

Transitioning away from fossil fuels to limit overshoot of 1.5°C

Policy brief submitted by the *Potsdam Institute for Climate Impact Research (PIK)* to inform the *COP30 Presidency Roadmap for Transitioning Away from Fossil Fuels in a Just, Orderly and Equitable Manner*.

Authors: Fabrice Lécuyer, Felix Schreyer, Alex K. Hagen, Robert Pietzcker, Leonie Schweiger, Elmar Kriegler, Johan Rockström, Gunnar Luderer.

Transitioning away from fossil fuels is a crucial step in limiting climate change and delivering the 1.5°C target, as recognised in the UNFCCC’s UAE consensus at COP28. However, the scale and speed of this transition remain uncertain: in the latest IPCC assessment (AR6), many Paris-aligned pathways still allowed for continued fossil fuel use, relying on large-scale carbon dioxide removal (CDR) to offset emissions. The role of fossil fuels thus needs to be reassessed in the light of recent emission trends and technological developments.

We aim to contribute to this discussion with new model-based analysis of Paris-aligned pathways that explore different options for transitioning away from fossil fuels. Our scenarios reach net-zero global CO₂ emissions by 2060 with a peak warming around 1.7°C and declining warming towards 1.5°C thereafter. The **Phase-out scenario** completely phases out fossil fuels by 2060, while a limited share remains in the **Least-cost scenario** (Figure 1). The results show that reaching global climate targets requires a rapid and deep decline in fossil fuel use, regardless of the scenario. This is achieved through electrification based on renewable energy and the development of alternative fuels. We also examine how demand-side measures can alleviate the cost of the transition.

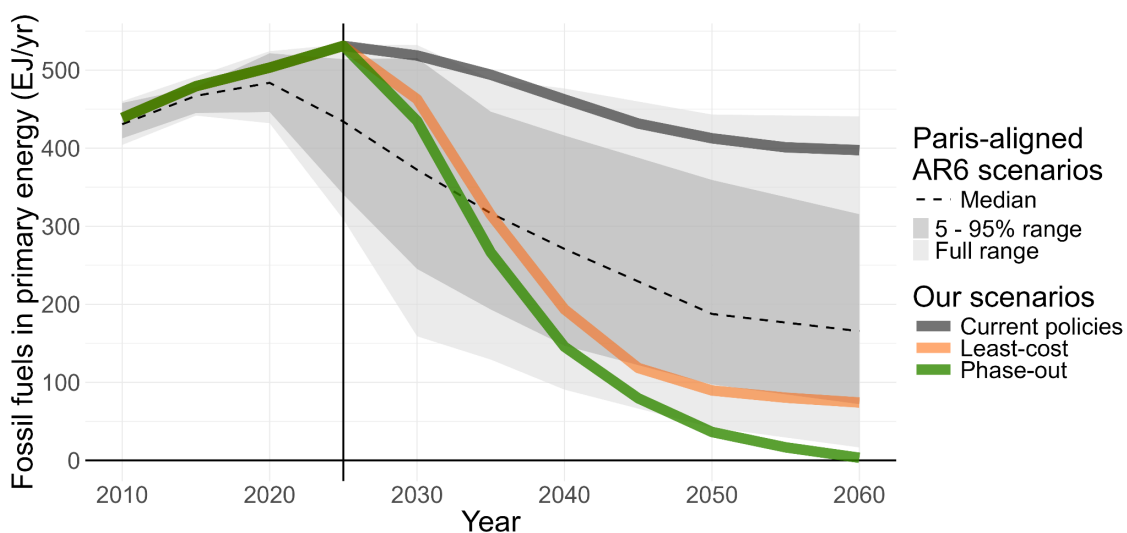


Figure 1: fossil primary energy in new scenarios compared to Paris-aligned scenarios of the AR6.

The bold lines show our scenarios Least-cost and Phase-out, with values before 2025 matching historical data. IPCC AR6 scenarios have been published in 2015-2020. As historical developments until 2025 have been higher than 95% of the Paris-aligned pathways of categories C1 and C2, pursuing 1.5°C now necessitates a steeper and deeper transition away from fossil fuels.

#1. Paris alignment implies near-complete transition away from fossil fuels

Returning warming to 1.5°C requires an immediate reduction of CO₂ emissions, of which fossil fuels are the main cause. Global warming is already approaching 1.5°C, and 88% of carbon dioxide emissions in 2025 are due to fossil fuel combustion. Our updated Paris-aligned scenarios reach net-zero global CO₂ emissions by 2060 with a peak warming around 1.7°C and declining warming towards 1.5°C thereafter. They indicate that global fossil fuel consumption falls by at least 86% between 2025 and 2060. This is a much steeper transition than assessed in the previous IPCC report, as the remaining carbon budget has narrowed in the face of ever increasing emissions (see Figure 1).

The decline of coal, natural gas and oil happens over different timelines. All fossil fuels face a steep decline in our Paris-aligned scenarios, but the timeline depends on their contribution to emissions and the available substitutes (Figure 2). The 2025 production of coal, gas and oil reduces by two thirds by 2035, 2040 and 2050 respectively. In all the scenarios, coal is fully phased out from the energy system by 2045, enabling the deep emission reductions required to limit overshoot. In our Least-cost scenario and its variations, gas and oil respectively shrink to 7–9% and 24–28% of their current production by 2060 (and by design to 0% in scenario Phase-out and its variations).

Residual fossil fuel can only remain if carbon removal technologies develop reliably. The Least-cost scenario and its variations retain limited fossil fuel use in 2060 (60–75 EJ per year), part of which is abated with carbon capture and storage (CCS) while the bulk is compensated with carbon dioxide removal (CDR). A complete transition away from fossil fuels reduces the reliance on CCS and CDR, but does not eliminate the need for net-negative CO₂ emissions to return to below 1.5°C after overshoot. Phase-out scenarios are less reliant on CCS and CDR than Least-cost scenarios, but they face the additional challenge of scaling up e-fuels to cover residual hydrocarbon use, see section #3.

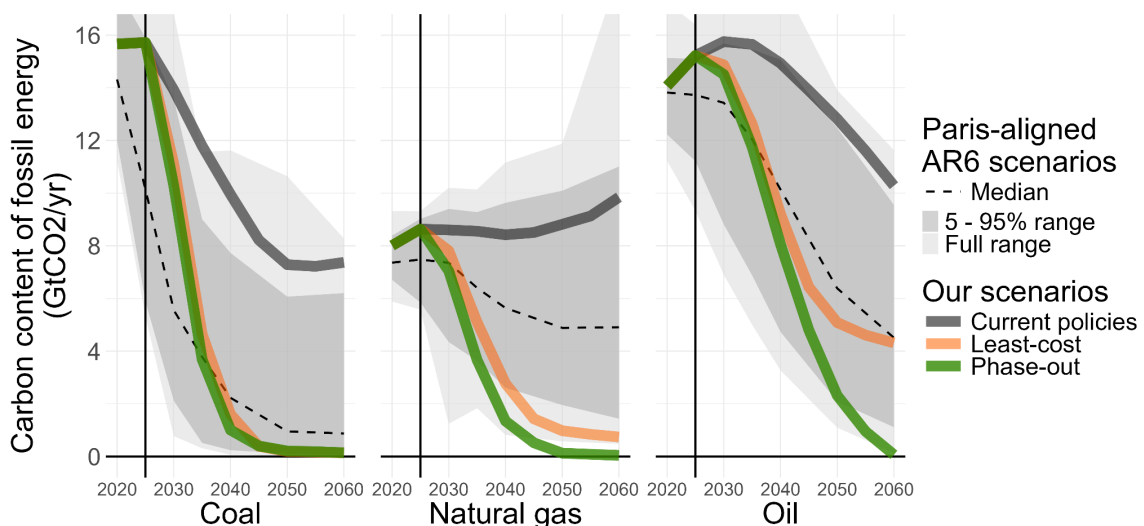


Figure 2: evolution of consumption of the different types of fossil fuels in terms of carbon content. Coal is phased-out faster than other fossil fuels in most Paris-aligned scenarios, and as early as 2045 in our Least-cost and Phase-out scenarios. This is due to its high carbon content: for the same energy content, coal emits around 70% more CO₂ than gas and 30% more than oil. The carbon content corresponds to the amount of CO₂ that the combustion of this fuel would emit.

Key numbers	Coal	Gas	Oil
Evolution from 2025 to 2040	-90 to -94%	-67 to -84%	-39 to -47%

#2. Established technologies can replace the bulk of fossil fuels

Wind and solar power are the central pillars of the power sector transition. Fossil fuels currently account for around 55% of global electricity production. Coal power alone contributes approximately 14 Gt of the total 53 Gt annual greenhouse gas emissions. A deep decarbonisation of the power sector is yet feasible over the coming decade as scalable wind, solar and battery technologies become increasingly competitive. All of our Paris-aligned scenarios show a swift decline in fossil-based electricity to negligible levels by 2040, at which point solar and wind provide 78–82% of the electricity (Figure 3). The Global Stocktake’s call to triple renewable capacity between 2023 and 2030 aligns well with these pathways, in which capacity keeps increasing thereafter: wind and solar capacity is 7–8 times higher in 2040 than in 2025, corresponding to 6–8 TW of wind and 20–23 TW of solar power.

Electrification of end-use sectors enables large-scale substitution of fossil fuels. Currently, electricity only accounts for around 21% of final energy demand, with the remainder being predominantly hydrocarbons supplied from fossil fuels. Our pathways achieve a deep reduction of demand-side fossil fuel use by increasing the share of electricity in final energy to more than 60% by 2050. This shift reflects major transitions happening in key sectors by 2050. In the buildings sector, the electricity share doubles from 40% to 80%, notably with the replacement of fossil heating by electric heat pumps. Today almost exclusively reliant on oil, road transport is almost fully electrified by 2050, with battery-electric vehicles accounting for 89–92% of passenger vehicles and trucks. In the industry, more electricity is used for low and medium temperatures and steel recycling, bringing the electricity share from 20% to 55–62%. Indirect electrification also plays a role, with hydrogen covering 4–5% of final energy demand as a substitute for hydrocarbons in industries like steel or as a storage and flexibility option for the power system.

Energy efficiency improves throughout the energy system. Electric technologies significantly reduce energy demand compared to fossil alternatives: electric drivetrains are two to four times more efficient than combustion engines, and heat pumps can deliver three to four units of heat per unit of electricity. In addition to other efforts and investments for efficiency, this allows for a relative decoupling of GDP from final energy demand: the energy intensity of GDP halves between 2025 and 2050.

Key numbers	VRE capacity	Electric vehicles for road transport	Energy efficiency
Evolution from 2025 to 2050	x11 to x14	reaches 90%	x2

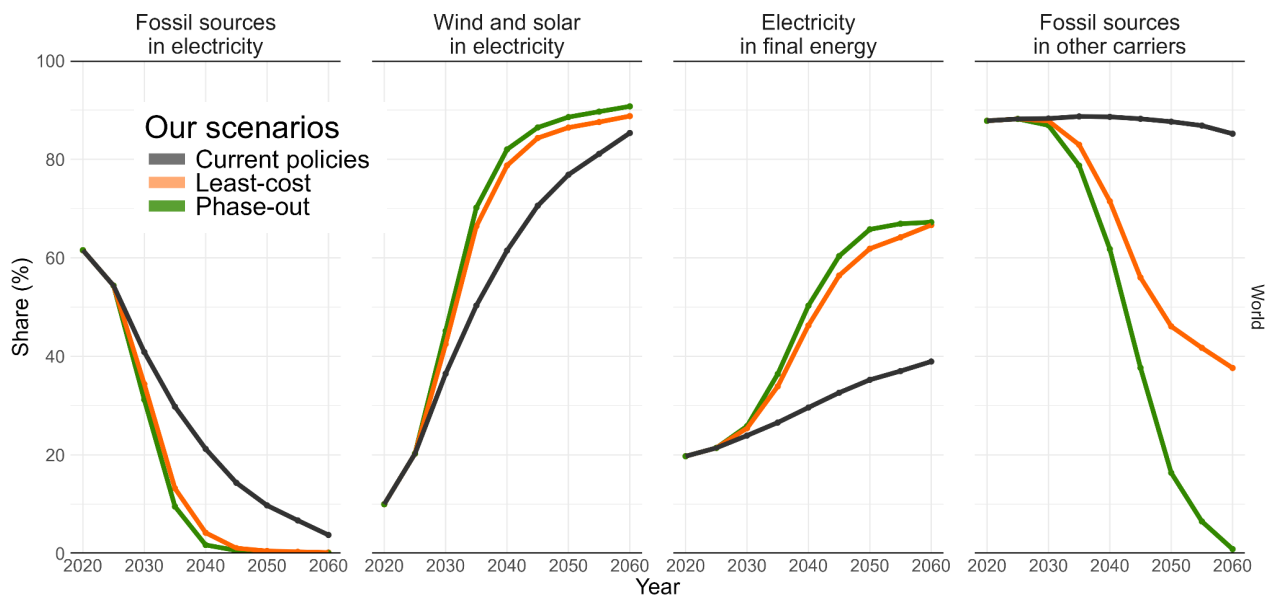


Figure 3: transformations of the energy system common to all of our Paris-aligned scenarios.

Fossil sources are coal, oil and natural gas. Electrification is defined as the ratio between electricity consumption and total final energy demand. Other carriers include solids, liquids, gases (like methane), hydrogen and heat.

#3. Remaining fossil dependence is concentrated in a small number of sectors

Residual demand for hydrocarbons in chemicals, aviation and shipping represent the core of the transition challenge. With the increased electrification of the energy system, total hydrocarbon final energy demand declines from around 360 EJ in 2025 to 93–116 EJ in 2060, almost 80% of which are liquid fuels. This remaining demand is concentrated in a few sectors where alternatives are limited: chemicals, aviation and shipping account for 76–80% of the residual demand. In the chemical sector, hydrocarbons are primarily used as feedstock for materials such as plastics. Aviation and shipping continue to rely on liquid fuels due to their high energy density.

Non-fossil hydrocarbons can substitute fossil fuels, but face scalability and cost challenges. Alternative options include biomass-based fuels and e-fuels produced from hydrogen and captured carbon. Biomass is constrained by land availability and sustainability considerations, while e-fuels require large amounts of electricity and remain costly and technologically immature at scale. The 2060 distribution of hydrocarbons between fossil, biomass and hydrogen sources depends on the scenario. The Least-cost scenario and its variations have 37–45% of bio-fuels and around 3% of e-fuels, leaving more than a half to fossil fuels. The Phase-out scenarios instead use 45–50% of bio-fuels and 48–53% of e-fuels, corresponding to a production of 45–56 EJ of e-fuels per year. This represents a major industrial transformation and necessitates rapid development of new infrastructure.

The high cost of a full fossil phase-out is limited to a small portion of the economy. Marginal abatement costs are up to 50% higher in the Phase-out scenario than in Least-cost scenario. However, these high marginal costs are confined to hard-to-abate sectors and have a limited impact on the overall cost of the energy transition: the cost differential between the Phase-out and Least-cost scenarios peaks at +13% in 2040, driven by the scale-up of e-fuel infrastructure, before decreasing and reaching parity by 2060.

Demand reduction in key sectors can substantially lower transition costs. As the burden of alternative hydrocarbons lies in a few bottleneck sectors, reducing demand in these sectors is a crucial opportunity to alleviate pressure on supply systems. In particular, our scenarios with reduced chemical demand, representing circular economy approaches, show a substantial decrease in overall system costs. Similar results are expected from measures targeting aviation and shipping demand. Policies promoting material efficiency and behavioural change in these sectors can significantly reduce costs and ease the transition by targeting the most expensive segments of the energy system.

Key numbers	Biomass-based hydrocarbons	Hydrogen-based hydrocarbons	Chemicals + aviation + shipping share of hydrocarbon demand
Share in 2060	37 to 50%	3 to 53%	76 to 80%

Work based on

Lécuyer, F., Schreyer, F., Luderer, G., and colleagues (2025)
Transitioning away from fossil fuels in a Paris-aligned scenario.

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New pathways for equitable climate action in line with the Paris Agreement and sustainable development - Project brief, November 2025. Zenodo.

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