyond*. https://www.legambiente.it/wp-content/uploads/2020/10/la-decarbonizzazione-in-italia_dossier2020.pdf

Eriksen, F. (2019). *Germany sets goal of cutting primary energy use by 30 percent by 2030*. Clean Energy Wire. https://www.cleanenergywire.org/news/germany-sets-goal-cutting-primary-energy-use-30-percent-2030

European Commission. (2020). *Impact Assessment; Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people*. https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en

European Commission. (2021a). *EU Reference Scenario 2020*. https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2020_en

European Commission. (2021b). *European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions*. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541

European Commission. (2021c). *Modernisation Fund*. https://ec.europa.eu/clima/policies/budget/modernisation-fund_en

Forum Energii. (2017). *Polish Energy Sector 2050 - Four Scenarios*. https://forum-energii.eu/en/analizy/polska-energetyka-2050-4-scenariusze

Fraunhofer ISE. (2020). *Paths to a Climate-Neutral Energy System*. https://www.ise.fraunhofer.de/en/publications/studies/paths-to-a-climate-neutral-energy-system.html

Fraunhofer ISI, & Öko-Institut. (2019). *GHG-neutral EU2050: scenario of a European Union with net-zero greenhouse gas emissions Technical Annex*. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-26_cc_40-2019_ghg_neutral_eu2050-technical-annex.pdf

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., Luderer, G., Nemet, G. F., Rogelj, J., Smith, P., Vicente, J. V., Wilcox, J., del Mar Zamora Dominguez, M., & Minx, J. C. (2018). Negative emissions - Part 2: Costs, potentials and side effects. *Environmental Research Letters*, *13*(6). https://doi.org/10.1088/1748-9326/aabf9f

German federal bureau of environment (Umweltbundesamt). (2021). *National Inventory Report - Germany*.

Gesley, J. (2020). *Germany : Law on phasing-out coal*. https://www.loc.gov/item/global-legal-monitor/2020-08-31/germany-law-on-phasing-out-coal-powered-energy-by-2038-enters-into-force/

Gidden, M., Riahi, K., Smith, S. J., Fujimori, S., Luderer, G., Kriegler, E., van Vuuren, D. P., van den Berg, M., Feng, L., Klein, D., Calvin, K., Doelman, J. C., Frank, S., Fricko, O., Harmsen, M., Hasegawa, T., Havlik, P., Hilaire, J., Hoesly, R., … Takahashi, K. (2019). Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development*, *12*, 1443–1475.

Government of Denmark. (2019). *Denmark's Fourth Biennial Report*. https://unfccc.int/sites/default/files/resource/Denmarks-BR4-under-the UNFCCC_20December2019.pdf

Government of Denmark. (2020). *National Energy and Climate Plan*. https://ec.europa.eu/energy/sites/default/files/documents/dk_final_necp_main_en.pdf

Government of Denmark. (2021a). *Denmark - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/273486

Government of Denmark. (2021b). *National Inventory Report - Denmark*. https://unfccc.int/documents/273129

Government of France. (2020a). *France's Fourth Biennial Report* (Issue January). https://unfccc.int/sites/default/files/resource/BR-EN-resubmission.pdf

Government of France. (2020b). *National Climate and Energy Plan*. https://ec.europa.eu/energy/sites/default/files/documents/fr_final_necp_main_en.pdf

Government of France. (2021a). *France - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/273487

Government of France. (2021b). *France 2021 GHG Inventory*. https://unfccc.int/documents/273487

Government of Germany. (2019). *National Energy and Climate Plan - Germany*.

Government of Germany. (2021). *Germany - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/271972

Government of Italy. (2019a). *Italy Fourth Biennial Report* (Issue December).

Government of Italy. (2019b). *National Energy and Climate Plan - Italy*. https://ec.europa.eu/energy/sites/default/files/documents/es_final_necp_main_en.pdf

Government of Italy. (2021). *Italy - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/271490

Government of Poland. (2019). *National Energy and Climate Plan - Poland*. https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#documents

Government of Poland. (2021a). *Energy Policy of Poland Until 2040*. https://www.gov.pl/attachment/62a054de-0a3d-444d-a969-90a89502df94

Government of Poland. (2021b). *National Inventory Report - Poland*. https://unfccc.int/documents/274762

Government of Poland. (2021c). *Poland - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/274751

Government of Portugal. (2019a). *National Energy and Climate Plan - Portugal*. https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#documents

Government of Portugal. (2019b). *Roadmap for Carbon Neutrality 2050 (RNC2050) Long-Term Strategy for Carbon Neutrality of the Portuguese Economy by 2050*. https://unfccc.int/sites/default/files/resource/RNC2050_EN_PT Long Term Strategy.pdf

Government of Portugal. (2021a). *National Inventory Report - Portugal*. https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#documents

Government of Portugal. (2021b). *Portugal - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/271506

Government of Romania. (2021a). *National Inventory Report - Romania*. https://unfccc.int/documents/274077

Government of Romania. (2021b). *Romania - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/275942

Government of Spain. (2020a). *Estrategia de Descarbonizacion a Largo Plazo 2050*. https://unfccc.int/sites/default/files/resource/LTS1_Spain_0.pdf

Government of Spain. (2020b). *Integrated national energy and climate plan 2021-2030* (Issue January 2020). https://ec.europa.eu/energy/sites/ener/files/documents/es_final_necp_main_en.pdf

Government of Spain. (2021a). *National Inventory Report - Spain*. https://unfccc.int/documents/274037

Government of Spain. (2021b). *Recovery and resilience plan for Spain*. https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility/recovery-and-resilience-plan-spain_en

Government of Spain. (2021c). *Spain - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/270987

Government of Sweden. (2020). *National Energy and Climate Plan - Sweden*. https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#documents

Government of Sweden. (2021a). *National Inventory Report - Sweden*. https://unfccc.int/documents/271847

Government of Sweden. (2021b). *Sweden - Common Reporting Format (CRF) Table*. https://unfccc.int/documents/271826

Greenpeace. (2020). *Poland could phase out coal by 2035 under business as usual*. https://www.greenpeace.org/static/planet4-poland-stateless/2020/08/d1d7c177-gp-pl-poland-could-phase-out-coal-by-2035-as-business-as-usual.speeding-up-needed.pdf

IEA. (2020). *World Energy Balances 2020*. https://www.iea.org/data-and-statistics/data-product/world-energy-balances

Luderer, G., Leimbach, M., Bauer, N., Kriegler, E., Baumstark, L., Bertram, C., Giannousakis, A., Hilaire, J., Klein, D., Levesque, A., Mouratiadou, I., Pehl, M., Pietzcker, R., Piontek, F., Roming, N., Schultes, A., Schwanitz, V. J., & Strefler, J. (2015). *Description of the Remind Model (Version 1.6)* (Issue November). http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2697070

Naturskyddsföreningen. (2019). *Fossilfritt, förnybart, flexibelt*. https://old.naturskyddsforeningen.se/sites/default/files/dokument-media/fossilfrittfornybartflexibelt_slutkorrad_rgb.pdf

Neagu, B., & Taylor, K. (2021). *Romania commits to phase out coal by 2032*. Euractiv. https://www.euractiv.com/section/energy/news/romania-will-phase-out-coal-by-2032/

négaWatt. (2017). *Scénario négaWatt 2017-2050*.

Olesen, G. B. (2010). *Energy Vision 2030 for Denmark*. https://www.inforse.org/europe/pdfs/EnergyVision2030-UK.pdf

PAC Consortium. (2020). *Paris Agreement Compatible Scenarios for Energy Infrastructure*. https://www.pac-scenarios.eu/

PIK. (2020). *EUCalc Transition Pathways Explorer*. Potsdam Institute of Climate Impact Research. https://www.european-calculator.eu/transition-pathways-explorer/

Potsdam Institute of Climate Impact Research. (2016). *REMIND*. https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/models/remind

REKK Foundation. (2019). *The Southeast European power system in 2030*. agora-energiewende.de/en/publications/the-southeast-european-power-system-in-2030/

Reuters. (2021a). *Italy says it plans to cut carbon emissions by 60% by 2030*. https://www.reuters.com/article/us-italy-climate-minister-idUSKBN2B31ML

Reuters. (2021b). *Italy to produce 70-72% of power from renewables in 2030*. http://cms.trust.org/item/20210428043025-6klwg

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Seferian, R., & Vilarino, M. V. (2018). Mitigation Pathways Compatible With 1.5°C in the Context of Sustainable Development. In *Global warming of 1.5°C. An IPCC Special Report [...]* (p. 82pp). IPCC.

Sferra, F., Krapp, M., Roming, N., Schaeffer, M., Malik, A., Hare, B., & Brecha, R. (2019). Towards optimal 1.5° and 2 °C emission pathways for individual countries: A Finland case study. *Energy Policy*, *133*.

Sferra, F., Schaeffer, M., & Torres, M. (2018). *Report on Implications of 1.5°C Versus 2°C for Global Transformation Pathways*.

UK Government. (2021). *End to coal power brought forward to October 2024*. https://www.gov.uk/government/news/end-to-coal-power-brought-forward-to-october-2024

Umwelt Bundesamt. (2020). *Abschätzung der Treibhausgasminderungswirkung des Klimaschutzprogramms 2030 der Bundesregierung*. https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-03-19_cc_33-2020_klimaschutzprogramm_2030_der_bundesregierung.pdf

UNFCCC. (2021a). *Key aspects of the Paris Agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement

UNFCCC. (2021b). *Nationally determined contributions under the Paris Agreement*. https://unfccc.int/sites/default/files/resource/cma2021_08_adv_1.pdf

University of Technology Sydney. (2020). *100% RENEWABLE ENERGY: An Energy [R]evolution for ITALY 2020*. https://www.uts.edu.au/research-and-teaching/our-research/institute-sustainable-futures/our-research/energy-futures/100-percent-renewable-energy-italy

van Vuuren, D. P., Lucas, P. L., & Hilderink, H. (2007). Downscaling drivers of global environmental change: Enabling use of global SRES scenarios at the national and grid levels. *Global Environmental Change*, *17*(1), 114–130.

Welle, T., Leinen, L., Bohr, Y., & Vorländer, A. K. (2020). *Waldvision Für Die Europäische Union*. https://naturwald-akademie.org/wp-content/uploads/2020/11/Waldvision-fuer-die-Europaeische-Union.pdf

World Wildlife Fund (WWF). (2020). *Reaching Climate Neutrality in Poland by 2050*. https://wwfeu.awsassets.panda.org/downloads/poland_and_climate_neutrality_en_executive_summary_october_2020.pdf

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. Our mission is to synthesise and advance scientific knowledge in the area of climate change.

climateanalytics.org

Acknowledgements

We would like to acknowledge the Swedish Postcode Foundation for providing funding for this project.

Climate Action Network (CAN) Europe and AirClim provided ongoing and invaluable coordination support but do not necessarily endorse all findings from this project.

View all the factsheets in this series

Denmark	France	Germany	Italy	Poland	Portugal	Romania	Spain	Sweden