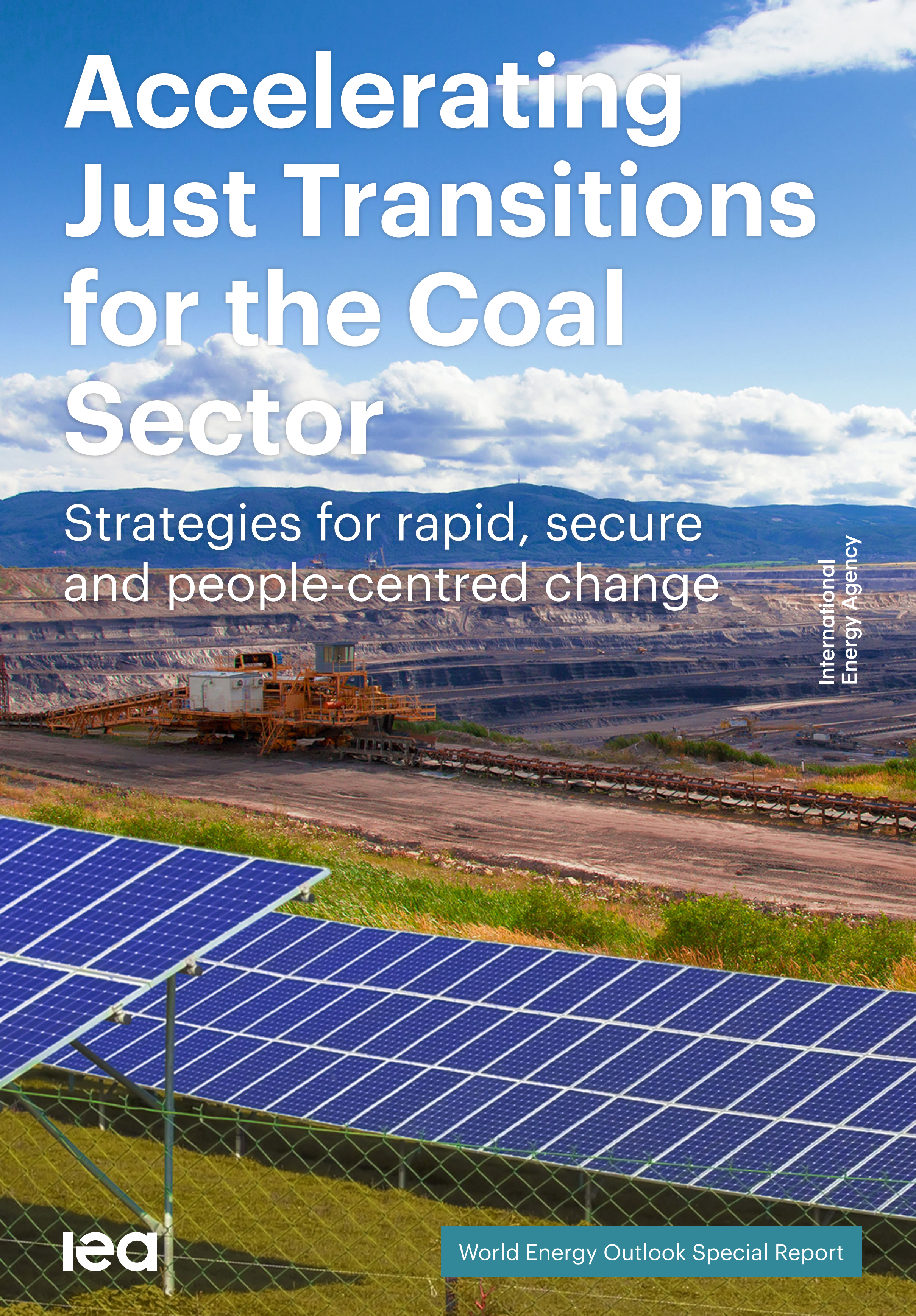
Accelerating Just Transitions for the Coal Sector

Strategies for rapid, secure and people-centred change



International Energy Agency

iea

World Energy Outlook Special Report

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 31 member countries, 13 association countries and beyond.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea
Lithuania
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Republic of Türkiye
United Kingdom
United States

The European Commission also participates in the work of the IEA

IEA association countries:

Argentina
Brazil
China
Egypt
India
Indonesia
Kenya
Morocco
Senegal
Singapore
South Africa
Thailand
Ukraine

Source: IEA.
International Energy Agency
Website: www.iea.org

This study was prepared by the Directorate of Sustainability, Technology and Outlooks and was designed and directed by **Laura Cozzi**, Director for Sustainability, Technology and Outlooks. **Daniel Wetzel**, Head of the Tracking Sustainable Transitions Unit and **Caleigh Andrews** co-ordinated the production of the report.

Principal authors of the report include: **Yasmine Arsalane** (economic outlook, power), **Tanguy de Bienassis** (investment and finance), **Carlos Fernández Alvarez** (coal), **Christophe McGlade** (supply), **Matthieu Prin** (people-centred transitions), **Thomas Spencer** (climate and environment), **Ryota Taniguchi** (policy commitments, power), **Brent Wanner** (power), and **Peter Zeniewski** (investment). **Reka Koczka** and **Marina Dos Santos** provided essential support.

Trevor Morgan provided writing support to the report and carried editorial responsibility.

Other valuable contributions were made by: Yunyou Chen, Ekko Chua, Julie Dallard, Shobhan Dhir, Eric Fabozzi, Mathilde Fajardy, Bruno Idini, Nikolaos Papastefanakis, Alessio Pastore, Diana Perez Sanchez, Ryszard Popsiech, Arthur Roge, Rebecca Ruff, Gabriel Saive, Max Schoenfisch**,** Leonie Staas, Jun Takashiro and Cecilia Tam.

Erin Crum was the copy-editor.

Valuable comments and feedback were provided by other senior management and numerous colleagues within the IEA, in particular, Tim Gould, Keisuke Sadamori, Pablo Hevia-Koch, Brian Motherway, Dennis Hesseling, and Timur Gül.

Thanks go to the IEA's Communications and Digital Office for their help in producing the report and website materials, particularly Poeli Bojorquez, Curtis Brainard, Jon Custer, Hortense De Roffignac, Astrid Dumond, Merve Erdem, Grace Gordon, Jethro Mullen, Isabelle Nonain-Semelin, Julie Puech, Clara Vallois and Therese Walsh. IEA's Office of the Legal Counsel, Office of Management and Administration and Energy Data Centre provided assistance throughout the preparation of the report.

The work was supported by the Ministry of Economy, Trade and Industry of the Government of Japan.

A consultation workshop was held at the beginning of December 2023 with representatives from the governments of the G7, Colombia and Indonesia. Other participants included representatives from the International Labour Organization, the Powering Past Coal Alliance, and other non-governmental organisations and academia. These participants offered valuable insights and feedback for this analysis and we are grateful for their input.

Comments and questions are welcome and should be addressed to:

Laura Cozzi

Directorate of Sustainability, Technology and Outlooks
International Energy Agency
9, rue de la Fédération
75739 Paris Cedex 15
France

E-mail: weo@iea.org

Web: www.iea.org/weo.

Annexes

In 2022, the IEA published its special report Coal in Net Zero Transitions. Since then, the policy and technology landscape continues to evolve. At the end of 2023, the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC) called for "transitioning away from fossil fuels in energy systems," including the specific call for parties to begin "accelerating efforts towards the phase-down of unabated coal power". This report, developed at the request of the Japanese Group of Seven (G7) Presidency, presents an update to our 2022 report, building on the analysis developed in the original report and complementing it with the latest data and scenarios from the IEA.

Net zero requires a rapid transition away from unabated coal-fired power

Achieving the goal adopted at COP28 of net zero emissions of greenhouse gases from the energy sector by 2050 hinges critically on the rapid transition away from the unabated use of coal for generating electricity. The scale of the task cannot be overstated: coal accounts for over one-third of global power supply, in many cases from recently built plants. As the most carbon-intensive fuel, coal's role in emissions is even bigger: globally, coal is responsible for over 40% of all energy sector CO_2 emissions. If existing coal power plants and industries were to continue to operate as they do today, they would "lock in" emissions pushing the world well beyond the 1.5 °C limit.

Global coal demand grew in 2023, despite rapid growth in renewables-based power generation. The largest uptick was observed in the People's Republic of China (hereafter, "China"), followed by India and other emerging and developing economies. Growing use of coal, mainly for power, has accounted for nearly all the increase in global CO_2 emissions since 2019. According to the latest IEA estimates, clean energy deployment since 2019 has helped to avoid coal demand of around 580 million tonnes of coal equivalent per year on average – equivalent to the coal demand for power generation of Indonesia and India combined.

A growing number of countries have adopted net zero emissions pledges, which is tantamount to phasing out completely the unabated use of coal and other fossil fuels. At the end of 2023, those pledges covered more than 85% of global energy sector emissions. More and more countries have also made specific commitments to phase down or out the use of unabated coal in power, covering 30% of current coal-fired generation – up from less than 20% in 2022.

Coal transitions hinge upon a fast scale-up of low-emissions power sources

Reducing reliance on unabated coal-fired power generation is possible only if alternative sources of power are developed quickly enough to meet rising electricity demand. In the Announced Pledges Scenario (APS), where all climate commitments made by governments worldwide are met in full and on time, nearly 75% of the drop in global coal-fired generation over 2022-2050 is compensated for by solar PV and wind power, followed by hydropower and other renewables and nuclear. At COP28, governments committed to tripling renewable capacity by 2030 in line with the IEA's Net Zero Emissions by 2050 Scenario, which if achieved, would be a crucial accelerant in the transition away from coal powered generation. The latest assessment of the announced pipeline of renewable power projects indicates that if these come to fruition, the world would already be nearly three-quarters of the way to the tripling target. However, critical investment gaps persist in many emerging market and developing economies.

Shifting coal plants from baseload generation to more flexible operation will reduce coal use while supporting the integration of alternative sources of electricity generation. This would lower emissions while preserving electricity security and can reduce the near-term impacts on jobs and the local economy. In the APS, the capacity factor of coal plants in emerging market and developing economies falls from around 55% in 2022 to around 45% in 2030, and around 40% in 2040. Alongside repurposing these plants towards providing grid support, countries should align their grid operation protocols and compensation schemes to encourage coal plants to operate more flexibly, which can also help offset the revenue losses associated with lower capacity factors. Some plants are also retired before their technical lifetimes, while others are retrofitted with carbon capture, utilisation and storage (CCUS) technology or co-fired with low-emissions fuels such as ammonia or biomass. The potential for adopting these approaches varies by country, and could consider a blend of direct regulation, financial incentives and market-based measures.

New approaches are needed to speed up the financing of coal transitions

Favourable economics for renewables will not, on their own, be sufficient to achieve the rapid transition away from coal power. In many regions, new renewables offer lower levelised costs of energy than the cost of operating existing coal plants. However, this is not the case everywhere, and in some regions coal plants have contract or dispatch agreements which shield them from market competition. Addressing these barriers and incentivising investment in low-emissions power is imperative to unlock the transition away from unabated coal power and the full potential of renewables. Over 2023-2030 in the APS, USD 890 billion needs to be invested annually in low-emissions power capacity and support, such as grids and battery storage, with around a third of new low-emissions power capacity additions dedicated to replacing coal generation, instead of meeting incremental demand. Mobilising this investment depends critically on bringing in more private sector investment, and finding the right financing mechanisms that address the problems posed by today's high interest rate environment, particularly in emerging and developing economies.

Policies to facilitate the financing of clean energy must go hand-in-hand with measures to end financing for new coal power and to finance the early retirement of some coal assets. Over 2023-2030, around 20 gigawatts of coal power plants operating today are retired before they reach 30 years in the APS. For many of these plants, especially in the emerging market and developing economies, large amounts of capital invested in them have yet to be recovered. There is no single blueprint for phasing out coal-fired generation. A variety of innovative financing mechanisms are under development to help shorten payback periods, refinance and restructure debt, and adjust contract terms in ways that avoid undermining investor confidence. In many regions, such policies must take account of the role currently played by coal in ensuring security of supply.

Coal transitions can be achieved affordably

Maintaining affordable electricity prices throughout the transition is paramount. In the APS, power sector investments climb steeply to 2030, but the costs of replacing coal generation and the system services it provides with low-emissions sources are more than offset by the fuel cost savings from reduced fossil fuel demand in the longer term. Appropriate policy frameworks can help ensure that the costs of these investments are recovered over a longer period, helping reduce the impact on the average cost per unit. In the APS, average electricity prices worldwide decline by over one-fifth between 2022 and 2050, though savings vary by region according to initial levels, carbon pricing and growth in electricity demand.

Policies to transition away from coal power must be people-centred and just

Accelerating coal transitions will impact workers and communities that depend on coal. For that reason, comprehensive stakeholder engagement and a set of policies to manage negative impacts, including on energy affordability, energy access and socioeconomic development, are essential. These need to cover the creation of decent work opportunities, support for workers affected by energy transitions and respect for fundamental labour principles and rights. Several countries, including Canada, the Czech Republic, Germany, Spain and South Africa, have convened national task forces or commissions to evaluate the socio-economic effects of coal transitions. The IEA has established its Global Commission on People-Centred Clean Energy Transitions to codify best practices.

National pledges to cut emissions and decarbonise power generation, if fully implemented, would inevitably lead to job losses in the coal sector, especially in mining. In the APS, total coal employment declines from 7.8 million people worldwide today to 5.6 million in 2030. Just over half of those job losses result from a fall in coal production, with the remainder attributable to mechanisation, automation and other improvements in labour productivity. Declines in coal employment have been navigated in the past in parts of Europe and North America, and more recently in China. Managing the economic and social consequences of coal transitions is vital to enduring progress on reducing energy sector emissions. New policy approaches are proving effective, including short-term income support, education and training, and new career opportunities for coal workers who are made redundant. At the end of 2023, just 14% of coal workers in coal-dependent countries were covered by such just transition policies, though this represents an improvement of 10 percentage points over 2022.

The social and economic impacts of transitioning away from the use of coal for power generation vary widely across and within countries, according to resource endowments, the structure of the economy, level of economic development, and the importance of the coal industry to local labour markets. National exposure to coal, as measured by our Coal Transition Exposure Index (CTEI), is highest in Indonesia, followed by Mongolia, China, Viet Nam, India and South Africa. Many coal regions in those and other emerging economies are characterised by low levels of economic diversification, limiting opportunities for alternative activities and jobs. Coal transition policies must seek to cushion the impact of job losses while supporting economic development through measures such as industrialisation or environmental rehabilitation initiatives.

Co-ordinated efforts are needed to accelerate coal transitions around the world

Commitments to transition away from unabated coal use for power set a direction; concrete policies are needed to meet them. Reaching long-term net zero goals requires unambiguous policy settings and near-term targets, which should be reflected in upcoming NDCs. While each country's circumstances vary, the global pledge to triple renewables and double efficiency by 2030 implies a coal transition, but this itself does not guarantee the reductions in coal emissions needed to be aligned with meeting national climate ambitions nor our collective target of limiting warming to 1.5^{o}C, underscoring the enduring importance of a dedicated focus on facilitating the global transition away from coal.

Coal, which is used mainly for generating electricity, is the most carbon-intensive major fossil fuel in use today and currently emits more CO_2 globally than either oil or gas. Reaching net zero emissions therefore requires cutting emissions from coal in power stations drastically in the near term. Achieving this will not be easy: coal remains a fundamental source of electricity generation in many regions, accounting for well over one-third of power supply and around one-quarter of total energy supply worldwide. Though coal demand has remained broadly stable over the last decade, coal-fired generation rebounded to record highs in 2021, 2022 and 2023 as the world economy recovered from the Covid-19 pandemic. Moreover, several countries have announced plans to expand the use of coal, at least temporarily, in response to concerns about the availability and price of natural gas in the wake of the Russian Federation's invasion of Ukraine.

Policy action to bring about a rapid transition away from coal-fired power generation must be grounded in an understanding of the factors underpinning the continuing heavy reliance on this fuel. Although its price in global markets rose sharply in 2022, it has since fallen back substantially. Coal has long been a relatively cheap fuel in many markets and its position in the electricity sector is often shielded from market competition by long-term power purchase agreements which have been used to rapidly expand power generation capacity in many developing economies over the last two decades. In addition, many coal-reliant economies see coal as an important pillar of their energy security and independence because they possess substantial domestic coal resources but have historically lacked significant and easily accessible alternative energy sources, although that is now changing with the competitiveness and wide availability of solar PV and wind energy. As a result, the global fleet of coal power plants has grown rapidly in the last two decades. Several emerging market and developing economies now have very young fleets of coal-fired power stations. Large amounts of capital investment have yet to be recovered from their operations, so shutting them down early could have major financial repercussions. The broader social and economic impact of phasing out coal will also be substantial. An estimated 7.8 million people are now employed in coal production, processing, transport and power generation around the world. Phasing out coal use will have far-reaching effects on the welfare of communities where those activities form an important part of the economic and social fabric.

In 2023 alone, significant progress was made in commitments to a transition away from coal. The Powering Past Coal Alliance gained 14 new members who committed to develop no new unabated coal-fired power plants and to phase out existing unabated plants, including the United States, which currently possesses the third-largest operational coal fleet by capacity. Japan also pledged to stop building unabated coal-fired power plants, and France announced that it will phase out all coal-fired plants by 2027 in addition to calling for a phase-out of unabated coal in Group of Seven (G7) countries by 2030. At the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2023, around 130 parties joined the Global Pledge on Tripling Renewable Energy and Doubling Energy Efficiency, which also includes a commitment to stop building new unabated coal-fired power plants. Just Energy Transition Partnerships (JETP) also made some headway as Indonesia and the International Partners Group agreed to the Comprehensive

Investment and Policy Plan. But faster progress yet is needed to realise the rapid and drastic cut in coal emissions required to achieve net zero emissions by 2050.

This report, which draws on the latest IEA scenarios and data, as well as on the analysis and framing of our Coal in Net Zero Transitions report released in 2022, was requested by the G7 Presidency of Japan and benefited from a workshop of industry stakeholders hosted by the IEA in December 2023. It identifies the main strategies and specific measures that governments around the world will need to consider putting in motion to bring about a rapid transition away from unabated coal-fired power generation while maintaining energy security and protecting local communities. The appropriate mix of measures in each country depends on national circumstances, notably the level of economic development. Several case studies are included to demonstrate successful policies to reduce reliance on coal for power and manage the socio-economic consequences.

The context

Turning a tanker

S U M M A R Y

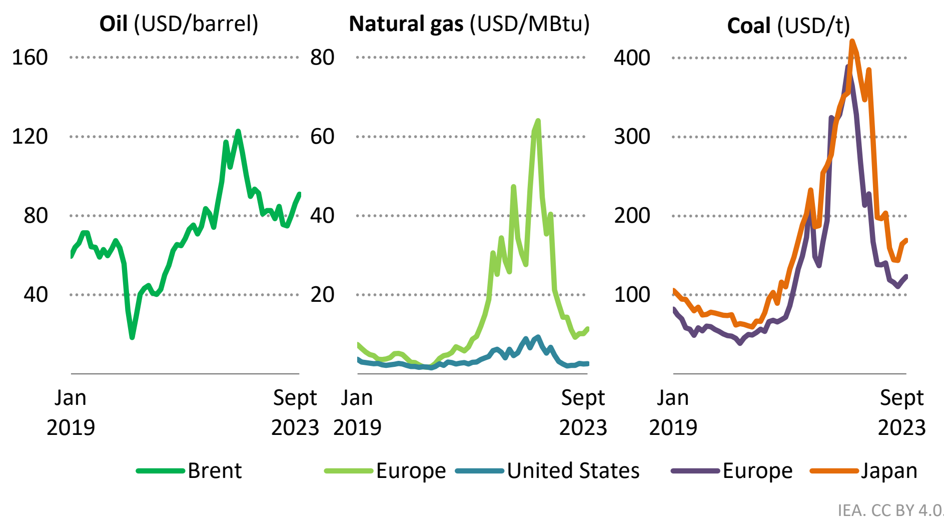
- Global coal demand has been broadly flat over the last decade, with the fuel accounting for about 25% of total energy supply in 2023. China dominates the market for coal, accounting for over 55% of world demand and more than half of global output, though growth in production slowed in 2023. India is also a notable user of coal with over 10% of all demand. Other emerging and developing economies (EMDE) account for 15% of global demand, with demand growth beginning to taper in recent years. Demand from advanced economies is just 15% of the global total, down from half in 2000 and continuing to drop. Coal is the largest source of electricity, and power generation is the biggest user of coal, making up two-thirds of the market.
- Coal demand starts to fall back over the rest of the current decade in all three scenarios as countries reorient towards lower-emissions power sources, though the pace of decline depends on the stringency of climate policies. In the Stated Policies Scenario (STEPS), demand falls by over 15% over 2023-2030 and by 40% to 2050. In the Announced Policies Scenario (APS), it falls by around 25% to 2030 and by nearly 75% to 2050 as renewables drive down the use of coal in power. In the Net Zero Emissions by 2050 (NZE) Scenario, demand falls by 45% to 2030 and by 90% to 2050; by 2040, there is no unabated coal power anywhere in the world.
- A growing number of countries have adopted net zero emissions pledges, which require very deep reductions in the use of unabated coal and other fossil fuels. At the end of 2023, those pledges covered more than 85% of global energy sector emissions. Some countries have made specific commitments to phase down or out the use of unabated coal, usually in the power sector. At the end of 2023, 80 countries had agreed to phase out coal or to develop no new unabated coal power, collectively accounting for 30% of current coal-fired generation, up from less than 20% in 2022.
- The nature and size of the effects of transitioning away from coal in power generation vary widely across and within countries, mainly according to indigenous resource endowments, the share of coal in the fuel mix, the structure of the economy, and labour markets. National exposure to coal is highest in Indonesia, followed by Mongolia, China, Viet Nam, India and South Africa.
- The potential impact of falling coal production depends on the overall level of economic development, which affects opportunities for alternative activities and employment. Today, many coal regions in emerging and developing economies are not diversified. Transition policies have the dual task of cushioning the impact of the declining jobs while also supporting economic development in coal communities.

1.1 Trends in coal use, production and emissions

1.1.1 Historical trends

Global demand for coal has been broadly stable for over a decade, with the fuel accounting for just over a quarter of the world's total energy supply in 2023 – the second-largest energy source after oil. Demand grew by just 0.3% per year between 2010 and 2020, compared with 4.7% over the previous decade. It fell sharply in 2020 because of the Covid-19 pandemic but bounced back by 11.2% between 2020 and 2023 as the world economy recovered from the impact of the pandemic and the surge in gas prices following the Russian Federation's (hereafter, "Russia") invasion of Ukraine, which outstripped that in coal prices and boosted the competitiveness of coal in power generation (Figure 1.1). Prices subsequently fell back but remain above their long-term level.

Figure 1.1 ▹ Wholesale fossil energy prices in selected markets

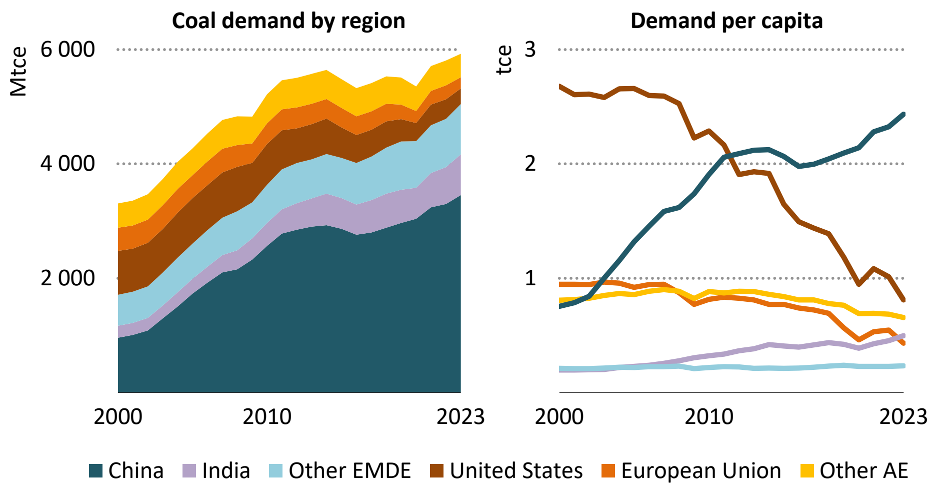


Russia's invasion of Ukraine exacerbated pre-existing tightness in energy markets, resulting in a full-blown global energy crisis, though coal prices generally rose less than those of gas

Notes: MBtu = million British thermal units; t = tonne.

The People's Republic of China (hereafter, "China") dominates the global market for coal to a much greater degree than for any other fuel, accounting for 58% of world demand (Figure 1.2) and driving growth through the 2010s. China's electricity sector alone is responsible for over one-third of global coal demand. China is also the largest coal producer by far, accounting for over half of global output, and is the largest coal importer. China has seen impressive deployment of clean energy technologies over the last decade or so. As a result, demand for coal is beginning to flatten in China, but coal still accounted for around 60% of its energy supply and electricity generation in 2023. India is the second-biggest single coal consumer, accounting for 12% of world coal demand. Like China, India has a population of around 1.4 billion people, but its per capita energy demand is one-quarter that of China's, reflecting lower GDP per capita. As in China, coal is the cornerstone of electricity generation in India, accounting for around three-quarters of total generation. Together, China and India account for over two-thirds of global coal demand.

Figure 1.2 ▷ Coal demand in total and per capita by country/region



IEA. CC BY 4.0.

Emerging market and developing economies now account for 85% of global coal demand, with China and India alone responsible for over two-thirds

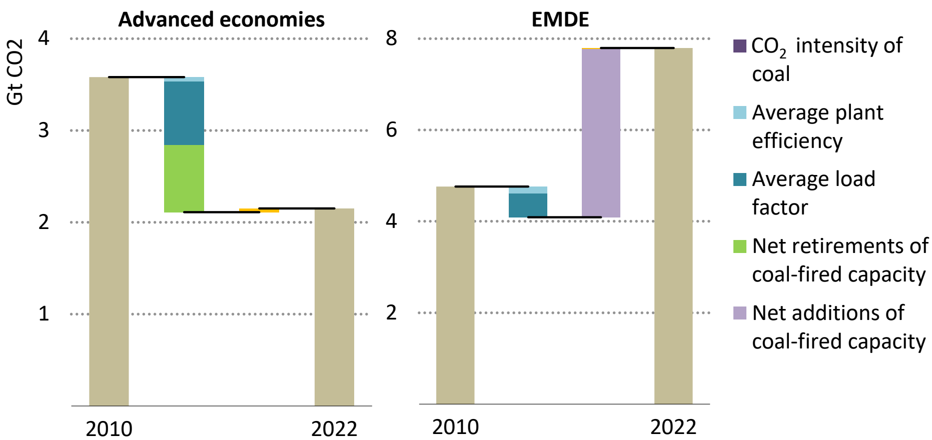
Notes: Mtce = million tonnes of coal equivalent; tce = tonne of coal equivalent. Other EMDE = emerging market and developing economies excluding China and India; Other AE = advanced economies excluding the United States and the European Union.

Other emerging market and developing economies accounted for 15% of global demand in 2023, resulting in a total share for emerging and developing economies of 85% – up from 52% in 2000. Coal demand in advanced economies has declined by almost half over the same period – equivalent in absolute terms to almost the total current coal demand of India. The United States accounts for about 5% of global coal use and the European Union for about 3%.

Power generation remains the biggest driver of global coal demand, making up two-thirds of the market. Although low-emissions sources of electricity generation as a group have recently overtaken it, coal is still the single largest source of electricity, meeting 36% of total generation. The share of coal in the generation mix has been declining slowly in recent years, while the share of electricity in total energy has been steadily increasing: since 1980, global total energy supply has increased by less than 2% per year on average whereas electricity demand has risen by almost 4% per year. The decline in the share of coal in electricity generation has been slower than the increase in electricity generation, and the output of coal-fired electricity has continued to increase. The global fleet of coal-fired power plants is relatively young, particularly in developing Asia, following a surge of capacity additions since the beginning of the century.

Since 2010, advanced economies have witnessed a 40% decline in emissions from coal-fired power generation. About half of this fall in emissions was achieved by retiring coal-fired capacity, with the other half mostly due to reducing plant load factors (Figure 1.3). However, the decrease in emissions from advanced economies has been more than offset by an increase from emerging and developing economies, where soaring electricity demand and insufficient growth in clean energy supply have motivated additions of coal-fired capacity and limited the scope for reducing coal plant load factors.

Figure 1.3 ▷ Changes in emissions from coal-fired power generation by region and causal factor, 2010-2022



Reducing plant load factors and retiring coal-fired capacity have contributed equally to reduced emissions from coal-fired power generation in advanced economies since 2010

Note: Gt = gigatonne.

1.1.2 Outlook

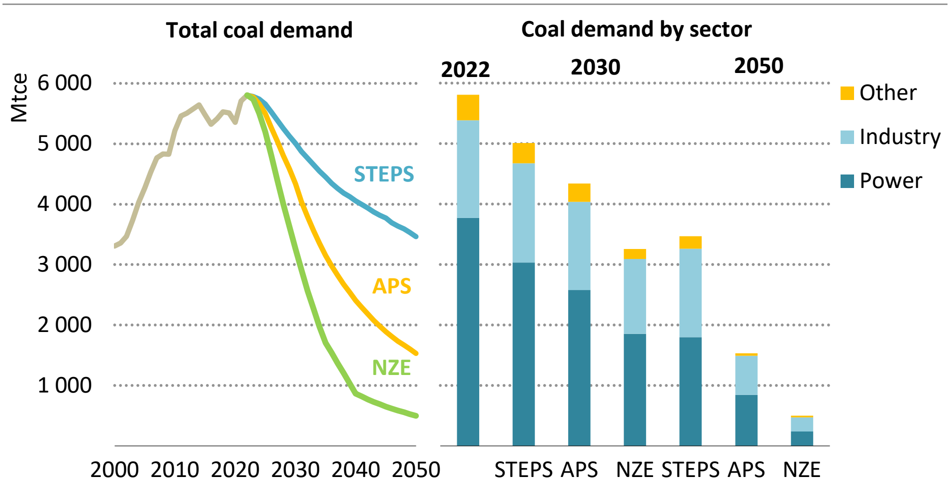
The projections of coal use, production and emissions presented here are based on the three main scenarios developed for the most recent World Energy Outlook (WEO), published in October 2023, and based on the IEA Global Energy and Climate Model (IEA, 2023a):

- The **Stated Policies Scenario** (STEPS), which considers established and announced policies and regulations.
- The **Announced Pledges Scenario** (APS), which assumes that all climate commitments made by governments around the world, including nationally determined contributions under the Paris Agreement and long-term net zero emissions pledges, are met in full and on time, regardless of whether those commitments are currently underpinned by detailed implementation laws, policies and regulations. As of the end of 2023, 56 countries had pledged to phase out unabated coal use altogether, and another 28 had pledged to stop building unabated coal power plants.

- The **Net Zero Emissions by 2050** (NZE) **Scenario**, which sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. In this scenario, advanced economies take the lead, but all regions achieve very rapid reductions in emissions, with residual global emissions in 2050 being offset by negative emissions using carbon removal technologies.

Each scenario sees a structural decline in coal demand over the rest of the current decade, though the pace of this decline varies according to the stringency and effectiveness of climate policies. In the STEPS, global coal demand falls by just over 15% between 2023 and 2030 and by more than 40% to 2050 (Figure 1.4). The reduction to 2030 occurs in the power sector and in advanced economies and China, while demand stays relatively stable in other emerging and developing economies and increases modestly in industry. In the APS, total coal demand falls by a quarter to 2030 and by nearly 75% to 2050, driven mainly by declines in the electricity sector, where renewables and other low-emissions sources expand and displace coal. Coal use in electricity falls by almost 30% to 2030 and by 75% to 2050 in the APS, with the drop steepest in advanced economies. In the NZE Scenario, global coal demand falls by 45% to 2030 and by 90% to 2050, again led by the electricity sector, where global coal use declines by over 50% between 2023 and 2030 as low-emissions sources of generation ramp up significantly. By 2040, there is no use of unabated coal for electricity generation anywhere in the world.

Figure 1.4 ▷ Global coal demand by sector and scenario



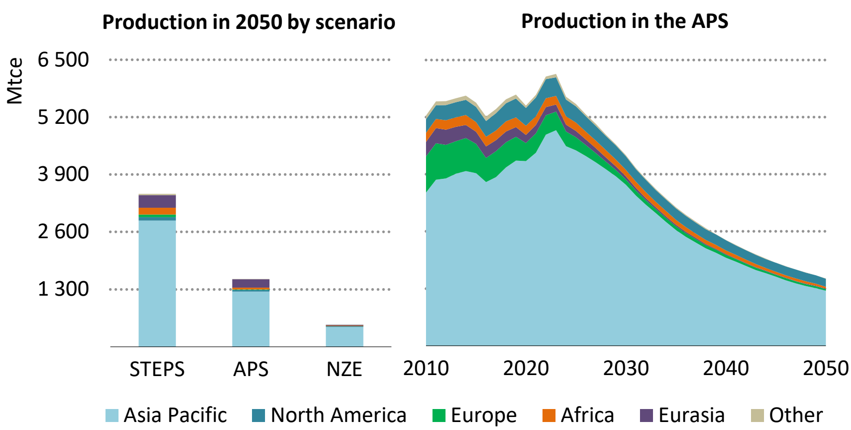
IEA. CC BY 4.0.

Coal use falls in all scenarios to 2050 – by over 70% in the APS and 90% in the NZE Scenario – according to the stringency of climate policies, with the power sector leading the decline

Notes: Other includes the small amounts of coal consumed in the buildings and transport sectors, and in other energy transformation. Power includes both electricity and heat production.

The projected declines in global coal demand are matched by falls in production in all IEA scenarios. In the APS, no new coal mines are needed in aggregate to meet demand, though existing mines need to be carefully managed to ensure timely supply (Figure 1.5). In advanced economies, coal consumption falls rapidly, with existing mines progressively shutting down as they reach the end of their economic lifetimes. In China, production peaks in the near term in response to current market conditions, then falls as demand for heavy industry output declines and as clean energy technologies are more widely deployed. In India, coal production increases by 3% between 2022 and 2030 but then drops by around 60% between 2030 and 2050. In the NZE Scenario, demand falls by 90% over 2023-2050, eliminating any need for new coal mines or mine lifetime extensions. Investment in coal supply in this scenario falls by over 70% from 2023-2030 and is focused on maintaining production and reducing emissions intensity as much as possible at existing mines as they wind down, including by cutting fugitive coal mine methane emissions.

Figure 1.5 ▷ Coal production by country/region and scenario

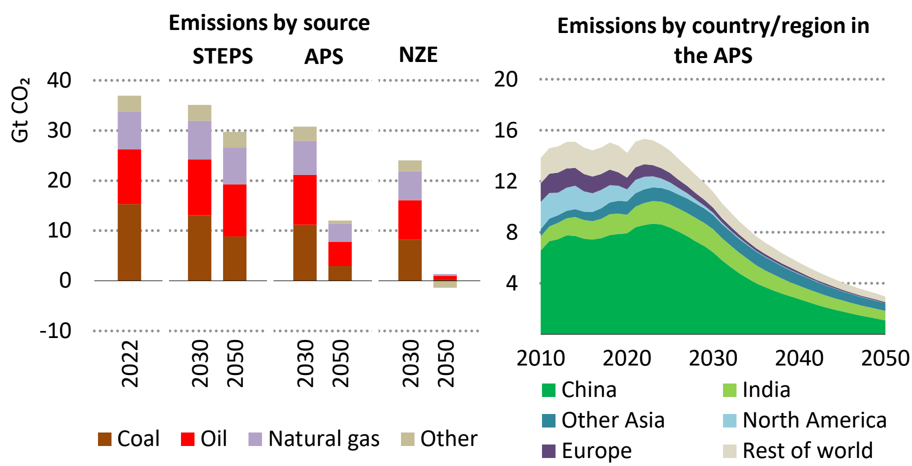


Coal demand declines rapidly in all regions in the APS and the NZE Scenario, such that no new coal mines are needed

Global CO_2 emissions from coal burning fall in all three scenarios, in line with declining coal use and, to a lesser extent, with the growing deployment of CCUS. Coal emissions exceeded 15 Gt, or 45% of total energy sector emissions, in 2023. China and India accounted for two-thirds of those emissions, with the United States, the European Union, Russia, Japan, Indonesia, South Africa and Korea responsible for most of the remainder. In the STEPS, emissions from coal decline by around 2.6 Gt between 2023 and 2030 (Figure 1.6). After 2030, coal emissions continue to decline, falling by an additional 4.2 Gt to 2050. In the APS, emissions from all fossil fuels decline to 2030, with coal leading the way. Coal emissions drop by nearly 30% between 2023 and 2030 (around 4% per year on average compared with 2% in the STEPS), accounting for 70% of the fall in total energy sector emissions. The rate of decline accelerates to 6.5% per year over 2030-2050 (compared with 2% in the STEPS). By

2050 in the APS, emissions from coal are 80% lower than in 2023. In the NZE Scenario, emissions from all fossil fuels decline even more rapidly. Emissions from coal drop by nearly half between 2023 and 2030, driven by the rapid rise of low-emissions sources of electricity generation, while emissions from oil and natural gas both fall by around one-quarter. By 2050, there is no use of unabated coal in power generation, and only marginal use in industry, with emissions offset by removals elsewhere in the energy system.

Figure 1.6 ⊳ Global energy sector CO_2 emissions by scenario

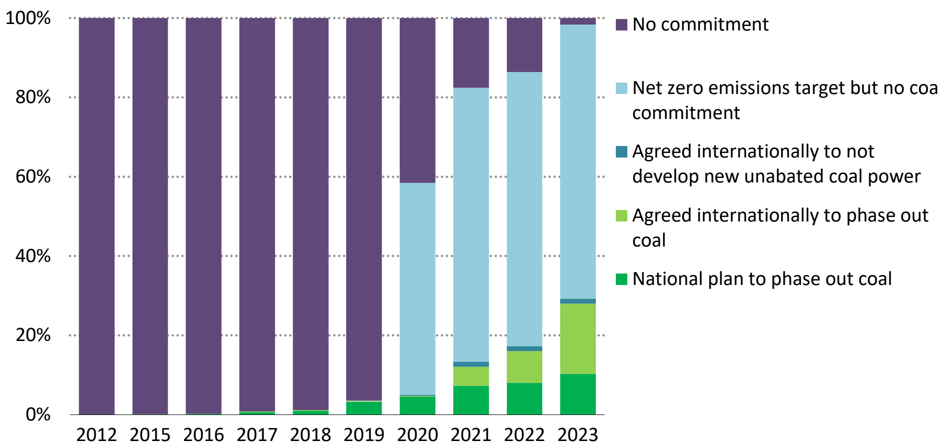


Emissions from coal burning fall in all three scenarios in line with declining coal use and, to a lesser extent, from the growing deployment of CCUS

1.2 Coal phase-out targets

A growing number of countries have adopted net zero emissions pledges, tantamount to phasing out completely the unabated use of coal and other fossil fuels. As of November 2023, 93 countries and the European Union have submitted those pledges, covering more than 85% of global energy-related emissions and nearly 90% of global GDP. Many countries have adopted a net zero target in national law, collectively accounting for about one-fifth of global energy sector emissions. Advanced economies in Asia Pacific and Europe are responsible for many of these policies, with 100% of energy-related emissions from advanced economies in Asia Pacific and about 80% in European advanced economies covered by net zero targets in national law. Most emissions in emerging and developing economies in North America, Central and South America, Eurasia and sub-Saharan Africa are also covered by net zero emissions targets, but these pledges are generally verbal or otherwise not legally binding. More than 97% of global coal consumption in electricity generation occurs in countries that have agreed to reduce coal use in the power sector, including those with net zero emissions pledges, albeit on different timescales and varying levels of legal status (Figure 1.7).

Figure 1.7 ▷ Share of coal consumption covered by coal power phase-out commitments and net zero emissions pledges

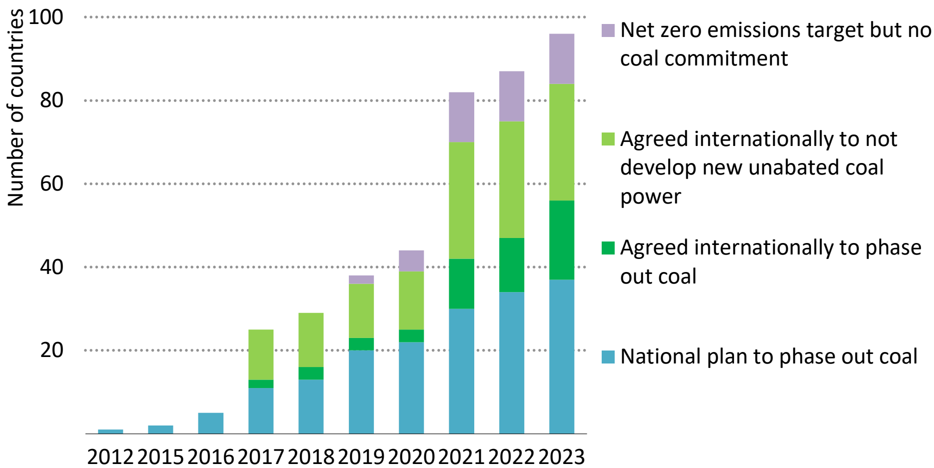


IEA. CC BY 4.0.

Countries representing around 70% of coal consumption in power do not have specific commitments to decrease coal use, despite having net zero pledges

In addition to aggregate net zero emissions pledges, an increasing number of countries, subnational regions and companies have made specific commitments to reduce or eliminate the use of unabated coal, usually in the power sector. In the Glasgow Climate Pact adopted at the 26th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2021, countries called for "accelerating efforts towards the phasedown of unabated coal power". In December 2023, the central outcome of COP28 reiterated the goals of the Glasgow pact and included for the first time an agreement to transition away from fossil fuels, including coal. At the end of 2023, 84 countries had agreed to phase out coal or to not to develop new unabated coal power plants, collectively accounting for around 30% of current coal-fired generation (Figure 1.8). Several major policy advances occurred in 2023, with 11 countries including the United States joining the Powering Past Coal Alliance and committing to phase out unabated coal use. Most of these countries have also adopted net zero targets. Another 12 countries have adopted net zero targets without any coal-specific targets, though in practice they will need to virtually phase out unabated coal by the date of their net zero target. Together these 96 countries account for nearly all coal-fired generation today, including the top five in the world (China, India, the United States, Japan and South Africa).

Figure 1.8 ▷ **Number of countries with plans to phase down coal use and net zero emissions pledges**

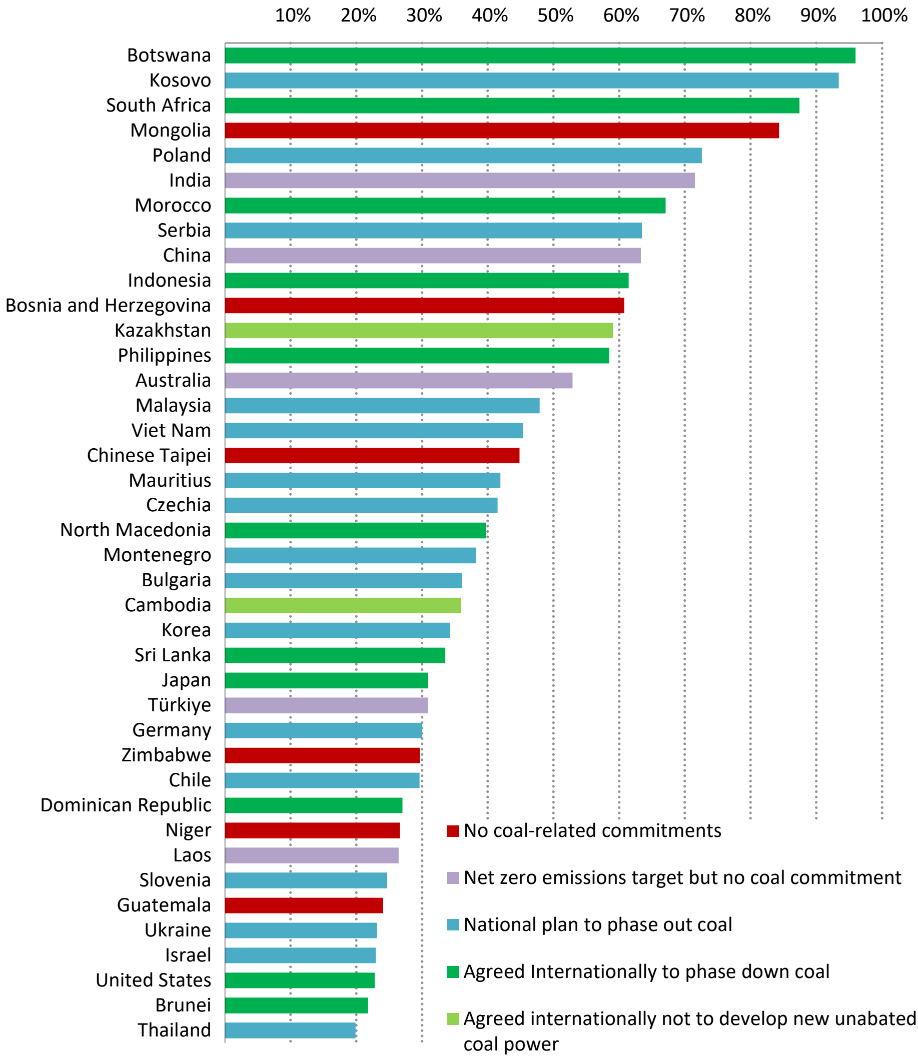


After years of growth in coal use, there are now 84 countries with explicit plans to move away from the fuel and another 12 countries that aim to reach net zero emissions

Note: At end-year.

Pledges to phase out coal use in power have taken the form of announcements, national plans and international initiatives. In 2017, Canada and the United Kingdom set up the Powering Past Coal Alliance (PPCA), the membership of which has since grown to 60 countries as well as 51 subnational governments and 71 global organisations (PPCA, 2024). Before its establishment, only six countries – Austria, Belgium, Canada, Finland, France and the United Kingdom – had pledged to phase out coal. The PPCA encourages all members of the Organisation for Economic Co-operation and Development (OECD) and the European Union to phase out unabated coal by 2030, and all other countries to do so by no later than 2040 (PPCA, 2024). Several countries also signed on to, in whole or in part, to the Global Coal to Clean Power Transition Statement (GCCPTS) at COP26 in November 2021 (Government of the United Kingdom, 2021). The GCCPTS calls for major economies to phase out coal in the 2030s (or as soon as possible thereafter) and for all other countries to do so in the 2040s (or as soon as possible thereafter), as well as stop issuing new permits for unabated coal plants and strengthen financial, technical and social support for affected communities. The Group of Seven (G7) countries in 2023 also reaffirmed their commitment to phasing out unabated coal-fired power in line with limiting temperature increase to 1.5° C (G7 Ministers' Meeting on Climate, Energy and Environment, 2023).

Figure 1.9 ▷ Share of coal in power generation and coal policies by country, 2023



13 of the 15 countries most reliant on coal-fired power for electricity have a national plan to phase it out, have agreed internationally to do so or have a net zero emissions target

Note: Data on coal consumption is from 2021; the top 40 countries with the highest share of coal in electricity generation that year are shown here. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law. This designation is without prejudice to positions on status, and is in line with United Nations Security Council Resolution 1244/99 and the Advisory Opinion of the International Court of Justice on Kosovo's declaration of independence. Other countries that use coal-fired power include (in descending order according to share of coal in the power mix): Pakistan, Madagascar, Romania, Russian Federation, the Netherlands, Denmark, Kyrgyzstan, Myanmar, Estonia, Greece, Croatia, Ireland, Hungary, Tajikistan, the Slovak Republic, Zambia, New Zealand, Senegal, Italy, Bangladesh, Colombia, Canada, Finland, Mexico, Panama, Brazil, Austria, Uzbekistan, Namibia, the United Kingdom, Spain, Belgium, Argentina, Portugal, France, Singapore and Honduras.

Countries that have made unabated coal phase-out commitments or have net zero emissions targets include those that have a high share of coal in power generation today, notably Botswana (96%), India (72%), China (63%), the Philippines (58%) and Australia (53%) (Figure 1.9). As of November 2023, 37 countries had incorporated coal phase-out targets with specified dates in national plans, mostly in Europe, including those with a high degree of reliance on coal-fired power such as Poland, the Czech Republic and Montenegro. They also include Germany, where the end date for the phase-out was recently brought forward from 2038 to 2030 for plants in the western state of North Rhine-Westphalia (Reuters, 2022). By the end of 2023, four countries – Austria, Belgium, Portugal and Sweden – had halted the use of coal in power generation (Beyond Fossil Fuels, 2023).

1.3 Coal dependence

The nature and size of the effects of phasing out the use of coal for power generation vary widely between countries, mainly according to indigenous resource endowments, the share of coal in the fuel mix, the structure of the economy, and labour markets. Because of the relatively high cost of transportation, most of the coal produced around the world supplies domestic markets, so any fall in the amount of coal used within a country has a direct impact on the domestic coal industry, though it may be economic in some present cases to export any surplus output. For example, South Africa exports a large share of its output, such that its coal industry is less affected by domestic demand.

To help evaluate the magnitude of the task that countries face in achieving the transition away from coal, the IEA has developed the Coal Transition Exposure Index (CTEI). The CTEI is made up of four components, each of which is measured using two indicators:

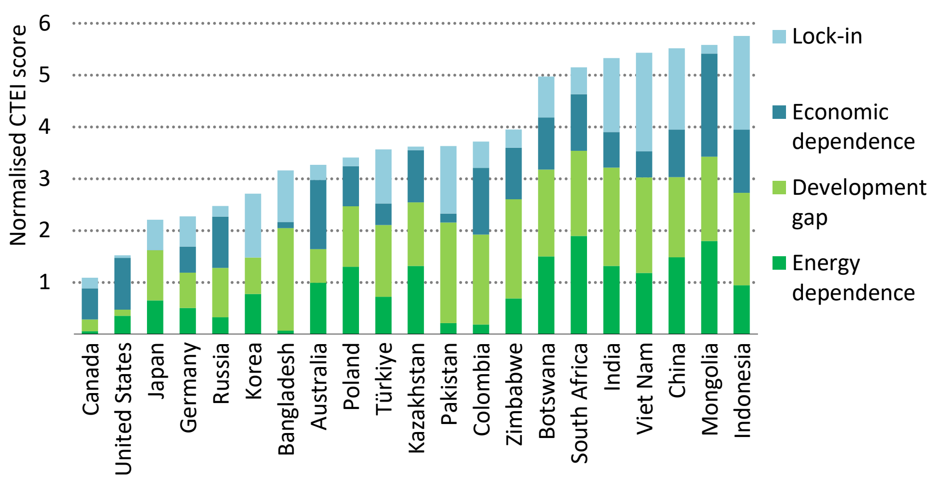
- Energy dependence on coal, quantified by its share in both total energy supply and electricity generation. This provides a broad indication of the overall impact of a phase-out of coal on the country’s energy system.
- The level of economic development, quantified by GDP per capita measured at PPP and total final energy consumption per capita. These indicators are proxies for a country’s future rate of energy demand growth and its financial and technological capacities. For example, in countries with stable energy demand, the generation of 1 megawatt-hour (MWh) of clean energy would replace 1 MWh of fossil fuel electricity. In countries with rapidly rising energy demand, clean energy supply needs to expand as fast as demand to avoid increased coal use, and even faster to reduce existing coal use.
- Economic dependence, measured by the share of coal in total goods exports and the share of coal produced domestically in total coal consumption. A country in which most coal needs are met through domestic production is more economically dependent on that fuel than one that imports its coal for a given level of consumption.

- The extent to which existing coal-fired capacity is "locked in", i.e. the amount of capacity that has not fully depreciated. This is measured by the capacity-weighted age of a country's coal-fired power plants, as well as that of its integrated steel mills.

To generate the index, the raw data for each of the eight indicators are normalised to assign a total score to each country. For each indicator, the country with the highest value is allocated a score of one, and the country with the lowest value receives zero. For example, Mongolia has the highest share of coal in its goods exports and therefore receives the highest score of one for this indicator, while Korea has the lowest and scores zero, with all the other countries receiving scores in between on a pro rata basis. Normalised scores are then combined to give an aggregate score.

We have calculated the CTEI for 21 countries, which together represent more than 90% of global coal production and consumption. They include the 15 largest coal producers and 15 largest coal consumers, as well as countries with particularly large energy needs and potential for growth in coal demand, such as Bangladesh and Pakistan, and countries with very large coal reserves, a high level of domestic dependency and low level of coal exports, such as Botswana and Zimbabwe. Indonesia scores highest, followed by Mongolia, China, Viet Nam, India and South Africa (Figure 1.10). The highest-placed OECD country is Türkiye, with a score of 3.5 compared with 5.7 for Indonesia.

Figure 1.10 ▹ Coal Transitions Exposure scores, 2022



Indonesia, Mongolia, China, Viet Nam, India and South Africa are most exposed to the effects of phasing out coal as part of clean energy transitions

There are also substantial differences in the extent of exposure to a decline in coal demand across provinces, states and regions within countries. Coal mining is usually highly regionalised within a country, so the impact of phasing out the use of coal both domestically and, in the case of exports, internationally will be much greater in mining communities. For example, the provinces of Kalimantan account for just 6% of Indonesia's population, but around 90% of its coal production. Similar levels of regional concentration characterise several other major coal-producing countries, including China and India. Mining seldom exceeds 3% of national GDP; the share is just 2% in South Africa and Indonesia – two of the world's biggest exporters – and 0.6% in China. But at the regional level, it can account for a far higher share; for example, it is more than one-third in Cesar and La Guajira in Colombia. Nonetheless, not all of the income and wealth generated remain in the region, as much of it normally accrues to the owners of the assets, which are not necessarily locally based, and to the central government as fiscal revenues.

Because workers generally spend most if not all of their income locally, the share of coal mining in local employment is a better metric to assess the importance of coal in regional economies. Coal mining typically accounts for less than 1% of national employment but can account for a much higher share in major coal mining regions. For example, the share is between 5% and 8% in Cesar in Colombia, East Kalimantan in Indonesia and Mpumalanga in South Africa. These shares are nonetheless much lower than those seen in the past in some mining regions, such as the United Kingdom (UK) and the United States, due to substantial improvements in labour productivity. For example, at its peak, coal mining accounted for 7% of total UK employment and far higher shares in the main producing regions.

The potential impact of falling coal production depends on the overall level of economic development, which affects opportunities for alternative activities and employment. For example, the large-scale loss of coal mining jobs in Wales in the 1950s and 1960s was largely offset by rising employment in non-coal industrial sectors, such as steel and engineering. A similar trend was observed in mining regions in the United States and Germany after the Second World War. In most advanced economies, the importance of industry in overall employment has diminished markedly over the last four decades, with a shift in employment towards services.

Today, many coal mining regions in emerging and developing economies are economically underdeveloped, which is reflected in low levels of industrialisation, urbanisation and labour productivity. For example, manufacturing employment accounts for around 8% of total employment in Jharkhand and around 5% in Chhattisgarh in India, while agriculture accounts for nearly 40% and 60%, respectively. At the district level in Korba, the most coal-intensive district in Chhattisgarh, coal mining accounts for about 15% of employment, while manufacturing accounts for less than 4%. Total industry employment, including mining, manufacturing, construction and utilities, accounts for one-quarter of employment in Korba, while agriculture accounts for more than one-third. The task of transition policies in these regions is not only to cushion the impact of the decline in mining on jobs, but also to support economic development broadly for coal miners and non-coal workers alike.

Managing the transition to low-emissions power

Everything, everywhere, all at once

SUMMARY

- Governments need to introduce policies to ensure that public and private actors in the power sector invest in clean energy and reduce coal use in line with emissions targets while minimising economic and social costs. The most cost-effective mix of direct regulation, financial incentives and market-based measures varies by country.
- Reducing reliance on unabated coal power calls for rapid growth in low-emissions fuels and technologies. Nearly 75% of the drop in global coal-fired generation over 2022-2050 in the APS is replaced by solar PV and wind, followed by hydropower and other renewables with 13% and nuclear with 8%. This expansion of solar PV and wind hinges on strong policy incentives as well as carefully implemented measures to enable the integration of variable renewables into the electricity system.
- Emissions from existing coal-fired plants can be cut by repurposing plants to provide load balancing services (adequacy and flexibility) rather than baseload power, retrofitting them with CCUS technology, retrofitting them to permit co-firing with low-emissions fuels such as ammonia or biomass, or retiring them early and converting existing sites to other uses. Were all the coal assets in industry and power around the world to continue to operate as they do today through to the ends of their normal operating lives, they would "lock in" over 300 Gt of cumulative emissions between 2023 and 2050, by themselves tipping the world past the 1.5° C limit.
- Repurposing coal plants for flexibility is widely adopted in the APS because it can limit losses of revenue and jobs while enabling the existing coal fleet to support the integration of renewables, yielding large emissions savings. As a result, the average annual capacity factor of unabated coal plants declines from 52% in 2022 to just 24% by 2050 in the APS. Retrofitting coal plants with CCUS also provides a means to preserve existing assets and jobs, supply dispatchable electricity, and help maintain grid stability. Global capacity of coal with CCUS expands rapidly after 2030 in the APS, reaching nearly 150 GW by 2050. Co-firing low-emissions ammonia or bioenergy in conjunction with coal also offers valuable system benefits as a source of dispatchable power. Other coal plants will need to be retired early; this is most feasible in advanced economies where plants tend to be older, and costs more easily absorbed.
- The system services provided by coal-fired power plants, as well as their electricity output, must be replaced as the transition progresses to ensure secure electricity supply. This is particularly important in emerging and developing economies, where electricity demand grows rapidly. In the APS, the global contribution of unabated coal-fired capacity to system adequacy declines by over 40 GW per year to 2050 and is replaced by a broad suite of technologies.

2.1 Policy approaches

It is the responsibility of governments to introduce new policies and reform existing ones to ensure that public and private actors in the power sector accelerate investments in clean energy and progressively reduce their use of coal in line with emissions targets, while minimising the economic and social costs. Broadly, there are three types of interventions available to policy makers that can be used alone or in combination to accelerate the transition away from coal-fired power generation by encouraging investment in clean energy, retiring coal assets early, repurposing coal plants from baseload operation to provide power system services and retrofitting existing plants with carbon capture, utilisation and storage (CCUS):

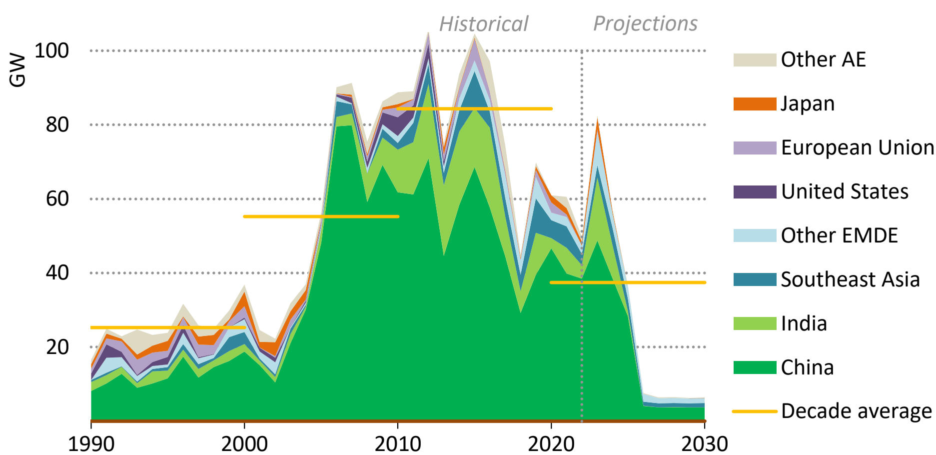
- Direct regulation, including reduced operations, a ban on the construction of new coal plants or mines, and the forced closure of a plant. Direct regulation is widely used in some countries, notably the People's Republic of China (hereafter, "China"), that have broad powers to impose sweeping changes on the economy. For example, China launched a drive in the 2010s to retire old coal stations and build new, more efficient ones. Regulations can also curb the operations of coal plants indirectly by regulating air quality.
- Financial incentives for owners to relinquish coal power plants or change the way they operate. They typically involve low-cost government debt such as securitised loans, debt purchases or loan guarantees. They are usually asset-specific and depend on the extent to which the asset is already depreciated and whether the cost of investing in an alternative clean energy technology yields a net financial benefit over the cost of continuing to operate the coal assets under existing market conditions and contractual arrangements. The most attractive targets for incentives from a policy perspective are assets which are not yet fully depreciated but for which replacement by a renewable energy alternative would immediately generate financial savings for consumers. In these cases, those savings can be used to pay back the upfront costs of the intervention, lowering the burden on taxpayers or ratepayers. Financial measures can also be used to encourage investment in clean energy.
- Market-based measures that make it less financially attractive to the owners of coal plants to continue high levels of unabated operation and favour competing clean energy sources. These include carbon pricing schemes and measures that reduce the revenues available beyond a limited number of operating hours through taxes, tenders or market rules. Auction-based capacity mechanisms, for example, can incentivise plant owners to reduce their operations in exchange for payments to remain online in case they are required by the system operator. Implementing electricity market reforms such as economic dispatch and must-run status for renewable energy projects can also boost the standing of low-emissions power sources in relation to coal.

Most countries currently rely primarily on financial and market-based measures to discourage coal-fired power generation and encourage investment in clean energy. In practice, the most cost-effective mix of policy approaches varies across countries depending on several factors, including the contribution of coal plants to overall electricity supply, ownership structures, electricity market rules, the maturity of capital markets, and other policies and political priorities.

2.2 Scaling up alternative low-emissions power sources

It will be possible to reduce reliance on unabated coal-fired power generation only if alternative sources of power are developed quickly enough to meet demand. In 2023, around 130 national governments including the European Union committed to collaborate to triple global installed renewable energy capacity by 2030, which would put renewable power capacity development in line with the Net Zero Emissions by 2050 (NZE) Scenario. Even under existing policies and market conditions, global renewable capacity is on a trajectory to reach about 2.5 times its current level by 2030 (IEA, 2023b). In the Announced Pledges Scenario (APS), the construction of unabated coal plants slows but does not stop by 2050. By 2027, capacity additions are set to fall to just over 6 gigawatts (GW) annually – far below that of any year over the last half a century (Figure 2.1). Beyond 2030, an average of 1.5 GW of new unabated coal plant capacity continues to be built each year through 2050 in the APS in countries that have not committed to phase out its use, mainly to replace old coal plants. In the NZE Scenario, the plants currently under construction are completed, but there are no further additions. In both scenarios, rising demand for electricity in all regions is met largely by a sharp increase in output from renewables and nuclear power.

Figure 2.1 ▷ Global coal-fired capacity additions in the APS



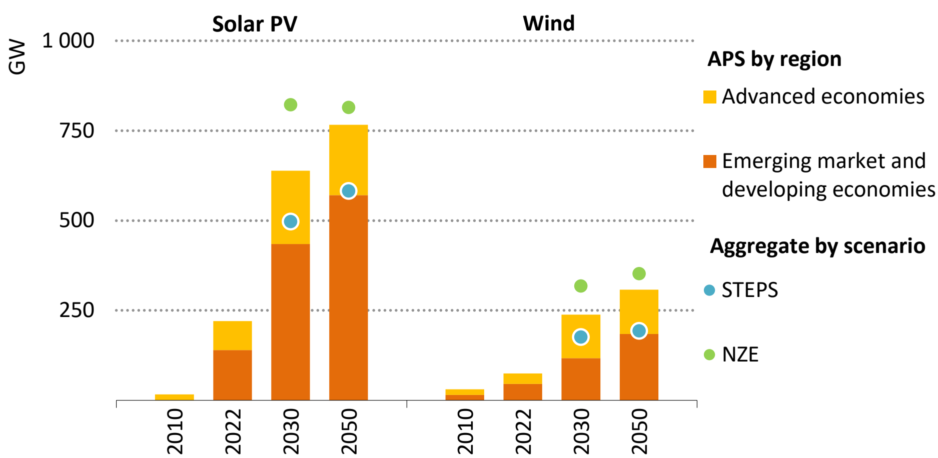
The construction of new coal plants, almost all of which are unabated, is set to slow rapidly in the late 2030s in all parts of the world under current policy pledges

Note: AE = advanced economies; EMDE = emerging market and developing economies.

Over three-quarters of the projected drop in global coal-fired generation between 2022 and 2030 in the APS is replaced by solar PV and wind, with another 11% replaced by hydropower and other renewables, 8% by nuclear power, and just 1-2% each of unabated natural gas, CCUS and hydrogen and ammonia. The limited role of unabated natural gas reflects the changing perceptions of that fuel following recent market volatility and supply concerns linked to Russia's invasion of Ukraine. By 2050, generation from existing unabated coal-fired power plants is less than 1 600 terawatt-hours (TWh), 85% lower than in in 2022, with other technologies replacing it in roughly the same proportions as in 2030, though the share of fossil fuels with CCUS rises to almost 5% as the technology advances in maturity.

The paths away from unabated coal differ between advanced economies and emerging and developing economies, but they share many elements. In the former, unabated coal-fired generation declines rapidly to 2030 in the APS and is replaced primarily by wind and solar PV, though a host of other sources also play a vital role. In the latter, it takes several years longer for the decline of unabated coal to take hold, with solar PV and wind emerging as the central replacements, with hydropower, nuclear power, other low-emissions sources and a small amount of unabated natural gas each also contributing.

Figure 2.2 ▷ Global capacity additions of solar PV and wind power by scenario



Solar PV and wind capacity additions triple between 2022 and 2030 in the APS to replace unabated coal and meet rising electricity demand

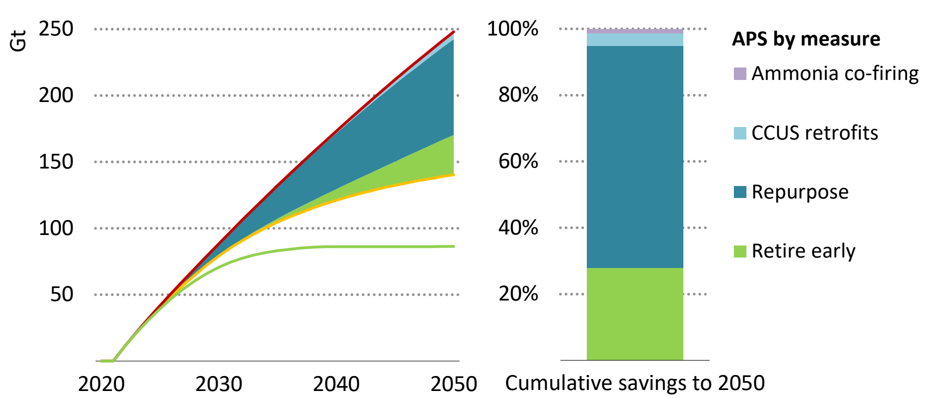
Solar PV and wind power dominate the replacement of coal-fired power because of their low costs and strong policy support, with measures in place in 174 countries as of 2022 (REN21, 2023). Building on the rapid growth of the past decade, global capacity additions of solar PV almost triple by the end of the decade in the APS, with 640 GW added in 2030 (compared with 220 GW in 2022), equivalent to more than half of all installed solar PV capacity today. Wind deployment also more than triples to add 240 GW in 2030 (compared with 75 GW in 2022) (Figure 2.2). Emerging and developing economies continue to account for the majority of solar PV and wind capacity additions, led by China, though Europe leads offshore wind deployment to 2030. The two technologies continue to scale up rapidly after 2030, with solar PV reaching 770 GW of additions and wind 310 GW in 2050. The NZE Scenario calls for a much faster scaling up by 2030, with additions reaching 820 GW for solar PV and 320 GW for wind power; that pace is broadly maintained through 2050. In both scenarios, the rapid expansion of solar PV and wind hinges on strong policies to incentivise investment in the installation of new generating capacity, as well as the development of robust supply chains with a diversity of market players at each stage (IEA, 2023a).

Rising penetration of wind and solar PV necessitates careful consideration of the effects of their variable output on the broader electricity system. In many cases, an increase in flexibility resources, including stronger grids, interconnections, demand-side measures, and dispatchable power and storage, will be necessary to ensure the smooth integration of these power sources into the system. Existing coal-fired generation assets can play a role in supplying system adequacy and flexibility resources by remaining available to produce electricity when system needs are highest, even if they no longer serve as a source of baseload power.

2.3 Tackling emissions from existing coal plants

There are four main ways of reducing emissions from existing coal-fired power plants: repurposing them to provide load balancing services rather than baseload power supply, retrofitting them with CCUS technology, retrofitting them to allow co-firing with low-emissions fuels such as ammonia or biomass, or retiring them early. In any case, the simultaneous development of sufficient alternative sources of power is a prerequisite to reducing emissions from coal plants. Were all the coal plants around the world to continue to operate as they do today until the ends of their normal operating lives, they would "lock in" cumulative emissions of nearly 250 gigatonnes (Gt) over 2023-2050. In the APS, they emit around 140 Gt, or 43% less, over the same period, with repurposing accounting for two-thirds of these reductions and early retirement for most of the rest (Figure 2.3). In the NZE Scenario, cumulative emissions level off at around 85 Gt soon after 2035 as all unabated coal plants are shuttered.

Figure 2.3 ▷ Global cumulative CO_2 emissions from existing coal-fired power plants by scenario



IEA. CC BY 4.0.

The fleet of existing coal-fired power plants could emit up to 250 Gt CO_2 by 2050, but there are several options to curb their emissions and keep the door open to 1.5° C

Note: Existing refers to plants in operation at the end of 2022. Repurpose refers to reducing power plant operations to focus on providing system adequacy or flexibility services instead of baseload power.

2.3.1 *Repurposing for flexibility*

Repurposing coal-fired power plants – reducing operations to focus on providing system adequacy (reserve capacity) or flexibility services – means that an unabated coal plant produces less electricity over a certain period but remains available for times when the system needs are highest, contributing to the reliability of power systems. By limiting the loss of revenue and jobs as well as the need for fresh investment, this may be an appealing alternative to outright closure for coal plant owners, the surrounding communities, electricity consumers and policy makers. Many plants are currently operated in a stable "baseload" mode, operating at close to full capacity most of the time, as coal is generally cheaper than gas or oil. In China, for example, the role of coal-fired power has shifted towards providing flexibility, and the average utilisation rate of the coal fleet has accordingly been dropping for years (S&P Global, 2023). Repurposing coal plants for flexibility usually requires minor equipment upgrades, changes to market designs and plant operations, and updates to contracts. Coal plants can generally run at partial load, producing a fraction of their maximum rated output, and can adjust output within minutes or hours.

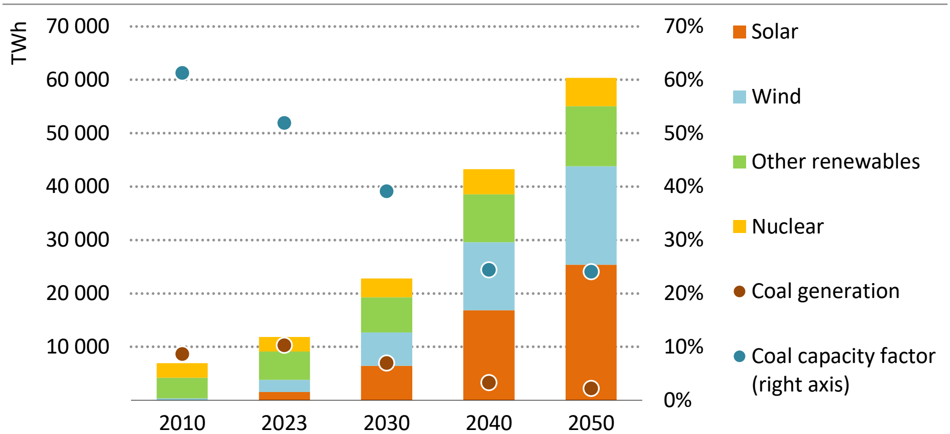
While repurposing for flexibility can lead to significant emissions savings, it can also generate financial challenges and accelerate the deterioration of plant equipment. Electricity supply contracts and system service provisions in electricity markets may also need to be reshaped to provide incentives for plant operators to switch to offering system flexibility services. Adjusting contracts to ensure that asset owners are not obliged to generate coal-fired power when cheaper electricity is available from low-emissions sources would also help to reduce both emissions and costs.

Larger targeted investments can further enhance the flexibility of coal plants. For example, retrofitting alternative boilers can lower the plant's stable minimum load, while upgrades to control systems and plant components can increase ramping speeds and allow plants to be operated at levels higher than their rated capacity for brief periods of time, though this may require more active roles for on-site staff. Other retrofit options, such as coupling the plant with battery energy storage, can further boost flexibility. They can also allow the plant to provide ancillary services such as fast frequency response or supplementary spinning reserves without burning additional fuel. Heat storage can be added to make coal co-generation plants more flexible.

There are several examples of repurposing of coal plants for flexibility that have led to lower coal use and lower emissions in both advanced economies and emerging and developing economies. In Denmark, where the rapid penetration of wind power in the generation mix has increased the need for flexibility and cut the need for baseload coal-fired generation, several co-generation plants have been repurposed through technical modifications to decouple output of heat and electricity by lowering minimum load and boosting maximum heat supply (Clean Energy Ministerial, 2018). In 2016, China launched a large flexibility retrofit programme involving 22 pilot projects (Liu et al., 2020). It doubled down on these efforts in the 14th Five-Year Plan for energy, increasing investments in flexibility from coal-fired power plants as well as battery storage and other dispatchable power sources and demonstrated ambition of retrofitting more than 200 GW of existing coal power to be retrofitted for flexibility by 2025 (National Development and Reform Commission of China, 2021).

Repurposing coal plants for flexibility is widely adopted in the APS because it enables the existing coal fleet to support and facilitate the integration of increasing shares of variable renewables. As a result, the average annual capacity factor[1] of the global unabated coal plant fleet declines from 52% in 2023 to below 40% by 2030 and 23% by 2050 in that scenario (Figure 2.4). In the NZE Scenario, unabated coal is phased down even more quickly, reducing the global capacity factor to less than 40% by 2030, under 20% by 2035 and zero by 2040. These reductions in operations yield large emissions savings, though they could create financial difficulties for plant owners depending on market design and the structure of pre-existing contracts. Ultimately, increasing alternate sources of low-emissions power must be the greatest priority, indeed a precondition, of repurposing the existing coal fleet for flexibility.

Figure 2.4 ⊳ Low-emissions power generation by source and average capacity factor of coal-fired power plants in the APS, 2010-2050



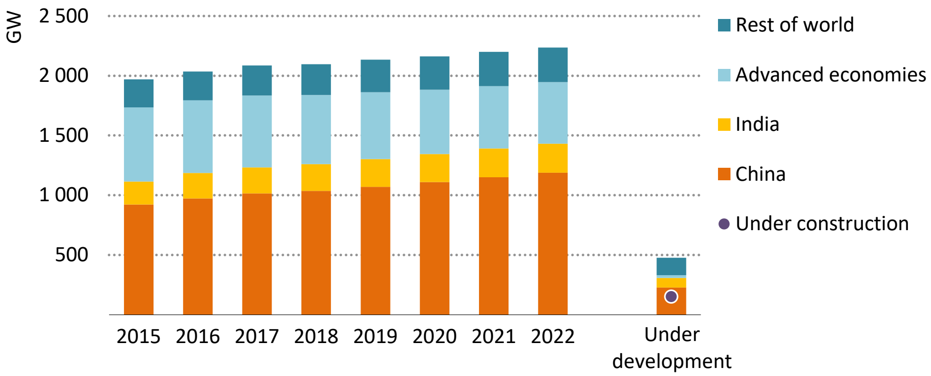
In the APS, the average capacity factor of the global coal fleet is more than halved by 2050 as clean power grows and coal-fired power plants reorient towards providing flexibility

An important consideration in all countries is the impact of the transition away from coal in power generation, including repurposing coal plants for flexibility, on the financial viability of power companies and the implications for the security of electricity supplies. There is a large amount of sunk capital in existing coal-fired plants that has yet to be recovered, especially in emerging and developing economies. There is a risk that some of this capital may not be recovered given government pledges to reduce coal burning and emissions, putting the financial stability of power companies and their ability to meet electricity needs in jeopardy (see section 3.1.2). This consideration also reveals the financial risks associated with constructing new coal capacity. If all coal-fired power plants currently under development

[1] Gross electricity generation divided by gross installed capacity.

are fully realised, these capacity additions will equal 20% of the existing fleet (Figure 2.5). However, less than one-third of this planned capacity has begun construction as of 2023.

Figure 2.5 ▷ Installed and planned capacity of coal-fired power generation by region, 2015-2022



IEA. CC BY 4.0.

Planned coal-fired capacity additions around the world are equivalent to 20% of the existing fleet, but less than a third of this new capacity has begun construction

Notes: Under development includes planned capacity additions and capacity already under construction as of 2023.

2.3.2 Retrofitting with CCUS

Retrofitting coal plants with CCUS provides a means to preserve existing assets, supply dispatchable electricity and help maintain grid stability while decarbonising coal use. CCUS technologies can be retrofitted to the entire facility or just part of it: the simplest form of retrofit involves rerouting the flue gas from a unit boiler through a CO_2 capture facility powered by heat extracted from the steam cycle or provided by an external heat source. More extensive modifications include conversion of the boiler to oxy-fuel combustion. In any case, plants selected for CCUS retrofits must have space available for additional on-site equipment, as well as solid transport links to manage captured CO_2. Operating a plant with CO_2 capture consumes a significant amount of energy, reducing net electricity output of the plant on average by around 20-25% for a given input of coal.

Only four commercial coal-fired power plants have been retrofitted with CCUS at a large scale to date: the Boundary Dam facility in Saskatchewan, Canada, the Petra Nova plant in Texas, United States, and two China Energy coal plants in China. The Boundary Dam CCUS project has been operating since 2014 and has a capture capacity of around 1 million tonnes (Mt) of CO_2 per year. The Petra Nova facility, which started operating in December 2016, has a capacity of 1.4 Mt CO_2/year.[2] In both cases, the captured CO_2 is used for enhanced oil recovery (EOR).[3] China Energy commissioned a 0.15 Mt CO_2/year demonstration plant at the Guohua Jinjie Power Plant in 2021. There are also plans for around 15 new projects at various

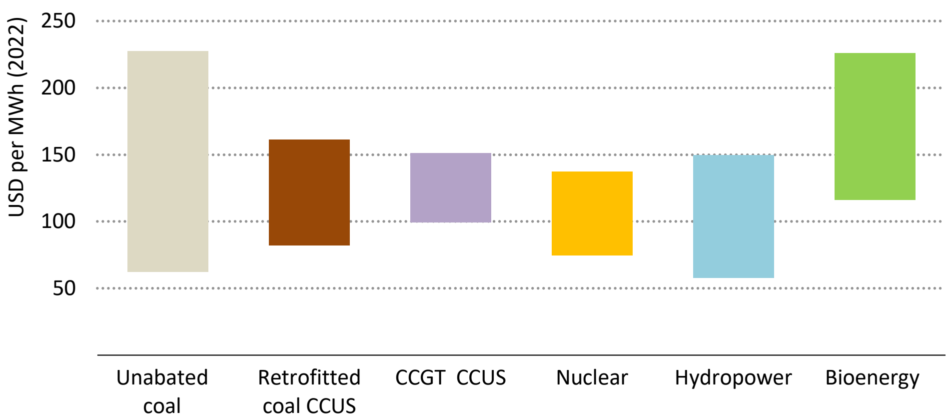
[2] Capture operations at Petra Nova were suspended in May 2020 as a result of the low oil prices associated with the economic impact of the Covid-19 pandemic but restarted in September 2023.

[3] While most of the CO_2 injected for EOR can be retained in the reservoir over the life of the project, additional monitoring and verification is required to confirm that the CO_2 has been permanently stored.

locations around the world. All but one of them are retrofits of existing coal plants, of which almost three-quarters are located in China or the United States, with tax credits providing up to USD 85 per tonne of CO_2 stored in the latter. If all planned projects proceed, global capture capacity from coal plants would reach around 28 Mt CO_2 in 2030.

The prospects for CCUS depend critically on costs. Capital costs make up the bulk of the cost of the first-generation CCUS retrofits at coal plants in operation today. Those costs are expected to fall as deployment expands, to around USD 1 million-USD 3 million per megawatt (MW) in 2030, yielding a levelised cost of electricity (LCOE) – the average net present cost of electricity generation over the lifetime of the asset including capital, operating and maintenance costs – of between USD 80 per megawatt-hour (MWh) and USD 160/MWh, including the efficiency penalty (Figure 2.6).[4] At this cost, coal plants with CCUS could be competitive with other dispatchable low-emissions sources, such as bioenergy or nuclear, in many markets. CCUS retrofitting may be a particularly attractive option to keep plants close to active coal mines in operation, thereby maintaining mining jobs and supporting mining communities. In the case of recently built plants, retrofitting with CCUS may be a compromise to avoid the closure and near full write-off of a plant.

Figure 2.6 ⊳ Levelised cost of electricity for selected dispatchable low-emissions generating technologies in the APS, 2030



The cost of retrofitting coal plants with CCUS is roughly on par with most other dispatchable low-emissions sources of electricity and can be cheaper than unabated coal

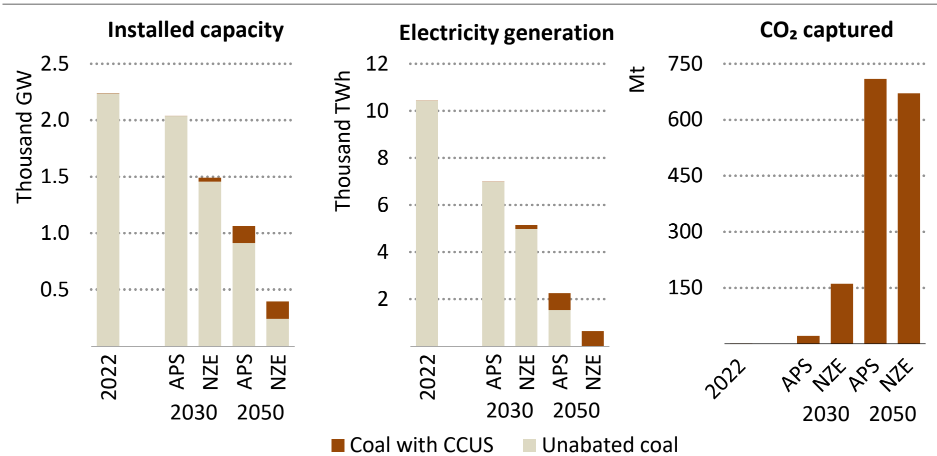
Notes: MER = market exchange rate; CCGT = combined-cycle gas turbine. Technology costs include the cost of emissions, with CO_2 prices reaching up to USD 135 per tonne in 2030. Retrofitted coal CCUS includes the capital and operating costs of the unabated coal plant and the CCUS retrofit.

[4] The efficiency penalty depends on the capture technology used. Additional operating expenses relate to the use of solvents, chemical reagents and catalysts, the disposal of waste products, and the additional staff needed to run the CCUS facilities.

The total capacity of coal power plants with CCUS worldwide in the APS increases marginally over the next five years and expands rapidly thereafter. By 2030, coal plants with CCUS provide 4 GW of capacity and generate around 22 TWh while capturing 22 Mt CO_2 (Figure 2.5). By 2050, over 150 GW of coal plants are equipped with CCUS, almost 75% in China, generating over 700 TWh and capturing about 700 Mt CO_2. In the NZE Scenario, the deployment is faster, with 36 GW of coal plants equipped with CCUS by 2030, generating 156 TWh and capturing over 160 Mt CO_2. By 2050, over 150 GW of coal-fired capacity is equipped with CCUS, generating about 640 TWh by 2050 and capturing 670 Mt CO_2. The contribution in 2050 is slightly lower in the NZE Scenario than in the APS due to a much shorter window of opportunity to deploy CCUS retrofits, as the electricity sector is fully decarbonised by 2040.

Higher CO_2 capture rates will become increasingly important in the transition to net zero emissions electricity systems. CCUS power plants operating today capture around 90% of the CO_2 from flue gas, but future plants could be designed to capture 99% or more. While there are no technical barriers to increasing capture rates beyond 90% for the most mature capture technologies, a better understanding of the modifications and associated costs is needed.

Figure 2.7 ▹ Global coal-fired power generating capacity, output and CO_2 capture by scenario



IEA. CC BY 4.0.

Coal capacity equipped with CCUS reaches over 150 GW in 2050 in the APS, generating over 700 TWh of electricity and capturing about 700 Mt of CO_2

2.3.3 Co-firing with clean fuels

Co-firing low-emissions ammonia or biomass in conjunction with coal is another option to cut CO_2 emissions from coal-fired power plants. In addition to lower emissions, co-firing offers valuable system benefits as a source of dispatchable power, which becomes increasingly important for system stability as the share of variable renewables in the electricity generation mix increases. Traditional coal-fired power plants have been used for co-firing with biomass for decades, notably in India, the United Kingdom and the United States, but recent advances in fuel mixing allow for the blending of ammonia as an alternative secondary fuel. As with biomass, using ammonia can reduce emissions, provided it is made from low-emissions sources.

Ammonia co-firing technology is at an early stage of development. The viability of 1% blending of ammonia has already been successfully demonstrated at a commercial coal plant (Box 2.1). For blends of up to 20% ammonia, the retrofits required mainly involve modifications to the burners, as well as the installation of on-site ammonia storage tanks, vaporisers and injection systems (JERA, 2021). Plants selected for ammonia co-firing need to have additional space available for added on-site equipment, access to a reliable supply of ammonia and good transport links. The high cost of transporting ammonia means that plants located near import terminals or inland transportation hubs are best suited for co-firing.

Box 2.1 ▹ Co-firing with ammonia in Japan

In 2017, Japanese utility Chugoku Electric Power successfully demonstrated the technical viability of blending 1% of ammonia into the coal inputs at its Mizushima power plant. Now, the Japanese power company JERA (a joint venture between Tokyo Electric Power and Chubu Electric Power), in partnership with the power technology company IHI, plans to begin 20% blending at a 1 GW unit at the company’s Hekinan coal plant have been brought forward to fiscal year 2023/24, marking the world's first trial in which a large amount of ammonia will be co-fired with coal at a sizeable commercial plant. A sales agreement covering the supply of ammonia with Mitsui was concluded in June 2023 to ensure adequate availability of the fuel. The Japanese governments sees co-firing and mono-firing of ammonia as a way of reducing emissions in pursuit of the national goal to achieve net zero greenhouse gas emissions by 2050, while simultaneously extending the lives of the country’s coal plants. However, as ammonia is anticipated to remain more expensive than coal as well as other sources of low-emissions power for the time being, generation is likely to be competitive only at the highest value times when renewables are least able to satisfy total electricity demand.

As with ammonia, biomass co-firing involves substituting a portion of the coal with biomass. Much higher percentage blends are already technically possible than for ammonia, in some cases exceeding half of the fuel mix. The share of biomass blended with coal in power plants today is mainly dependent on price and availability of sustainable biomass supply. Agricultural and forestry residues that may otherwise be burned without any benefit offer a pragmatic solution, but the size of a typical coal plant means that it can be difficult to find the quantities of sustainable biomass nearby needed for high blending rates or full conversion to biomass. For example, a 1 GW wood-fired power plant with a capacity factor of 70% and conversion efficiency of 35% would require an annual harvest of plantation growth equivalent to approximately 3 300 square kilometres (Smil, 2010). The Drax coal-fired power station in the United Kingdom, which began co-firing of biomass in 2003, is a leading example. The proportion of biomass in the fuel mix has increased over time, with coal burning halted entirely in 2023. Plans are in place to convert the plant into a bioenergy with carbon capture and storage (BECCS) facility to generate negative emissions by permanently removing CO_2 from the atmosphere.

The potential for co-firing inevitably depends largely on cost, which hinges in each case on carbon pricing, relative fuel costs and retrofit costs, as well as on the success of cost-reducing innovation. Ammonia and, in some cases, biomass can cost significantly more than coal, though carbon penalties may in some cases be high enough to offset the higher fuel cost and yield a return on investing in plant modifications. In practice, uncertainty about future fuel costs and carbon penalties may impede financing.

2.3.4 Retiring plants and converting sites

Another option to cut emissions from unabated coal-fired power plants is simply to retire them before they reach the end of their technical lifetimes, and potentially convert the site to another use. The technical lifetime of a coal plant is generally 40-50 years, though its economic lifetime – the period over which the capital invested is expected to be recovered – is usually 20-30 years. As coal plants age, asset owners face decisions about whether to invest in refurbishments, creating opportunities for policy makers and financial institutions to encourage early retirements.

Of all the coal plants worldwide operating today, only one-quarter, or about 500 GW, will have reached 50 years of operations by 2040. If lifetimes were shortened to 40 years, another 240 GW of capacity would be retired by then, 80% in Asia Pacific. This approaches the amount retired in the APS in line with planned phase-outs and early retirements of uneconomic units. If all coal plants were shut after 25 years of operations, then about 80% of the existing fleet would be retired by 2040, leaving just over 300 GW in operation in 2040. Continued coal capacity additions in recent years are responsible for the lingering operations, even with shortened lifespans: 50 GW of new coal-fired generation capacity was added in 2022, with additions in 2023 likely to have surpassed this number. Early retirement is likely to be more economically and politically feasible in advanced economies, where coal plants tend to be older, and the cost more easily absorbed. Since 2010, coal power plant retirements worldwide have averaged around 25 GW each year, largely as a result of the closure of ageing plants in Europe and the United States in the face of declining competitiveness, increased regulation in the form of pollution limits and carbon taxes, and increased competition from renewable energy sources and natural gas. In some cases, retirement is a necessary consideration to limit the costs of keeping many coal plants online at lower utilisation rates.

A coal power plant contains a variety of useful assets, which can make the reconversion of the site for a variety of electricity-related or industrial applications an attractive option (Box 2.2). Those assets include the boiler, the water/steam and cooling systems, the turbine/generator and transformer, and equipment for handling materials. The land on which the plant is located and its grid connection are also valuable assets, as are a skilled workforce, auxiliary industry and services developed around the plant, the licence to operate, and the support of the local community. For example, a coal boiler could be reused for thermal energy storage: when surplus variable renewables-based electricity supply is available, electricity can be converted to heat in the form of steam or hot water and stored, to provide ancillary services as and when required for grid stability. Another option is to reuse a former coal plant site as a brownfield site for alternative electricity generating technologies, such as nuclear power plants based on small modular reactor (SMR) technology.

There is considerable potential for converting existing coal-fired power plants to other energy uses, including electrical battery or thermal storage and SMRs. The possibility of converting such plants to other uses should be assessed before any decision to close them. The financial viability of doing so in each case hinges on the strength of policy support. For example, a number of projects are under way in the United States, including a plant in Illinois that is being converted to a battery storage facility for locally produced renewable power, one in Louisiana that closed in 2021 and is now being converted to a solar farm, and a huge battery storage facility now being built with Tesla Megapack batteries near a former coal plant in Hawaii. All of these projects are benefiting from the provisions of the Inflation Reduction Act of 2022, which extended existing tax credits for wind and solar power and introduced a new credit for batteries. The law also offers loans to reinvest in communities with old infrastructure, including support for the shift to clean energy. TerraPower and GE-Hitachi have selected the retiring Naughton coal power plant in Wyoming as the site for their Department of Energy-backed advanced nuclear reactor demonstration project, citing the community's skilled coal workforce and existing energy infrastructure as primary motivations for their site choice.

Policy and regulatory support will be particularly crucial in the case of SMRs – an emerging technology – in order to stimulate innovation and their commercialisation (IEA, 2022). This support needs to go beyond funding of research and development and demonstration projects. Adapting and streamlining licensing and regulatory frameworks to take account of the unique safety features of SMRs is an important element. Enhancing regulatory processes, including the harmonisation of licensing processes across countries, could greatly improve the future competitiveness of SMRs by facilitating the emergence of a global market, which could take full advantage of the economies of scale of large-scale production of individual reactors. Policy makers also need to look at ways of mitigating risks for technology and project developers. As with large-scale nuclear projects, the cost of capital, which reflects risk allocation and mitigation decisions, is expected to remain a key driver of the competitiveness of SMRs. Both public and private financing will be required as SMRs move from the demonstration stage to commercial deployment.

Box 2.2 ▹ Converting the site of a coal power plant to other energy uses

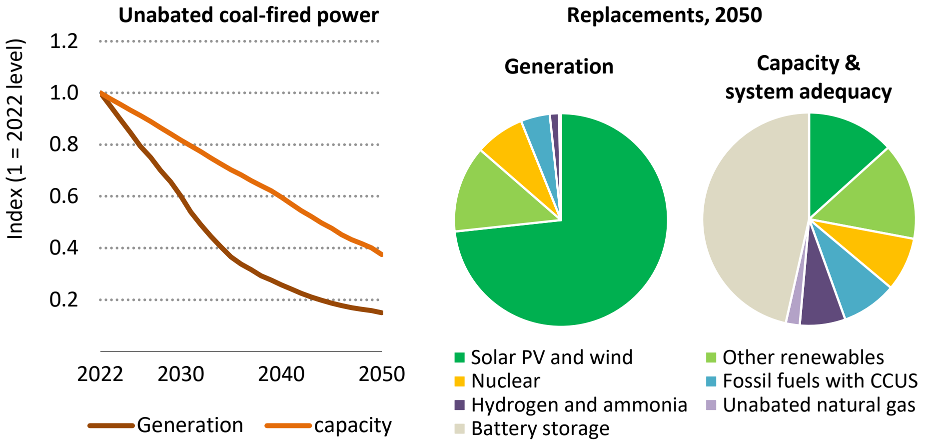
A growing number of coal station sites around the world are being converted to alternative energy uses. In South Africa, for example, the state-owned power company, Eskom, is converting its previously mothballed Komati power plant into a renewable generation site – one of the world's largest-ever coal-fired power plant repurposing projects – involving the installation of 150 MW of solar, 70 MW of wind and 150 MW of battery storage capacity. As part of the project, which is being implemented under the country's Just Energy Transition Strategy, the Komati Retraining Facility is being developed to reskill, retrain and upskill Eskom employees and members of the local community (see Chapter 4). In Ontario, Canada, a 44 MW solar facility has been built on the grounds of the retired Nanticoke coal plant, making use of the existing transmission switch yard to connect to the grid.

2.4 Ensuring electricity security

The system services provided by coal-fired power plants, as well as their electricity output, need to be replaced as the transition away from unabated coal progresses in order to ensure the security of electricity supply. Coal plants contribute to the adequacy of power systems by ensuring that electricity supply is sufficient to meet demand at all times throughout the year. This is particularly important in emerging and developing economies, where electricity demand continues to grow rapidly. They also contribute to system flexibility by being able to adjust output in hours or, in some cases, minutes to match supply and demand, and support grid stability by providing inertia – the energy stored in large rotating generators and motors, as they continue to rotate or spin for a while after the energy input has ceased.

In the APS, the global contribution of unabated coal-fired capacity to system adequacy declines by over 40 GW per year to 2050 and is replaced by contributions from a broad suite of technologies. Demand response – encouraging customers to shift electricity demand to times when electricity is more plentiful or other demands are lower, typically through prices or monetary incentives, in order to balance the system – becomes increasingly important in all scenarios to provide system flexibility and to reduce peak demand, thereby limiting system adequacy needs. To then meet those needs, battery storage is the primary replacement for coal, making up just under half of the total in 2050, followed by hydropower and other dispatchable renewables (15%), solar PV and wind (13%), nuclear, fossil fuels with CCUS, and hydrogen and ammonia (7-8% each) and new unabated natural gas-fired capacity (2%) (Figure 2.6). Solar PV and wind contribute less to replacing coal in terms of system adequacy and other system services than to replacing electricity output from coal.

Figure 2.8 ▷ Replacements for unabated coal-fired power capacity's contribution to system adequacy by region in the APS



Battery storage is the largest single replacement for coal's contributions to system adequacy, flexibility and grid stability, complemented by other dispatchable technologies

Both advanced economies and emerging and developing economies rely heavily on batteries to replace coal's contributions to system adequacy, as well as system flexibility and stability, in the APS. Global battery storage deployment grows more than ten-fold between 2022 and 2030 to 70 GW, with most of the growth occurring in advanced economies. The market for batteries continues to expand after 2030 in all regions: it exceeds 160 GW in 2040 (including replacements) and 200 GW in 2050. In the NZE Scenario, battery storage expands even faster to help replace system services from coal, with capacity additions reaching 140 GW in 2030 and close to 300 GW by 2040. This topic will be explored further in the IEA's upcoming special report on batteries. The relative importance of other dispatchable technologies to replace coal varies between advanced economies and emerging and developing economies in both scenarios. The former rely more on blending hydrogen in gas-fired power plants, particularly in the United States, Japan and the European Union, while the emerging and developing economies rely more on blending ammonia in coal plants, hydropower and other renewable sources, and unabated natural gas plants. CCUS retrofits of coal-fired power plants also play a significant role in those countries, notably China.

Financing the shift away from coal

Who will foot the bill?

SUMMARY

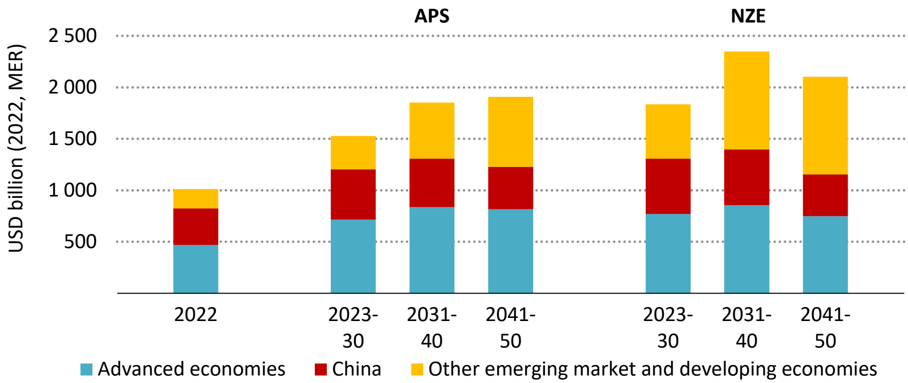
- Clean energy investment must be scaled up massively and urgently to enable coal transitions. In the APS, global investment in low-emissions power averages around USD 960 billion per year from 2023 to 2030 – around 30% of total energy investment, up from 25% the last few years. The substantial capital invested in existing coal plants that has yet to be recovered from operation revenues is potentially a major barrier to coal transitions, especially in emerging and developing economies, as under-recovery presents risks to the financial stability of stakeholders.
- For many countries, raising debt and attracting the financing required to invest in clean energy, pay for retrofits or retire coal assets early has become much harder in recent years due to cost inflation, rising borrowing costs and the dislocation of global supply chains. In emerging and developing economies, private finance will need to play a key role in decreasing coal power given constraints on public budgets. Phasing out older coal plants will be necessary to secure these investments, though honouring existing contracts remains important to avoid spooking the market. In the APS, over half of funding from 2023-2030 is from the private sector, 35% from state-owned enterprises and 15% from other public funds.
- Policies to facilitate the financing of clean energy must go hand in hand with measures to restrict the financing of the construction of new coal plants, as well as investments in existing ones. New coal plants continue to be built in some countries, notably China. Several governments and financial institutions have announced policies to restrict or prohibit financing for coal power projects and investments in recent years, including China's halt to all financing for new overseas plants in 2021. However, any such policies must ensure that there is no disruption to security of electricity supply, which remains the ultimate priority throughout the coal transition.
- Bringing forward the retirement of both existing and yet-to-be built coal-fired power plants and their replacement with clean generating technologies will need to play an increasingly important role in lowering emissions in those countries where coal still accounts for a significant share of the generating mix. Over 2023-2030, around 20 GW of coal power plants operating today are retired before they reach 30 years, of which about 50% are retired before the age of 20, in the APS.
- There is no single blueprint to phase out coal-fired generation; any action must be tailored to the age and type of coal plants, as well as to the varied market structures within which they operate. The many options include nationalising or buying out plants to retire them; creating mechanisms to monetise saved emissions; funds to compensate owners of retired plants; securitisation; accelerated depreciation; and concessional debt or refinancing mechanisms.

3.1 Investment needs

3.1.1 Clean power sector investment

Investment in clean power sector technologies needs to be scaled up massively and urgently to replace coal plants worldwide. In the Announced Pledges Scenario (APS), average annual clean power investment jumps from around USD 1 trillion (in 2022 dollars) in 2022 to USD 1.5 trillion in 2023-2030 and over USD 1.8 trillion in 2030-2050. Around half of the investment over the rest of the current decade immediately yields zero-emissions reductions; the other half consists of contingent and incremental investment, mostly in grid infrastructure such as battery storage, that yields emissions reductions progressively as clean generating technologies are adopted. In both the APS and the Net Zero Emissions by 2050 (NZE) Scenario, the bulk of investment needs in clean generating technologies over 2023-2050 are in emerging market and developing economies (Figure 3.1).

Figure 3.1 ▻ Average annual investment in clean power sector technologies by region and scenario

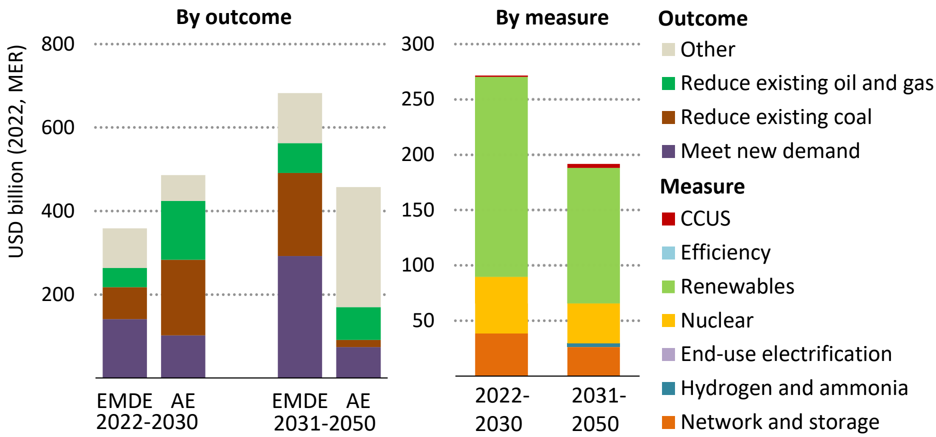


In both the APS and the NZE Scenario, the bulk of investment in clean power technologies over 2023-2050 is needed in emerging and developing economies

Note: MER = market exchange rate; other emerging and developing economies = emerging and developing economies excluding China.

The bulk of investment in clean power sector technologies in the APS is needed to meet new demand for electricity in emerging and developing economies, while most of the remainder displaces fossil fuels, predominantly coal-fired (Figure 3.2). That investment enables global CO_2 emissions from coal-fired generation to fall from 15 gigatonnes (Gt) in 2021 to 12 Gt in 2030, i.e. around USD 32 of investment for each tonne of emissions saved – one of the cheapest ways of bringing down emissions in the energy sector. The investment cost to 2050 is of a similar magnitude with continuing declines in the cost of solar PV, wind and other renewables. Around USD 260 billion per year is needed over 2023-2030 to replace the use of unabated coal with low-emissions sources, primarily wind and solar PV (including associate investments in networks and battery storage). Capital spending somewhat falls after 2030, as scale and technological learning effects cut the costs of adding renewables and deploying flexibility tools such as storage to balance power grids.

Figure 3.2 ▻ Average annual investment in clean power sector technologies to replace coal by region, outcome and measure in the APS



IEA. CC BY 4.0.

Both the advanced and emerging economies need to invest much more in meeting new energy demand than cutting coal use

Notes: AE = advanced economies; EMDE = emerging market and developing economies. Other includes capital spent to maintain transmission and distribution networks and investments in electrification and energy efficiency that are unrelated to fossil fuel transitions.

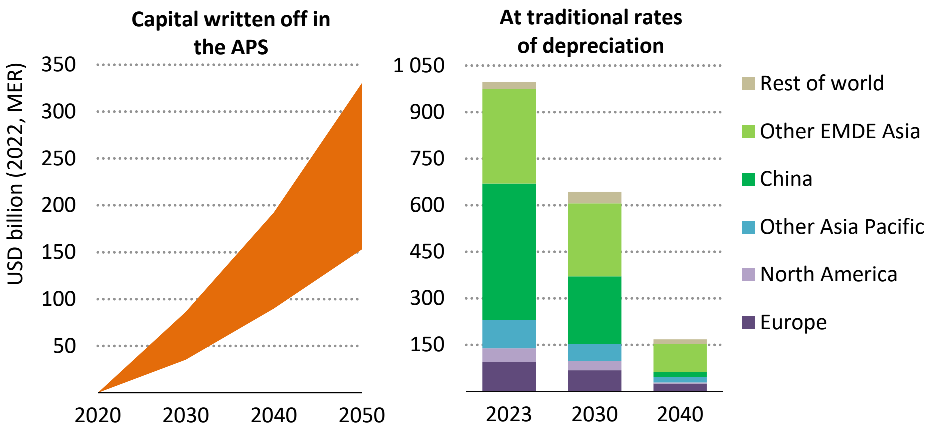
3.1.2 Unrecovered capital risks for coal plants

The large amount of capital invested in existing coal-fired power stations that has yet to be recovered through the revenues obtained from operating those assets is potentially a major barrier to the transition away from unabated coal use, especially in emerging and developing economies. Investors in over 1 400 gigawatts (GW) worth of plants, accounting for close to 70% of the world's coal-fired power fleet, have yet to recoup over USD 1 trillion (in 2022 dollars) of invested capital (Figure 3.3). Over 40% of this unrecovered capital is in the People's Republic of China (hereafter, "China") and 35% in other emerging and developing economies. At traditional rates of depreciation, this would drop to USD 640 billion by 2030 assuming none of them are retired before the end of their normal economic lifetimes.[1] Given that

[1] The period over which plant owners or investors may expect to receive income from the operation of the plant in the form of cash flows or dividend payments that cover the initial invested capital and an expected

many governments have pledged to reach net zero emissions and have committed to phase out their use of unabated coal, implying the early retirement of some plants, some of this capital may never be recovered, presenting a risk to the financial stability of stakeholders.

Figure 3.3 ▷ Unrecovered capital from the existing global coal-fired power plant fleet



Unrecovered capital in coal-fired plants could reach as much as USD 90 billion in 2030 and USD 270 billion in 2050 if current policy pledges are met

Note: The range in the right-hand chart represents differences in the assumptions about the weighted average cost of capital (5% to 10% in real terms) and utilisation rates.

The potential for capital under-recovery from coal plants is very sensitive to the pace of the transition away from unabated coal, as well as the cost of capital. In the APS, the amount of capital that is written off (i.e. never recovered) is relatively modest, as the majority of the 1 300 GW of coal capacity that are retired between 2022 and 2050 would have operated for at least 30 years – the typical economic lifetime of coal plants. In advanced economies, only around 25 GW of capacity is retired before reaching 20 years of operation, and another 50 GW are retired after operating for less than 30 years. In emerging and developing economies, more coal capacity is retired early, but it still represents a small share of the total coal capacity installed today. Because most coal plants in this scenario are retired after their economic lifetimes, total capital written off by 2030 represents a modest 4-8% of the total remaining capital to be recovered worldwide as of today. The bulk of the capital written off in 2030 is in advanced economies, where rapid transitions drive down capacity factors for unabated coal plants sharply, significantly reducing the ability to recover capital over the remaining lifetime of these assets. By 2050, emerging and developing economies account for

return (based on the asset-level or firm-level weighted average cost of capital). Economic lifetimes hinge on the annual rate of capital recovery, which can vary depending on plant utilisation rates and profitability.

most of the capital written off, as post-2050 climate policy pledges force the early retirement of a growing number of recently built plants. This analysis demonstrates the importance of halting the construction of new coal plants as soon as possible, both to limit emissions and to reduce the risk of large financial losses later on.

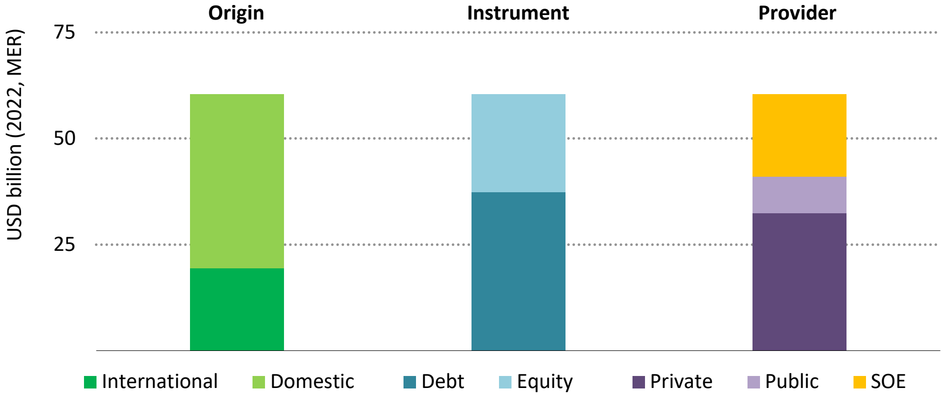
3.2 Sources and types of finance

Financing the coal transition requires a policy approach that is integrated into broader energy and developmental goals and tailored to national circumstances. There are a number of interlocking elements that must be co-ordinated and sequenced so as to reduce emissions from existing coal-fired assets, while ensuring that the energy services provided by them are effectively provided by other means and that the social implications of change are addressed (see chapter 4).

Many of the key clean energy technologies that can replace coal are already very cost-competitive, but accelerating the transition away from the most polluting assets calls for adequate financing. For many countries, especially emerging and developing economies, raising debt and attracting the financing required to invest in clean energy, pay for retrofits or retire coal assets early have become considerably more difficult in recent years as a result of cost inflation, rising borrowing costs and the dislocation of global supply chains. Public finance, together with policy incentives and international collaboration, are indispensable to overcome these hurdles. Some financing tools are tried and tested, especially those aimed at building clean energy infrastructure. But other approaches are new, notably how to deal with the owners of emissions-intensive assets to change the way that they operate, or to retire them early. In practice, there may be difficult judgement calls to be made about how this support is structured and implemented so as to secure reductions in emissions without unduly compensating entities for their earlier investment in polluting technologies.

Private sources of finance will need to play a leading role in moving away from coal in the power sector in emerging and developing economies given constraints on public budgets. Of the USD 60 billion per year of investment needed on average until 2030 in the APS, over half comes from the private sector, 30% from state-owned enterprises (SOEs) and the rest from other public funds (Figure 3.4). The share of the public sector (including SOEs) is nonetheless higher than in the advanced economies, largely because investment in grids and energy storage, which are typically the responsibility of SOEs, form a large part of the total capital outlay to support the transition from coal to renewables in the power sector. Almost one-third of the capital required comes from international sources in the APS, including foreign project developers, international commercial banks and public finance, including multilateral development banks (MDBs). This share – amounting to almost USD 20 billion per year – may in fact underestimate the importance of international support, as much of the domestic capital raised would rely on the catalytic role of foreign investment. A relatively large share of capital spending is financed through raising debt. In view of rising debt-to-GDP ratios and interest rates, as well as an unfavourable macroeconomic environment in many emerging and developing economies, new clean energy projects will need to be based on strong financial fundamentals.

Figure 3.4 ▷ Average annual investment in cutting emissions from coal-fired power plants in emerging and developing economies by origin, instrument and provider in the APS, 2023-2030

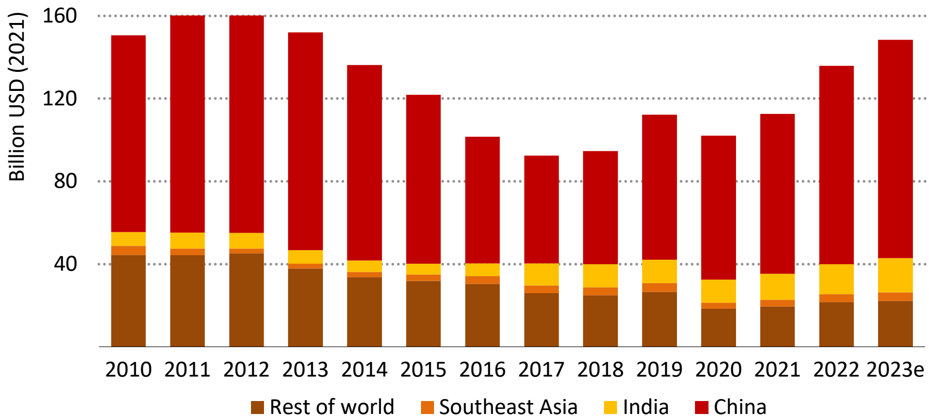


Private sources of finance, catalysed by public spending and international funds, will need to play a key role in moving away from power in emerging and developing economies

3.3 Policies to restrict financing of coal plants

Policies to facilitate the financing of clean energy must go hand in hand with measures to restrict the financing of the construction of new coal plants, as well as investments in existing ones. New coal plants continue to be built in some countries, notably China, where 40 GW of capacity received a final investment decision in 2022, with this number expected to grow in 2023. The number of final investment decisions on new plants worldwide have, nonetheless, dropped sharply since 2015 and overall investment remains below levels seen in the early 2010s (Figure 3.5). Until recently, financing was typically made on a utility balance sheet with a high proportion of equity, but it now relies more on project finance with higher levels of debt. In aggregate, nearly 60% of coal investments over the past seven years have been debt financed, mainly through domestic sources, with SOEs providing the bulk of funding. In most cases, capital is recovered through regulated tariffs or, in the case of most independent power producers (IPPs), indexed prices under long-term contracts.

Figure 3.5 ▹ **Global investment in coal supply, 2010-2023**



Investment in coal supply has risen since 2020 as a result of the post-pandemic economic recovery, the war in Ukraine and a near-term focus on energy security in China

Note: 2023e = estimated data for 2023.

A number of governments and financial institutions have announced policies to restrict or prohibit financing for coal-fired power projects and investments in recent years. Many major economies have developed sustainable finance guidelines, though not all preclude domestic financing of coal (Table 3.1). A key move was the decision by the Chinese government to halt all financing for new overseas coal plants from September 2021. Almost all the MDBs and export credit agencies have also announced restrictive lending criteria or outright prohibitions on financing coal-related projects. In addition, many institutional investors, pension funds, banks, insurance companies and other financial institutions have committed to reduce or end their involvement in coal. For example, many large institutional investors have signed the Powering Past Coal Alliance Finance Principles, which consists of a series of restrictions aimed at phasing out coal for power in Organisation for Economic Co-operation and Development (OECD) countries and the European Union by 2030 and no later than 2050 in the rest of the world (PPCA, 2023). Commitments by banks to reduce their involvement in coal primarily take the form of lending restrictions together with broader efforts to decarbonise their loan books and increase the portion allocated to “green” assets. While the full effects of these commitments have not yet materialised and given that coal capacity and demand continue to increase to unprecedented levels, it is crucial that these “divestment” decisions are coupled with heightened investments in clean energy to mitigate any potential threats to energy security.

In bond markets, many capital providers have opted for sustainable issuances as they seek to reduce fossil fuel lending unless it is associated with achieving sustainability targets. This is particularly the case in Europe, where sustainable finance regulations are most advanced. In equity markets, some institutional investors have tended either to divest their stakes or to use their ownership to engage with the company and seek strategy changes. In practice, a combination of both active stakeholder engagement and selected divestment may prove most effective, along with a series of other coal phase-out financing mechanisms (see next section). However, such moves are unlikely to impact coal projects that are underpinned by domestic finance, including SOEs, which account for almost 60% of coal investments globally and nearly 90% in China. Institutional investors are generally involved with SOEs only through either international bonds issued by the companies or sovereign bonds. Applying restrictions on bond purchases that are linked to fossil fuel use may reduce available capital or push up the cost of capital to SOEs, but otherwise financial institutions and institutional investors have limited ability to influence the strategy of SOEs, instead requiring policy intervention to affect investment decisions.

Table 3.1 ▹ Policy restriction on financing and financial products of coal-fired power plants in selected countries and regions

Country	Target	Regulations and initiatives
Canada	Phase out coal power by 2030	In October 2021, Canada, along with other OECD nations, agreed to end export credits for unabated coal-fired power plants. The government of Canada is undertaking the next steps to develop a taxonomy that is aligned with reaching net zero by 2050.
China	No financing for new overseas coal plants from September 2021	The latest version of the Green Bond Endorsed Project Catalogue (often referred to as China's green bond taxonomy) recently removed investment in clean coal, i.e. supercritical coal technology. Green credit guidelines do not include coal.
European Union	Reduce CO_2 emissions by 55% from 1990 levels by 2030	The European Investment Bank ended financing for traditional fossil fuel energy projects, including coal, at the end of 2021, making it the first international finance institution to formally discontinue financing for fossil fuel projects. The European Union's sustainable taxonomy entered into force in 2020.
Germany	Phase out coal in electricity generation by 2038	In 2019, German state-owned development bank KfW expanded its existing policy to not finance new coal power plants, ending financing of all coal-related activities including mining, transport, power and heat. The bank also placed limitations on financing of grids that have a significant share of coal-generated power feed-in unless located in a region with an ambitious climate strategy.
India	Half of installed power capacity to come from non-fossil fuel sources by 2030	The government is currently working on a sustainable taxonomy. Indian financial institutions often report their carbon emissions and increasingly their carbon risks, but coal is rarely excluded from funding.
Japan	Phase out inefficient thermal coal plants	Japan agreed to end new direct government support for unabated international thermal coal power generation by the end of 2021 and proposed a phase-out plan for inefficient thermal coal power plants in the period to 2030. The energy ministry published guidance about climate transition finance in 2021. It also published Green Bond Guidelines in 2017 which include a non-exhaustive list of bond uses.

Country	Target	Regulations and initiatives
Korea	Phase out coal in electricity generation by 2050	Public banks, including the Exim bank, must abide by government plans to phase out coal by 2050, but currently there are no fixed coal financing restrictions in place. The environment ministry published a national green taxonomy guideline in December 2021, but it is not legally binding.
United Kingdom	Phase out coal power plants by 2025	The government has proposed a series of regulations similar to those agreed upon in the European Union, including on sustainability disclosure and a green taxonomy. The United Kingdom agreed to stop providing export credits for unabated coal-fired power plants in October 2021.
United States	Reduce greenhouse gas emissions 50-52% from 2005 levels by 2030	The approach to coal financing varies by state. At the federal level, the government ended export credits for unabated coal-fired power plants in October 2021 before banning government financing of overseas unabated coal projects altogether in December of the same year. In April 2022, the Securities and Exchange Commission published proposed regulations related to environment, social and governance disclosures and product labelling but these fell short of including specifics on financing for fossil fuels.

3.4 Policies to bring forward the retirement of coal plants

Bringing forward the retirement of both existing and yet-to-be-built coal-fired power plants and their replacement with clean generating technologies will need to play an increasingly important role in lowering emissions in those countries where coal still accounts for a significant share of the generating mix. In some cases, plants that have not even reached the end of their economic lifetimes will need to close. Over the period 2023-2030, around 21 GW of coal power plants operating today are retired before they reach 30 years, of which about 50% are retired before the age of 20, in the APS. For this to happen, stronger financial incentives or regulatory interventions than those already in place would be required.

Retirement decisions are typically taken by plant owners when the costs of continued operation outweigh risk-adjusted projected revenues. This often occurs near the end of the plant's design life when the owner is faced with a decision about whether to refurbish the plant to extend its economic and technical lifetime or to shut it down permanently. It can occur earlier, for example, if rising renewables-based generation reduces the need for baseload coal-fired power and existing contracts do not cover the costs of operating at lower utilisation levels. The introduction of pollution controls or carbon pricing may also undermine the viability of operating a coal plant, forcing its early retirement. In China, for example, several recent policies have mandated the closure of polluting or inefficient power stations and incentivised the construction of more efficient replacements.

Government interventions to encourage plant retirements should focus on bringing forward the date at which the owner calculates it is no longer effective to keep capital tied up in the asset because it no longer generates a profit. In recent years, several new financial instruments aimed at coal plants have been designed by MDBs and governments to do exactly this, complementing broader energy and climate policies aimed at encouraging investment in clean generating technologies. Approaches vary with local market and technical considerations. For example, governments typically do not know the expected net present value of plants that are not publicly owned. There is less uncertainty where plants are operated by regulated utility generators, which is partly why these plants have received most attention to date. Retirement decisions are influenced by state-owned utility strategies and contracts with plant owners, as well the existence of capacity tariffs that are designed to ensure capital recovery under long-term contracts.

One of the major hurdles to encouraging the retirement of coal-fired power plants is the fact that they are often shielded from market competition. Around 60% of coal power plants operating today in emerging and developing economies were financed by SOEs, and many of the rest were built based on a single-buyer model, whereby IPPs transact with a single utility on the basis of regulated pricing. Very little coal-fired generation in those countries is currently produced on a pure merchant basis, in contrast to Europe and North and South America, where generators compete to sell power in wholesale markets.

There is no single blueprint for governments to manage the phase-out of coal-fired generation, but a number of options are available. They include nationalising or buying out privately owned power plants in order to retire them; creating a mechanism that monetises the emissions saved by retiring a plant; setting up a fund to compensate owners of retired plants selected through an auction process; ratepayer-backed securitisation; sustainability-linked bonds; accelerated depreciation; and concessional debt or refinancing mechanisms. Each option, discussed in turn below, can be tailored to coal plants of different types and ages and to the varied market structures in which they operate. However, they also need to be applied in such a way as to not produce adverse outcomes; for example, retiring a specific coal plant early may raise the utilisation of the remaining coal fleet, resulting in no overall reduction in emissions. Transitions require a range of financial mechanisms that are tailored to coal plants of different types and age, as well as to the varied market structures within which they operate (IEA, 2021).

3.4.1 Nationalise or buy out plants

By nationalising a power plant, the government can exercise its power as owner to retire or, where appropriate, repurpose the plant. However, many countries do not have the financial resources to do that, such that alternative privately funded mechanisms to buy out plants may be required. One such example is a new market-based instrument, known as the Energy Transition Mechanism (ETM), being piloted by the Asian Development Bank (ADB), which aims to accelerate the move away from unbated coal in the Asia Pacific region (Box 3.1).

Box 3.1 ▹ The Energy Transition Mechanism

The ADB is working with regional and international partners to support, study and pilot an ETM. The objective is to pool low-cost capital from various concessional and private sources, including governments, MDBs, private investors and philanthropies, to finance country-specific initiatives to retire coal power plants on an earlier schedule than if they remained with their current owners, or to repurpose them. The ETM also aims to support new investment in clean energy, networks or storage infrastructure in place of the coal plants. The ETM has two funding vehicles: a carbon reduction facility tasked with refinancing or purchasing coal assets and the clean energy facility, which facilitates investment in clean energy. Monetising the CO_2 emissions savings resulting from the accelerated closure of a plant through carbon credits could supplement revenue streams.

Under the ETM programme, the ADB is in discussions with Cirebon Electric Power and partners in Indonesia to explore the potential to retire early a unit at the Cirebon coal plant. Concessional capital and capital would come from ADB's Private Sector Operations Department, and possibly donor-supported funds from ADB's ETM Partnership Trust Fund and a portion of the recently approved Indonesia allocation from the Climate Investment Fund's Accelerating Coal Transition window. Several financial entities and philanthropies have expressed interest in participating in the deal, which the ADB hoped to finalise by the end of 2023 (ADB, 2023).

Mechanisms such as the ETM could, in principle, help to coalesce multiple pools of finance, but they have yet to be demonstrated at scale. The willingness of governments and plant owners to transfer ownership of strategic assets to MDBs remains uncertain. As in any other transaction, asset owners will naturally seek to maximise concessions from MDBs and international sources of finance, so negotiations would need to be handled carefully. The extent to which freed capital will be shifted to renewables and other clean energy technologies is also uncertain.

3.4.2 Monetise emissions reductions through carbon pricing

Carbon pricing incentivises the retirement of coal assets by taxing or setting a cap on emissions, thus making coal-fired generation more expensive and less profitable. Carbon pricing can take the form of carbon taxes or emissions trading. One example of the latter is the European Union Emissions Trading Scheme (EU-ETS), which requires operators of thermal power stations and other emissions-intensive industrial activities to purchase emissions allowances for each tonne of CO_2 emitted. The scheme is widely seen as having accelerated the adoption of renewables as well as coal-to-gas switching across Europe since its launch in 2005. Several other schemes are in operation around the world, including in China and parts of the United States, and are under consideration in a number of other countries.

Several programmes have been established to trade carbon offsets and credits nationally and internationally, including those generated under emissions trading schemes, as well as other emissions reduction projects.[2] They can be used to monetise emissions reductions that result from a lower share of coal in the power generation mix. Dedicated methodologies for calculating carbon crediting baselines for fuel switching projects have been developed under the United Nations Framework Convention on Climate Change Clean Development Mechanism. Other monetisation mechanisms have also been established. In Chile, for instance, Engie Energia received a USD 125 million loan from the Inter-American Development Bank, the Climate Investment Funds (CIF) Clean Technology Fund and the Chinese Fund for Co-financing in Latin America and the Caribbean to fund the development of wind generation projects and close two coal-fired power plants. The deal is structured in such a way that the CO_2 emissions reductions resulting from the closure of the coal plants are given a value and that, should a carbon credit market develop in the future, the company will be free to sell them and share the profits with lenders.

3.4.3 Organise auctions

Some countries are studying and piloting the concept of using auction-based compensation mechanisms that allocate funding to plants owners in exchange for early retirement. The objective is to provide funding to compensate the owner for the capital that is yet to be recovered from the operation of the plant. The competitive nature of the auction mechanism aims to reveal the lowest amount of compensation that plant owners will accept in exchange for early retirement, reducing the risk of overcompensation. Auctions are being used successfully in various parts of the energy system, particularly in soliciting investment in new power generating capacity. By fostering competition and making prices transparent, they have been instrumental in bringing down the cost of renewables. Some governments, including in Germany, have decided to harness the power of auctions to provide incentives for early phase-out of coal in a cost-competitive way (World Bank, 2022).

3.4.4 Customer-backed securitisation

Customer-backed securities could be used by utilities to ease the strain on their balance sheets caused by the early retirement of coal-fired plants. Securitisation is the process of converting an asset or liability into a marketable security. IPPs in the United States have been piloting securitisation mechanisms in which a low-rate bond is issued to pay off the remaining debt tied to a coal plant that is then retired early. The bond is generally issued by a special purpose vehicle (SPV) set up for that purpose, so that it does not add

[2] Carbon credits generally represent a reduction in CO_2 emissions, whereas carbon offsets can represent removals, such as through reforestation.

to the general debt burden of the issuer – a key feature for usually heavily indebted utilities. An increase in the regulated tariffs paid by the utility's customers, which would normally be modest, is used to finance the coupon payments on the bond by the SPV. The increase in costs to consumers could be offset, at least in part, by any savings from switching to less expensive renewables generation.

There is considerable potential for securitisation to help utilities and customers absorb the costs of accelerating the phase-out of coal-fired power, though it does depend on the existence of a mature and developed financial market and a sophisticated regulatory regime. In the United States, one utility – Public Service of New Mexico – has already issued a bond specifically for the purpose of retiring the San Juan coal plants, and four others are currently working on similar bonds. But the ability of utilities to use securitisation is being challenged in court on several grounds, including that energy consumers should not have to bear the cost of closing coal plants.

3.4.5 Sustainability-linked bonds

Other forms of company- or organisation-wide securitisation could help to bring about the early retirement of coal plants. Sustainability linked bonds (SLBs) are a type of green balance-sheet debt, whereby the issuer commits to meet certain sustainability targets – including early retirement of coal plants – in exchange for reduced coupon rates (the reduction disappears if they fail to meet the targets). For example, Banco Santander co-ordinated the issuance of such a bond on behalf of Tauron Polska Energia in 2020, with EUR 220 million in funding used in part to reduce the share of coal in the generation mix. However, the targets in the SLBs that have been issued to date have often been weak, and the bond structure has allowed early repayments before the penalty actually kicks in. Green taxonomies, environmental, social and governance frameworks, and public opinion might also hinder investor willingness to participate in financial transactions involving coal, even when the objective is to retire capacity early.

If implemented properly, this type of finance has the potential to allow utilities to harness the power of global capital markets and lower the cost of coal retirements. This could be especially useful in emerging and developing economies, where the issuance of green debt has been lagging behind that in advanced economies (OECD, 2022). One possibility could be for emerging and developing economies to package ambitious commitments on coal phase-outs into a green financing product to raise international funding, though it is uncertain whether this would yield a financing premium (sometimes referred to as a "greenium"). Another possibility is some form of debt-for-climate swap, whereby a creditor offers to reduce debt obligations in a borrowing country in exchange for commitments to reduce emissions. Neither has yet been implemented.

3.4.6 Accelerated depreciation

Several utilities in the United States have gained regulatory approval to accelerate the depreciation schedule of their coal plants. This allows them to record higher yearly depreciation charges than initially planned and recoup their initial investment faster by passing the additional cost on to their customers. Accelerated depreciation allows a utility to completely write off a coal plant more quickly while not forgoing any of its future cash flows, as would be the case with securitisation. It results in higher energy bills for its customers in the short term, though they should benefit in the longer term from a faster transition to cheaper renewables-based generation.

3.4.7 Concessional debt and refinancing

Concessional debt – loans at highly favourable interest rates, extended grace periods, other favourable lending terms and grants – and refinancing of existing debt can be used by MDBs to help heavily indebted and financially weak utilities in emerging and developing economies retire coal plants and cut emissions. Access to lower borrowing rates can be tied to specific climate-related targets or the creation of a just transition support mechanism. Typically, concessional finance is supported by technical assistance and used to leverage private investment.

The ability of MDBs to engage more directly in coal retirement will be critical in accelerating coal transitions in emerging and developing economies. MDBs have historically been prudent about the amount of debt they take on, but they are coming under pressure to issue more bonds to raise funds to tackle today's multiple crises, including climate change. MDBs could establish dedicated investment vehicles, such as loans, grants and guarantees, that target coal and refinance them through new bond issuances. Up to now, MDBs have been quite cautious with their level of gearing, staying well below a 1:1 debt-to-capital ratio that does not consider the additional callable portion of the capital they can potentially draw upon from their government shareholders in special cases.

Increasing leverage may require MDBs to increase the quality and liquidity of their overall asset portfolio, and that may make them wary about getting involved in riskier investment areas such as the early retirement of coal-fired power plants. The Independent Review of Multilateral Development Bank Capital Adequacy Frameworks, commissioned by the Group of 20 (G20), proposed ways for MDBs to ramp up lending, notably by refining risk tolerance, giving further consideration to callable capital in financial decisions and attracting private sector finance through financial innovation (Kessler, 2022).

Policies for people-centred and just transitions

Ensuring a fair energy future for everyone

SUMMARY

- Coal transitions in the power sector must be people-centred and just, involving comprehensive stakeholder engagement with the goal of reaching broad consensus around the transitions and on a set of policies to deal with their consequences.
- An estimated 7.8 million people worldwide, including informal workers, worked in coal-related activities in 2022, of which 3.1 million worked in coal mining. Coal accounts for just 0.25% of global employment, but the share can be much higher in areas around coal mines. Coal jobs are concentrated in Asia – 3.9 million in China, 2.1 million in India and 0.4 million in Indonesia. In recent years, employment has declined as labour productivity has improved, due mainly to mechanisation in China, where 2.6 million mining jobs have been made redundant since 2000 despite rising production. While formally employed coal miners around the world tend to be relatively well paid, a large share of informal workers suffer from low pay and dangerous work conditions.
- National pledges to cut emissions and decarbonise power, if fully implemented, would have a huge impact on coal-related employment, especially coal mining. In the APS, total coal employment declines to 5.6 million in 2030, with over half of the job losses resulting from a fall in coal production and consumption (mainly in the power sector), though productivity improvements mean that jobs would decline substantially even if there were no decrease in coal use. Of the jobs lost globally, around 1.9 million are in emerging and developing economies and 325 000 in advanced economies.
- The public acceptability and justness of coal transitions depend on effective policy measures to address the loss of jobs. Options include short-term income support such as severance compensation packages, welfare payments and provisions for early retirement. Some governments offer education and training, career counselling and job assistance for coal workers who are made redundant. At the end of 2023, just 14% of coal workers in the most coal-dependent countries were covered by just transition policies, though this represents an improvement of 10% over 2022. Measures such as industrialisation or environmental rehabilitation initiatives are also needed to support economic development in coal-dependent regions, which may be underdeveloped.
- The transition away from unabated coal-fired power can be achieved without decreasing the affordability of electricity, thanks to the competitiveness of alternative clean power sources. In the APS, the costs of replacing coal-fired generation and the system services provided by coal as well as upgrading and expanding the grid are more than offset by the massive fuel cost savings from reduced demand for coal, resulting in the average cost per unit of electricity worldwide decreasing by over one-fifth between 2022 and 2050, though savings vary by region.

4.1 Developing a framework for applying best practices

Accelerating coal transitions in the power sector is essential to achieving the climate goals of the Paris Agreement but will inevitably have less-welcome implications for the coal industry, workers and countries that now depend on coal, even if new opportunities emerge as the clean energy economy expands. For that reason, it is vital that coal transitions are both people-centred and just. People-centred transitions – a broad concept promoted by the Global Commission on People-Centred Clean Energy Transitions – take account of the labour market transition associated with transitions to clean energy alongside broad concerns such as energy affordability, energy access and socio-economic development, and incorporate an inclusive approach to policy making (IEA, 2021). Just transitions, as defined by the International Labour Organization, seek to ensure that the shift away from fossil energy leads to the creation of decent work opportunities, support for workers impacted by energy transitions, effective social dialogue among all affected groups and respect for fundamental labour principles and rights (ILO, 2016). Experience in countries that have already launched or gone through the process show that well-designed and effective transition programmes require time, preparation and learning by doing (IDDRI, 2018).

4

There is no single blueprint for managing the phase-out of coal-fired capacity because a great deal inevitably depends on local circumstances and priorities. An important first step is comprehensive stakeholder engagement with the goal of reaching broad consensus around the transition. Mapping existing human resources and infrastructure in affected communities can be useful to identify alternative industries that could make the most of local comparative advantage. Several countries, including Canada, the Czech Republic, Germany, Spain, and South Africa, have convened national task forces or commissions to evaluate the financial implications of the socio-economic effects of coal transitions and to provide policy recommendations. Once a timeline has been established for the coal transition, the next step is to agree on a set of just policies. To date, such policies have tended to address three complementary objectives:

- **support workers** and companies directly affected by the energy transition, including through inclusive policy-making processes
- **develop alternative industries** and stimulate macroeconomic growth in the region to provide additional opportunities for local workers and companies
- **improve quality of life** and strengthen social cohesion, for example by promoting environmental rehabilitation in the affected area, thereby enhancing its attractiveness and growth potential and fostering local culture and identity.

Many governments have introduced specific measures to supplement existing labour policies for coal workers in recognition of the reality that accelerated coal transitions generally happen over a short period of time and are concentrated in specific areas. (Table 4.1 gives examples of just transition policies). Measures include short-term income support such as severance compensation packages, welfare payments and provisions for early retirement (see below). Still, across the 21 most coal-dependent countries, only an estimated 14% of coal workers are covered by coal-specific just transition policies, and just 4% in countries where those policies are not just announced or under discussion, but in law with funding.

This nonetheless represents significant progress versus the year prior, when a meagre 4% were covered by any coal-specific just transition policy, regardless of its status.

Some governments have also introduced measures that aim to boost economic development in coal-dependent regions, such as re-employment of coal mine workers in environmental rehabilitation efforts or industrialisation initiatives. This is particularly critical in emerging and developing economies, where many coal mining regions are highly dependent on coal and may be generally underdeveloped (see Chapter 1). Economic development strategies need to pay careful attention to regional comparative advantages in order to develop realistic plans and projects, and at the same time examine how best to improve connectivity. For example, the European Union Just Transition Fund makes provisions to support investments that improve connectivity – both digital and physical – on the grounds that these will facilitate economic diversification in the long run. While carbon capture, utilisation and storage (CCUS) is unlikely to preserve coal consumption at current levels in most cases, it can preserve some coal-dependent infrastructure and jobs, while reducing emissions from coal combustion.

Table 4.1 ▹ Just transition policies in selected countries

	Canada	Germany	Korea	South Africa
Target				
Net zero emissions	2050	2045	2050	2050
Coal phase-out	2030	2035	2050	-
Support for workers				
Direct payments and compensation	🟢	🟢	🟠	🟠
Retraining, education & outplacement	🟢	🟠	🟠	🟢
Support for economic diversification in coal communities				
Coal decommissioning or retrofits	🟢	🟢	🟠	🟠
Clean energy industries	🟢	🟢	🟠	🟠
Non-energy industries	🟢	🟢	🟠	🟠
Holistic support for coal communities				
Environmental rehabilitation		🟢		🟠
Community identity & cohesion				🟠

🟢 Policy enacted with funding 🟠 Policy announced or recommended by a just transition commission.
Notes: Both national and subnational policies are included. Broader labour market policies are not included.

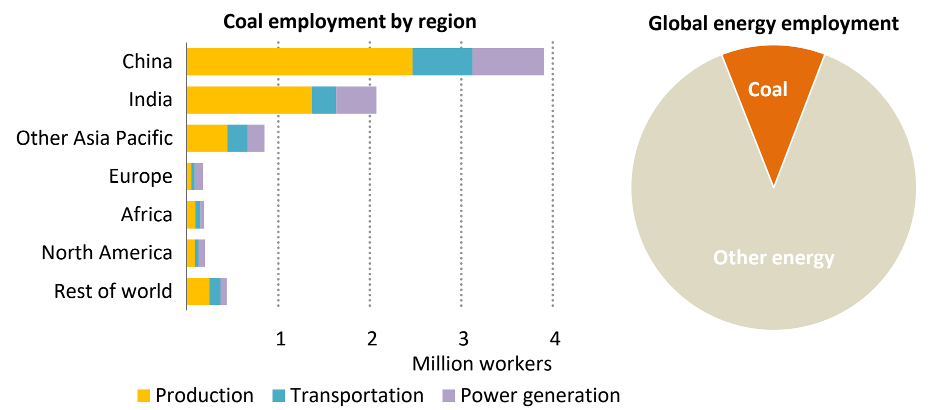
Coal transition policies also need to take account of gender aspects. Coal miners are predominantly male, but job losses have repercussions for women too. Historically, during and after coal transitions, more women have entered the labour market in order to supplement household income, primarily taking up low-paid jobs in the services sector (Walk et al., 2021). Interviews also show that men losing jobs in coal mining are reluctant to take up domestic chores, preferring to remain in manual work (Braunger and Walker, 2022). In the light of this, there is a case for governments to provide additional childcare services and to extend career services to all members of coal miner households during coal transitions. For example, the Philippines has been proactive in developing bottom-up and gender-inclusive coal transition policies by engaging heavily with coal communities, local government units and indigenous populations (UN Women, 2022). A number of initiatives in Indonesia are also pushing to ensure the representation of women in decision-making processes related to local coal transitions (World Bank, 2022a)

4.2 Addressing shifts in employment

4.2.1 Current and projected jobs

An estimated 7.8 million people worldwide worked in coal-related activities in 2022, with 4.8 million in production, including mining, washing and processing; 1.4 million in transportation; and 1.7 million in power generation (Figure 4.1). These estimates include informal workers, which make up a significant share of the total workforce in some emerging market and developing economies, as well as indirect jobs in the manufacturing of specialised mining and conveyance equipment (though these make up a small share of the total; see World Energy Employment 2023 for more breakdowns) (IEA, 2023). Coal-related activities account for close to 12% of total energy sector employment and around 0.25% of global employment, but the shares can be much higher in regions with coal mines, where the local economy and community may be highly dependent on income generated from coal production and related industries.

Figure 4.1 ▷ Coal employment by country/region and activity, and share of global energy employment, 2022



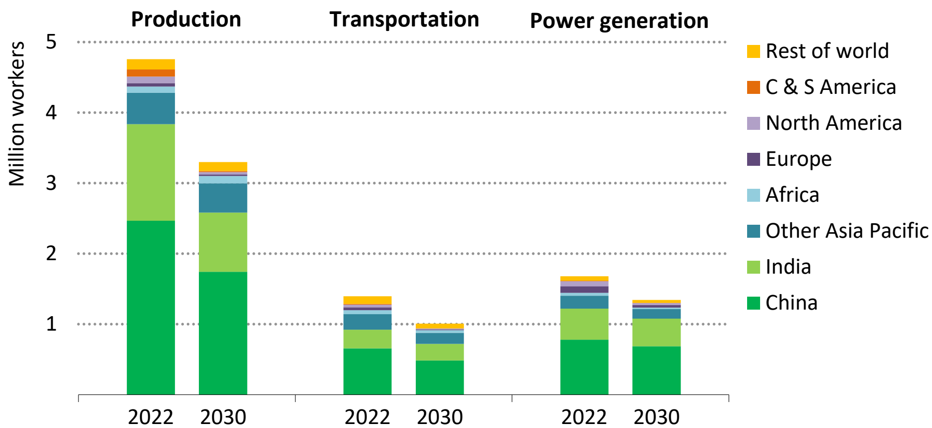
Most of the world's 7.8 million coal workers are in China and India, employed mainly in mining, then in power generation

Coal supply jobs, which do not include workers in power generation, are concentrated in Asia, with 3.1 million coal workers in the People's Republic of China (hereafter, "China"), 1.6 million in India and over 400 000 in Indonesia. These three countries, which together account for over 80% of all coal supply jobs worldwide, have less mechanised coal industries than in advanced economies, requiring more direct labour. In recent years, employment in some large coal producers has declined as labour productivity has improved, thanks mainly to mechanisation. For example, for each coal mining job created in China between 2000 and 2022 due to increased production, 1.5 jobs were rendered redundant by productivity improvements generated by technological advancements and state efforts to consolidate inefficient mines and boost productivity. As a result, mining employment in China dropped by over 2.6 million during this period while output grew by more than 5% per year on average. Fewer workers are needed in coal-fired power generation, but the numbers are still substantial and have been rising as global capacity has increased. Unsurprisingly, China has the biggest workforce in this sector with an estimated 780 000 workers in 2022, followed by India with 440 000 workers. In Europe and North America, where jobs in coal power have been declining for years, just 90 000 and 70 000 people work in this sector, respectively.

Formally employed coal miners around the world tend to be relatively well paid, amplifying the importance of employment in the coal industry to local economies. This stems in part from well-established labour representation, which has pushed for higher pay and benefits as well as better health and safety standards. The wage premium for coal miners over industrial workers (in manufacturing, construction and utilities) varies considerably, ranging from roughly 50% in South Africa, 100% in Indonesia and 60% in China to 200% in Colombia and 300% in India. In the United States, annual wages average USD 75 000 in coal supply and USD 99 000 in fossil fuel power generation, both of which represent a substantial premium over median economy-wide wages (US Bureau of Labour Statistics, 2022). Some 12% of US coal supply workers are unionised, compared with a 7% average across the private sector (US DOE, 2022). By contrast, pay and working conditions are often poor for informal coal workers in emerging and developing economies, especially in illegal mining operations, where informal coal miners generally earn a fraction of what a formal worker makes.

National pledges to cut emissions and decarbonise power generation, if fully implemented, would have a huge impact on coal-related employment. Countries with net zero emissions targets or coal phase-out commitments currently account for more than 95% of coal consumption and employment. In the Announced Pledges Scenario (APS), total coal employment declines from 7.8 million in 2022 to 5.6 million in 2030 (Figure 4.2). Roughly half of this decline is due to a fall in coal production and consumption (mainly in the power sector), and the other half to improvements in productivity through increased mechanisation. Of the jobs lost globally, around 1.9 million are in emerging and developing economies and 325 000 in advanced economies. The bulk of the 2.2 million jobs lost globally are in coal supply, due to a 30% fall in production. In China, 425 000 jobs are lost in coal mining, of which over a third are related to improvements in labour productivity (IEA, 2021). Global job losses in coal-fired power generation total around 340 000, around 20% of current employment in this sector.

Figure 4.2 ▹ Coal employment by country/region and activity in the APS



IEA. CC BY 4.0.

Under current climate pledges, coal employment is set to drop 30% to 5.6 million in 2030 amidst increased mechanisation and policies to phase down coal use in power generation

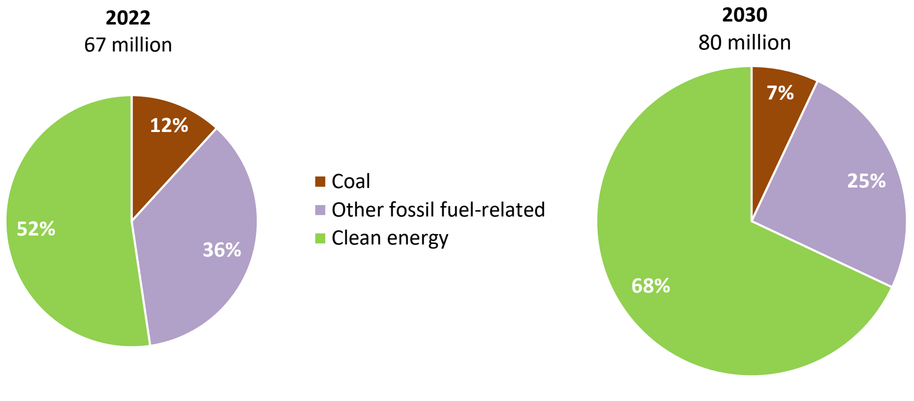
Note: C & S America = Central and South America.

The share of coal-related jobs in total energy sector employment, unsurprisingly, falls sharply in the APS, from 12% in 2022 to just 7% in 2030, with the increase in employment at coal plants retrofitted with CCUS facilities not nearly sufficient to offset other losses (Figure 4.3). Coal employment sees a sharper decline than either oil or natural gas employment, though all decrease as clean energy grows to dominate the energy sector, with corresponding employment increasing from around 35 million in 2022 to 54 million in 2030, thanks mainly to low-emissions power generation, the shift to electric vehicles and improvements in end-use efficiency.

4.2.2 Labour policy measures

The public acceptability and justness of coal transitions depend on effective policy measures to address the loss of jobs in coal-related activities, including coal-fired power generation. Many governments have in the past introduced measures to supplement existing labour policies for coal workers where accelerated coal transitions have led to the sudden loss of large numbers of jobs concentrated in specific regions. Those measures include short-term income support such as severance compensation packages, welfare payments and provisions for early retirement. In Poland, for instance, the government provides tax-free income support and a subsidy for health insurance to coal workers who are made redundant. In Poland, government and trade unions have signed an agreement that allows coal miners to retire early or receive compensation if they take new jobs with lower pay (World Bank, 2022b).

Figure 4.3 ▷ **Global energy sector employment by fuel in the APS**



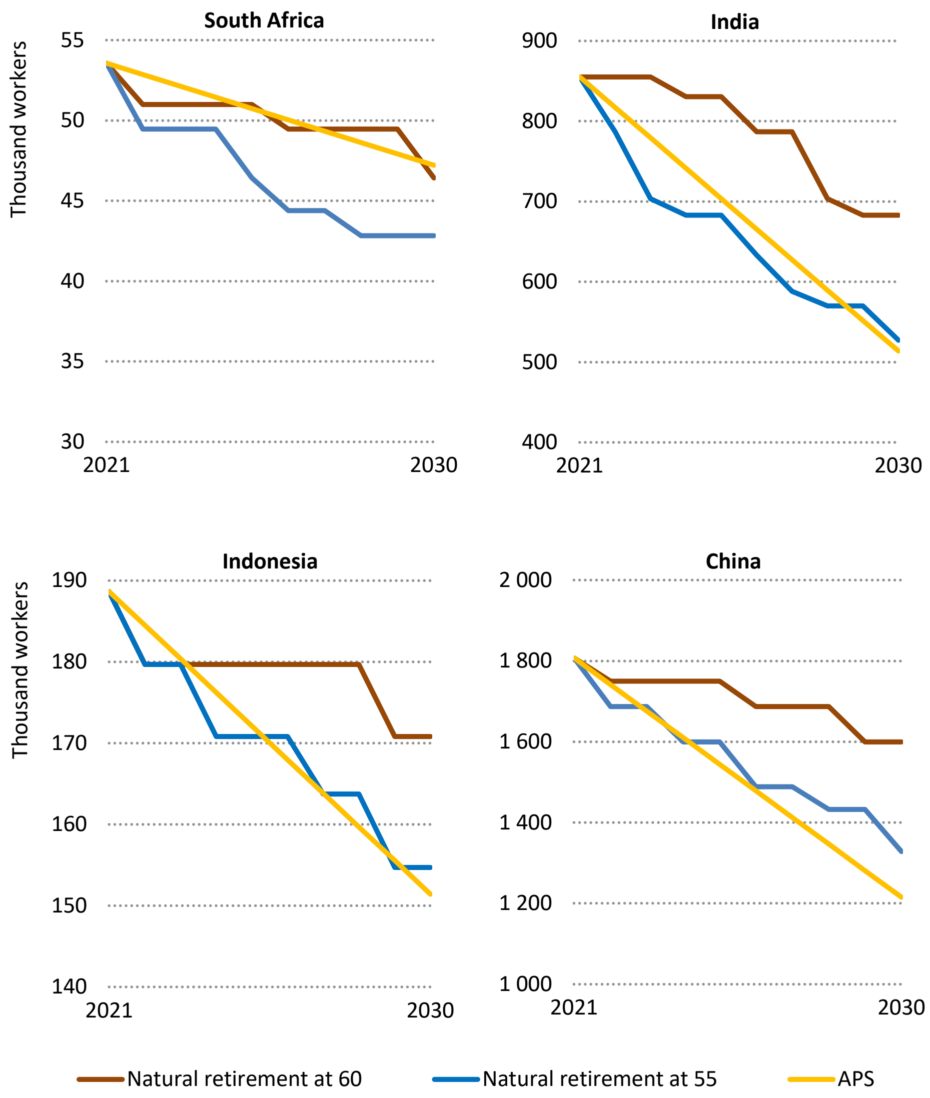
Total energy sector employment increases by one-fifth to 80 million by 2030 in the APS, with new clean energy jobs more than offsetting losses in coal, oil and gas

Notes: Coal includes employment in coal supply and coal-fired power generation. Other fossil fuel-related includes employment in oil and natural gas supply and power, and manufacturing of internal combustion engine vehicles.

Some governments offer education and training, career counselling and job search assistance for coal workers who are made redundant. For example, the Canadian Coal Transition Initiative, established in 2018, provides USD 26 million over five years for economic diversification and skills development, and has established transition centres in coal regions. It is complemented by a related Coal Transition Infrastructure Fund supplying another USD 118 million for coal communities through 2025 (Government of Canada, 2023). In October 2018, the Spanish government and unions struck a deal, commonly referred to as the Plan Del Carbón, for USD 284 million to be invested in mining regions over the next decade, encompassing early retirement schemes, local re-employment in environmental restoration work and reskilling programmes for green industries (WRI, 2021). Leading coal producers in emerging and developing economies have also introduced targeted measures to compensate and help retrain coal workers (Box 4.1).

Labour measures need to consider the age profile of coal sector workers, which determines the natural retirement rate of workers and the number of workers who are likely to remain economically active after leaving the sector through redundancy. For example, Indonesia, South Africa, India and China represent nearly 90% of all coal mining employment worldwide. But in all these countries except South Africa, fewer coal miners are projected to be needed in the APS in 2030 that would still be employed based on a typical retirement age of 60, assuming no new recruitment. In total in the four countries, around 570 000 workers would need to retire early by 2030, two-thirds of them in China (Figure 4.4). Were the retirement age to be brought forward to 55, the number falls to around 130 000.

Figure 4.4 ▹ Coal mining employment in selected countries by assumed retirement age in the APS



About 570 000 workers would need to retire early by 2030 in the four leading coal-producing countries assuming a retirement age of 60 and no new recruitment

Box 4.1 ▹ Support for coal workers in South Africa, India and China

Retraining programmes targeting coal workers for jobs in renewables, ecotourism and agribusiness are at the heart of South Africa's Just Transition Strategy. Under a partnership agreement, the governments of France, Germany, the United Kingdom and the United States, and the European Union, are making available USD 8.5 billion in the form of grants and highly concessional loans to support the closure of Eskom's coal plants and just energy transition initiatives, including developing green hydrogen and boosting electric vehicles. Mpumalanga, where 90% of the country's coal production and 70% of its coal-fired power generation are concentrated, will be the region most affected by the phase-down of coal in South Africa. The region already suffers from high unemployment, so generating new jobs is the focus of transition management discussions. Even in regions where coal phase-out is not immediately looming, it is critical to begin planning early as implementation and training workers for alternate employment can take years (Center for Strategic and International Studies, 2021).

In India, the government is developing training, skills and educational programmes, as well as reskilling and upskilling initiatives, to tackle the imminent decline in coal sector employment. In 2008, the Ministry of Finance established the National Skills Development Corporation to engage both the public and private sectors in the creation of large vocational institutions that will boost the general skill level of the Indian workforce. More recently, the Ministry of New and Renewable Energy has established the Skill Council for Green Jobs (SCGJ) – a non-profit, independent, industry-led organisation – to expand vocational training in schools, universities and engineering institutions, as well as certification programmes, to encourage new entrants to the labour market to work in the renewable energy sector and help coal workers move to it. SCGJ has so far developed 44 nationally approved qualifications across various subdomains, including renewable energy, and a network of over 400 affiliated institutions/centres along with over 4 000 trainers and assessors countrywide across green business domains. Through its partners, it has also trained over 100 000 candidates in the solar and other renewable energy sectors (IEA, 2022).

As a part of its efforts to reduce its coal capacity, China has introduced measures to support coal workers made redundant following the closures of several state-owned coal mines with reskilling, job reallocation services and retirement plans. The central government established a CNY 100 billion (Yuan renminbi) (USD 15 billion at contemporaneous exchange rates) fund in 2016 to finance a range of incentives, compensatory measures and retraining for miners made redundant, though payments were limited to workers in state-owned mines. When the fund closed in 2020, it had helped an estimated 1 million former coal workers find new employment (IN-EN, 2021).

4.2.3 Support for economic diversification

Some governments have implemented measures designed to boost economic development and diversification in coal-dependent regions (Box 4.2). This is particularly critical in emerging and developing economies, where many coal mining regions depend very heavily on that activity and are generally underdeveloped economically. Effective economic development strategies need to pay careful attention to regional comparative advantages in order to develop realistic plans and projects, including infrastructure improvements. For example, some legacy coal regions in the United States, such as West Virginia, are making significant investments into community infrastructure such as railroads, community colleges, rural broadband and sanitation to address the effects of incremental coal divestment on the community.

A key implementation mechanism for Spain's Just Transition Strategy, which will be updated every five years, is the negotiation of Just Transition Agreements, integrated regional plans which seek to boost economic activity, diversification and employment in areas that will be affected by the phase-out of coal – notably Aragón, Castilla y León and Asturias. Each agreement includes detailed timelines for implementation, which includes demarcating the relevant territory, assessing the economic and employment profile of the region, and negotiations involving local authorities and a broad range of other stakeholders. While coal mines have attracted the most attention, coal-fired thermal power plants are also set to close, implicating approximately 2 300 workers. In April 2020, an agreement was reached among the government, trade unions and three power generators – Endesa, Iberdrola and Naturgy – covering public and private investment in new business opportunities in the regions, as well as retraining and re-employment of power plant workers.

Box 4.2 ▹ Support for economic diversification in emerging and developing economies

Initiatives to promote economic development in regions most affected by the contraction of the coal industry have been launched in several emerging and developing economies, usually involving a holistic policy approach that takes account of all the economic and social consequences of coal transitions, as well as the barriers to and opportunities for regional redevelopment. Prominent examples include the following:

- In the face of declining coal production in regions such as La Guajira, Colombia is using incentives and policies to stimulate other industries, including renewable energy and tourism (KCI, 2022). The rehabilitation plan for the closure of coal mines in the La Guajira region in Colombia has included projects covering reforestation, water resource management and support for indigenous communities. In 2021, the mining company Cerrejon signed an agreement with a Wayuu indigenous community to undertake an environmental rehabilitation programme, including the construction of community facilities and measures to address health and restore affected lands (Reuters, 2021).

- The government of Indonesia aims to diversify the economy of the East Kalimantan coal province by boosting tourism and encouraging investment in geothermal energy. The potential for rehabilitating coal mines into productive land, used for agriculture, fisheries or reforestation, is also being investigated (Setiawanet al., 2021).
- Chile is examining the potential for replacing coal with green hydrogen through incentives and infrastructure support. The goal is to develop local hubs for investment, innovation and economic activity (Government of Chile, 2020).
- Some coal provinces in China have begun to implement economic diversification programmes, targeting investment in tech hubs, renewable energy and tourism. For example, in Liaoning, the provincial government is investing CNY 600 billion (USD 84 billion) in new renewable energy projects, such as wind turbines, in former coal-dependent towns such as Fuxin. In Xuzhou, Jiangsu province, a lake formed by coal mine subsidence was transformed into the Pan'an Lake Wetland Park, improving biodiversity and climate resilience while boosting the local economy as a popular tourist attraction (APF Canada, 2023).

Post-mining land reclamation initiatives in forest restoration and drought alleviation involving local communities have been established in parts of Thailand, coal-rich regions of India such as Jharkhand and the Mpumalanga region in South Africa.

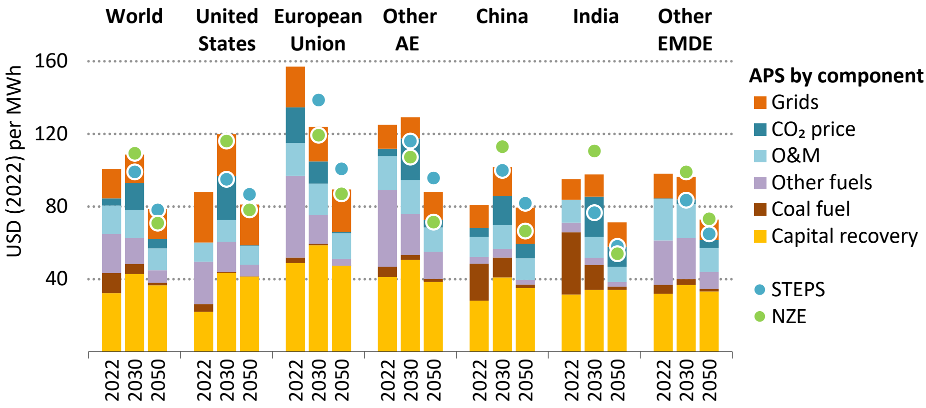
4.3 Making electricity affordable

4.3.1 Cost of supply

The transition away from unabated coal-fired power can be achieved without an increase in the overall cost of electricity supply thanks to the expected continued improvement in the competitiveness of alternative clean technologies. In the APS, average electricity system costs worldwide initially increase, from just over USD 100 per megawatt-hour (MWh) in 2022 to USD 109/MWh in 2030 (in 2022 prices), but then fall back to USD 79/MWh in 2050 – 22% below the 2022 level (Figure 4.5). A huge amount of investment is required to replace coal-fired generation and the system services provided by coal, as well as upgrade and expand the grid to support the expansion of alternative sources in this scenario. But these costs are more than offset by massive fuel cost savings that come from reduced demand for coal. A major effort to implement energy efficiency measures also helps to moderate system costs by making the most of existing and new power plants and grid infrastructure. The decrease in costs varies by region and scenario, but the European Union sees the greatest decline in all scenarios due to its elevated starting point, caused by soaring gas prices in 2022 following the Russian Federation's invasion of Ukraine. The faster energy transition in the Net Zero

Emissions by 2050 (NZE) Scenario would cost more than the APS to 2030 in most regions, but less by 2050 in advanced economies, China and India.

Figure 4.5 ▷ Electricity system costs by component, region and scenario



IEA. CC BY 4.0.

Average electricity system costs drop by over one-fifth between 2022 and 2050 in the APS and 30% in the NZE Scenario, with lower fuel costs more than offsetting higher capital costs

Note: AE = advanced economies; EMDE = emerging market and developing economies; O&M = operation and maintenance; STEPS = Stated Policies Scenario.

4.3.2 Impact on affordability for consumers

The above analysis suggests that coal transitions, even in coal-dependent countries, are likely to have limited adverse consequences for the affordability of electricity for households in the near term and would reduce bills substantially in the longer term. However, energy subsidies complicate the comparison of household energy spending over time, not least because they can change rapidly. For example, some advanced economies, particularly in Europe, introduced electricity subsidies in 2022 to cushion households from surging prices. Policies to reduce subsidies are implemented in all three scenarios, accelerating after the current energy crisis fades. They are phased out completely by 2030 in most regions in the APS and NZE Scenario, while they decline much more gradually in the STEPS. The picture inevitably varies widely from country to country. In some emerging and developing economies, such as Indonesia, consumers switch from non-commercial fuels to electricity or gain access to it: this increases energy bills as a share of disposable income but brings significant welfare benefits.

ANNEXES

Definitions

This annex provides general information on terminology used throughout this report including: units and general conversion factors; definitions of fuels, processes and sectors; regional and country groupings; and abbreviations and acronyms.

Units

Area	km^2	square kilometre
	Mha	million hectares
Batteries	Wh/kg	watt hours per kilogramme
Coal	Mtce	million tonnes of coal equivalent (equals 0.7 Mtoe)
Distance	km	kilometre
Emissions	ppm	parts per million (by volume)
	t CO_2	tonnes of carbon dioxide
	Gt CO_2-eq	gigatonnes of carbon-dioxide equivalent (using 100-year global warming potentials for different greenhouse gases)
	kg CO_2-eq	kilogrammes of carbon-dioxide equivalent
	g CO_2/km	grammes of carbon dioxide per kilometre
	g CO_2/kWh	grammes of carbon dioxide per kilowatt-hour
	kg CO_2/kWh	kilogrammes of carbon dioxide per kilowatt-hour
Energy	EJ	exajoule (1 joule x 10^{18})
	PJ	petajoule (1 joule x 10^{15})
	TJ	terajoule (1 joule x 10^{12})
	GJ	gigajoule (1 joule x 10^{9})
	MJ	megajoule (1 joule x 10^{6})
	Boe	barrel of oil equivalent
	Toe	tonne of oil equivalent
	Ktoe	thousand tonnes of oil equivalent
	Mtoe	million tonnes of oil equivalent
	bcme	billion cubic metres of natural gas equivalent
	MBtu	million British thermal units
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
	Gcal	gigacalorie
Gas	bcm	billion cubic metres
	tcm	trillion cubic metres
Mass	kg	kilogramme
	t	tonne (1 tonne = 1 000 kg)
	kt	kilotonne (1 tonne x 10^3)
	Mt	million tonnes (1 tonne x 10^6)
	Gt	gigatonne (1 tonne x 10^9)

Monetary	USD million	1 US dollar x 10^6
	USD billion	1 US dollar x 10^9
	USD trillion	1 US dollar x 10^{12}
	USD/t CO_2	US dollars per tonne of carbon dioxide
Oil	barrel	one barrel of crude oil
	kb/d	thousand barrels per day
	mb/d	million barrels per day
	mboe/d	million barrels of oil equivalent per day
Power	W	watt (1 joule per second)
	kW	kilowatt (1 watt x 10^3)
	MW	megawatt (1 watt x 10^6)
	GW	gigawatt (1 watt x 10^9)
	TW	terawatt (1 watt x 10^{12})

General conversion factors for energy

		Multiplier to convert to:					
		EJ	Gcal	Mtoe	MBtu	bcme	GWh
Convert from:	EJ	1	2.388 x 10^8	23.88	9.478 x 10^8	27.78	2.778 x 10^5
	Gcal	4.1868 x 10^{-9}	1	10^{-7}	3.968	1.163 x 10^{-7}	1.163 x 10^{-3}
	Mtoe	4.1868 x 10^{-2}	10^7	1	3.968 x 10^7	1.163	11 630
	MBtu	1.0551 x 10^{-9}	0.252	2.52 x 10^{-8}	1	2.932 x 10^{-8}	2.931 x 10^{-4}
	bcme	0.036	8.60 x 10^6	0.86	3.41 x 10^7	1	9 999
	GWh	3.6 x 10^{-6}	860	8.6 x 10^{-5}	3 412	1 x 10^{-4}	1

Note: There is no generally accepted definition of barrel of oil equivalent (boe); typically the conversion factors used vary from 7.15 to 7.40 boe per tonne of oil equivalent. Natural gas is attributed a low heating value of 1 MJ per 44.1 kg. Conversions to and from billion cubic metres of natural gas equivalent (bcme) are given as representative multipliers but may differ from the average values obtained by converting natural gas volumes between IEA balances due to the use of country-specific energy densities. Lower heating values (LHV) are used throughout.

Currency conversions

Exchange rates *(2022 annual average)*	1 US dollar (USD) equals:
British Pound	0.81
Chinese Yuan Renminbi	6.74
Euro	0.95
Indian Rupee	78.60
Japanese Yen	131.50

Source: OECD Data (database): Exchange rates (indicator), https://data.oecd.org/conversion/exchange-rates.htm, accessed October 2023.

Definitions

Advanced bioenergy: Sustainable fuels produced from wastes, residues and non-food crop feedstocks (excluding traditional uses of biomass), which are capable of delivering significant life cycle greenhouse gas emissions savings compared with fossil fuel alternatives and of minimising adverse sustainability impacts. Advanced bioenergy feedstocks either do not directly compete with food and feed crops for agricultural land or are only developed on land previously used to produced food crop feedstocks for biofuels.

Agriculture: Includes all energy used on farms, in forestry and for fishing.

Agriculture, forestry and other land use (AFOLU) emissions: Includes greenhouse gas emissions from agriculture, forestry and other land use.

Ammonia (NH_3): Is a compound of nitrogen and hydrogen. It can be used as a feedstock in the chemical sector, as a fuel in direct combustion processes in fuel cells, and as a hydrogen carrier. To be considered a low-emissions fuel, ammonia must be produced from hydrogen in which the electricity used to produce the hydrogen is generated from low-emissions generation sources. Produced in such a way, ammonia is considered a low-emissions hydrogen-based liquid fuel.

Aviation: This transport mode includes both domestic and international flights and their use of aviation fuels. Domestic aviation covers flights that depart and land in the same country; flights for military purposes are included. International aviation includes flights that land in a country other than the departure location.

Back-up generation capacity: Households and businesses connected to a main power grid may also have a source of back-up power generation capacity that, in the event of disruption, can provide electricity. Back-up generators are typically fuelled with diesel or gasoline. Capacity can be as little as a few kilowatts. Such capacity is distinct from mini-grid and off-grid systems that are not connected to a main power grid.

Battery storage: Energy storage technology that uses reversible chemical reactions to absorb and release electricity on demand.

Biodiesel: Diesel-equivalent fuel made from the transesterification (a chemical process that converts triglycerides in oils) of vegetable oils and animal fats.

Bioenergy: Energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. It includes solid bioenergy, liquid biofuels and biogases. Excludes hydrogen produced from bioenergy, including via electricity from a biomass-fired plant, as well as synthetic fuels made with CO_2 feedstock from a biomass source.

Biogas: A mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment.

Biogases: Include both biogas and biomethane.

Biogasoline: Includes all liquid biofuels (advanced and conventional) used to replace gasoline.

Biojet kerosene: Kerosene substitute produced from biomass. It includes conversion routes such as hydroprocessed esters and fatty acids (HEFA) and biomass gasification with Fischer-Tropsch. It excludes synthetic kerosene produced from biogenic carbon dioxide.

Biomethane: Biomethane is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any carbon dioxide and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. It is also known as renewable natural gas.

Buildings: The buildings sector includes energy used in residential and services buildings. Services buildings include commercial and institutional buildings and other non-specified buildings. Building energy use includes space heating and cooling, water heating, lighting, appliances and cooking equipment.

Bunkers: Includes both international marine bunker fuels and international aviation bunker fuels.

Capacity credit: Proportion of the capacity that can be reliably expected to generate electricity during times of peak demand in the grid to which it is connected.

Carbon capture, utilisation and storage (CCUS)**:** The process of capturing carbon dioxide emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO_2 emissions can be stored in underground geological formations, onshore or offshore, or used as an input or feedstock in manufacturing.

Carbon dioxide (CO_2)**:** A gas consisting of one part carbon and two parts oxygen. It is an important greenhouse (heat-trapping) gas.

Chemical feedstock: Energy vectors used as raw materials to produce chemical products. Examples are crude oil-based ethane or naphtha to produce ethylene in steam crackers.

Clean cooking systems: Cooking solutions that release less harmful pollutants, are more efficient and environmentally sustainable than traditional cooking options that make use of solid biomass (such as a three-stone fire), coal or kerosene. This refers to improved cook stoves, biogas/biodigester systems, electric stoves, liquefied petroleum gas, natural gas or ethanol stoves.

Clean energy: In *power*, clean energy includes: renewable energy sources, nuclear power, fossil fuels fitted with CCUS, hydrogen and ammonia; battery storage; and electricity grids. In *efficiency*, clean energy includes energy efficiency in buildings, industry and transport, excluding aviation bunkers and domestic navigation. In *end-use applications*, clean energy includes: direct use of renewables; electric vehicles; electrification in buildings, industry and international marine transport; CCUS in industry and direct air capture. In *fuel supply*, clean energy includes low-emissions fuels, direct air capture, and measures to reduce the emissions intensity of fossil fuel production.

Coal: Includes both primary coal, i.e. lignite, coking and steam coal, and derived fuels, e.g. patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas works gas, coke-oven gas, blast furnace gas and oxygen steel furnace gas. Peat is also included.

Coalbed methane (CBM)**:** Category of unconventional natural gas that refers to methane found in coal seams.

Coal-to-gas (CTG)**:** Process in which coal is first turned into syngas (a mixture of hydrogen and carbon monoxide) and then into synthetic methane.

Coal-to-liquids (CTL)**:** Transformation of coal into liquid hydrocarbons. One route involves coal gasification into syngas (a mixture of hydrogen and carbon monoxide), which is processed using Fischer-Tropsch or methanol-to-gasoline synthesis. Another route, called direct-coal liquefaction, involves reacting coal directly with hydrogen.

Coking coal: Type of coal that can be used for steel making (as a chemical reductant and a source of heat), where it produces coke capable of supporting a blast furnace charge. Coal of this quality is commonly known as metallurgical coal.

Concentrating solar power (CSP)**:** Thermal power generation technology that collects and concentrates sunlight to produce high temperature heat to generate electricity.

Conventional liquid biofuels: Fuels produced from food crop feedstocks. Commonly referred to as first generation biofuels and include sugar cane ethanol, starch-based ethanol, fatty acid methyl ester (FAME), straight vegetable oil (SVO) and hydrotreated vegetable oil (HVO) produced from palm, rapeseed or soybean oil.

Critical minerals: A wide range of minerals and metals that are essential in clean energy technologies and other modern technologies and have supply chains that are vulnerable to disruption. Although the exact definition and criteria differ among countries, critical minerals for clean energy technologies typically include chromium, cobalt, copper, graphite, lithium, manganese, molybdenum, nickel, platinum group metals, zinc, rare earth elements and other commodities, as listed in the Annex of the IEA special report on the *Role of Critical Minerals in Clean Energy Transitions* available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

Decomposition analysis: Statistical approach that decomposes an aggregate indicator to quantify the relative contribution of a set of pre-defined factors leading to a change in the aggregate indicator. The *World Energy Outlook* uses an additive index decomposition of the type Logarithmic Mean Divisia Index (LMDI).

Demand-side integration (DSI)**:** Consists of two types of measures: actions that influence load shape such as energy efficiency and electrification; and actions that manage load such as demand-side response measures.

Demand-side response (DSR)**:** Describes actions which can influence the load profile such as shifting the load curve in time without affecting total electricity demand, or load shedding such as interrupting demand for a short duration or adjusting the intensity of demand for a certain amount of time.

Direct air capture (DAC)**:** A type of CCUS that captures CO_2 directly from the atmosphere using liquid solvents or solid sorbents. It is generally coupled with permanent storage of the CO_2 in deep geological formations or its use in the production of fuels, chemicals, building materials or other products. When coupled with permanent geological CO_2 storage, DAC is a carbon removal technology, and it is known as direct air capture and storage (DACS).

Dispatchable generation: Refers to technologies whose power output can be readily controlled, i.e. increased to maximum rated capacity or decreased to zero in order to match supply with demand.

Electric arc furnace: Furnace that heats material by means of an electric arc. It is used for scrap-based steel production but also for ferroalloys, aluminium, phosphorus or calcium carbide.

Electric vehicles (EVs)**:** Electric vehicles comprise of battery electric vehicles (BEV) and plug-in hybrid vehicles.

Electricity demand: Defined as total gross electricity generation less own use generation, plus net trade (imports less exports), less transmission and distribution losses.

Electricity generation: Defined as the total amount of electricity generated by power only or combined heat and power plants including generation required for own use. This is also referred to as gross generation.

Electrolysis: Process of converting electric energy to chemical energy. Most relevant for the energy sector is water electrolysis, which splits water molecules into hydrogen and oxygen molecules. The resulting hydrogen is called electrolytic hydrogen.

End-use sectors: Include industry, transport, buildings and other, i.e., agriculture and other non-energy use.

Energy-intensive industries: Includes production and manufacturing in the branches of iron and steel, chemicals, non-metallic minerals (including cement), non-ferrous metals (including aluminium), and paper, pulp and printing.

Energy-related and industrial process CO_2 emissions: Carbon dioxide emissions from fuel combustion, industrial processes, and fugitive and flaring CO_2 from fossil fuel extraction. Unless otherwise stated, CO_2 emissions in the *World Energy Outlook* refer to energy-related and industrial process CO_2 emissions.

Energy sector greenhouse gas (GHG) **emissions:** Energy-related and industrial process CO_2 emissions plus fugitive and vented methane (CH_4) and nitrous dioxide (N_2O) emissions from the energy and industry sectors.

Energy services: See useful energy.

Ethanol: Refers to bioethanol only. Ethanol is produced from fermenting any biomass high in carbohydrates. Currently ethanol is made from starches and sugars, but second-generation technologies will allow it to be made from cellulose and hemicellulose, the fibrous material that makes up the bulk of most plant matter.

Fischer-Tropsch synthesis: Catalytic process to produce synthetic fuels, e.g. diesel, kerosene or naphtha, typically from mixtures of carbon monoxide and hydrogen (syngas). The inputs to Fischer-Tropsch synthesis can be from biomass, coal, natural gas, or hydrogen and CO_2.

Fossil fuels: Include coal, natural gas and oil.

Gaseous fuels: Include natural gas, biogases, synthetic methane and hydrogen.

Gases: See gaseous fuels.

Gas-to-liquids (GTL)**:** A process that reacts methane with oxygen or steam to produce syngas (a mixture of hydrogen and carbon monoxide) followed by Fischer-Tropsch synthesis. The process is similar to that used in coal-to-liquids.

Geothermal: Geothermal energy is heat from the sub-surface of the earth. Water and/or steam carry the geothermal energy to the surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean electricity if the temperature is adequate.

Heat (end-use)**:** Can be obtained from the combustion of fossil or renewable fuels, direct geothermal or solar heat systems, exothermic chemical processes and electricity (through resistance heating or heat pumps which can extract it from ambient air and liquids). This category refers to the wide range of end-uses, including space and water heating, and cooking in buildings, desalination and process applications in industry. It does not include cooling applications.

Heat (supply)**:** Obtained from the combustion of fuels, nuclear reactors, large-scale heat pumps, geothermal or solar resources. It may be used for heating or cooling, or converted into mechanical energy for transport or electricity generation. Commercial heat sold is reported under total final consumption with the fuel inputs allocated under power generation.

Heavy-duty vehicles (HDVs): Include both medium freight trucks (gross weight 3.5 to 15 tonnes) and heavy freight trucks (gross weight >15 tonnes).

Heavy industries: Iron and steel, chemicals and cement.

Hydrogen: Hydrogen is used in the energy system as an energy carrier, as an industrial raw material, or is combined with other inputs to produce hydrogen-based fuels. Unless otherwise stated, hydrogen in this report refers to low-emissions hydrogen.

Hydrogen-based fuels: See low-emissions hydrogen-based fuels.

Hydropower: Refers to the electricity produced in hydropower projects, with the assumption of 100% efficiency. It excludes output from pumped storage and marine (tide and wave) plants.

Improved cook stoves: Intermediate and advanced improved biomass cook stoves (ISO tier > 1). It excludes basic improved stoves (ISO tier 0-1).

Industry: The sector includes fuel used within the manufacturing and construction industries. Key industry branches include iron and steel, chemical and petrochemical, cement, aluminium, and pulp and paper. Use by industries for the transformation of energy into another form or for the production of fuels is excluded and reported separately under other energy sector. There is an exception for fuel transformation in blast furnaces and coke ovens, which are reported within iron and steel. Consumption of fuels for the transport of goods is reported as part of the transport sector, while consumption by off-road vehicles is reported under industry.

International aviation bunkers: Include the deliveries of aviation fuels to aircraft for international aviation. Fuel used by airlines for their road vehicles are excluded. The domestic/international split is determined on the basis of departure and landing locations and not by the nationality of the airline. For many countries this incorrectly excludes fuels used by domestically owned carriers for their international departures.

International marine bunkers: Include the quantities delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded. The domestic/international split is determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship. Consumption by fishing vessels and by military forces is excluded and instead included in the residential, services and agriculture category.

Investment: Investment is the capital expenditure in energy supply, infrastructure, end-use and efficiency. Fuel supply investment includes the production, transformation and transport of oil, gas, coal and low-emissions fuels. *Power sector* investment includes new construction and refurbishment of generation, electricity grids (transmission, distribution and public electric vehicle chargers), and battery storage. *Energy efficiency* investment includes efficiency improvements in buildings, industry and transport. *Other end-use* investment includes the purchase of equipment for the direct use of renewables, electric vehicles, electrification in buildings, industry and international marine transport, equipment for the use of low-emissions fuels, and CCUS in industry and direct air capture. Data and projections reflect spending over the lifetime of projects and are presented in real terms in year-2022 US dollars converted at market exchange rates unless otherwise stated. Total investment reported for a year reflects the amount spent in that year.

Levelised cost of electricity (LCOE): LCOE combines into a single metric all the cost elements directly associated with a given power technology, including construction, financing, fuel, maintenance and costs associated with a carbon price. It does not include network integration or other indirect costs.

Light-duty vehicles (LDVs)**:** Include passenger cars and light commercial vehicles (gross vehicle weight < 3.5 tonnes).

Light industries: Include non-energy-intensive industries: food and tobacco; machinery; mining and quarrying; transportation equipment; textiles; wood harvesting and processing; and construction.

Lignite: A type of coal that is used in the power sector mostly in regions near lignite mines due to its low energy content and typically high moisture levels, which generally make long-distance transport uneconomic. Data on lignite in the *World Energy Outlook* include peat.

Liquid biofuels: Liquid fuels derived from biomass or waste feedstock, e.g. ethanol, biodiesel and biojet fuels. They can be classified as conventional and advanced biofuels according to the combination of feedstock and technologies used to produce them and their respective maturity. Unless otherwise stated, biofuels are expressed in energy-equivalent volumes of gasoline, diesel and kerosene.

Liquid fuels: Include oil, liquid biofuels (expressed in energy-equivalent volumes of gasoline and diesel), synthetic oil and ammonia.

Low-emissions electricity: Includes output from renewable energy technologies, nuclear power, fossil fuels fitted with CCUS, hydrogen and ammonia.

Low-emissions fuels: Include modern bioenergy, low-emissions hydrogen and low-emissions hydrogen-based fuels.

Low-emissions gases: Include biogas, biomethane, low-emissions hydrogen and low-emissions synthetic methane.

Low-emissions hydrogen: Hydrogen that is produced from water using electricity generated by renewables or nuclear, from fossil fuels with minimal associated methane emissions and processed in facilities equipped to avoid CO_2 emissions, e.g. via CCUS with a high capture rate, or derived from bioenergy. In this report, total demand for low-emissions hydrogen is larger than total final consumption of hydrogen because it additionally includes hydrogen inputs to make low-emissions hydrogen-based fuels, biofuels production, power generation, oil refining, and hydrogen produced and consumed onsite in industry.

Low-emissions hydrogen-based fuels: Include ammonia, methanol and other synthetic hydrocarbons (gases and liquids) made from low-emissions hydrogen. Any carbon inputs, e.g. from CO_2, are not from fossil fuels or process emissions.

Low-emissions hydrogen-based liquid fuels: A subset of low-emissions hydrogen-based fuels that includes only ammonia, methanol and synthetic liquid hydrocarbons, such as synthetic kerosene.

Lower heating value: Heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapour and the heat is not recovered.

Marine energy: Represents the mechanical energy derived from tidal movement, wave motion or ocean currents and exploited for electricity generation.

Middle distillates: Include jet fuel, diesel and heating oil.

Mini-grids: Small electric grid systems, not connected to main electricity networks, linking a number of households and/or other consumers.

Modern energy access: Includes household access to a minimum level of electricity (initially equivalent to 250 kilowatt-hours (kWh) annual demand for a rural household and 500 kWh for an urban household); household access to less harmful and more sustainable cooking and heating fuels, and improved/advanced stoves; access that enables productive economic activity; and access for public services.

Modern gaseous bioenergy: See biogases.

Modern liquid bioenergy: Includes biogasoline, biodiesel, biojet kerosene and other liquid biofuels.

Modern renewables: Include all uses of renewable energy with the exception of the traditional use of solid biomass.

Modern solid bioenergy: Includes all solid bioenergy products (see solid bioenergy definition) except the traditional use of biomass. It also includes the use of solid bioenergy in intermediate and advanced improved biomass cook stoves (ISO tier > 1), requiring fuel to be cut in small pieces or often using processed biomass such as pellets.

Natural gas: Includes gas occurring in deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both non-associated gas originating from fields producing hydrocarbons only in gaseous form, and associated gas produced in association with crude oil production as well as methane recovered from coal mines (colliery gas). Natural gas liquids, manufactured gas (produced from municipal or industrial waste, or sewage) and quantities vented or flared are not included. Gas data in cubic metres are expressed on a gross calorific value basis and are measured at 15 °C and at 760 mm Hg (Standard Conditions). Gas data expressed in exajoules are on a net calorific basis. The difference between the net and the gross calorific value is the latent heat of vaporisation of the water vapour produced during combustion of the fuel (for gas the net calorific value is 10% lower than the gross calorific value).

Natural gas liquids (NGLs)**:** Liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilisation of natural gas. NGLs are portions of natural gas recovered as liquids in separators, field facilities or gas processing plants. NGLs include, but are not limited to, ethane (when it is removed from the natural gas stream), propane, butane, pentane, natural gasoline and condensates.

Near zero emissions capable material production capacity: Capacity that will achieve substantial emissions reductions from the start – but fall short of near zero emissions material production initially (see following definition) – with plans to continue reducing emissions over time such that they could later achieve near zero emissions production without additional capital investment.

Near zero emissions material production: For steel and cement, production that achieves the near zero GHG emissions intensity thresholds as defined in *Achieving Net Zero Heavy Industry Sectors in G7 Members* (IEA, 2022). The thresholds depend on the scrap share of metallic input for steel and the clinker-to-cement ratio for cement. For other energy-intensive commodities such as aluminium, fertilisers and plastics, production that achieves reductions in emissions intensity equivalent to the considerations for near zero emissions steel and cement.

Near zero emissions material production capacity: Capacity that when operational will achieve near zero emissions material production from the start.

Network gases: Include natural gas, biomethane, synthetic methane and hydrogen blended in a gas network.

Non-energy-intensive industries: See other industry.

Non-energy use: The use of fuels as feedstocks for chemical products that are not used in energy applications. Examples of resulting products are lubricants, paraffin waxes, asphalt, bitumen, coal tars and timber preservative oils.

Non-renewable waste: Non-biogenic waste, such as plastics in municipal or industrial waste.

Nuclear power: Refers to the electricity produced by a nuclear reactor, assuming an average conversion efficiency of 33%.

Off-grid systems: Mini-grids and stand-alone systems for individual households or groups of consumers not connected to a main grid.

Offshore wind: Refers to electricity produced by wind turbines that are installed in open water, usually in the ocean.

Oil: Includes both conventional and unconventional oil production. Petroleum products include refinery gas, ethane, liquid petroleum gas, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirits, lubricants, bitumen, paraffin, waxes and petroleum coke.

Other energy sector: Covers the use of energy by transformation industries and the energy losses in converting primary energy into a form that can be used in the final consuming sectors. It includes losses in low-emissions hydrogen and hydrogen-based fuels production, bioenergy processing, gas works, petroleum refineries, coal and gas transformation and liquefaction. It also includes energy own use in coal mines, in oil and gas extraction and in electricity and heat production. Transfers and statistical differences are also included in this category. Fuel transformation in blast furnaces and coke ovens are not accounted for in the other energy sector category.

Other industry: A category of industry branches that includes construction, food processing, machinery, mining, textiles, transport equipment, wood processing and remaining industry. It is sometimes referred to as non-energy-intensive industry.

Passenger car: A road motor vehicle, other than a moped or a motorcycle, intended to transport passengers. It includes vans designed and used primarily to transport passengers. Excluded are light commercial vehicles, motor coaches, urban buses and mini-buses/mini-coaches.

Peat: Peat is a combustible soft, porous or compressed, fossil sedimentary deposit of plant origin with high water content (up to 90% in the raw state), easily cut, of light to dark brown colour. Milled peat is included in this category. Peat used for non-energy purposes is not included here.

Plastic collection rate: Proportion of plastics that is collected for recycling relative to the quantity of recyclable waste available.

Plastic waste: Refers to all post-consumer plastic waste with a lifespan of more than one year.

Power generation: Refers to electricity generation and heat production from all sources of electricity, including electricity-only power plants, heat plants, and combined heat and power plants. Both main activity producer plants and small plants that produce fuel for their own use (auto-producers) are included.

Process emissions: CO_2 emissions produced from industrial processes which chemically or physically transform materials. A notable example is cement production, in which CO_2 is emitted when calcium carbonate is transformed into lime, which in turn is used to produce clinker.

Process heat: The use of thermal energy to produce, treat or alter manufactured goods.

Productive uses: Energy used towards an economic purpose: agriculture, industry, services and non-energy use. Some energy demand from the transport sector, e.g. freight, could be considered as productive, but is treated separately.

Rare earth elements (REEs)**:** A group of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. REEs are key components in some clean energy technologies, including wind turbines, electric vehicle motors and electrolysers.

Renewables: Include bioenergy, geothermal, hydropower, solar photovoltaics (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation.

Residential: Energy used by households including space heating and cooling, water heating, lighting, appliances, electronic devices and cooking.

Road transport: Includes all road vehicle types (passenger cars, two/three-wheelers, light commercial vehicles, buses and medium and heavy freight trucks).

Self-sufficiency: Corresponds to indigenous production divided by total primary energy demand.

Services: A component of the buildings sector. It represents energy used in commercial facilities, e.g. offices, shops, hotels, restaurants, and in institutional buildings, e.g. schools, hospitals, public offices. Energy use in services includes space heating and cooling, water heating, lighting, appliances, cooking and desalination.

Shale gas: Natural gas contained within a commonly occurring rock classified as shale. Shale formations are characterised by low permeability, with more limited ability of gas to flow through the rock than is the case within a conventional reservoir. Shale gas is generally produced using hydraulic fracturing.

Shipping/navigation: This transport mode includes both domestic and international navigation and their use of marine fuels. Domestic navigation covers the transport of goods or people on inland waterways and for national sea voyages (starts and ends in the same country without any intermediate foreign port). International navigation includes quantities of fuels delivered to merchant ships (including passenger ships) of any nationality for consumption during international voyages transporting goods or passengers.

Single-use plastics (or disposable plastics)**:** Plastic items used only one time before disposal.

Solar: Includes both solar photovoltaics and concentrating solar power.

Solar home systems (SHS)**:** Small-scale photovoltaic and battery stand-alone systems, i.e. with capacity higher than 10 watt peak (Wp) supplying electricity for single households or small businesses. They are most often used off-grid, but also where grid supply is not reliable. Access to electricity in the IEA definition considers solar home systems from 25 Wp in rural areas and 50 Wp in urban areas. It excludes smaller solar lighting systems, e.g. solar lanterns of less than 11 Wp.

Solar photovoltaics (PV)**:** Electricity produced from solar photovoltaic cells including utility-scale and small-scale installations.

Solid bioenergy: Includes charcoal, fuelwood, dung, agricultural residues, wood waste and other solid biogenic wastes.

Solid fuels: Include coal, modern solid bioenergy, traditional use of biomass and industrial and municipal wastes.

Stand-alone systems: Small-scale autonomous electricity supply for households or small businesses. They are generally used off-grid, but also where grid supply is not reliable. Stand-alone systems include solar home systems, small wind or hydro generators, diesel or gasoline generators. The difference compared with mini-grids is in scale and that stand-alone systems do not have a distribution network serving multiple costumers.

Steam coal: A type of coal that is mainly used for heat production or steam-raising in power plants and, to a lesser extent, in industry. Typically, steam coal is not of sufficient quality for steel making. Coal of this quality is also commonly known as thermal coal.

Synthetic methane: Methane from sources other than natural gas, including coal-to-gas and low-emissions synthetic methane.

Synthetic oil: Synthetic oil produced through Fischer-Tropsch conversion or methanol synthesis. It includes oil products from CTL and GTL, and non-ammonia low-emissions liquid hydrogen-based fuels.

Tight oil: Oil produced from shale or other very low permeability formations, generally using hydraulic fracturing. This is also sometimes referred to as light tight oil. Tight oil includes tight crude oil and condensate production except for the United States, which includes tight crude oil only (US tight condensate volumes are included in natural gas liquids).

Total energy supply (TES)**:** Represents domestic demand only and is broken down into electricity and heat generation, other energy sector and total final consumption.

Total final consumption (TFC)**:** Is the sum of consumption by the various end-use sectors. TFC is broken down into energy demand in the following sectors: industry (including manufacturing, mining, chemicals production, blast furnaces and coke ovens); transport; buildings (including residential and services); and other (including agriculture and other non-energy use). It excludes international marine and aviation bunkers, except at world level where it is included in the transport sector.

Total final energy consumption (TFEC)**:** Is a variable defined primarily for tracking progress towards target 7.2 of the United Nations Sustainable Development Goals (SDG). It incorporates total final consumption by end-use sectors, but excludes non-energy use. It excludes international marine and aviation bunkers, except at world level. Typically this is used in the context of calculating the renewable energy share in total final energy consumption (indicator SDG 7.2.1), where TFEC is the denominator.

Traditional use of biomass: Refers to the use of solid biomass with basic technologies, such as a three-stone fire or basic improved cook stoves (ISO tier 0-1), often with no or poorly operating chimneys. Forms of biomass used include wood, wood waste, charcoal agricultural residues and other bio-sourced fuels such as animal dung.

Transport: Fuels and electricity used in the transport of goods or people within the national territory irrespective of the economic sector within which the activity occurs. This includes: fuel and electricity delivered to vehicles using public roads or for use in rail vehicles; fuel delivered to vessels for domestic navigation; fuel delivered to aircraft for domestic aviation; and energy consumed in the delivery of fuels through pipelines. Fuel delivered to international marine and aviation bunkers is presented only at the world level and is excluded from the transport sector at a domestic level.

Trucks: Includes all size categories of commercial vehicles: light trucks (gross vehicle weight < 3.5 tonnes); medium freight trucks (gross vehicle weight 3.5-15 tonnes); and heavy freight trucks (gross vehicle weight > 15 tonnes).

Useful energy: Refers to the energy that is available to end-users to satisfy their needs. This is also referred to as energy services demand. As result of transformation losses at the point of use, the amount of useful energy is lower than the corresponding final energy demand for most technologies. Equipment using electricity often has higher conversion efficiency than equipment using other fuels, meaning that for a unit of energy consumed, electricity can provide more energy services.

Value-adjusted levelised cost of electricity (VALCOE)**:** Incorporates information on both costs and the value provided to the system. Based on the LCOE, estimates of energy, capacity and flexibility value are incorporated to provide a more complete metric of competitiveness for power generation technologies.

Variable renewable energy (VRE)**:** Refers to technologies whose maximum output at any time depends on the availability of fluctuating renewable energy resources. VRE includes a broad array of technologies such as wind power, solar PV, run-of-river hydro, concentrating solar power (where no thermal storage is included) and marine (tidal and wave).

Zero carbon-ready buildings: A zero carbon-ready building is highly energy efficient and either uses renewable energy directly or an energy supply that can be fully decarbonised, such as electricity or district heat.

Zero emissions vehicles (ZEVs)**:** Vehicles that are capable of operating without tailpipe CO_2 emissions (battery electric and fuel cell vehicles).

Regional and country groupings

Advanced economies: OECD regional grouping and Bulgaria, Croatia, Cyprus[1,2], Malta and Romania.

Africa: North Africa and sub-Saharan Africa regional groupings.

Asia Pacific: Southeast Asia regional grouping and Australia, Bangladesh, Democratic People's Republic of Korea (North Korea), India, Japan, Korea, Mongolia, Nepal, New Zealand, Pakistan, The People's Republic of China (China), Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[3]

Caspian: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

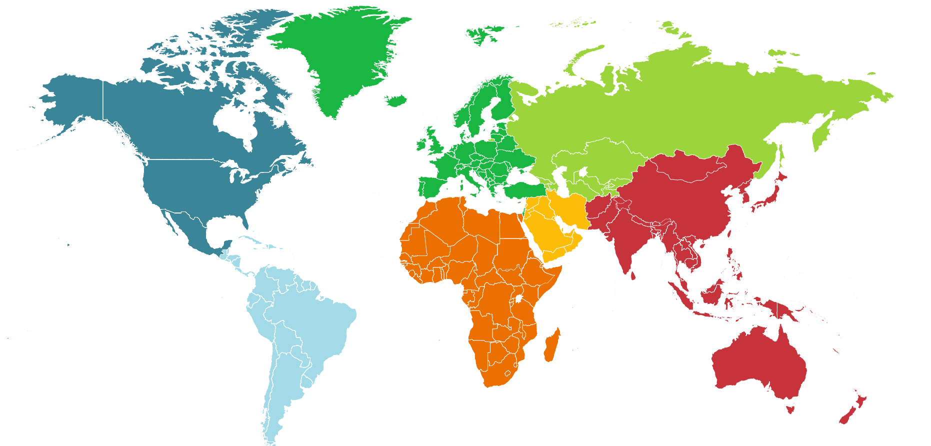
Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay and other Central and South American countries and territories.[4]

China: Includes (The People's Republic of) China and Hong Kong, China.

Developing Asia: Asia Pacific regional grouping excluding Australia, Japan, Korea and New Zealand.

Emerging market and developing economies: All other countries not included in the advanced economies regional grouping.

Figure C.1 ▷ Main country groupings



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Eurasia: Caspian regional grouping and the Russian Federation (Russia).

Europe: European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel[5], Kosovo, Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

IEA (International Energy Agency)**:** OECD regional grouping excluding Chile, Colombia, Costa Rica, Iceland, Israel, Latvia and Slovenia.

Latin America and the Caribbean (LAC)**:** Central and South America regional grouping and Mexico.

Middle East: Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

Non-OECD: All other countries not included in the OECD regional grouping.

Non-OPEC: All other countries not included in the OPEC regional grouping.

North Africa: Algeria, Egypt, Libya, Morocco and Tunisia.

North America: Canada, Mexico and United States.

OECD (Organisation for Economic Co-operation and Development)**:** Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, United Kingdom and United States.

OPEC (Organization of the Petroleum Exporting Countries)**:** Algeria, Angola, Bolivarian Republic of Venezuela (Venezuela), Equatorial Guinea, Gabon, Iraq, Islamic Republic of Iran (Iran), Kuwait, Libya, Nigeria, Republic of the Congo (Congo), Saudi Arabia and United Arab Emirates.

OPEC+: OPEC grouping plus Azerbaijan, Bahrain, Brunei Darussalam, Kazakhstan, Malaysia, Mexico, Oman, Russian Federation (Russia), South Sudan and Sudan.

Southeast Asia: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Sub-Saharan Africa: Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Kingdom of Eswatini, Madagascar, Mauritius, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo (Congo), Rwanda, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Uganda, Zambia, Zimbabwe and other African countries and territories.[6]

Country notes

[1] Note by Republic of Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

[2] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[3] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.

[4] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten (Dutch part), Turks and Caicos Islands.

[5] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[6] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone and Somalia.

Abbreviations and acronyms

ADB	Asian Development Bank
APS	Announced Pledges Scenario
BECCS	bioenergy equipped with CCUS
CAAGR	compound average annual growth rate
CIF	Climate Investment Funds
CCGT	combined-cycle gas turbine
CCUS	carbon capture, utilisation and storage
CHP	combined heat and power; the term co-generation is sometimes used
CNY	Yuan renminbi
CO_2	carbon dioxide
CO_2-eq	carbon-dioxide equivalent
COP	Conference of Parties (UNFCCC)
CTEI	Coal Transition Exposure Index
EOR	Enhanced oil recovery
EMDE	Emerging market and developing economies
ESG	Environmental, social and governance
ETM	Energy Transition Mechanism
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FDI	Foreign direct investment
FID	Final investment decision
G20	Group of Twenty
G7	Group of Seven
GCCPTS	Global Coal to Clean Power Transition Statement
GEC	global energy and climate (IEA model)
GDP	gross domestic product
GHG	greenhouse gases
GTL	gas-to-liquids
HEFA	hydrogenated esters and fatty acids
HFO	heavy fuel oil
HVDC	high voltage direct current
IAEA	International Atomic Energy Agency
ICT	information and communication technologies
IEA	International Energy Agency
IGCC	integrated gasification combined-cycle
IPP	independent power producer
IMF	International Monetary Fund
IOC	international oil company
IPCC	Intergovernmental Panel on Climate Change
JETP	Just Energy Transition Partnership
LCOE	levelised cost of electricity
LED	light-emitting diode

LNG	liquefied natural gas
LPG	liquefied petroleum gas
LULUCF	land use, land-use change and forestry
MDB	Multilateral development bank
MEPS	minimum energy performance standards
MER	market exchange rate
NDCs	Nationally Determined Contributions
NEA	Nuclear Energy Agency (an agency within the OECD)
NGLs	natural gas liquids
NGV	natural gas vehicle
NOC	national oil company
NPV	net present value
NO_X	nitrogen oxides
N_2O	nitrous dioxide
NZE	Net Zero Emissions by 2050 Scenario
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PM	particulate matter
$PM_{2.5}$	fine particulate matter
PPA	power purchase agreement
PPCA	Powering Past Coal Alliance
PPP	purchasing power parity
PV	photovoltaics
R&D	research and development
RD&D	research, development and demonstration
SCGJ	Skill Council for Green Jobs
SDG	Sustainable Development Goals (United Nations)
SLBs	Sustainability linked bonds
SME	small and medium enterprises
SMR	small modular reactor
SOEs	state-owned enterprises
SO_2	sulphur dioxide
SPV	special purpose vehicle
STEPS	Stated Policies Scenario
T&D	transmission and distribution
TES	thermal energy storage
TFC	total final consumption
TFEC	total final energy consumption
TPED	total primary energy demand
TSO	transmission system operator
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme

UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USGS	United States Geological Survey
VALCOE	value-adjusted levelised cost of electricity
VRE	variable renewable energy
WACC	weighted average cost of capital
WEO	World Energy Outlook
WHO	World Health Organization

References

Chapter 1: The context

Beyond Fossil Fuels. (2023). EUROPE'S COAL EXIT. https://beyondfossilfuels.org/europes-coal-exit/

G7 Ministers' Meeting on Climate, Energy and Environment. (2023). G7 Climate, Energy and Environment Ministers' Communique. https://www.meti.go.jp/information/g7hirosima/energy/pdf/G7MinistersCommunique2023.pdf

IEA. (2023a). World Energy Outlook 2023. Retrieved from https://www.iea.org/reports/world-energy-outlook-2023

PPCA. (2024). https://poweringpastcoal.org/

Reuters. (2022). Germany's cabinet approves accelerated coal exit by 2030 in western state. https://www.reuters.com/business/energy/germanys-cabinet-approves-accelerated-coal-exit-by-2030-western-state-2022-11-02/

Chapter 2: Managing the transition to low-emissions power

Clean Energy Ministerial. (2018). Thermal Power Plant Flexibility, a publication under the Clean Energy Ministerial campaign. https://www.ea-energianalyse.dk/wp-content/uploads/2020/02/thermal_power_plant_flexibility_2018_19052018.pdf

IEA. (2022). Nuclear Power and Secure Energy Transitions. https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions

IEA. (2023a). World Energy Outlook 2023. https://www.iea.org/reports/world-energy-outlook-2023

IEA. (2023b). Renewables 2023. https://www.iea.org/reports/renewables-2023

JERA. (2021, 05 24). JERA and IHI to Start a Demonstration Project Related to Ammonia Co-firing at a Large-Scale Commercial Coal-Fired Power Plant. https://www.jera.co.jp/en/news/information/20210524_677

Liu et al., J. (2020). Multi-Technical Flexibility Retrofit Planning of Thermal Power Units Considering High Penetration Variable Renewable Energy: The Case of China. Sustainability. https://www.mdpi.com/2071-1050/12/9/3543

National Development and Reform Commission of China. (2021). "十四五"现代能源体系规划. https://www.nea.gov.cn/1310524241_16479412513081n.pdf

REN21. (2023). Renewables 2023 Global Status Report. https://www.ren21.net/gsr-2023/

S&P Global. (2023, April 27). China's record coal capacity approvals in 2022: Will carbon targets still be met? https://www.spglobal.com/commodityinsights/en/ci/research-analysis/chinas-record-coal-capacity-approvals-in-2022-carbon-targets.html

Smil, V. (2010). Power Density Primer: Understanding the Spatial Dimension of the Unfolding Transition to Renewable Electricity Generation (Part II – Coal- and Wood-Fired Electricity Generation). https://www.vaclavsmil.com/wp-content/uploads/docs/smil-article-power-density-primer.pdf

Chapter 3: Financing the shift away from coal

ADB. (2023). Asian Development Bank. https://www.adb.org/what-we-do/energy-transition-mechanism-etm

IEA. (2021). Financing clean energy transitions in emerging and developing economies. https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies

Kessler, M. (2022). Supercharging Multilateral Development Banks. https://findevlab.org/supercharging-multilateral-development-banks/

OECD. (2022). Green, social, sustainability and sustainability-linked bonds in developing countries: How can donors support public sector issuances? https://www.oecd.org/dac/green-social-sustainability-and-sustainability-linked-bonds.pdf

PPCA. (2023). Private Finance. https://poweringpastcoal.org/strands-of-work/private-finance/

World Bank. (2022). Use of Auctions for Decommissioning Coal Power Globally. https://openknowledge.worldbank.org/entities/publication/bf9f40a4-4412-524f-a9ee-14ef8e5ab54d

Chapter 4: Policies of people-centred and just transitions

APF Canada. (2023). What Does a Just Energy Transition Look Like for China's Coal Sector? https://www.asiapacific.ca/publication/what-does-just-energy-transition-look-chinas-coal-sector

Center for Strategic and International Studies. (2021). UNDERSTANDING JUST TRANSITIONS IN COAL-DEPENDENT COMMUNITIES. https://www.csis.org/analysis/understanding-just-transitions-coal-dependent-communities

Government of Canada. (2023). Canada Coal Transition Initiative. Government of Canada: https://www.canada.ca/en/atlantic-canada-opportunities/services/canada-coal-transition-initiative.html

Government of Chile. (2020). National Green Hydrogen Strategy. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf

IDDRI. (2018). Insights from case studies of major coal-consuming economies. https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/201809-Synthesis%20Report%20Iddri-COALTRANSITIONS-def.pdf

IEA. (2021). Recommendations of the Global Commission on People-Centred Clean Energy Transitions. https://www.iea.org/reports/recommendations-of-the-global-commission-on-people-centred-clean-energy-transitions

IEA. (2022). Skills Development and Inclusivity for Clean Energy Transitions. https://www.iea.org/reports/skills-development-and-inclusivity-for-clean-energy-transitions

IEA. (2023). World Energy Employment 2023. https://www.iea.org/reports/world-energy-employment-2023

ILO. (2016). Guidelines for a just transition towards environmentally sustainable economies and societies for all. https://www.ilo.org/global/topics/green-jobs/publications/

IN-EN. (2021, March 04). China Coal Industry Association releases "2020 Coal Industry Development Annual Report". https://www.in-en.com/finance/html/energy-2245895.shtml

KCI. (2022). IMPLEMENTATION OF JUST TRANSITION AND ECONOMIC DIVERSIFICATION STRATEGIES. https://unfccc.int/sites/default/files/resource/A%20compilation%20of%20best%20practices%20on%20JT%20and%20EDT.pdf

Reuters. (2021). Coal miner Cerrejon says reached deal with indigenous community on environment, health. https://www.reuters.com/business/environment/coal-miner-cerrejon-says-reached-deal-with-indigenous-community-environment-2021-02-26/

Setiawanet al., I. (2021). Evaluation of Environmental and Economic Benefits of Land Reclamation in the Indonesian Coal Mining Industry. Resources 2021, 10, 60. doi:https://doi.org/10.3390/resources10060060

UN Women. (2022). State of Gender Equality and Climate Change in ASEAN. https://asean.org/wp-content/uploads/2022/08/State-of-Gender-Equality-and-Climate-Change-in-ASEAN_FINAL-1.pdf

US Bureau of Labour Statistics. (2022, May). May 2022 National Industry-Specific Occupational Employment and Wage Estimates. https://www.bls.gov/oes/current/oessrci.htm

US DOE. (2022). United States Energy and Employment Report 2022. https://www.energy.gov/policy/us-energy-employment-jobs-report-useer

Walk et al., P. (2021). Strengthening Gender Justice in a Just Transition: A Research Agenda Based on a Systematic Map of Gender in Coal Transitions. https://www.mdpi.com/1996-1073/14/18/5985/htm

B

World Bank. (2022a). Expanding the Role of Women in Indonesia's Extractives Sector. https://www.worldbank.org/en/news/feature/2022/03/21/expanding-the-role-of-women-in-indonesia-s-extractives-sector

World Bank. (2022b). Support for Polish Coal Regions in Transition. https://www.worldbank.org/en/country/poland/publication/support-for-polish-coal-regions-in-transition

WRI. (2021). Spain's National Strategy to Transition Coal-Dependent Communities. https://www.wri.org/update/spains-national-strategy-transition-coal-dependent-communities

IEA Publications
International Energy Agency
Website: www.iea.org
Contact information: www.iea.org/contact

Typeset in France by IEA - March 2024
Cover design: IEA
Photo credits: © Shutterstock

Accelerating Just Transitions for the Coal Sector

World Energy Outlook Special Report

Coal is the most carbon-intensive major fossil fuel in use today and is deeply entrenched in the power system, but drastic reductions in its consumption are required to achieve net-zero emissions. *Accelerating Coal Transitions* provides an update on the IEA's 2022 report *Coal in Net Zero Transitions* at the request of the Japanese G7 Presidency. It comes out two years after Russia's invasion of Ukraine prompted a surge in coal-fired generation. The report offers pragmatic strategies for policymakers to transition away from unabated coal power while maintaining energy security, affordability, and protecting local communities deeply connected to coal production and use. This update also includes a series of case studies highlighting successful policy examples across diverse national circumstances.