

Net Zero Roadmap

A Global Pathway to
Keep the 1.5 °C Goal
in Reach

2023 Update – Executive summary

International
Energy Agency

INTERNATIONAL ENERGY AGENCY

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*In 2021, the IEA published its landmark report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Since then, the energy sector has seen major shifts. Based on the latest data on technologies, markets and policies, this report presents an updated version of the *Net Zero Emissions by 2050 (NZE) Scenario*; a pathway, but not the only one, for the energy sector to achieve net zero CO₂ emissions by 2050 and play its part, as the largest source of greenhouse gas emissions, in achieving the 1.5 °C goal.*

The path to 1.5 °C has narrowed, but clean energy growth is keeping it open

The case for transforming the global energy system in line with the 1.5 °C goal has never been stronger. August 2023 was the hottest on record by a large margin, and the hottest month ever after July 2023. The impacts of climate change are increasingly frequent and severe, and scientific warnings about the dangers of the current pathway have become stronger than ever.

Global carbon dioxide (CO₂) emissions from the energy sector reached a new record high of 37 billion tonnes (Gt) in 2022, 1% above their pre-pandemic level, but are set to peak this decade. The speed of the roll-out of key clean energy technologies means that the IEA now projects that demand for coal, oil and natural gas will all peak this decade even without any new climate policies. This is encouraging, but not nearly enough for the 1.5 °C goal.

Positive developments over the past two years include solar PV installations and electric car sales tracking in line with the milestones set out for them in our 2021 *Net Zero by 2050* report. In response to the pandemic and the global energy crisis triggered by Russia's invasion of Ukraine, governments around the world announced a raft of measures designed to promote the uptake of a range of clean energy technologies. Industry is ramping up quickly to supply many of them. If fully implemented, currently announced manufacturing capacity expansions for solar PV and batteries would be sufficient to meet demand by 2030 in this update of the NZE Scenario.

We have the tools needed to go much faster

Ramping up renewables, improving energy efficiency, cutting methane emissions and increasing electrification with technologies available today deliver more than 80% of the emissions reductions needed by 2030. The key actions required to bend the emissions curve sharply downwards by 2030 are well understood, most often cost effective and are taking place at an accelerating rate. The scaling up of clean energy is the main factor behind a decline of fossil fuel demand of over 25% this decade in the NZE Scenario. But well-designed policies, such as the early retirement or repurposing of coal-fired power plants, are key to facilitate declines in fossil fuel demand and create additional room for clean energy to expand. In the NZE Scenario, strong growth in clean energy and other policy measures together lead to energy sector CO₂ emissions falling by 35% by 2030 compared to 2022.

Renewables and efficiency are key to drive fossil fuel demand down

Tripling global installed renewables capacity to 11 000 gigawatts by 2030 provides the largest emissions reductions to 2030 in the NZE Scenario. Renewable electricity sources, in particular solar PV and wind, are widely available, well understood, and often rapidly deployable and cost effective. Current policy settings already put advanced economies and China on track to achieve 85% of their contribution to this global goal, but stronger policies and international support are required in other emerging market and developing economies. For all countries, speeding up permitting, extending and modernising electricity grids, addressing supply chain bottlenecks, and securely integrating variable renewables are critical.

Doubling the annual rate of energy intensity improvement by 2030 in the NZE Scenario saves the energy equivalent of all oil consumption in road transport today, reduces emissions, boosts energy security and improves affordability. Although the mix of priorities will differ by country, at the global level energy intensity improvements stem from three equally important actions: improving the technical efficiency of equipment such as electric motors and air conditioners; switching to more efficient fuels, in particular electricity, and clean cooking solutions in low-income countries; and using energy and materials more efficiently.

These two actions reduce fossil fuel demand, enabling continued adherence to a key milestone of our 2021 report: an immediate end to new approvals of unabated coal plants.

Accelerating electrification and cutting methane are also essential

Booming technologies like electric vehicles and heat pumps drive electrification across the energy system, providing nearly one-fifth of the emissions reductions to 2030 in the NZE Scenario. Recent growth puts electric car sales on track to account for two-thirds of new car sales by 2030 – a critical milestone in the NZE Scenario. Announced production targets from car makers underscore that this high share is achievable. Heat pump sales increased by 11% globally in 2022, and many markets, notably in the European Union, are already tracking ahead of the roughly 20% annual growth rate needed to 2030 in the NZE Scenario. China remains the world's largest market for heat pumps.

Cutting methane emissions from the energy sector by 75% by 2030 is one of the least cost opportunities to limit global warming in the near term. Strong reductions in both energy sector CO₂ and methane emissions are essential to meeting the 1.5 °C goal. Without efforts to reduce methane emissions from fossil fuel supply, global energy sector CO₂ emissions would need to reach net zero by around 2045, with important implications for equitable pathways. Reducing methane emissions from oil and natural gas operations by 75% costs around USD 75 billion in cumulative spending to 2030, equivalent to just 2% of the net income received by the oil and gas industry in 2022. Much of this would be accompanied by net cost savings through the sale of captured methane.

Innovation is already delivering new tools and lowering their cost

In the 2021 NZE Scenario, technologies not available on the market at the time delivered nearly half of the emissions reductions needed in 2050 to reach net zero; that number has fallen to around 35% in this update. Progress has been rapid: for example, the first commercialisation of sodium-ion batteries was announced for 2023, and commercial-scale demonstrations of solid oxide hydrogen electrolyzers are now underway.

But we still need to do much more, notably on infrastructure

Today much of the momentum is in small, modular clean energy technologies like solar PV and batteries, but these alone are not sufficient to deliver net zero emissions. It will also require: large new, smarter and repurposed infrastructure networks; large quantities of low-emissions fuels; technologies to capture CO₂ from smokestacks and the atmosphere; more nuclear power; and large land areas for renewables.

Electricity transmission and distribution grids need to expand by around 2 million kilometres each year to 2030 to meet the needs of the NZE Scenario. Building grids today can take more than a decade, with permitting a particularly time-consuming bottleneck. The same is true for other kinds of energy infrastructure. Policy makers, industry and civil society need to work together to nurture a “build big” mentality and to expedite decision making, while preserving public engagement and respecting environmental safeguards.

Carbon capture, utilisation and storage (CCUS), hydrogen and hydrogen-based fuels, and sustainable bioenergy are critical to achieve net zero emissions; rapid progress is needed by 2030. The history of CCUS has largely been one of underperformance. Although the recent surge of announced projects for CCUS and hydrogen is encouraging, the majority have yet to reach final investment decision and need further policy support to boost demand and facilitate new enabling infrastructure.

Increasing clean energy investment in developing countries is vital

The world is set to invest a record USD 1.8 trillion in clean energy in 2023: this needs to climb to around USD 4.5 trillion a year by the early 2030s to be in line with our pathway. Clean energy investment is paid back over time through lower fuel bills. By 2050, energy sector investment and fuel bills are lower than today as a share of global GDP. The sharpest jump in clean energy investment is needed in emerging market and developing economies other than China, where it surges sevenfold by the early 2030s in the NZE Scenario. This will require stronger domestic policies together with enhanced and more effective international support. Annual concessional funding for clean energy in emerging market and developing economies will need to reach around USD 80-100 billion by the early 2030s.

As clean energy expands and fossil fuel demand declines in the NZE Scenario, there is no need for investment in new coal, oil and natural gas

Stringent and effective policies in the NZE Scenario spur clean energy deployment and cut fossil fuel demand by more than 25% by 2030 and 80% in 2050. Coal demand falls from around 5 800 million tonnes of coal equivalent (Mtce) in 2022 to 3 250 Mtce by 2030 and around 500 Mtce by 2050. Oil declines from around 100 million barrels per day (mb/d) to 77 mb/d by 2030 and 24 mb/d by 2050. Natural gas demand drops from 4 150 billion cubic metres (bcm) in 2022 to 3 400 bcm in 2030 and 900 bcm in 2050.

No new long-lead time upstream oil and gas projects are needed in the NZE Scenario, neither are new coal mines, mine extensions or new unabated coal plants. Nonetheless, continued investment is required in existing oil and gas assets and already approved projects. Sequencing the decline of fossil fuel supply investment and the increase in clean energy investment is vital if damaging price spikes or supply gluts are to be avoided.

The drop in fossil fuel demand and supply reduces traditional risks to energy security, but they do not disappear – especially in a complex and low trust geopolitical environment. In the NZE Scenario, higher cost producers are squeezed out of a declining market and supply starts to concentrate in large resource-holders whose economies are most vulnerable to the process of change. But attempts by governments to prioritise domestic production must recognise the risk of locking in emissions that could push the world over the 1.5 °C threshold; and that, if the world is successful in bringing down fossil demand quickly enough to reach net zero emissions by 2050, new projects would face major commercial risks.

The net zero emissions transition must be secure and affordable

Particular attention needs to be paid to bridging the looming supply and demand gap for critical minerals. Announced mining projects for minerals such as nickel and lithium fall short of booming demand in the NZE Scenario in 2030. New projects, innovative extraction techniques, more recycling and material-efficient design can help to bridge this gap.

Extraordinary advances in clean energy technology supply chains have kept the door to net zero emissions open, but have been accompanied by a high degree of geographical concentration. The mining and refining of critical minerals are similarly highly concentrated. This presents an increased risk of disruption, such as from geopolitical tensions, extreme weather events or a simple industrial accident. While more diverse and resilient supply chains are highly desirable, the pace at which clean energy must be scaled up will be even harder to achieve without open supply chains.

As electricity becomes the “new oil” of the global energy system in the NZE Scenario, secure electricity supplies become even more important. The hugely increased need for electricity system flexibility requires massive growth of battery energy storage and demand response; expanded, modernised and cybersecure transmission and distribution grids, and more dispatchable low-emissions capacity, including fossil fuel capacity with CCUS, hydropower, biomass, nuclear, and hydrogen and ammonia-based plants.

By 2030 in the NZE Scenario, total household energy expenditure in emerging market and developing economies decreases by 12% from today's level, and even more in advanced economies. The decrease reflects large energy and cost savings from energy efficiency and electrification. However, policy makers need to support households, particularly low-income ones, to meet the often higher upfront costs of clean energy technologies.

There is no low international co-operation route to limit warming to 1.5 °C and no slow route either

By 2035, emissions need to decline by 80% in advanced economies and 60% in emerging market and developing economies compared to the 2022 level. Current Nationally Determined Contributions are not in line with countries' own net zero emissions pledges, and those pledges are not sufficient to put the world on a pathway to net zero emissions by 2050. COP28 and the first Global Stocktake under the Paris Agreement provide a key opportunity to enhance ambition and implementation.

As part of an equitable pathway to the global goal of net zero emissions by 2050, almost all countries need to bring forward their targeted net zero dates. In the NZE Scenario, advanced economies take the lead and reach net zero emissions by around 2045 in aggregate; China achieves net zero emissions around 2050; and other emerging market and developing economies do so only well after 2050. The NZE Scenario is a global but differentiated pathway: each country will follow its own route based on its resources and circumstances. However, all must act much more strongly than they are today. The net zero pathway achieves full access to modern forms of energy for all by 2030 through annual investment of nearly USD 45 billion per year — just over 1% of energy sector investment.

Our *Delayed Action Case* shows that failure to increase ambition to 2030 would create additional climate risks and make achieving the 1.5 °C goal dependant on the massive deployment of carbon removal technologies which are expensive and unproven at scale. Nearly 5 Gt CO₂ would have to be removed from the atmosphere every year during the second half of this century. If carbon removal technologies fail to deliver at such scale, returning the temperature to 1.5 °C would not be possible. Removing carbon from the atmosphere is costly and uncertain. We must do everything possible to stop putting it there in the first place.

The fierce urgency of now

The energy sector is changing faster than many people think, but much more needs to be done and time is short. Momentum is coming not just from the push to meet climate targets but also from the increasingly strong economic case for clean energy, energy security imperatives, and the jobs and industrial opportunities that accompany the new energy economy. Yet, momentum must be accelerated to be in line with the 1.5 °C goal and to ensure that the process of change works for everyone. Above all, this needs to be a unified effort in which governments put tensions aside and find ways to work together on what is the defining challenge of our time. All of us, and in particular future generations, will remember with gratitude those who act upon the urgency of now.

International Energy Agency (IEA)

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In May 2021, the IEA published its landmark report *Net Zero Emissions by 2050: A Roadmap for the Global Energy Sector*. The report set out a narrow but feasible pathway for the global energy sector to contribute to the Paris Agreement's goal of limiting the rise in global temperatures to 1.5 °C above pre-industrial levels. The *Net Zero Roadmap* quickly became an important benchmark for policy makers, industry, the financial sector and civil society.

Since the report was released, many changes have taken place, notably amid the global energy crisis triggered by Russia's invasion of Ukraine in February 2022. And energy sector carbon dioxide emissions have continued to rise, reaching a new record in 2022. Yet there are also increasing grounds for optimism: the last two years have also seen remarkable progress in developing and deploying some key clean energy technologies.

This 2023 update to our *Net Zero Roadmap* surveys this complex and dynamic landscape and sets out an updated pathway to net zero by 2050, taking account of the key developments that have occurred since 2021.

