

World Energy Investment 2022

iea



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, 10 association countries and beyond.

Please note that this publication is subject to specific restrictions that limit its use and distribution. The terms and conditions are available online at www.iea.org/t&c/

This publication and any map included herein are 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.

Source: IEA. All rights reserved.
International Energy Agency
Website: www.iea.org

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
Turkey
United Kingdom
United States

IEA association countries:

Argentina
Brazil
China
Egypt
India
Indonesia
Morocco
Singapore
South Africa
Thailand

Abstract

This year's edition of the World Energy Investment report provides a full update on the investment picture in 2021 and full-year estimates of the outlook for 2022. It examines how investors are assessing risks and opportunities across all areas of fuel and electricity supply, critical minerals, efficiency and research and development, against a backdrop of uncertainties over how events will play out in 2022, namely the ongoing war in Ukraine, the outlook for the global economy, and in some countries the continuing public health risks from the pandemic.

The report focuses on some important features of the new investment landscape which are already visible, including the energy security lens through which many investments are now viewed, widespread cost pressures, the major boost in revenues that high fuel prices are bringing to traditional suppliers, and burgeoning expectations in many countries that investments will be aligned with solutions to the climate crisis.

Table of contents

Introduction	5	Industry	159
Overview and key findings.....	8	Implications	164
Power sector.....	27	R&D and technology innovation	167
Overview of power investment	28	Spending on energy R&D	170
Generation.....	35	Venture capital funding of early-stage energy technology companies ..	180
Final investment decisions	42	Implications	191
Electricity grids and battery storage	50	Finance	194
Implications.....	56	Overview	195
Fuel supply	59	Sustainable finance.....	204
Overview.....	60	Emerging markets and developing economies	213
Upstream oil and gas.....	65		
Midstream and downstream oil and gas	76		
Oil and gas industry transitions	81		
Low emissions fuels	86		
Coal	98		
Implications.....	103		
Critical mineral supply.....	111		
Overview.....	112		
Investment trends	118		
Trends by individual commodity	123		
Implications.....	132		
Energy end use and efficiency	136		
Overview.....	137		
Buildings	145		
Transport	152		

Introduction

The spotlight is on energy investment, as never before

High fuel prices, inflationary pressures and supply chain bottlenecks, the urgent need to accelerate the energy sector's transformation to net zero, and the Russian invasion of Ukraine are creating a potent mix of pressures and incentives for energy investors. This new World Energy Investment 2022 (WEI 2022) report is the seventh in our [annual series](#) where we provide the global benchmark for tracking capital flows in the energy sector. The importance of this issue has never been higher, for consumers, investors, policy makers and the planet.

Investment trends in recent years have contributed to the crisis that we see today. Previous editions of WEI have repeatedly highlighted shortfalls in energy investment and the possible implications for energy markets, security and emissions. For example, on the opening page of [WEI 2019](#), the Executive Director observed how our analysis highlighted several mismatches demanding a hard look by policy makers and other stakeholders:

“Current market and policy signals are not incentivising the major reallocation of capital to low-carbon power and efficiency that would align with a sustainable energy future. In the absence of such a shift, there is a growing possibility that investment in fuel supply will also fall short of what is needed to satisfy growing demand. And to meet sustainable development goals, much more investment is needed in

the regions that face the highest economic and financial constraints, such as in sub-Saharan Africa.”

These risks and mismatches have been exacerbated in the period since 2019. Investment in energy transitions has remained relatively robust, but is still far short of the levels that – according to the IEA's landmark [Net Zero by 2050 Roadmap](#) – would be sufficient to meet rising demand for energy services in a sustainable way. The amount of money going into traditional areas of energy supply, including oil and gas, fell further in 2020 due to the worldwide shock caused by the Covid pandemic. And the worst effects of the pandemic and the economic slump have been felt by the most vulnerable citizens and countries around the world, pushing millions of people back into or towards energy poverty and lessening the investment funds available in developing economies for sustainable recovery; how to accelerate these investments is the crucial issue examined in the 2021 IEA report on [financing clean energy transitions in emerging and developing economies](#).

For these reasons, warning signs about investment in global energy were flashing red well in advance of the Russian invasion of Ukraine. Russia's aggression has now added another layer of expectation and uncertainty to the picture. Russia is the world's largest exporter of oil and gas, and the largest single provider of oil, gas and coal to Europe. Meeting in Versailles in early March, European leaders committed

themselves to reducing their dependence on these Russian imports as soon as possible. Following through on this commitment will have momentous implications for energy investment flows. In the near term, the scramble for alternative sources of fossil fuels creates clear openings for non-Russian suppliers. But these opportunities may be time-limited if Europe also responds to today's crisis with a determined acceleration of investment in efficiency, renewables and other clean technologies.

In the new WEI 2022 we provide a full update on the investment picture in 2021 and an initial reading of the emerging picture for 2022. There remain huge uncertainties over how events will play out in 2022, namely the ongoing war in Ukraine, the outlook for the global economy, and in some countries the continuing public health risks from the pandemic. But some important features of the new investment landscape are already visible, including the energy security lens through which many investments are now viewed, widespread cost pressures, the major boost in revenues that high fuel prices are bringing to traditional suppliers, and burgeoning expectations in many countries that investments will be aligned with solutions to the climate crisis.

The structure of this year's WEI 2022 is as follows:

In Chapter 1 we present the overview and **key findings**. Chapter 2 covers the **power sector**, while Chapter 3 reviews the latest

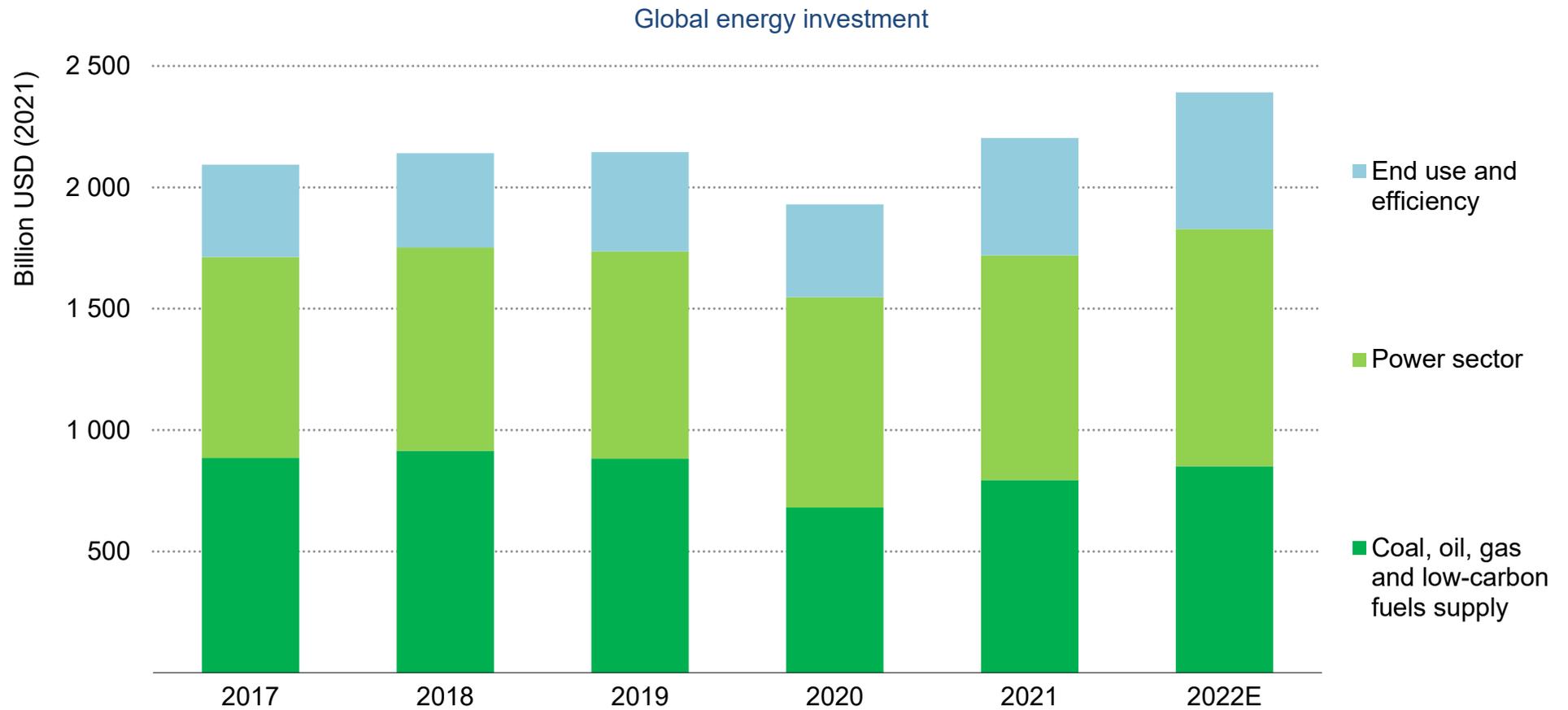
developments and trends in **fuel supply** investment. Chapter 4 represents a new departure for the WEI in covering investment in **critical minerals**, an increasingly strategic aspect of energy transitions. Chapter 5 deals with investment in **energy efficiency and the end-use sectors**, and Chapter 6 brings insights on energy **research and development and innovation**. The concluding Chapter 7 considers trends in **energy finance**.

While the focus of WEI 2022 is to track investment and financing trends in 2021 and provide an early indication for 2022, the report also benchmarks today's trends against future scenarios from the IEA [World Energy Outlook 2021](#). The **Stated Policies Scenario (STEPS)** is based on today's policy settings and considers aspirational targets only insofar as they are backed by detailed policies. The **Announced Pledges Scenario (APS)** assumes that all climate commitments and net zero targets made by governments around the world will be met in full and on time. The **Net Zero Emissions by 2050 Scenario (NZE Scenario)** sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO₂ emissions by 2050.

The preparation of this report benefited greatly from the insights gained at a workshop convened by the IEA on 8 March 2022, which brought together leading experts and practitioners from across the world of energy finance.

Overview and key findings

Energy investment is set to pick up by 8% in 2022 against the backdrop of the global energy crisis, but almost half of the increase in capital spending is linked to higher costs



IEA. All rights reserved.

High prices, rising costs, economic uncertainty, energy security concerns and climate imperatives amount to a powerful cocktail of factors bearing on global energy investment

Investment is central to tackling the multiple strands of today's energy crisis: to relieve pressure on consumers, to get the world on a net zero pathway, to spur economic recovery, and – for Europe in particular – to reduce reliance on the Russia Federation (hereafter “Russia”) following its invasion of Ukraine. Governments, companies and investors face a complex situation as they decide which energy projects to back, with urgent short-term needs not automatically aligned with long-term goals. A lot is riding on these choices.

Our updated tracking, across all sectors, technologies and regions, suggests that world energy investment is set to rise over 8% in 2022 to reach a total of USD 2.4 trillion, well above pre-Covid levels. Investment is increasing in all parts of the energy sector, but the main boost in recent years has come from the power sector – mainly in renewables and grids – and from increased spending on end-use efficiency. Investment in oil, gas, coal and low-carbon fuel supply is the only area that, in aggregate, remains below the levels seen prior to the pandemic in 2019. This is despite sky-high fuel prices that are generating an unprecedented windfall for suppliers: net income for the world's oil and gas producers is set to double in 2022 to an unprecedented USD 4 trillion.

Almost half of the additional USD 200 billion in capital investment in 2022 is likely to be eaten up by higher costs, rather than bringing additional energy supply capacity or savings. Costs are rising due to

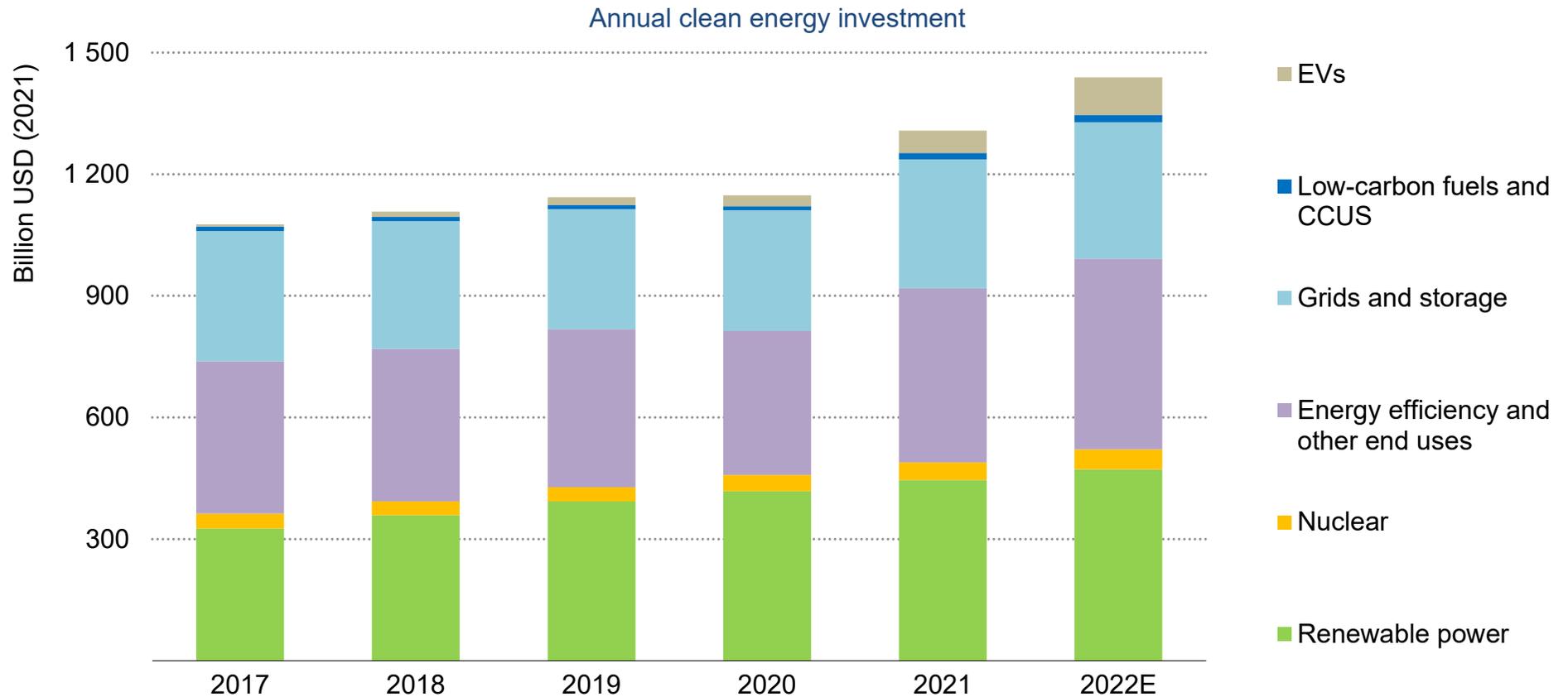
multiple supply chain pressures, tight markets for specialised labour and services, and the effect of higher energy prices on essential construction materials like steel and cement.

These cost pressures are most visible in fuel supply, but are affecting clean energy technologies as well: after years of declines, the costs of solar panels and wind turbines are up by between 10% and 20% since 2020. Concerns about cost inflation are a brake on the willingness of companies to increase spending, despite the strong price signals.

Easing the burden on consumers is an immediate priority for many policy makers: the total energy bill paid by the world's consumers is likely to top USD 10 trillion for the first time in 2022, hitting the poorest parts of society the hardest and putting pressure on governments to cushion the blow via fiscal measures and price interventions.

High prices are encouraging some countries to step up fossil fuel investment, as they seek to secure and diversify their sources of supply. However, the lasting solutions to today's crisis lie in speeding up clean energy transitions via greater investment in efficiency, clean electricity and a range of clean fuels. These elements are central, for example, to the European Union's REPowerEU plan to reduce reliance on Russia. There are many ways to respond to the immediate energy crisis that can pave the way to a cleaner and more secure future.

After remaining flat for several years, global clean energy spending is finally ramping up



IEA. All rights reserved.

Notes: Energy efficiency and other end-use includes spending on energy efficiency, renewables for end use and electrification in the buildings, transport and industry sectors. Low carbon fuels include modern liquid and gaseous bioenergy, low-carbon hydrogen, as well as hydrogen-based fuels that do not emit any CO₂ from fossil fuels directly when used and also emit very little when being produced.

Renewable power, efficiency and EVs are leading the clean energy push

Clean energy investment is – finally – starting to pick up and is expected to exceed USD 1.4 trillion in 2022, accounting for almost three-quarters of the growth in overall energy investment. The annual average growth rate in clean energy investment in the five years after the signature of the Paris Agreement in 2015 was just over 2%. Since 2020 the rate has risen to 12%, well short of what is required to hit international climate goals, but nonetheless an important step in the right direction. The highest clean energy investment levels in 2021 were in China (USD 380 billion), followed by the European Union (USD 260 billion) and the United States (USD 215 billion).

The gains have been underpinned by the increasing cost-competitiveness of many clean energy technologies and by policy and fiscal measures enacted to support transitions, often as part of efforts to ensure sustainable post-pandemic recoveries. The IEA Sustainable Recovery Tracker estimated in early 2022 that governments worldwide earmarked USD 710 billion for long-term clean energy and sustainable recovery measures.

Renewable power is at the heart of the positive trend; even though costs have risen in recent months, clean technologies such as wind and solar PV remain the cheapest option for new power generation in many countries, even before accounting for the exceptionally high prices seen in 2022 for coal and gas. Renewables, grids and storage now account for more than 80% of total power sector investment.

Solar PV makes up almost half of new investment in renewable power, with spending divided equally between utility-scale projects and distributed solar PV systems. The focus for wind power is shifting offshore: whereas 2020 was a record year for onshore deployment, 2021 was a record year for offshore, with more than 20 GW commissioned and around USD 40 billion of expenditure.

Investment in **improved efficiency** is another major growth area, driven by higher fuel prices and government incentives. A 16% increase in buildings efficiency investment in 2021 led the way, by far the largest annual increase since we started tracking these investment flows. Policy makers are attempting to move the global annual rate of building retrofits above the 1% mark, where it has been stuck for many years, and many countries, notably Japan, China and some in Europe, are putting increasing emphasis on high energy performance standards for new construction.

The upward trend in efficiency spending is expected to be maintained in 2022. The spike in fuel prices is prompting increasing interest in technologies like electric heat pumps (sales of which grew by 15% in 2021). However, efficiency investment faces headwinds, with higher borrowing costs, flat household incomes, and lower consumer and business confidence. As ever, much hinges on continued government support to shape consumer and corporate demand.

Electrification of mobility is a key contributor to rising clean end-use spending by consumers. Sales of EVs more than doubled in 2021 on the previous year and are continuing to rise strongly in 2022. Back in 2012 just 120 000 EVs were sold worldwide. In 2021 more than that number were sold each week. One uncertainty is whether automakers can keep up with orders, given supply chain issues (see section on critical minerals) and the global semiconductor shortage.

Electrification is not only about cars; sales of electric two- and three-wheelers have been buoyant, and investment in the electrification of buses and commercial vehicles is also strong. Most electric buses are still deployed in China, but investment elsewhere is growing: in early 2022 India ordered more than 5 000 electric buses for five major cities, awarded at half the price reached in previous tenders.

There are signs of life among important new and emerging technologies, where absolute investment remains relatively small but growth rates are high.

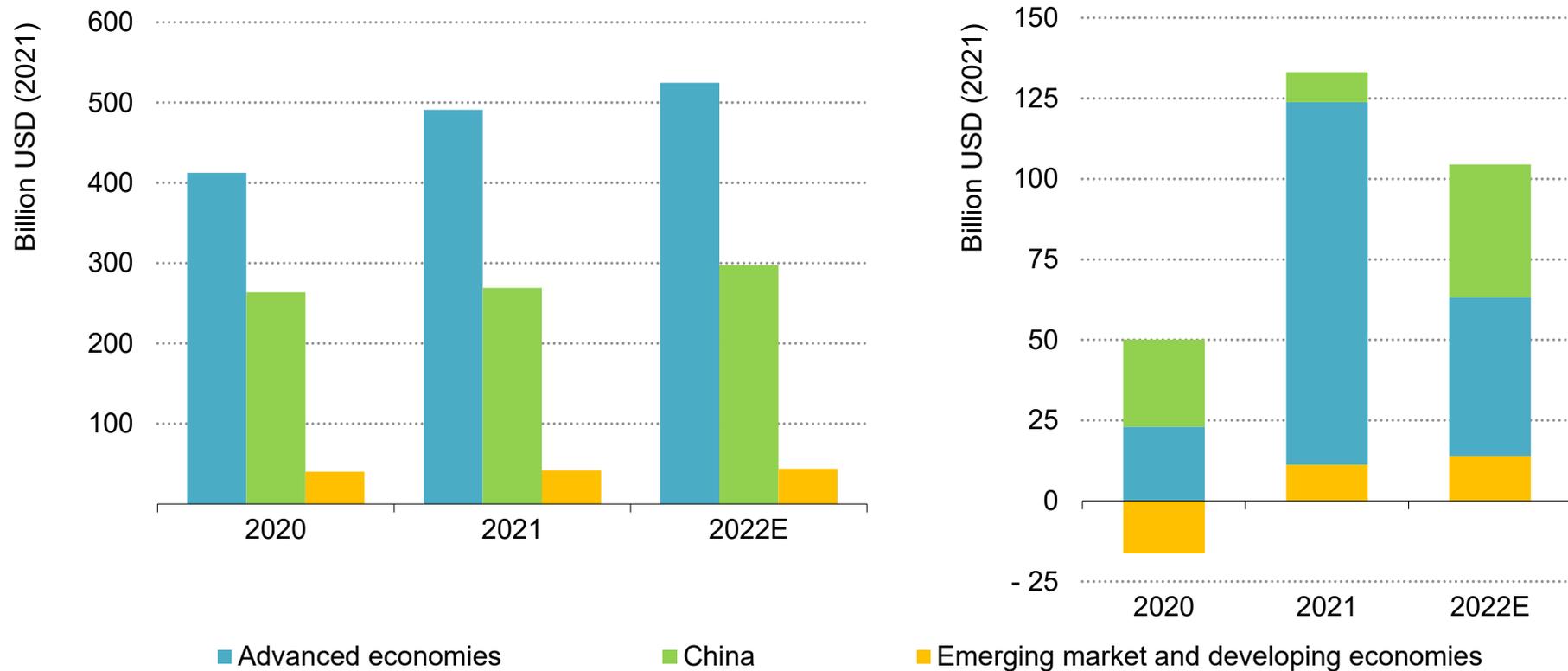
- Investment in **battery energy storage** is hitting new highs and is expected to more than double to reach almost USD 20 billion in 2022. This is led by grid-scale deployment, which represented more than 70% of total spending in 2021. The pipeline of projects is immense, with China targeting around 30 GW of non-hydro energy storage capacity by 2025 and the United States having more than 20 GW of grid-scale projects either planned or under construction.

- The momentum behind **low-emissions hydrogen** has been reinforced by Russia's invasion of Ukraine, which has bolstered policy support, especially in Europe. Clean hydrogen-focused companies are raising more money than ever before, and the value of a portfolio of leading firms in this space has quadrupled since the end of 2019. Annual investment in low-carbon hydrogen stands at around USD 0.5 billion; to supply the extra 15 Mt of hydrogen targeted in the REPowerEU plan, we estimate that cumulative capital investment totalling around USD 600 billion globally would be needed up to 2030, with 60% of this for infrastructure outside the European Union.
- Plans for around 130 commercial-scale **CO₂ capture** projects in 20 countries were announced in 2021. They aim to capture CO₂ from a range of applications, including hydrogen and biofuel production, which combined account for almost half of newly announced projects. Investment has also risen, to around USD 1.8 billion in 2021, as six CCUS projects took FID last year. Significant amounts of private capital are starting to flow to young companies with costly technologies to remove CO₂ from the air and store or use it.

The momentum behind early-stage emerging technologies is being maintained by rising public funding support for energy innovation. Start-ups in the United States and Europe have raised record funds, in particular for promising energy storage, hydrogen and renewable energy technologies.

Major regional variations in clean energy investment trends underline the risk of new dividing lines on energy and climate

Per-capita clean energy investment (left) and annual change in clean energy investment (right), by region, 2020-2022E



IEA. All rights reserved.

Accelerating investment in emerging and developing economies is essential to boost energy transitions and energy security

While global clean energy investment is now well above where it was at the time the Paris Agreement was signed, the rise has been concentrated in advanced economies and China. Clean energy spending in emerging and developing economies (excluding China) remains stuck at 2015 levels. These funds go further than they used to, as technology costs are significantly lower than they were, and there are some bright spots – utility-scale renewables in India, wind and distributed PV in Brazil, among others. But overall, the relative weakness of clean energy investment across much of the developing world is one of the most worrying trends revealed by our analysis.

Investment in many emerging and developing economies is more dependent on public sources; state-owned enterprises account for around half of energy investment in these economies. But public funds are typically scarce, many state-owned utilities are highly indebted and a worsening global economic outlook reduces governments' ability to fund energy projects. Of the stimulus spending mobilised to support a sustainable recovery, more than 90% is in advanced economies. High costs of capital and rising borrowing costs threaten to undercut the economic attractiveness of capital-intensive clean technologies: an increase of 2 percentage points in the cost of capital for solar PV and wind can lead to a 20% increase in overall levelised costs.

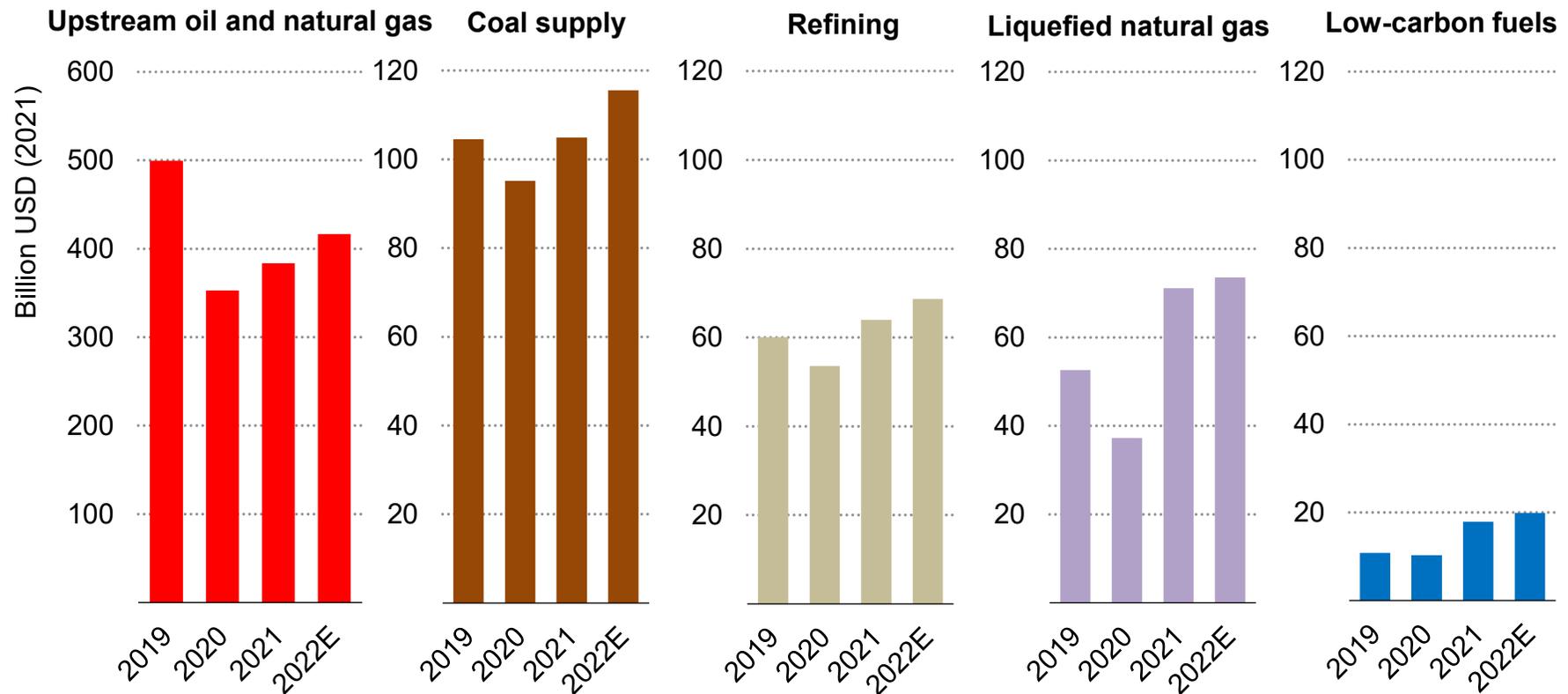
Most of the positive trends in clean energy investment leave developing economies behind. Virtually all of the global increase in spending on renewables, grids and storage since 2020 has taken place elsewhere. More than 80% of EV sales are concentrated in China and Europe; more than 90% of global spending on public EV recharging infrastructure is in China, Europe and the United States.

High prices are a blunt instrument to foster more sustainable choices, especially in poorer countries, in the absence of supportive policies. There is a real risk that today's energy crisis will push millions back towards energy poverty: nearly 90 million people in Asia and Africa who had previously gained access to electricity, can no longer afford to pay for their basic energy needs.

Much more needs to be done to bridge the gap between emerging and developing economies' one-fifth share of global clean energy investment, and their two-thirds share of the global population. Additional financial and technical support, including concessional capital, private sector capital, and inflows from international carbon markets, will all be crucial. If clean energy investment does not rapidly pick up in emerging and developing economies, the world will face a major dividing line in efforts to address climate change and reach other sustainable development goals.

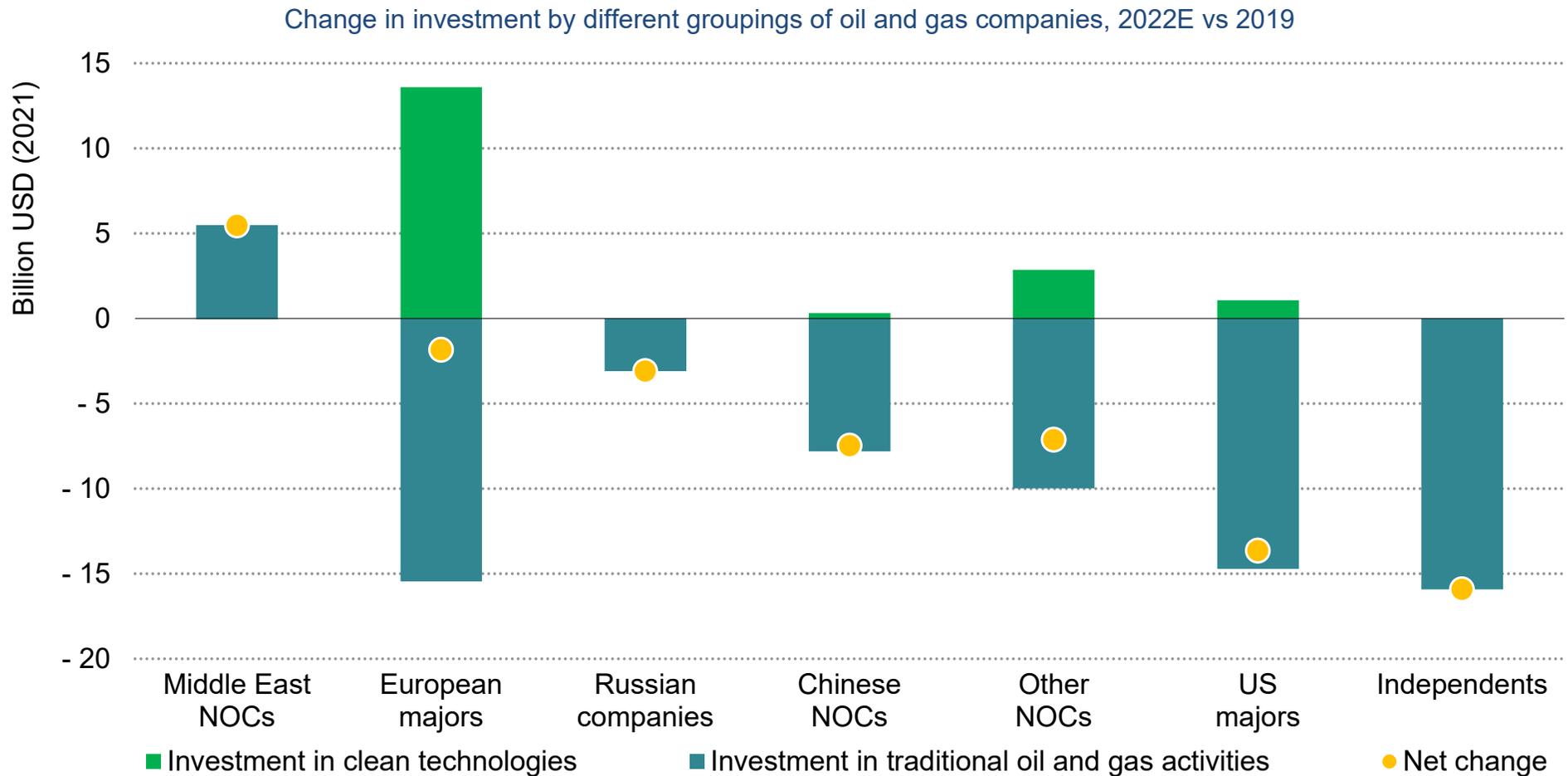
The energy crisis and Russia’s invasion of Ukraine are spurring new investment in fuels, including an expansion of coal supply in emerging Asian economies

Change in fuel supply investment, 2019-2022E



IEA. All rights reserved.

There is a wide range of investment strategies across different parts of the oil and gas industry; only the Middle East NOCs are planning to spend more in 2022 than in 2019



IEA. All rights reserved.

Fossil fuel investment is responding to price signals, but with some hesitation

Investment in fossil fuels is on a rising trend, but is still almost 30% below where it was when the Paris Agreement was signed. The cyclical incentive to invest in times of high prices is being reinforced in some areas by policy drive to diversify away from Russian supply and address near-term market tensions, but there are constraints on this price responsiveness. Policy uncertainty is high, financing can be difficult to secure and companies are generally shying away from large commitments of capital that may take many years to pay back.

Investment in **coal supply** is much less capital-intensive than oil and gas, and has been less subject to large year-on-year variations. Around USD 105 billion was invested in the coal supply chain in 2021, an increase of 10% year-on-year, and a further 10% rise is expected in 2022 as tight supply continues to attract new projects. This is a long way from the market situation implied by international climate goals and the Glasgow commitment to “phase down” coal.

This increase is being led by China and India, the dominant players in global coal markets. Coal shortages and power rationing in China in 2021 made energy security the main priority in near-term Chinese policy, and more than 350 Mt per year of new coal mining capacity was brought on stream in the second half of the year. Although China has pledged to stop building coal-fired plants abroad, there is still significant new capacity coming onto the domestic market, with more

than 20 GW approved for development in both 2020 and 2021, and more than 15 GW approved so far in the first half of 2022.

India is also looking to increase domestic coal supply in the face of a squeeze in 2022 that increased the use of more expensive imported coal. Other markets, including in Europe, are using more coal (at least temporarily) without necessarily pushing up investment in coal supply, which is constrained in many cases by an increasingly restrictive financial and regulatory environment.

The **oil and gas sector** is showing a similar variability in the response to high prices. Spending by Middle East National Oil Companies (NOCs) is now well above pre-crisis levels, as major resource holders look to bolster dwindling spare capacity. Saudi Aramco and ADNOC have announced plans to increase investment spending by about 15-30% in 2022. Russian companies, led by Rosneft, had also announced significant investment hikes for 2022, but are now reviewing their investment programmes in the light of sanctions, increasing restrictions on access to Western markets, and the announced exit of international players and service companies that have supported Russian production growth in the past.

Among the Western and international companies, some of the largest increases in upstream investment in 2022 are expected to come from the US majors, which are planning to increase spending by more than

30% in 2022. Meanwhile, planned upstream capex is essentially flat for the European majors in 2022, underscoring that their investment plans are driven more by long-term strategy commitments than by short-term prices.

In a situation where commodity prices are high and supplies are scarce, the focus of investment is squarely on projects that can deliver new volumes in a hurry. Methane abatement and flaring reductions fall into this category. Increased output of US shale oil and gas would be another possibility because of its short investment cycle. However, investment in this area has been relatively slow to pick up, held back by tight supply chains as well as a continued focus among operators on profitability and capital discipline.

Europe's move away from Russian gas is putting new demands on **LNG markets**, but the implications for new LNG investment are complicated by the fact that most projects face a three to four year construction period and payback periods for invested capital that go well beyond the immediate European scramble for alternative supply. The uptick in long-term LNG commitments is still being led by Asian buyers, and only two new LNG projects have so far reached FID since gas prices started rising in mid-2021 (the USD 11 billion Pluto expansion in Australia and the USD 13 billion Plaquemines project in Louisiana).

High prices also raise questions about the outlook for gas demand, especially in price-sensitive developing economies. The 45 GW of new gas-fired capacity achieving FID in 2021 was the lowest in

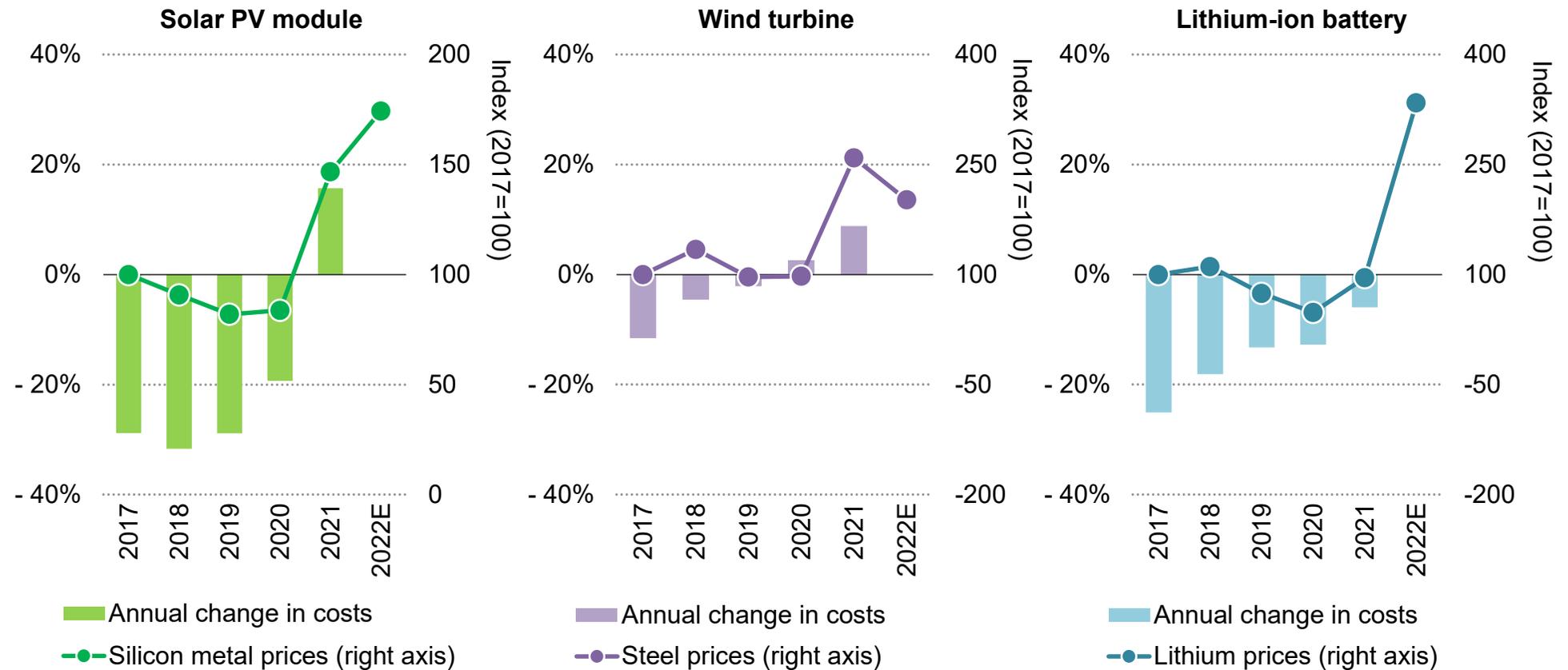
15 years. Moreover, most of the decisions to invest in new gas turbines were in gas-importing countries that are exposed to international price volatility.

The **refining** sector saw its first reduction in global refining capacity in 30 years in 2021, as the 1.8 mb/d of retirements outpaced relatively modest additions in China and the Middle East. This presaged and contributed to the extraordinary rise in refining margins seen during the crisis in 2022. However, the strong financial performance and high utilisation rates seen in recent months may not necessarily translate into higher investment levels given lingering uncertainty around the long-term outlook for oil demand.

Some oil and gas companies are under pressure to adapt their investments to the **demands of energy transitions**. Reducing emissions from their own operations – notably methane leaks – is a first-order priority for all, but beyond this, strategic choices vary widely. Spending by oil and gas companies outside “traditional” areas of supply is set to reach 5% of total spending in 2022. But this average masks a wide range of approaches. The majors and Equinor accounted for about 90% of total clean energy investment by the oil and gas industry in 2021 and almost all of the investment tracked so far in 2022. Overall, European companies are out in front for diversified spending, with major roles as investors in offshore wind.

Critical minerals threaten to reverse the trend of declining costs for clean energy technologies

Technology cost trends and key material prices for a solar PV module, wind turbine and lithium-ion battery, 2017-2022



IEA. All rights reserved.

Notes: Solar PV module costs are based on a multicrystalline silicon module. Wind turbine costs are based on global average prices excluding installation costs by signing date. Lithium-ion battery costs are based on battery pack cost. Steel prices are indexed prices for US Hot Rolled Steel Bars, Plates, and Structural Shapes, Alloy. Lithium prices are based on Lithium Carbonate Global Average by S&P Global. 2022 material prices are average prices between January and March. Source: IEA analysis based on BNEF (2022) and S&P Global (2022).

Rising prices for critical minerals are provoking a supply response; investment in mining, refining and processing comes into focus as a major pillar of energy transitions

For the first time, this year's WEI includes a detailed review of investment trends for the minerals and metals that are vital to energy transitions. The price increases for these critical minerals since the start of 2021 – notably for lithium, but also for cobalt, nickel, copper and aluminium – have been greater than at any point in the 2010s, due to a combination of rising demand, disrupted supply chains and concerns around tightening supply.

This surge in prices has been a major factor in reversing, at least temporarily, the trajectory of declining costs for some clean energy technologies. The share of cathode material costs (including lithium, nickel, cobalt and manganese) in the costs of an EV battery has risen from 5% in the mid-2010s to more than 20% today, at a time when some 300 new gigafactories are in planning and construction.

Market tensions are exacerbated by questions over Russian supply. Russia is the world's leading producer of palladium (43%), used for catalytic converters in cars. It is the largest producer of battery-grade Class 1 nickel, with 20% of the world's mined supply. Russia is the world's second largest producer of aluminium (6%), and the second and fourth largest producer of cobalt and graphite respectively.

In contrast to fossil fuels, elevated critical mineral prices are accompanied by expectations of rapid demand growth, and this helps to underpin expansive investment plans. The combined operating profits of 18 major mining companies with a strong presence in developing energy transition minerals more than doubled in 2021.

This helped to underpin a 20% increase in overall investment in non-ferrous metal production in 2021, with the pace of increase even faster among companies focusing on specific minerals. Lithium-focused companies increased their spending by 50% to record highs. Investment growth is expected to remain strong in 2022.

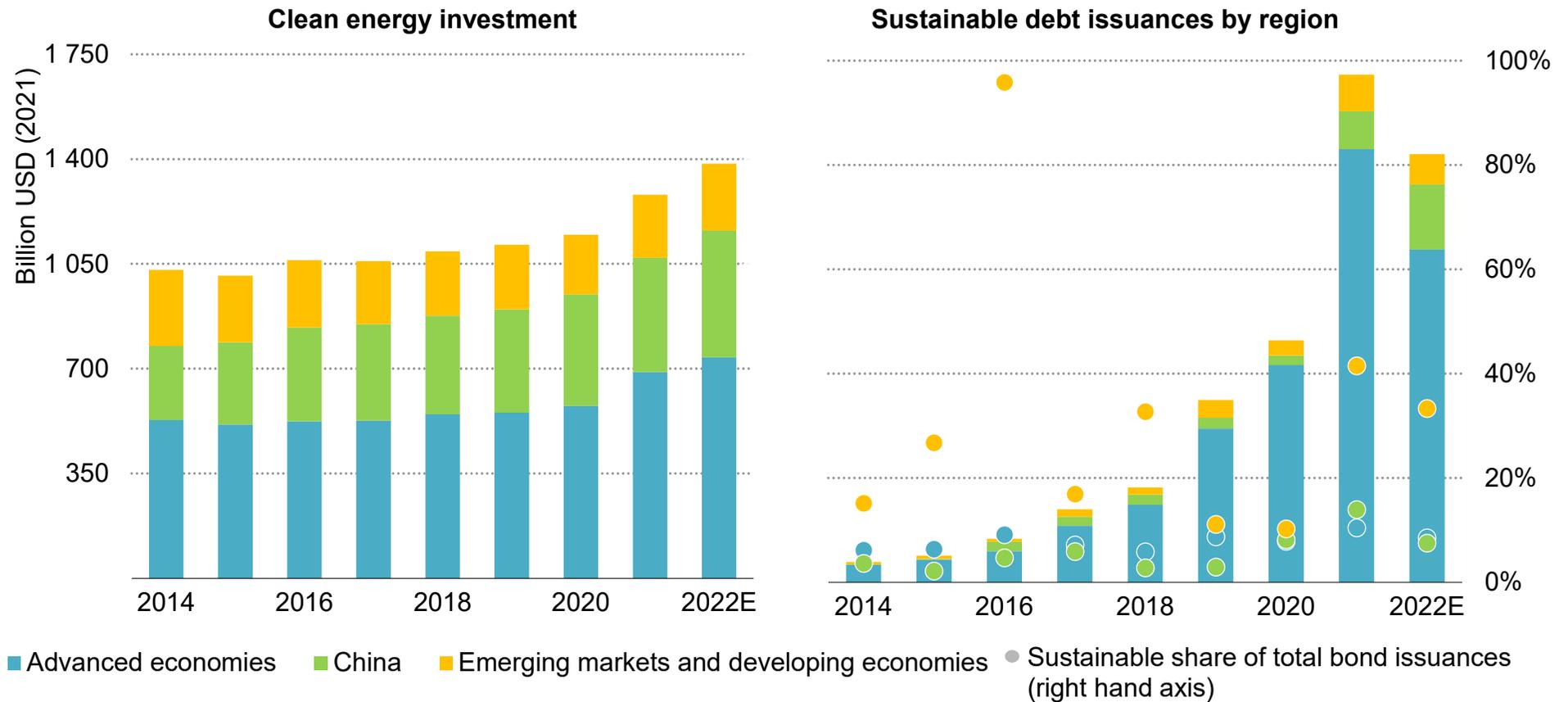
Exploration spending recorded a 30% uptick in 2021, with the United States, Canada and Latin America driving the bulk of the growth. This increase should help to diversify future sources of supply, although it takes time for exploration spending to translate into output growth.

Many governments are promoting investment activities with the aim of ensuring secure mineral supplies for their domestic clean energy supply chains, while also supporting innovation and recycling. There is more government funding going to critical minerals within energy research and development activities. Venture capital money for EVs is increasingly going to battery designs and recycling approaches that seek to tackle critical mineral issues, with a lower share going to vehicle makers than in the past

There are also signs that the pool of investors in the sector is widening, as vehicle and battery manufacturers (including Volkswagen, Tesla, CATL and LG Energy Solution) get involved directly in the mining and processing of critical minerals in order to safeguard their production pipelines.

The rise of sustainable finance presents a major opportunity to fund energy transitions, but the effects are concentrated in advanced economies

Sustainable debt issuances compared with clean energy investment, 2014-2022E



IEA. All rights reserved.

Note: 2022 sustainable debt estimate based on level of issuances in Q1 2022.

Source: Sustainable debt data are from Bloomberg and Refinitiv (2022).

Sustainable finance faces growing pains, but remains important for clean energy financing

Financial conditions for clean energy businesses have been volatile in recent years, but many listed energy-related businesses started 2022 with relatively strong balance sheets. Measures of liquidity, profitability and equity market valuations all improved or stayed steady compared with the year before the pandemic. This positive signal for energy investment was far from universal, however, with acute financial strains still visible among many (often state-owned) energy companies in emerging and developing economies.

Oil and gas companies have continued to benefit from the run-up in prices, while the rising cost of financing and raw materials has threatened already narrow profit margins in some clean energy suppliers. Nonetheless, risk-adjusted returns for renewable energy companies still outperform those for fossil fuel companies on financial markets over the past decade.

Advanced economies have seen a recent surge in sustainable finance, providing an important tailwind for renewables in particular. Sustainable debt issuances reached more than USD 1.7 trillion in 2021, with the vast majority of green bonds designed to finance renewables and low-carbon buildings and transport. 2021 saw a rise in sustainability-linked debt, which is conditional on achieving targets (such as company-wide emissions reduction goals) rather than being project-focused, greatly widening possible uses. Despite this, the rapid growth and geographic spread of sustainable finance is not well

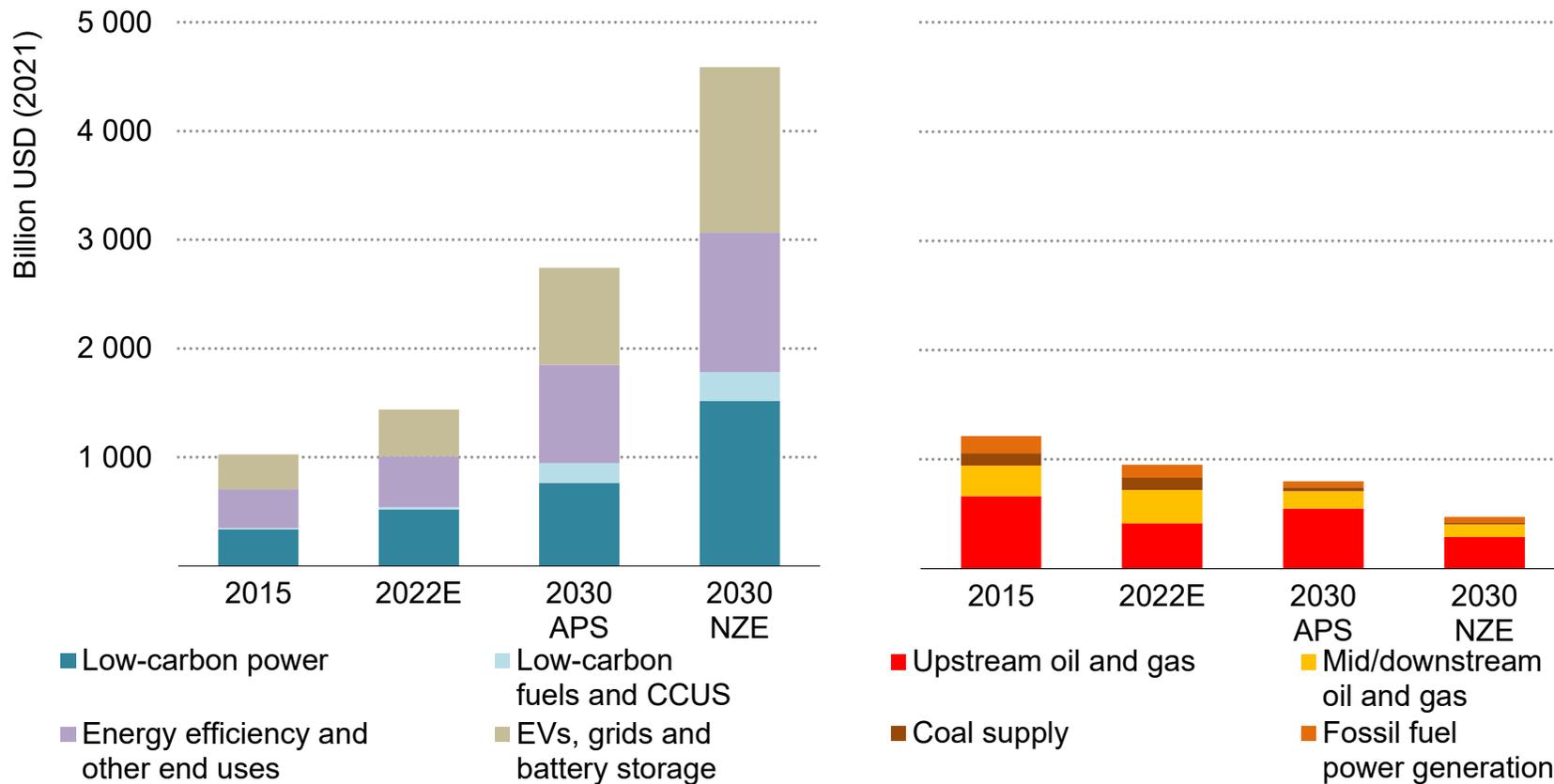
correlated with our clean energy investment figures. Sustainable debt has proven an effective way for emerging markets and developing economies (EMDEs) to access capital, with sustainable bonds making up a significant share of their total issuances, but the absolute values are still low compared to advanced economies.

The current energy crisis has also been a crisis of sorts for ESG investing, with the concept simultaneously decried from different quarters as ineffective (legitimising greenwashing) and too effective (starving funds from emitting but essential sectors). Our analysis highlights three important avenues for further work:

- There is a need to align ESG taxonomies and standardise reporting frameworks, and thereby to improve the quality of engagement between investors and companies.
- Channels need to remain open to support the credible transition plans of carbon-intensive companies, recognising that half of the investment required to get on track for net zero over the next decade goes to projects that do not immediately deliver zero-emission energy or energy services.
- If ESG investing is to tackle the biggest deficits in decarbonisation, it must find a way to channel financing towards the EMDEs where the needs are greatest.

A secure and affordable energy transition relies on a massive scale-up of investment in clean energy infrastructure

Annual global energy investment benchmarked against the needs in 2030 in IEA scenarios, 2015-2030



IEA. All rights reserved.

Notes: APS = Announced Pledges Scenario, the spending required to meet all country and regional climate pledges on time and in full. NZE = Net Zero Emissions by 2050 Scenario, the spending required to get the global energy sector to net zero by mid-century.

As things stand, today's energy investment trends show a world falling short on climate goals, and on reliable and affordable energy

Investment to bring more clean and affordable energy into the system is rising, but not yet quickly enough to forge a path out of today's crisis or to bring emissions down to net zero by mid-century – a critical but formidable challenge that the world needs to overcome if it is to have any chance of limiting global warming to 1.5°C. Without a massive surge in spending on efficiency, electrification and low-carbon supply, rising global demand for energy services will simply not be met in a sustainable way.

There are signs – notably in Europe's REPowerEU plan – that the crisis is acting as an accelerant for energy transitions. But even in a world of high and volatile fossil fuel prices, it cannot be taken for granted that today's cost advantages for clean, efficient equipment will translate into more sustainable investment choices. There is a host of non-market barriers that policy makers need to tackle, such as permitting requirements and preferential arrangements for incumbent producers and technologies, as part of urgent efforts to expand and strengthen clean energy supply chains. Higher and more diversified investment in critical minerals is a vital part of the solution, as is greater support for innovation and emerging clean technologies.

Power sector investment is the closest to a sustainable trajectory. If today's annual expenditure of USD 900 billion continues to grow at the same rate seen over the last three years for the remainder of this

decade, that would be consistent in aggregate with the USD 1 200 billion annual average to 2030 that we estimate is required to meet existing climate pledges. But these pledges are not yet consistent with reaching net zero emissions by 2050, a pathway that would require annual spending this decade of more than USD 2 trillion.

The NZE Scenario also requires the rapid uptake of electrification of transport, heating, cooling and industrial production, and a massive effort to speed up retrofits and spending on new energy-efficient buildings. By 2030 annual spending under this scenario on energy efficiency, electrification and renewables for end use is almost four times higher than today.

The shortfalls are particularly striking in many emerging and developing economies. Power sector investment in this grouping would need to grow at an annual rate of more than 25% for the rest of this decade to get on track for a net zero by 2050 pathway. This compares with just 3% annual average growth seen over the last few years. Accelerating investment across all aspects of energy transitions in developing economies needs to be a first-order priority, including for international financial institutions, their donors, multilateral development banks and many other actors.

Where does this crisis leave fossil fuel producers? In the short term it leaves most of them considerably wealthier. High prices are generating an unprecedented windfall, especially for oil and gas suppliers. This is a once-in-a-generation opportunity for producer economies to fund diversification activities and for the major oil and gas companies to deliver more diversified spending.

Some of this revenue will be ploughed back into supply, but the case for investment in fossil fuels – and the risks associated with this spending – rests on the strength of global efforts to curb demand. Our estimates for 2022 suggest that today's aggregate fossil fuel investment is broadly aligned with the near-term needs of a scenario in which countries hit their climate pledges, but this depends crucially on additional efforts from governments to curb fuel demand in line with these pledges. Without these additional efforts, today's level of capital spending would further reduce the ability of markets to weather volatility.

If countries move beyond their existing pledges and get on track for a 1.5°C cap on global warming, then the case for committing capital to new fossil fuel projects becomes very weak. The landmark IEA Roadmap to Net Zero Emissions by 2050 published in May 2021, indicated that declining fossil fuel demand in this scenario, arising from a massive surge in investment in renewables, energy efficiency and other clean energy technologies, could be met through continued investment in existing production assets, but without any need for new oil or gas fields, and no new coal mines or mine extensions.

In the short term the scramble to diversify supplies away from Russia and to meet associated supply shortages implies some near-term investment upside for other producers, as well as some new LNG infrastructure, even in a world working towards net zero emissions by 2050. However, no one should imagine that Russia's invasion of Ukraine can justify a wave of new large-scale fossil fuel infrastructure in a world that wants to limit global warming to 1.5 C.

Ultimately, it is for governments to take the lead and show the way. There are many parts of society that need to work together to deliver a new global energy economy that is much safer and much more sustainable than the one we have today. But governments have unique capabilities to act and to guide the actions of others.

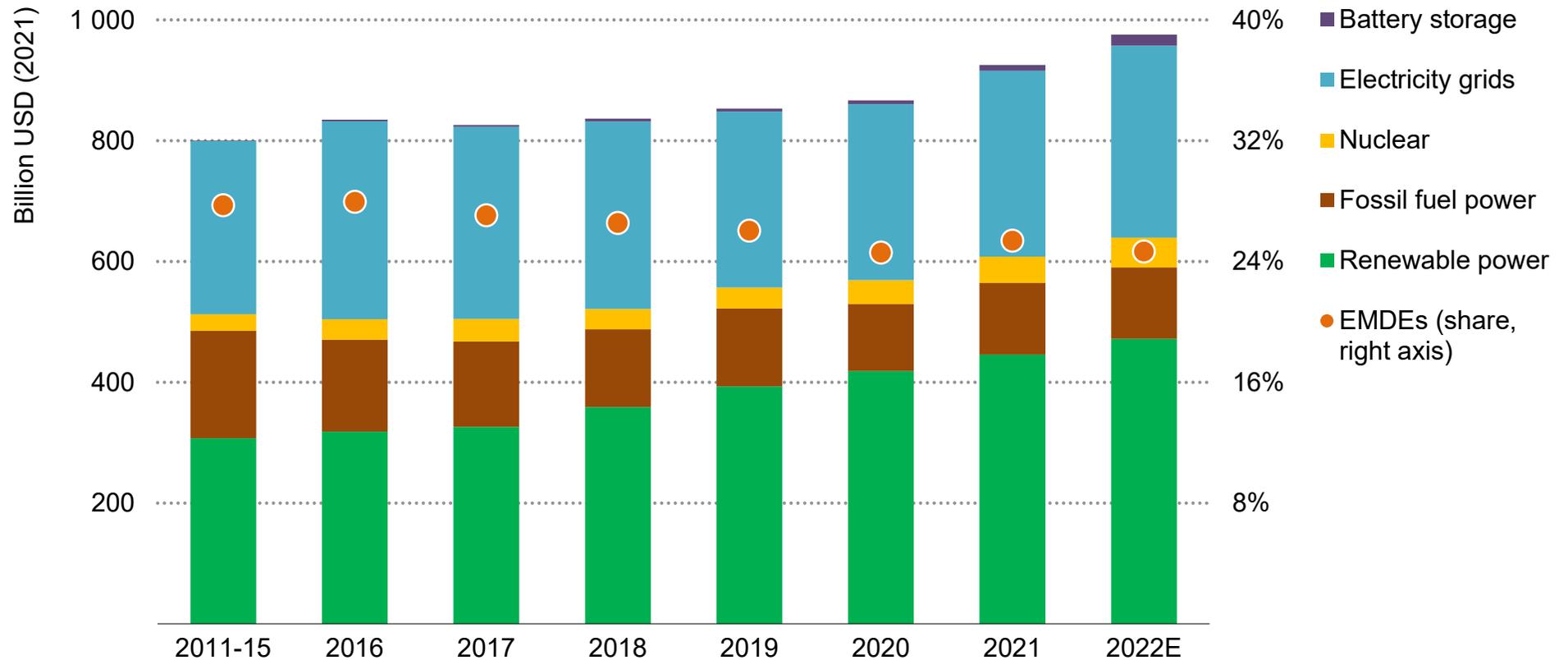
They can lead the way by providing the strategic vision, the spur to innovation, the incentives for consumers, the policy signals and the public finance that catalyses private investment, and the support for communities where livelihoods are affected by rapid change. They also have the responsibility to avoid unintended consequences for the security and affordability of supply.

Power sector

Overview of power investment

Robust power sector investment is central to clean and secure energy transitions

Global annual investment in the power sector by category, 2011-2022E

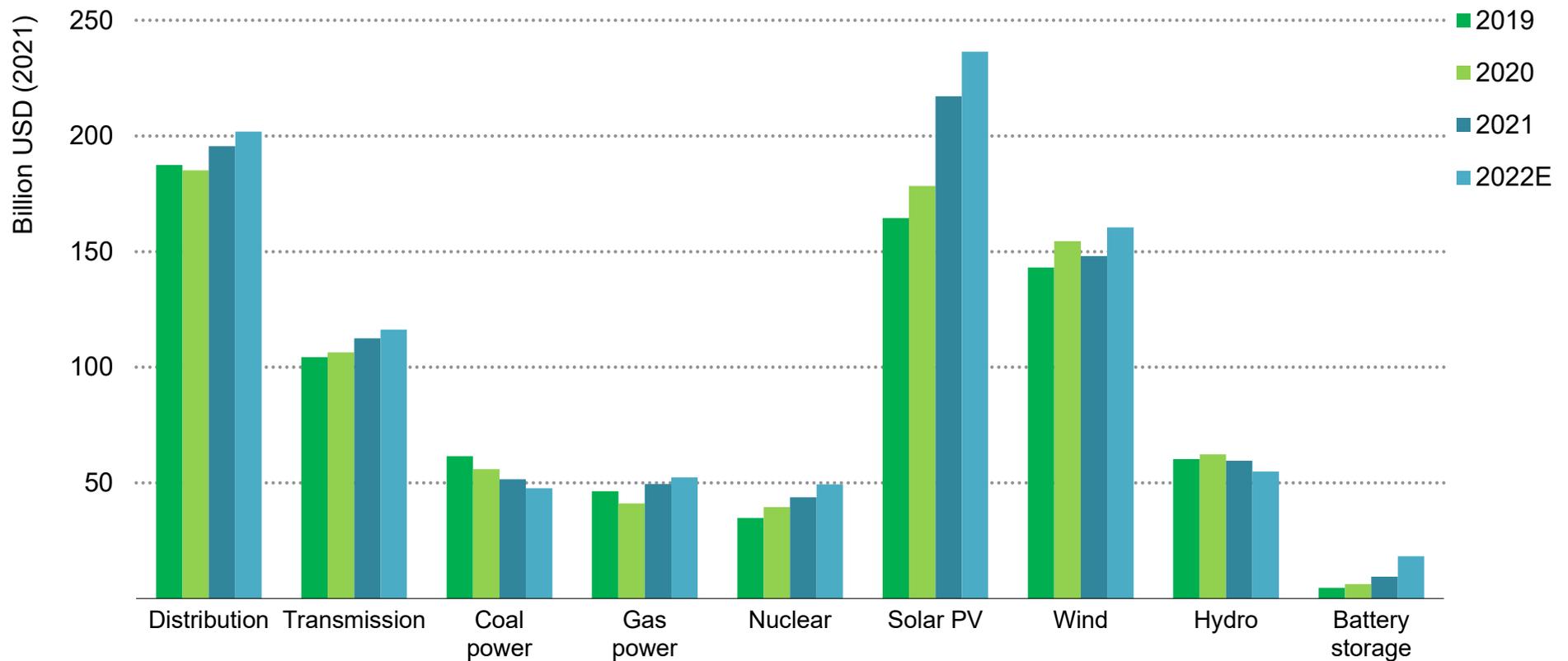


IEA. All rights reserved.

Notes: Investment is measured as ongoing capital spending on power capacity. EMDEs = emerging markets and developing economies, excluding China.

Solar PV is leading power sector investment, with positive signs for transmission and distribution networks and an acceleration in battery energy storage

Global annual investment in the power sector by technology, 2019-2022E



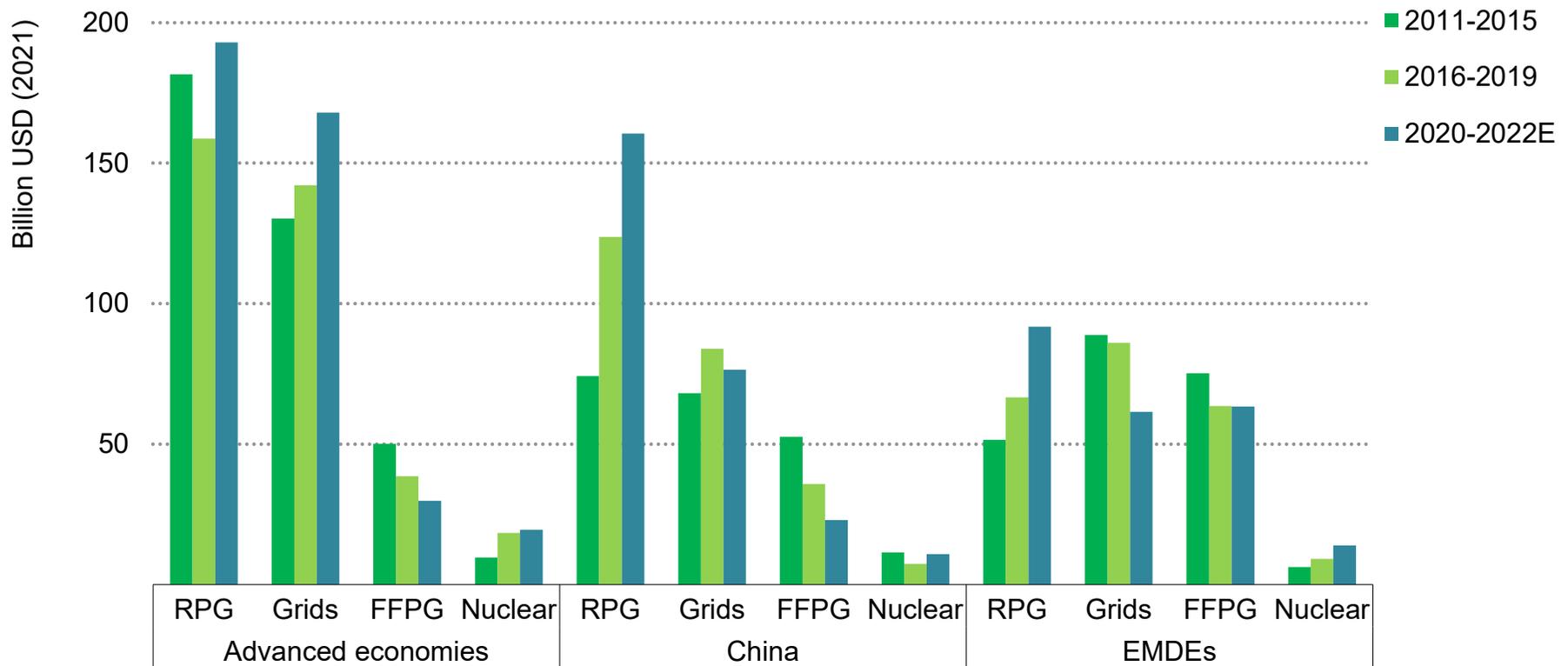
IEA. All rights reserved.

Notes: Gas-fired generation investment includes both large-scale plants and small-scale generating sets and engines; hydropower includes pumped-hydro storage.

Sources: IEA analysis based on calculations from IRENA (2022) and Platts (2022).

But regional indicators highlight the continuing challenges many EMDEs face in mobilising sufficient capital for clean electricity and grids

Average annual investment in the power sector by geography and category, 2011-2022E



IEA. All rights reserved.

Notes: RPG = renewable power generation; FFPG = fossil fuel power generation.

Capital expenditure on low-emission technologies in the power sector is picking up, underscoring the central role of clean electricity in a sustainable energy future

Power sector investment is expected to grow by 6% in 2022 after a strong rebound of 7% in 2021 from 2020's Covid-affected levels. Governments, companies and consumers are pushing for greater electrification of the economy and acceleration of clean energy transitions. Investment in 2022 is expected to follow the growth trend seen in 2021, led by renewables, electricity grids and battery storage, which have accounted for more than 80% of total power sector investment since 2019. [Governments alone, as part of their clean recovery packages, had committed USD 75 billion of spending as of 31 March 2022 on low-carbon electricity generation, transmission and distribution through tax credits, auctions, consumer subsidies and direct funding of manufacturing facilities. This could mobilise an additional USD 475 billion from the private sector through to 2023.](#)

Renewables are set to remain the number one power sector category for investment in 2022, after a record year in 2021 when more than USD 440 billion was spent for the first time ever. Despite numerous issues affecting the sector, including inflationary pressures, tighter financing conditions and supply chain bottlenecks, there is a solid pipeline of projects that stem from more ambitious climate goals and robust policy support: [renewable capacity is forecast to account for almost 95% of the increase in global power capacity through to 2026.](#) Solar PV became the leader in power sector investment in 2021 and

comprised nearly half of all renewables investment. Spending is almost evenly divided between utility-scale projects and distributed solar PV systems, with each subcategory to pass the USD 100 billion mark in 2022. For wind, while 2020 was a record year for onshore deployment, 2021 was a record year for offshore deployment, with more than 20 GW commissioned and around USD 40 billion of expenditure. Similar to the onshore peak in 2020, developers pushed to commit offshore wind projects in 2021 before the expiry of subsidy regimes in China.

Investment in fossil fuel power generation is expected to be flat in 2022, consolidating the rebound experienced in 2021, with higher spending on natural gas compensating for the decrease in spending on coal-fired power generation. Capital expenditure on these technologies remains over USD 100 billion when combined, despite announcements from governments and companies of a move away from unabated fossil fuels and the current uncertainties affecting fuel prices after Russian's invasion of Ukraine.

Investment in clean dispatchable generation has been stable at around USD 100 billion per year over the past four years, with a steady rise in spending on nuclear outweighing a decline in hydropower. Nuclear investment is accelerating on the construction of new nuclear reactors in China, Europe and Pakistan, and the

refurbishment, modernisation and life extension of existing reactors in France, the United States and Russia.

Capital spending on electricity grids showed a strong rebound of 6% in 2021, with advanced economies accelerating investment to support and enable the electrification of buildings, industry and transport and to accommodate variable renewables on the power system. Based on these trends, investment in electricity grids is set to grow by 3% in 2022.

After solid growth in 2021, battery energy storage investment is expected to hit a record high and approach USD 20 billion in 2022, based on the existing pipeline of projects and new capacity targets set by governments. Batteries' versatility, complementarity with renewables and favourable operation in volatile electricity markets are outweighing their drawbacks in the form of tight markets for some critical minerals and other inflationary cost pressures.

Finally, despite it being an auspicious moment for the power sector, it faces significant barriers and uncertainties that could cloud the investment environment for 2022, especially for renewables and energy storage. The length and magnitude of Russia's invasion of Ukraine and the duration of lockdowns in China to control Covid-19 infections are among the greatest uncertainties affecting supply chains and commodity prices. But other events, such as a tightening monetary policy from central banks, an amplified supply crunch for critical minerals or a lack of qualified workforce in the power sector, can have a significant impact in the form of project delays and cancellations.

Investment is concentrated in regions where energy transitions are at a more advanced stage

During the past decade, investment to support energy transitions has accelerated in advanced economies and China, with spending in EMDEs lagging behind, [even though most of these countries are facing rapid growth in electricity demand and have some of the most cost-effective opportunities to reduce emissions](#). In advanced economies and China, capital spending devoted to renewables and electricity grids grew from the early 2010s to the early 2020s by an annual average of USD 50 billion and USD 90 billion respectively. By contrast, it grew by only USD 10 billion in EMDEs (despite hosting almost two-thirds of the global population). Some of the barriers preventing greater investment in these assets in EMDEs include higher financing costs and higher curtailment risk, lack of liquid electricity markets, and regulatory and country risks.

Investment in unabated fossil fuel power remained relatively resilient in EMDEs, where capital spending in this area continued at around 30% of total power investment throughout the past ten years. This investment was in response to growing electricity demand in most regions, and the availability of indigenous fossil fuel resources in some countries. Over the same period, both advanced economies and China reduced investment in fossil fuel fired power generation, which now account for under 10% of total annual spending on power.

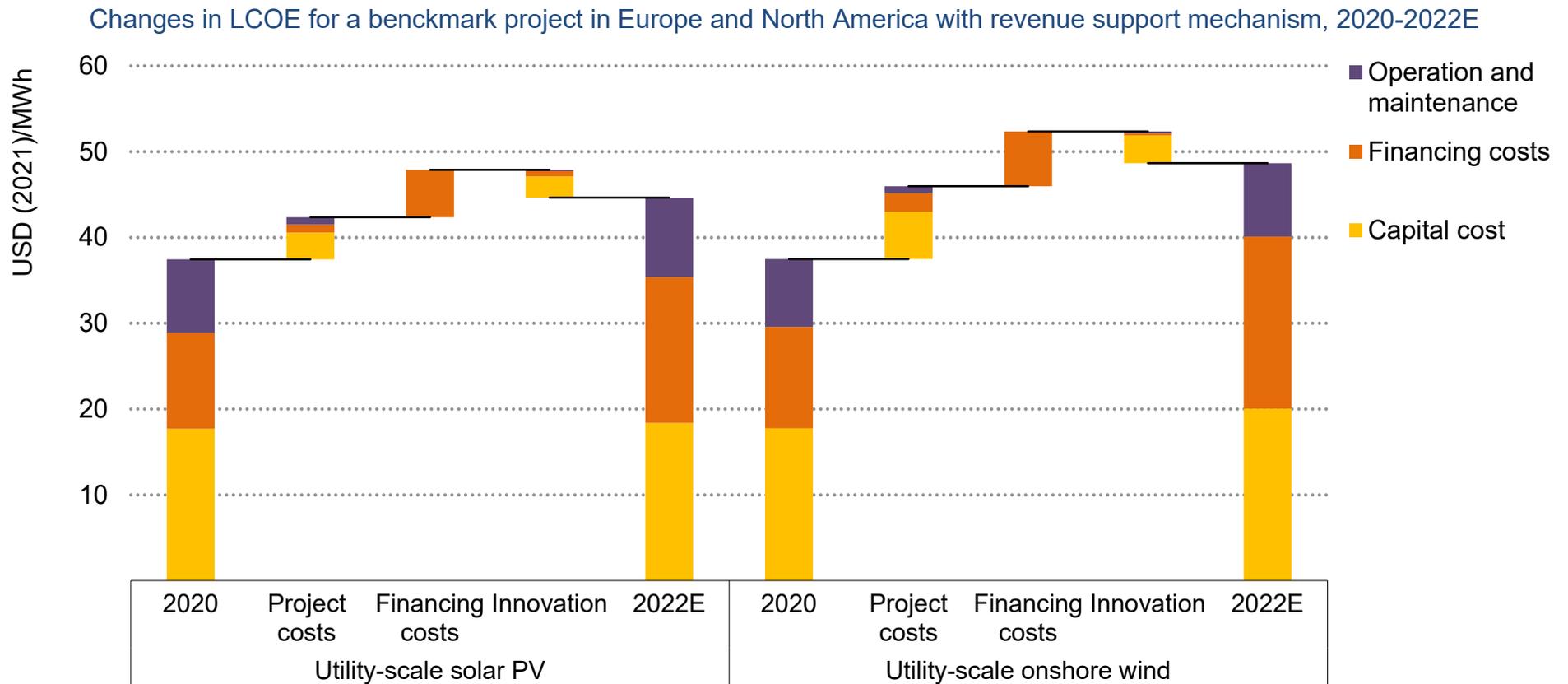
Renewables have been the major focus of investment in the past decade, especially solar PV and wind, which expanded almost

everywhere and now account for more than 80% of total investment in renewables globally. Overall expansion has been most visible in China and EMDEs, where capital expenditure rose by 115% and 75% respectively in a decade. Advanced economies spent slightly more on renewables in the early 2020s than in the early 2010s, but are now bringing online considerably more renewable capacity and energy than ten years ago, thanks to major reductions in capital costs, technological innovation and higher efficiency. Renewable technologies have accounted for 70% of all power sector investment supported by public finance institutions since 2010.

More than 60% of investment in renewables is from the private sector, although the role of governments in providing strong policy support has been key. Public sources underpin spending on grids, especially in EMDEs where they account for around 80% of total grid investment. The decline in investment in transmission and distribution in EMDEs in recent years is a worrying symptom of the poor financial situation of many state-owned utilities and the limited fiscal capacity of governments in these regions. This situation worsened with the Covid-19 pandemic, and highlights a major challenge for clean energy transitions and the acceleration of electrification in these economies, which rely on power systems with high system losses, higher risk of renewables curtailment and more frequent power interruptions.

Generation

Supply chain bottlenecks, higher commodity prices and tighter financing conditions are putting upward pressure on renewables costs for the first time in a decade

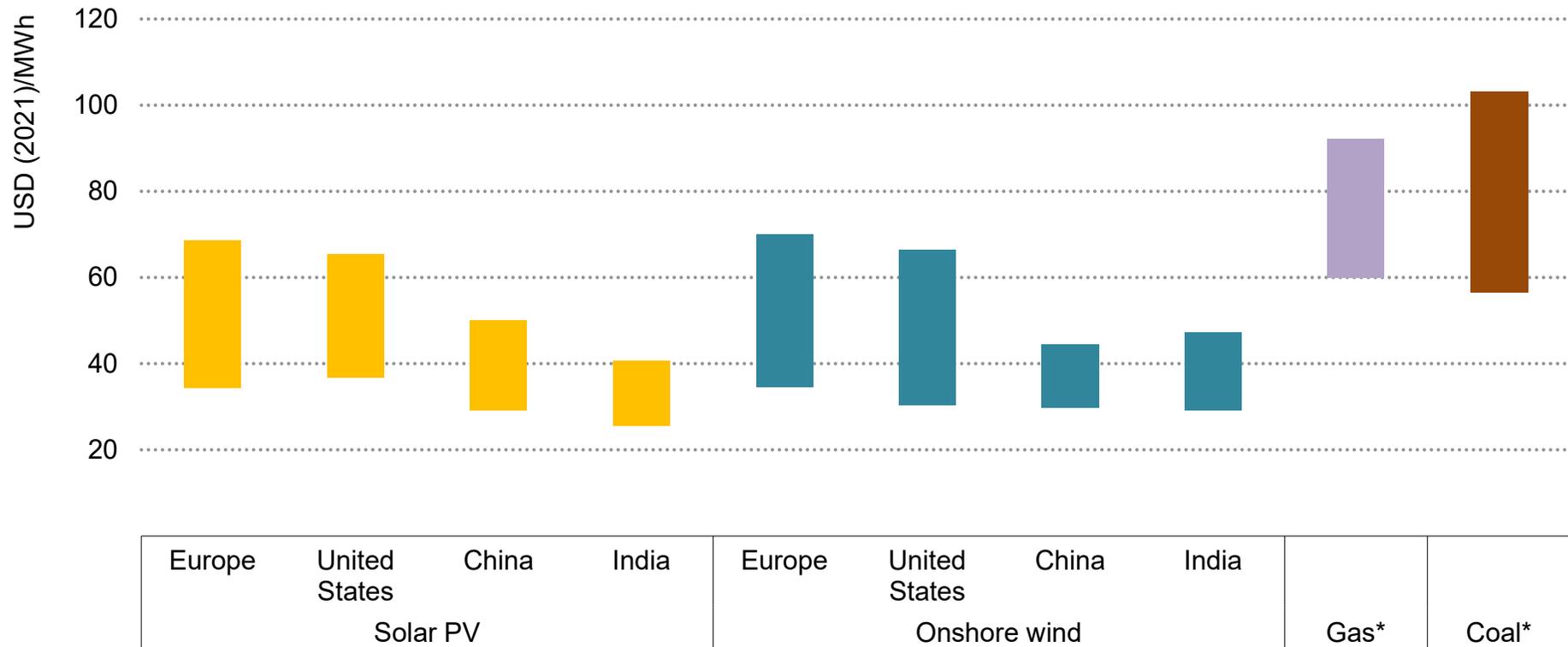


IEA. All rights reserved.

Notes: LCOE = levelised cost of electricity. Revenue support mechanisms include feed-in tariffs, contracts for difference, long-term power purchase agreements and bilateral agreements. Assumptions: variations in capex are based on IEA Renewables Market Report (2022); weighted average cost of capital (WACC) increases by 200 basis points; Innovation assumes one-fifth of the historical compounded annual learning rates in the last decade on capex cuts, capacity factor gains and operation and maintenance reductions, as sourced from IRENA; construction time increases by six months.

Nonetheless, renewables remain a more attractive proposition than fossil fuel power for new generation (all the more so with recent record high prices for natural gas and coal)

LCOE of utility-scale solar PV and onshore wind vs unabated fossil fuel power generation, 2022E



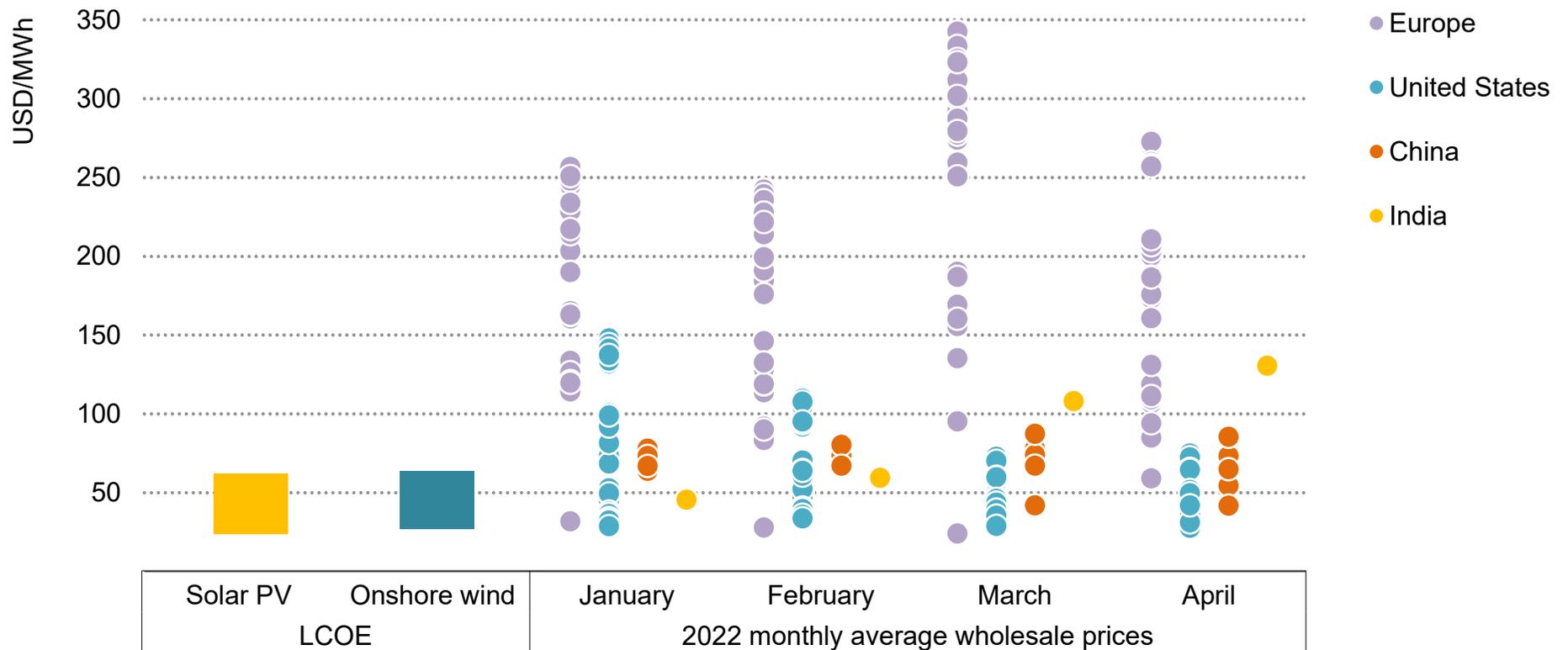
IEA. All rights reserved.

*Refers to same regions within the figure: Europe, United States, China and India.

Notes: Gas refers to a combined-cycle gas turbine (CCGT) and coal to supercritical; fuel costs for gas and coal and CO₂ prices reflect the levels projected in the IEA World Energy Outlook 2021 STEPS (Stated Policies Scenario), and do not consider actual spot and forward market prices; variable renewables remain competitive in terms of value-adjusted LCOE (VALCOE) (Box 1.1).

It is not only about policy support: High wholesale electricity prices are providing strong market signals to scale up investment in renewables

LCOE of renewables vs average monthly wholesale electricity prices in selected countries and regions, 2022E



IEA. All rights reserved.

Sources: IEA analysis using data accessed via the ENTSO-E Transparency Platform; CAISO (2022); ERCOT (2022); MISO (2022); NYISO (2022); PJM (2022); Polaris Electricity network (2022); IEX (2022), Area Prices.

Inflationary pressures have brought the first increases in the cost of renewables in a decade...

The Covid-19 pandemic presented a significant test for investors in the power sector, but one that proved the resilience of renewables. They benefited from the combination of favourable decisions by governments, companies and consumers to accelerate the clean energy transition and from central banks maintaining an expansionary monetary policy stance to keep financing costs at record low levels. Another and more recent test is today's inflationary pressures. As capital-intensive technologies, renewables face a stronger impact from pressures affecting the cost of raw materials and financing than other forms of power generation.

Russia's invasion of Ukraine has exacerbated strains on markets for certain critical minerals that are indispensable for solar PV and wind. At the end of 2021, polysilicon prices had risen by 200%, steel by 70% and aluminium by 40% with respect to the end of 2020 figures, reflecting supply chain disruption induced by responses to Covid-19, and energy and commodity price hikes affecting the mining, refining and freight sectors. Renewable equipment manufacturers are passing on some of these pressures in their products, with increases in the cost of solar PV panels and wind turbines of 10-20% and attempts to renegotiate existing contracts, depending on the technology and region.

Financing costs are an important part of renewables' LCOE, accounting for up to 60% of total costs, especially in EMDEs, where

the cost of capital can be up [to seven times higher](#) than that in advanced economies. Given the high global inflation rates, central banks are turning hawkish, reducing their balance sheets and increasing interest rates (with some exceptions, such as China). This is being translated into higher short-, medium- and long-term rates on the yield curve. An increase of 200 basis points in the cost of capital for solar PV and wind leads to a 20% increase in the final LCOE.

Despite the cost pressures, renewables continue to benefit from economies of scale and technological innovation that allow for further cost reductions, higher efficiency and higher capacity factors. Wind turbine manufacturers are installing larger turbines and rotors. In 2022 companies announced new models that will achieve annual energy production gains of around 10%. Solar panel efficiencies are also increasing, with better manufacturing processes and advanced technologies moving to commercial scale from the research stage. Digital technologies such as machine learning, drones and process automation are also pushing down operation and maintenance costs and raising asset performance.

However, all in all, increases in project financing costs are trumping innovation gains, with power purchase agreements (PPAs) in Europe and the United States already reflecting this. PPA prices for wind and solar PV in Q1 2022 have risen by more than 25% in these regions, compared with 2021 levels.

...but the sector remains very attractive given its competitiveness and role in energy transitions

Given these cost pressures, we estimate that the LCOE from variable renewables is set to become between 20% and 30% more expensive in 2022, compared with 2020 levels. Nonetheless, these technologies remain the most cost-efficient option for new power generation in many countries, even before accounting for the exceptionally high prices seen in 2022 for coal and gas (i.e. assuming average fuel costs for unabated fossil power generation before the energy crunch). In practice, spot market prices for these commodities have been at remarkable levels, with TTF gas trading at more than EUR 100 per MWh and API2 coal at more than USD 300 per tonne in Q1 2022. This short-term shock is also affecting longer-term market expectations. For instance, Henry Hub gas futures for 2025 are trading at more than USD 4 per MBtu, a 25% premium versus the average price in the 2010s. Carbon prices (where they exist) underscore further the cost advantages of low-carbon technologies.

As coal and natural gas are the principal marginal technologies in spot electricity markets, the prevailing market dynamics of these commodities are being almost directly transferred into spot electricity prices. Day-ahead electricity prices in Europe have seen the biggest pressures, trading at more than USD 200 per MWh on average in the last four months in many countries, and pressures are accelerating in India, surpassing USD 100 per MWh on average in April. Price pressures are also reflected in longer-term expectations, with

average baseload prices trading at more than EUR 100 per MWh for both Germany and France to 2030. This provides a significant incentive for consumers to opt for renewable PPAs at much lower prices, even if their variable production patterns incur a cost in the form of a hedge for consumption-production mismatch. In addition, current short-term prices are offering attractive opportunities for merchant solar PV and onshore wind farms, although they are perceived as higher-risk assets due to the variability in future cash flows and cannibalisation price risk. A merchant solar PV plant built in Europe at the beginning of 2021 would have reduced its payback period by between two and four years at current prices (if no restrictions on windfall profits or caps on allowed returns are applied).

Renewables have also played an important role in energy independence in the energy crunch, especially in Europe. Solar PV and wind produced almost 550 TWh in 2021, avoiding the potential consumption of around 100 bcm of natural gas equivalent in Europe, at a moment of great stress in gas supply.

Finally, the sustainable finance boom is also an important tailwind for renewable power. Sustainable debt issuance in 2021 reached more than USD 1.6 trillion, with investors eager to support solar PV and wind projects, the most mature technologies in the clean energy space. Renewables accounted for the largest use of proceeds across all sectors (see the section on finance).

Box 2.1 Renewables remain competitive in the near term even considering their VALCOE

The LCOE is the most commonly used metric for assessing the cost competitiveness of power generation technologies. It brings together all the costs directly associated with a given technology, including construction, financing, fuel and maintenance costs, and combines them into a single metric. However, the LCOE does not provide a complete measure of competitiveness, as it takes no account of impacts on and interactions with the overall power system.

The IEA uses the value-adjusted LCOE (VALCOE), which is a more complete metric of competitiveness for [power generation technologies than the LCOE alone, as it combines a technology's LCOE with the simulated value of three system services: energy, flexibility and capacity](#). Hence, a technologies' VALCOE does not solely depend on its cost, but also on the value that it provides to the power system. Power systems might have different needs depending on electricity demand patterns, the overall generation mix and renewables penetration. A rising share of variable renewables leads to higher cannibalisation effects, which tend to make variable renewables less competitive than the LCOE alone would suggest. These effects are reflected in a higher VALCOE for solar PV and wind (compared with the LCOE) and a lower VALCOE for dispatchable sources of electricity in the future.

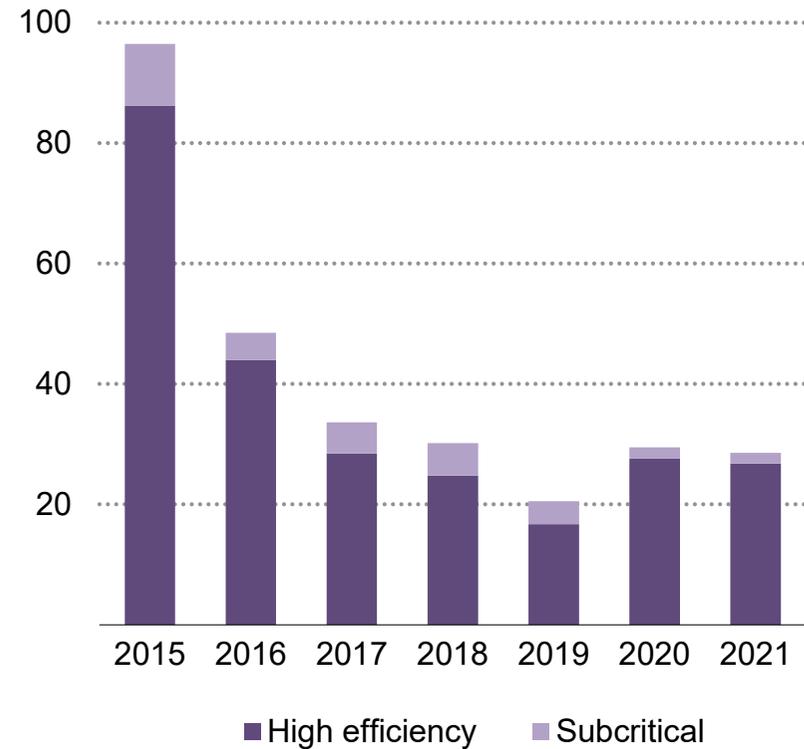
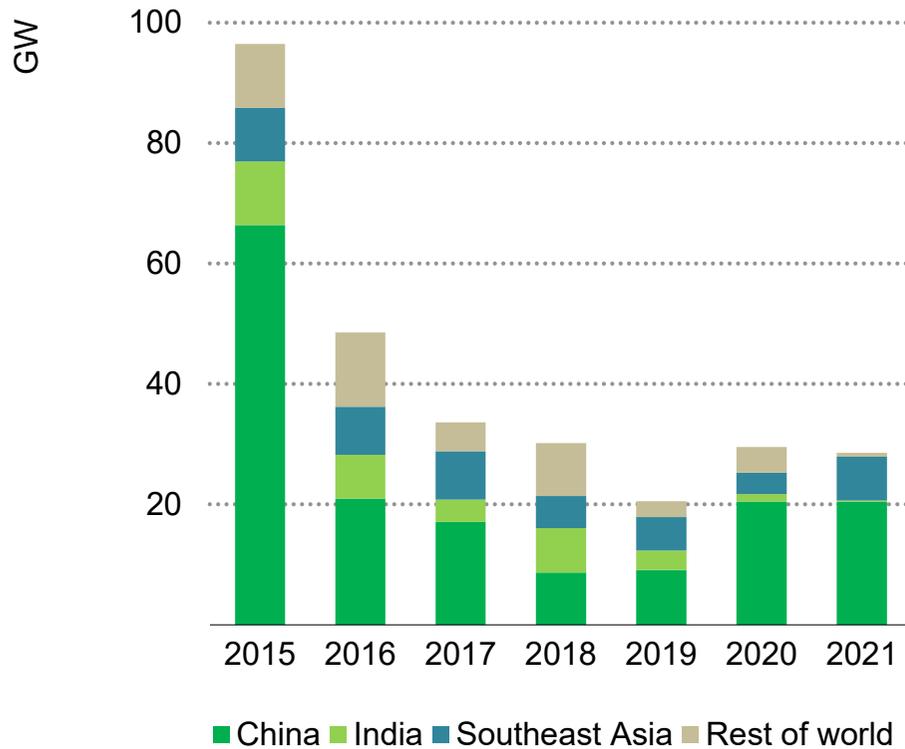
Variable renewables still remain competitive in VALCOE terms with respect to coal and natural gas in the short term. As revealed in [IEA-NEA \(2020\)](#), value adjustments in 2025 under the STEPS for solar PV, wind, coal and natural gas are modest in most cases, with the exception of peaking power plants that have relatively high value (and costs). The modest value adjustments also reflect the relatively low share of variable renewables in power systems in 2025. Considering the simulated energy, flexibility and capacity values for technologies in the United States, European Union, China and India in the STEPS, variable renewables remain more competitive than thermal power plants in the near term. As clean energy transitions progress, the importance of looking beyond the LCOE increases. A rising share of variable renewables and continued electricity market reforms mean that the overall competitiveness of power generation technologies will be even more strongly influenced by their operational attributes. For instance, VALCOEs in 2050 under the STEPS (WEO 2021) greatly differ from LCOEs, as power systems will be dominated by solar PV and wind generation at that stage.

Finally, although the VALCOE goes beyond the LCOE and provides a fuller and more accurate measure of competitiveness, it is not all-encompassing: it does not yet account for network integration and other indirect costs, such as those related to pollution.

Final investment decisions

Around 30 GW of new coal-fired plants were approved in 2021, hardly a positive signal for a “phase-down” of unabated coal power

Coal-fired power generation capacity subject to a FID by geography (left) and segment (right), 2015-2021

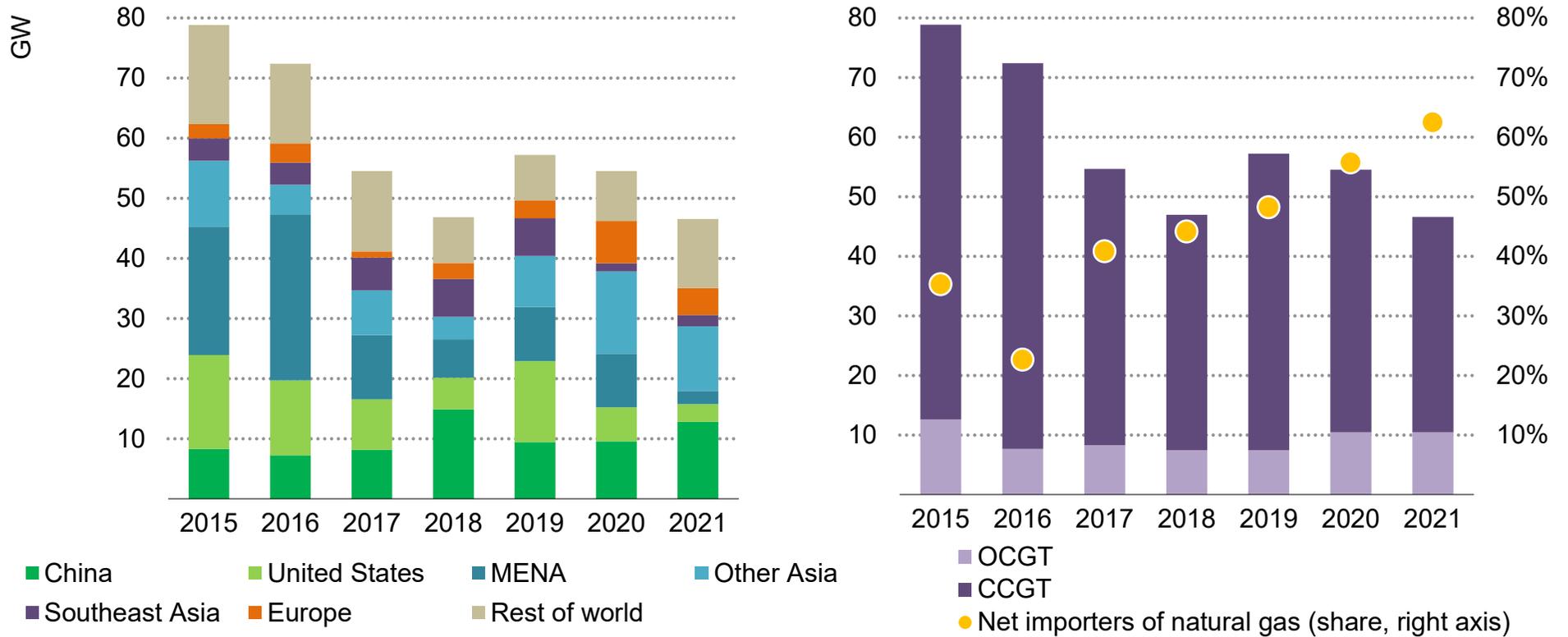


IEA. All rights reserved.

Notes: FID = final investment decision. The IEA tracks projects that reach financial close or begin construction to provide a forward-looking indicator of future activity. Source: IEA calculations based on McCoy Power Reports (2022).

FIDs for natural gas power generation declined in 2021 and were concentrated in gas-importing regions, despite the higher volatility of natural gas markets

Gas-fired power generation capacity subject to a FID by geography (left) and segment (right), 2015-2021



IEA. All rights reserved.

Notes: MENA = Middle East and North Africa; CCGT = combined-cycle gas turbine; OCGT = open-cycle gas turbine.

Source: IEA calculations based on McCoy Power Reports (2022).

FIDs for unabated fossil fuel generation are decreasing, but still play an important role – especially in China and EMDEs

Globally FIDs for unabated fossil fuel power generation decreased in 2021, mostly due to a 15% reduction in newly awarded natural gas capacity. Compared with the situation in 2015, the number of FIDs for new natural gas and coal power plants was almost 60% lower in 2021, with coal accounting for most of the fall. However, these 75 GW of new fossil fuel power generation will still play a major role in many power systems, especially in EMDEs.

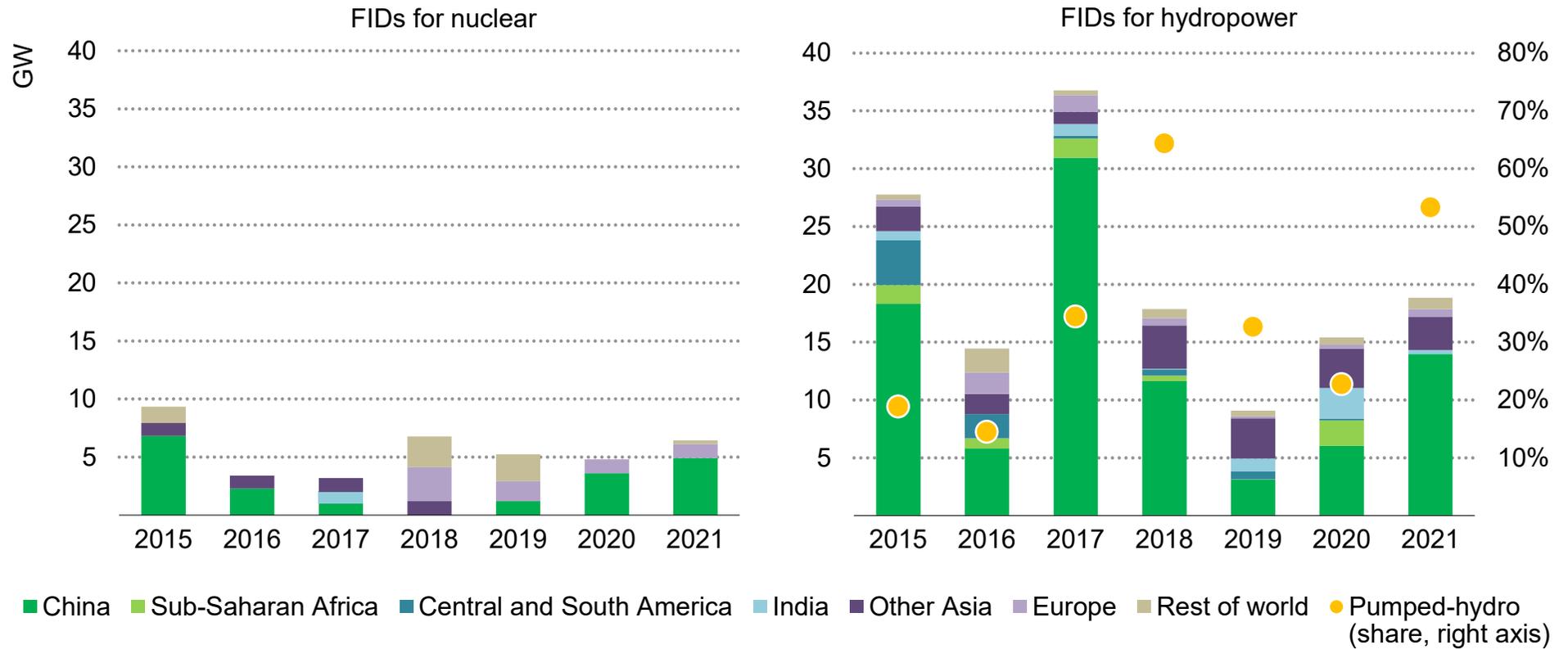
Coal power FIDs remained at similar levels to 2020, at just under 30 GW of capacity. Although China has pledged to stop building coal-fired plants abroad, there is still significant new capacity coming onto the domestic market, with more than 20 GW approved for development in both 2020 and 2021, and more than 15 GW approved so far in H1 2022. The energy crisis that unfolded in China in 2021, resulting in programmed power rationing in some provinces, has made energy security the main priority for near-term Chinese policy (although the medium-term commitment for emissions to peak before 2030 remains an important policy driver). The number of coal FIDs grew in 2021 in Viet Nam and Indonesia, where indigenous coal is seen as an important contributor to electricity security. Most coal plants approved for development worldwide have relatively high efficiency, but some subcritical facilities (albeit less than 10% of the total) are still being given the green light.

FIDs for natural gas power generation in 2021 stood at around 45 GW, their lowest level in 15 years, even before Russia's invasion of Ukraine aggravated the existing tensions in international natural gas markets. Most of the decisions to invest in new CCGTs and OCGTs came from gas-importing countries that are more exposed to international price volatility and that benefited from liquid and competitive liquefied natural gas (LNG) markets until 2021. Led by China, they accounted for more than 60% of total FIDs in 2021, more than twice the level in 2016. Natural gas is seen as a transition fuel in many regions due to its lower emissions intensity than coal and its high flexibility. But this trend might reverse given the ongoing high natural gas prices.

The share of OCGTs in natural gas power generation increased again in 2021 and is now twice the size as it was in 2016, as the increasing penetration of renewables makes the baseload operation of natural gas plants increasingly challenging. In this context, OCGTs are better suited to business cases calling for flexibility and firm capacity procurement, despite being less efficient. In addition, the average capacity of sanctioned CCGT projects has fallen from around 220 MW in 2015 to less than 150 MW in 2021, while OCGT projects have increased their average capacity from 80 MW to 100 MW in the same period.

China has been the main force behind the growth in FIDs for hydropower and nuclear in 2020 and 2021

Large-scale dispatchable low-carbon power generation capacity subject to a FID, 2015-2021

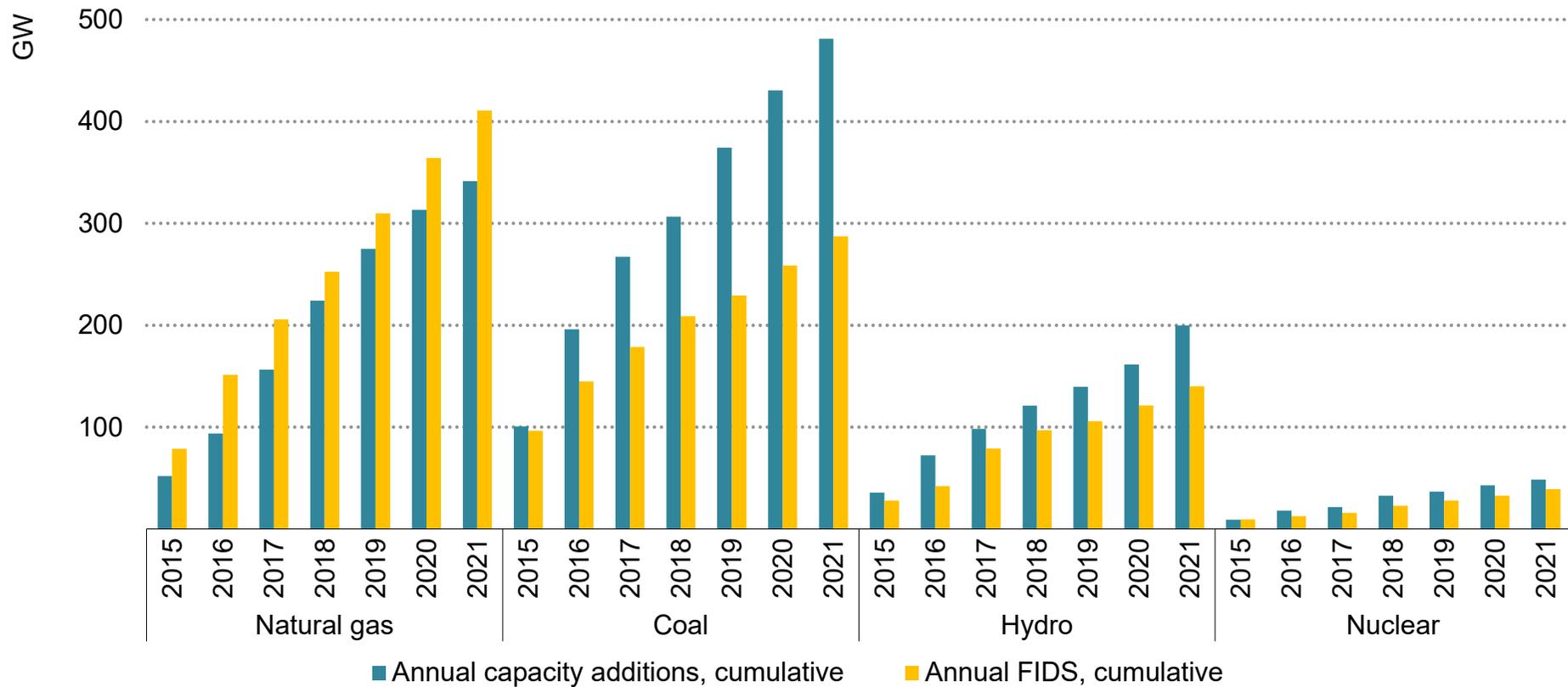


IEA. All rights reserved.

Sources: IEA calculations based on McCoy Power Reports (2022) and IAEA (2022).

The pipeline of new coal, hydropower and nuclear projects has weakened in recent years, but the number of gas-fired projects under development continues to grow

Annual FIDs and annual additions by capacity, cumulative, 2015-2021

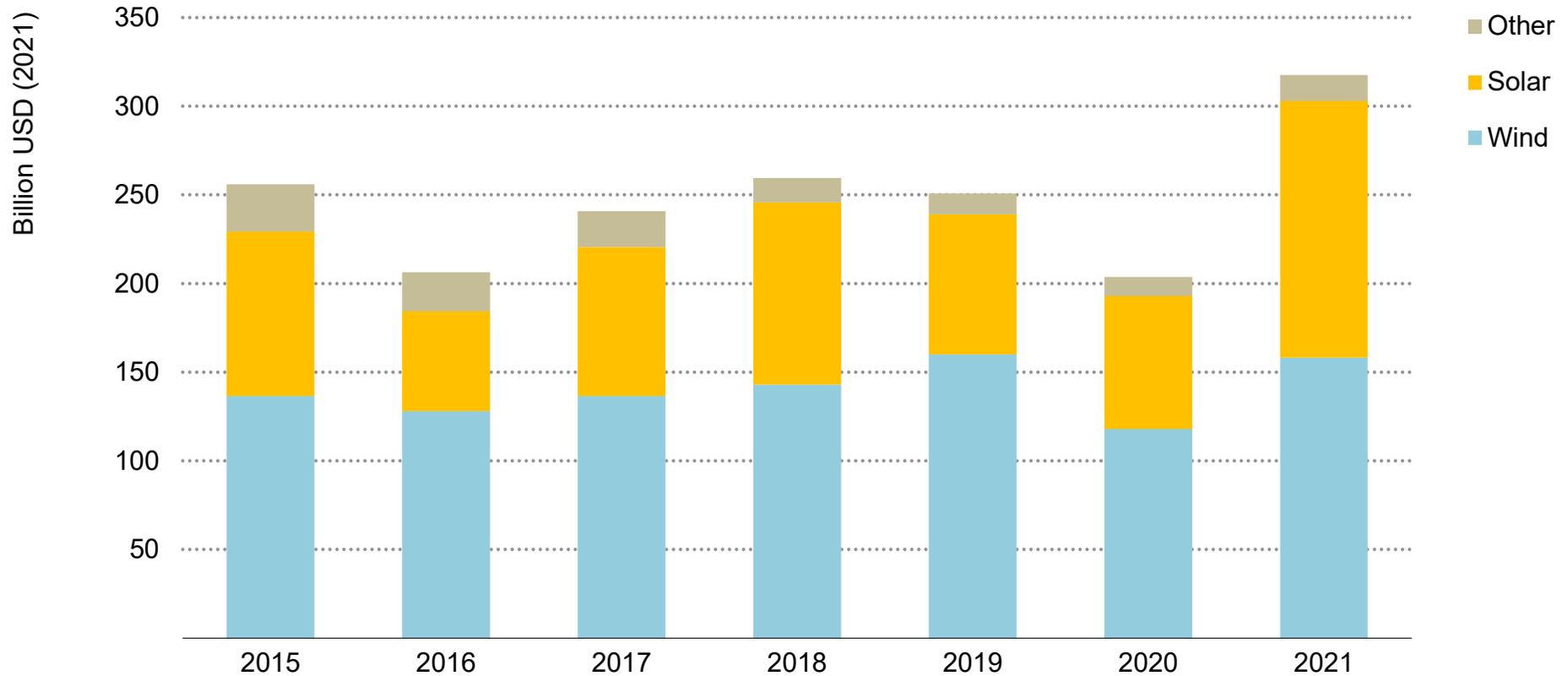


IEA. All rights reserved.

Sources: IEA calculations based on McCoy Power Reports (2022), Platts (2022) and IAEA (2022).

FIDs for utility-scale renewables hit new records in 2021, with a large jump in solar projects

FIDs for utility-scale renewable plants, 2015-2021



IEA. All rights reserved.

Notes: Excludes large hydropower. Other includes biomass, waste-to-energy, geothermal, small hydro and marine.
 Source: IEA calculations based on Clean Energy Pipeline (2022).

New project approvals are buoyant for solar and wind, but slower for dispatchable technologies that will be crucial for electricity security during clean energy transitions

In 2021 new FIDs for large-scale dispatchable low-carbon generation reached their highest level in three years, both for nuclear and hydropower, although they remain at a relatively moderate level when compared with variable renewables. China has a dominant position in these areas, accounting for more than 50% of all FIDs committed for nuclear and hydropower since 2015. This leadership is even higher for pumped-hydro storage, China accounting for more than 80% of all project FIDs since 2015. These technologies have high upfront capital needs, long construction times of 5 to 20 years and exhaustive permitting, environmental and legal processes.

During the last six years the pipeline of dispatchable generation projects has expanded for natural gas, while shrinking for coal, nuclear and hydro. The pipeline is measured as the GW capacity of FIDs minus the GW capacity of projects entering operation, on a cumulative basis. This reflects a robust business case for investment in CCGTs and OCGTs due to relatively low gas prices over this period, as well as environmental advantages over coal. However, this trend might reverse given the effect that Russia's invasion of Ukraine is having on natural gas prices and the greater focus of countries on energy independence. The signals are more worrying for hydropower and nuclear, as the pipeline of projects has reduced while it should be increasing, given the important roles they play in managing overall

power sector emissions and electricity security. Nevertheless, FIDs in these sectors are not a complete indicator of investment spending, as increasing capital is being spent on refurbishing, modernising and extending the lifetimes of existing hydro and nuclear power generation plants.

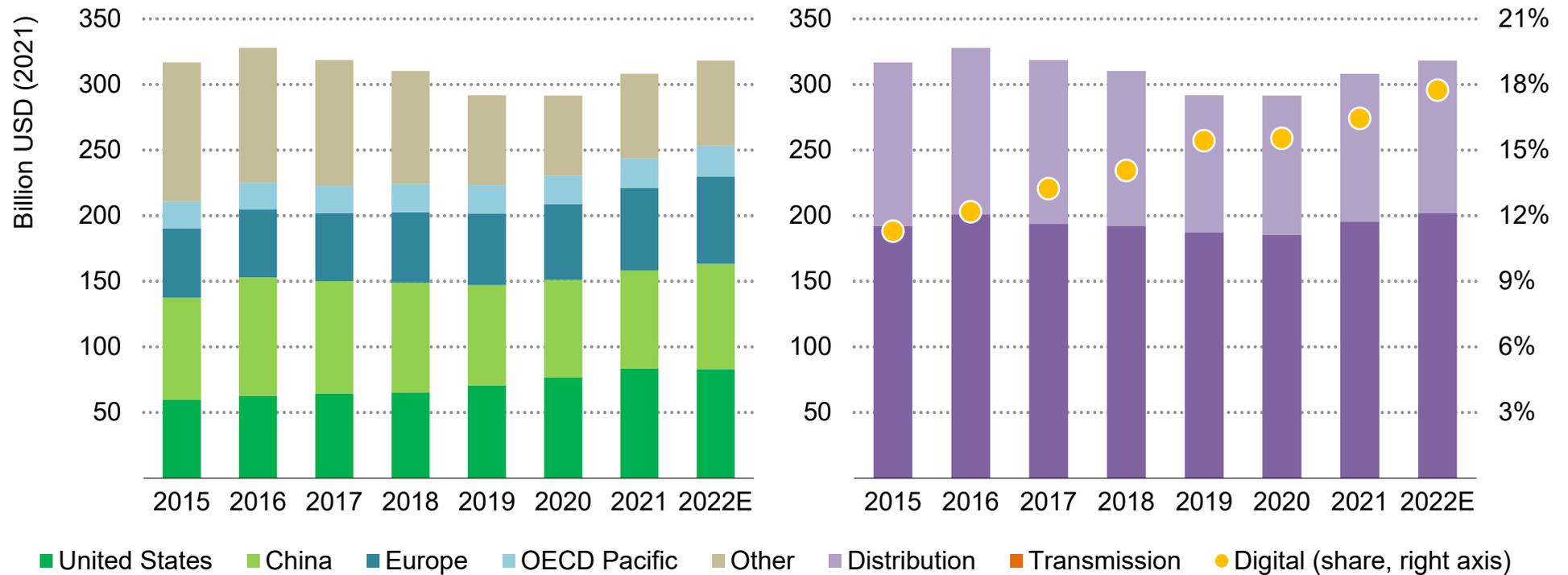
2021 was not only a record year for renewables investment spending as a whole, but also for FIDs for utility-scale renewables (excluding large hydropower). After a dip in 2020's numbers given Covid-related uncertainties, approvals for utility-scale renewables rebounded strongly in 2021, with new wind and solar project FIDs totalling around USD 150 billion each. Solar saw the greatest acceleration, nearly doubling from 2020. For wind, onshore FIDs surpassed the USD 100 billion level again, after a major decline in 2020, whereas offshore FIDs remained stable at more than USD 50 billion.

These robust figures for utility-scale FIDs set the stage for further growth in investment in renewables, at a moment when the environment and sustainability are among the most repeated words in the finance community. However, supply chain bottlenecks, rising costs, access to critical minerals and long permitting processes represent significant barriers. Relieving these obstacles will be essential to achieve a further acceleration in clean energy spending in the power sector.

Electricity grids and battery storage

Investment in electricity grids is recovering, with more ambitious network plans to facilitate the electrification of the economy and the integration of renewables

Investment in electricity grids by geography (left) and segment (right), 2015-2022E



IEA. All rights reserved.

Note: Digital includes public EV charging infrastructure, transmission and distribution automation, networking and communications, analytics (asset performance management, power quality and grid operations), smart meters, advanced distribution management systems, energy management systems, transmission line sensors, vegetation management, dynamic line rating and digitalisation of power transformers and substations.

Source: IEA analysis based on Guidehouse (2022).

Promising signs for grid investment are concentrated in advanced economies and China

Investment in electricity grids is set to continue recovering in 2022 after a strong rebound in 2021, when capital expenditure rose by 6% from Covid-19-affected 2020 levels (the lowest in the last eight years). Advanced economies are leading the way in the electrification of the economy, and investment in these regions rose at a higher speed than elsewhere, accounting for more than 55% of grid spending in 2021 from around 43% in 2015. In addition, spending on electricity networks is being boosted by the fiscal support that governments are providing in response to the economic crisis induced by the pandemic. [The IEA tracked around USD 20 billion that is due to be spent on transmission and distribution directly by governments up to 2023, which, along with regulatory approval for new assets, is expected to mobilise around USD 225 billion from the private sector.](#)

Investment in electricity grids is not immune to cost pressures and tight markets for critical minerals. More than 5 Mt of copper and 9 Mt of aluminium were used to build electricity grids in 2020. The price of these minerals has spiked in recent months, with copper trading at over USD 10 000 per tonne and aluminium surpassing USD 3 000 per tonne, compared with average prices in the last decade of USD 7 000 and USD 2 000 per tonne respectively. [At today's prices, copper and aluminium now represent around 30% of the cost of new](#)

[grid investment, 10 percentage points higher than in the investments made between 2010 and 2020.](#)

Investment in the United States is set to moderate after an increasing trend since 2013 (expenditure in 2021 was 80% higher than that in 2013). Network spending in the country has outpaced electricity demand growth, as increasing capital is devoted to replacing and upgrading equipment and strengthening structures against weather-related damage (only around 30% of investment was devoted purely to expansion in 2021).

China is expected to accelerate investment in 2022, with the State Grid Corporation of China budgeting more than CNY 500 billion for the first time ever and focusing on ultra-high-voltage projects, the upgrading of the distribution network and raising levels of digitalisation of its grids.

European distribution and transmission system operators are also foreseeing higher investment needs, which stems from the expansion of the network to integrate more renewables. The focus is particularly on connecting offshore wind farms, the modernisation of ageing infrastructure and the digitalisation of grids to allow demand-side load management, electric vehicle charging and the electrification of industry. However, investment levels will not accelerate unless policy

makers improve investment frameworks, facilitate access to funds and shorten assessment and permit-granting processes.

Capital spending on electricity networks in EMDEs stood at around USD 60 billion in 2021, similar to 2020, and is expected to remain flat in 2022. These are very low levels compared to the USD 100 billion spent in 2015 and 2016, especially given the transmission and distribution investment needed to keep these regions in line with a net zero trajectory. The weak financial situation of some distribution companies, the lack of adequate investment frameworks (such as performance-based regulation), the lack of least-cost system plans, and high operational and commercial losses are among the most important factors that should be tackled in EMDEs to encourage investment.

Global investment in digital technologies rose again in 2021 after a slowdown in 2020, and is expected to count for more than 15% of total investment in electricity grids. The distribution sector is leading the digitalisation path (accounting for around 75% of all investment in digital) with the roll-out of smart meters and the automation of substations, feeders, lines and transformers via the deployment of sensors and monitoring devices. These systems, while improving grid performance and uptime, also provide utilities with dynamic control over fluctuating voltage levels, two-way power flows and intermittent renewable generation. In the transmission business, digital

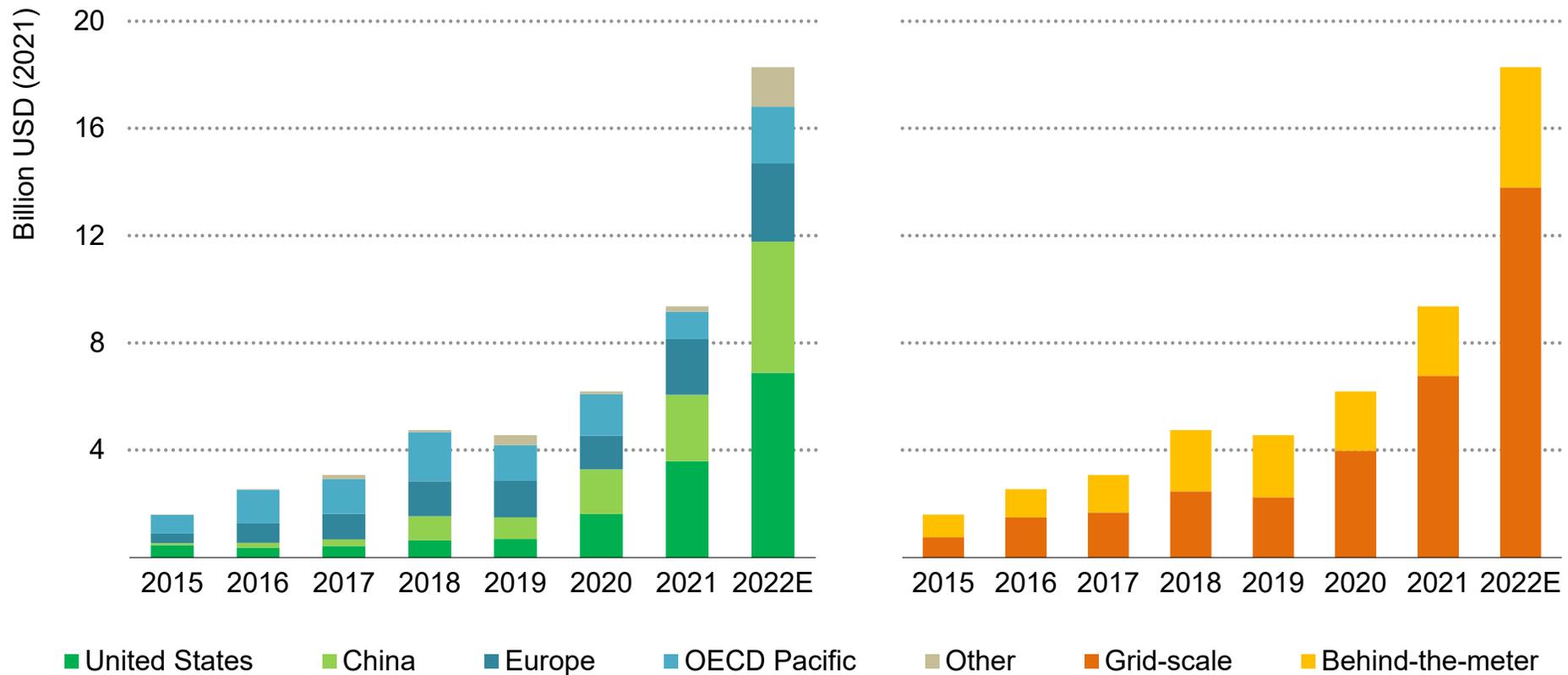
investment is primarily devoted to the digitalisation of power transformers, the automation of substations and the development of energy management systems, which are used to monitor, control and optimise the performance of the generation and transmission system.

Large-scale interconnectors remain a principal focus of investment in transmission, with projects under construction or planned in Europe, China, North America, India and Australia. They are a valuable tool to balance supply and demand across regions, access remote energy resources and integrate variable renewables. In the European Union, for instance, the REPowerEU plan proposes additional investment of EUR 29 billion to stimulate the development of interconnectors.

Finally, investment in public EV charging infrastructure continued to increase in 2021, by more than 20%, and is expected to approach USD 10 billion in 2022. However, that still comprises less than 5% of total distribution investment. China, Europe and the United States are also leading investment in these technologies and account for more than 90% of global spending.

2022 promises to be a take-off year for investment in battery energy storage, doubling the spending seen in 2021

Battery storage investment by geography (left) and segment (right), 2015-2022E



IEA. All rights reserved.

Sources: IEA calculations based on Clean Horizon (2022), BNEF (2022), China Energy Storage Alliance (2022).

Battery energy storage: The United States and China are leading a new market that is poised for rapid expansion, recalling the growth potential of the solar PV industry in the early 2010s

Investment in battery energy storage is currently experiencing the biggest momentum in the power sector, with capital spending expected to nearly triple in just two years. It is led by grid-scale deployment, which represented more than 70% of total spending in 2021 and by lithium ion batteries, which took more than 90% of total deployments in 2020 and 2021. The pipeline of projects is immense, with China targeting around 30 GW of non-hydro energy storage capacity by 2025 and the United States having more than 20 GW of grid-scale projects either planned or under construction. The sector is gaining traction in other markets as well, such as Europe, Korea, Japan and Australia. Helped by economies of scale from growing demand for EVs and technological innovation in new chemistries and configurations, battery energy storage systems should continue to decrease in cost (China expects costs to reduce by 30% by 2025).

However, batteries are, among energy assets, one of the most sensitive to critical mineral supply chains. Depending on the chemistry, they require lithium, cobalt, nickel, graphite, copper and manganese, supplies of which are under high stress and majorly controlled by Chinese actors. The supply chain bottlenecks and price spikes affecting these minerals could limit growth in the sector, and capital costs for batteries are expected to rise by between 5% and

10% in 2022, the first time in a decade, leading to possible delays and rescheduling in project deployment.

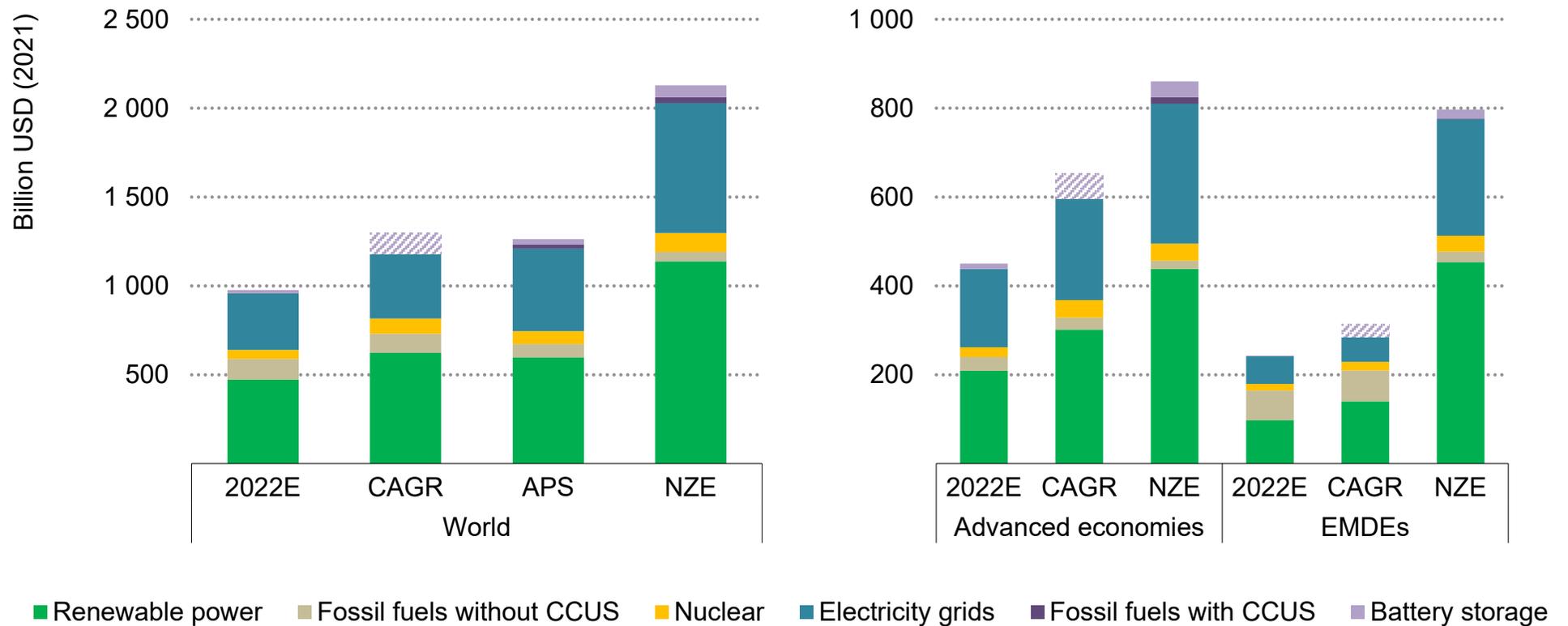
Grid-scale battery energy storage systems are focused on short-term applications; developers are choosing average energy durations of around two hours. However they are showing great versatility and are increasingly used for different purposes. Grid-scale batteries have been primarily used for frequency control regulation (more than 60% of the capacity deployed from 2010 to 2018), but as the market grows, they are now being devoted to load shifting, energy arbitrage and firm capacity procurement (frequency control services only supplied by around 30% of the total capacity deployed between 2019 and 2021). The co-location of batteries with renewables is becoming mainstream too (more than 25% of total capacity installed in the last four years). This format is favoured by cost-competitive advantages, regulatory incentives and innovative auction and PPA designs, which are open to hybrid renewables plus storage projects in countries such as India, Germany, Australia, the United States and Portugal.

Behind-the-meter storage is lagging behind, as it has been more affected by supply chain impacts and cost inflation. Projects are concentrated in countries such as Germany and Japan where residential batteries are a very attractive proposition for lowering consumer bills.

Implications

A cleaner and more electrified energy future needs an acceleration of investment in clean energy infrastructure, especially in EMDEs and for a net zero pathway

Investment in the power sector in 2022 compared with annual average investment for scenarios between 2023 and 2030



IEA. All rights reserved.

Notes: CAGR = compound annual growth rate – a projection applying CAGR between 2019 and 2022 to future investments, except for battery storage, where CAGR between 2015 and 2022 is applied (striped colour to indicate this difference). APS = Announced Policies Scenario. NZE = Net Zero Emissions by 2050 Scenario.

Renewables need to grow more than three times faster and electricity grids more than six times faster to be on track for net zero

Despite robust growth in clean energy investment in the power sector over the last three years, investment levels in these technologies are still short of the spending required to meet announced climate pledges, and much further away from a pathway consistent with achieving global net zero emissions by 2050. Even if investment keeps growing at the pace seen since 2019, much more rapid acceleration is needed in a range of renewable technologies, nuclear power and electricity grids to get on track for a 1.5°C stabilisation of the rise in global average temperatures – alongside a faster move away from high dependence on unabated fossil fuels.

We estimate power investment in 2022 to total around USD 975 billion, as compared with an annual requirement from 2023 to 2030 of more than USD 1 200 billion under the APS and more than USD 2 trillion under the NZE Scenario. However, if capital expenditure in the power sector were to continue growing to 2030 at the same CAGR seen in the last three years, it would reach annual average levels of almost USD 1 300 billion, which is in line with the APS values.

Growth at today's CAGR would be inconsistent with a net zero pathway for every technology, except battery energy storage. Capital expenditure would need to increase at a CAGR of around 20% for renewables and more than 15% for electricity grids, more than three

and six times the current growth rates for the sectors, and at a CAGR of more than 15% for nuclear. Within renewables, investment in solar PV and wind needs to accelerate to almost twice the current growth rate, to a CAGR of 20%, and investment in hydro, biomass and other renewables needs to increase at a CAGR of 30%, whereas investment has decreased since 2019.

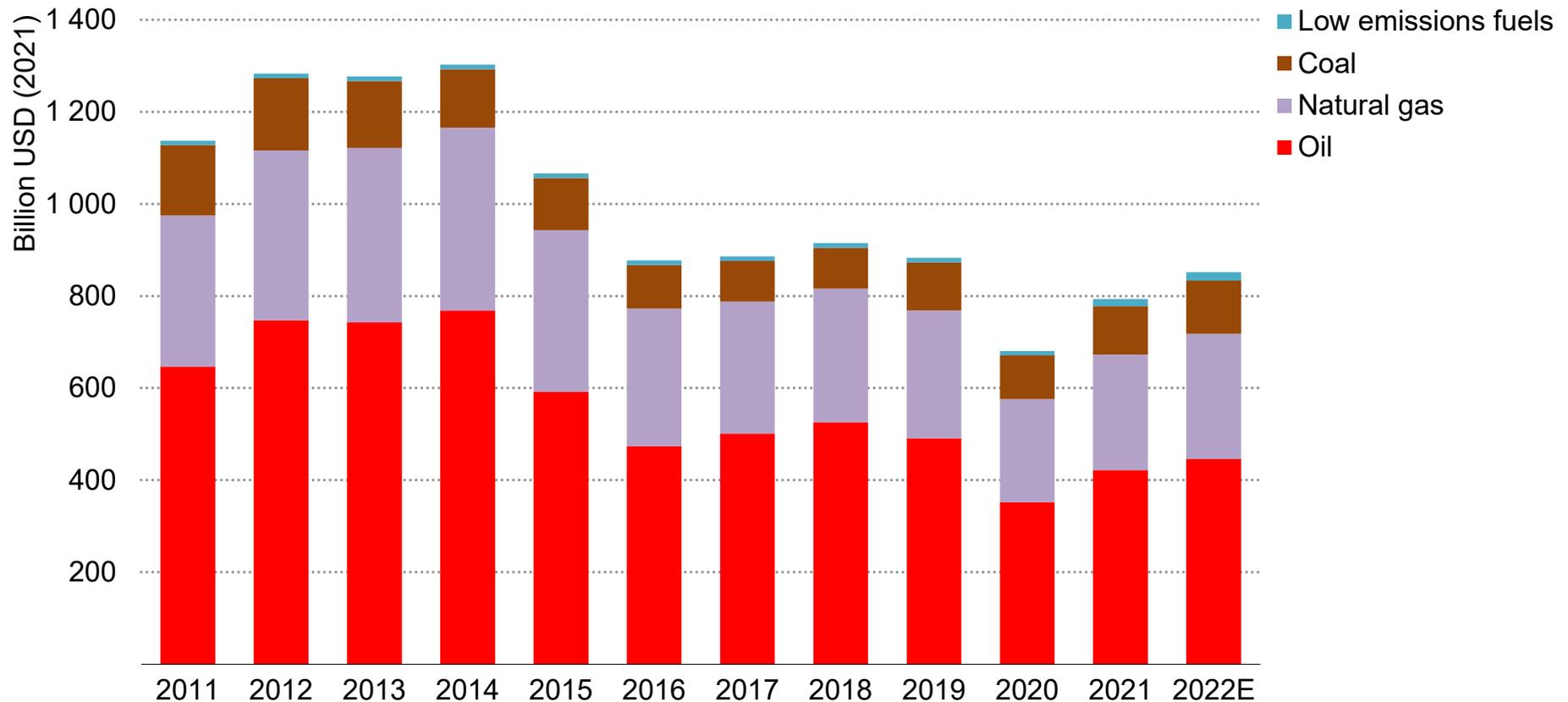
The shortfalls are striking on a regional basis, particularly in EMDEs. Power sector investment in EMDEs needs to grow at a CAGR of more than 25% to reach NZE Scenario levels, twice the pace of advanced economies. This would imply increasing the modest investment growth rate of 3% seen in EMDEs between 2019 and 2022 by nearly 10 times. In particular, investment in renewable generation through to 2030 in EMDEs should average more than four times the USD 100 billion that we anticipate will be spent in 2022, while advanced economies “only” need to double the annual investment devoted to renewables. Electricity networks are another area with a large regional disparity, as EMDEs require more than USD 250 billion per year through to 2030, whereas in reality investment in electricity transmission and distribution in these countries is only around USD 60 billion annually. In advanced economies the annual investment gap in electricity grids, at around USD 140 billion, is smaller but still significant.

Fuel supply

Overview

Global investment in fuels is set to rise in 2022, but remains below pre-pandemic levels

Global investment in fuel supply, 2011-2022E



IEA. All rights reserved.

Note: Low emissions fuels include modern liquid and gaseous bioenergy, low-carbon hydrogen, as well as hydrogen-based fuels that do not emit any CO₂ from fossil fuels directly when used and also emit very little when being produced. For accounting purposes, this excludes fossil fuel use for power generation or industry where the resulting emissions are subject to carbon capture, storage and/or utilisation or where the fuels are used for non-energy purposes.

High prices and Russia's invasion of Ukraine mean that fuel supply investment is currently viewed through an energy security lens, but climate pressures cannot be put aside

Russia's invasion of Ukraine has upended the fuel investment landscape and intensified a commodity price shock. There is now immense pressure to close down one of the main arteries of international energy trade: Russian oil, gas and coal deliveries to Europe, worth an estimated USD 150 billion in 2021 and over USD 500 million each day so far in 2022. Several oil majors and oilfield service companies have pledged to make no further investment in the country, and some are winding down existing operations. The conflict and its aftermath is certain to reverberate across the fuel investment landscape for years to come.

Global upstream investment in oil and natural gas rose to over 380 USD billion in 2021, but this is still below pre-pandemic levels and cost escalation is diminishing the impact of higher spending on activity levels. A noticeable uptick in investment by national oil companies (NOCs), especially in the Middle East, accounted for about 80% of the increase in upstream investment in 2021. Exploration spending in 2021 remained below pre-pandemic levels, although project approvals jumped by 85% year-on-year. The majority of conventional sanctioned projects are natural gas projects, underpinned by a strong recovery in investment in upstream fields linked to new LNG projects. Investment in new refineries and upgrades increased by about 30% in 2021, but a near-record level of refining capacity was retired.

In a world where commodity prices are high and supplies are scarce, the focus of investment is squarely on projects that can deliver new volumes in a hurry. The shale patch in the United States is finally showing signs of life, even if activity levels fall short of previous cycles, while the LNG industry is focused on maximising existing capacity and delivering modular projects and brownfield extensions to meet urgent European calls for additional cargoes.

It is not yet clear whether the current price environment will attract new investment in capital-intensive projects with long lead times. Huge question marks also appear next to the declared ambitions of Russian companies to increase investment and output. However, the anticipated easing of production restraints among OPEC countries is likely to boost upstream investment and capacity expansion in major oil and gas fields across the Middle East.

A huge windfall awaits the oil and gas industry in 2022 from high prices. While this may come as a relief to producer economies that were starved of income in the immediate aftermath of the pandemic, further volatility and exposure to downside risks should not be discounted, particularly as reducing dependence on fossil fuel imports becomes as much a geopolitical priority as a climate-related one. The USD 2 trillion windfall expected in 2022 could be put to good use: the additional income expected would be enough to fund nearly

a decade of investment in low emissions fuels and CCUS in the NZE Scenario, enabling governments and energy companies to strategically position themselves for clean energy transitions.

A focus on energy security is set to boost fuel investment, but the level remains caught between different visions of the future. The average level of investment in oil and gas expected in 2022 is higher than the level projected in the NZE Scenario. The concern for climate-oriented investors and observers is whether the current energy crisis opens up space for greater near-term investment in fossil fuel supply alongside efforts to bring down demand. Some countries and companies are looking to move ahead with the exploration and approval of large longer-term supply projects. But it typically takes many years for such projects to start producing, so they are not a good match for immediate energy security needs. Long-lived assets also carry a dual risk of locking in fossil fuel use that would prevent the world from meeting its climate goals, or of failing to recover their upfront development costs if the world brings down fossil demand in line with the NZE Scenario.

China saw a substantial ramp-up in coal supply investment in 2021 to combat a power generation deficit. Around USD 105 billion was

invested in the coal supply chain, an increase of 10% on 2020 and a return to levels seen in 2019.

Total investment in low emissions fuels reached USD 16 billion in 2021, including a more than doubling of investment in liquid biofuels. Biogases and low emissions gases are set to receive a substantial additional boost as countries seek sustainable alternatives to high-priced supply in general, and Russian supply in particular. Net zero pledges and anticipated low-carbon hydrogen demand could trigger additional investment in CCUS; 2021 saw six final investment decisions (FIDs), as public funding announcements stepped up to USD 18 billion.

Oil and gas companies are already undertaking a wide variety of approaches in response to energy transitions. Spending by oil and gas companies outside “traditional” supply continues to grow, to an expected 5% of their upstream spending in 2022. But the average masks a wide range of company strategies, where European companies are by far the largest investors in clean energy technologies.

What does Russia's invasion of Ukraine mean for investment in fuels?

Tightness in fuel markets, already visible at the start of 2022, have been accentuated by Russia's invasion of Ukraine. Natural gas prices in Europe and coal prices globally have soared to record levels in 2022; prices for oil reached levels not seen since 2014. The world may well be facing its biggest fuel supply shock in decades, with consumers around the world seeing the cost of energy skyrocketing.

The crisis is set to pull fuel investment in different directions. The classic cyclical investment response to high fossil fuel prices is now overlaid with urgent energy security priorities, as Europe in particular scrambles to secure non-Russian supplies. European leaders, meeting in Versailles soon after the invasion, [committed](#) themselves to a "thorough reassessment of how we ensure the security of our energy supplies" and "to phase out our dependency on Russian gas, oil and coal imports as soon as possible". The crisis is also overlaid with intensifying pressure in many countries to accelerate energy transitions and reduce emissions. Near-term energy security imperatives could well be an accelerant for some aspects of energy transitions, but this alignment is far from complete or automatic.

This policy push to diversify supply implies a near-term investment upside for some non-Russian fossil fuel producers, especially those able to deliver additional volumes to market in a short period of time. Investment in low emissions fuels, gases in particular, is likely to gain further momentum from a potent combination of higher fuel prices and stronger policy support (such as the upward revision to the EU

2030 biomethane target). However, potential competition between biofuels and food production will intensify during a period of rising food prices. The energy crisis could also provide a powerful boost to efficiency and end-use spending.

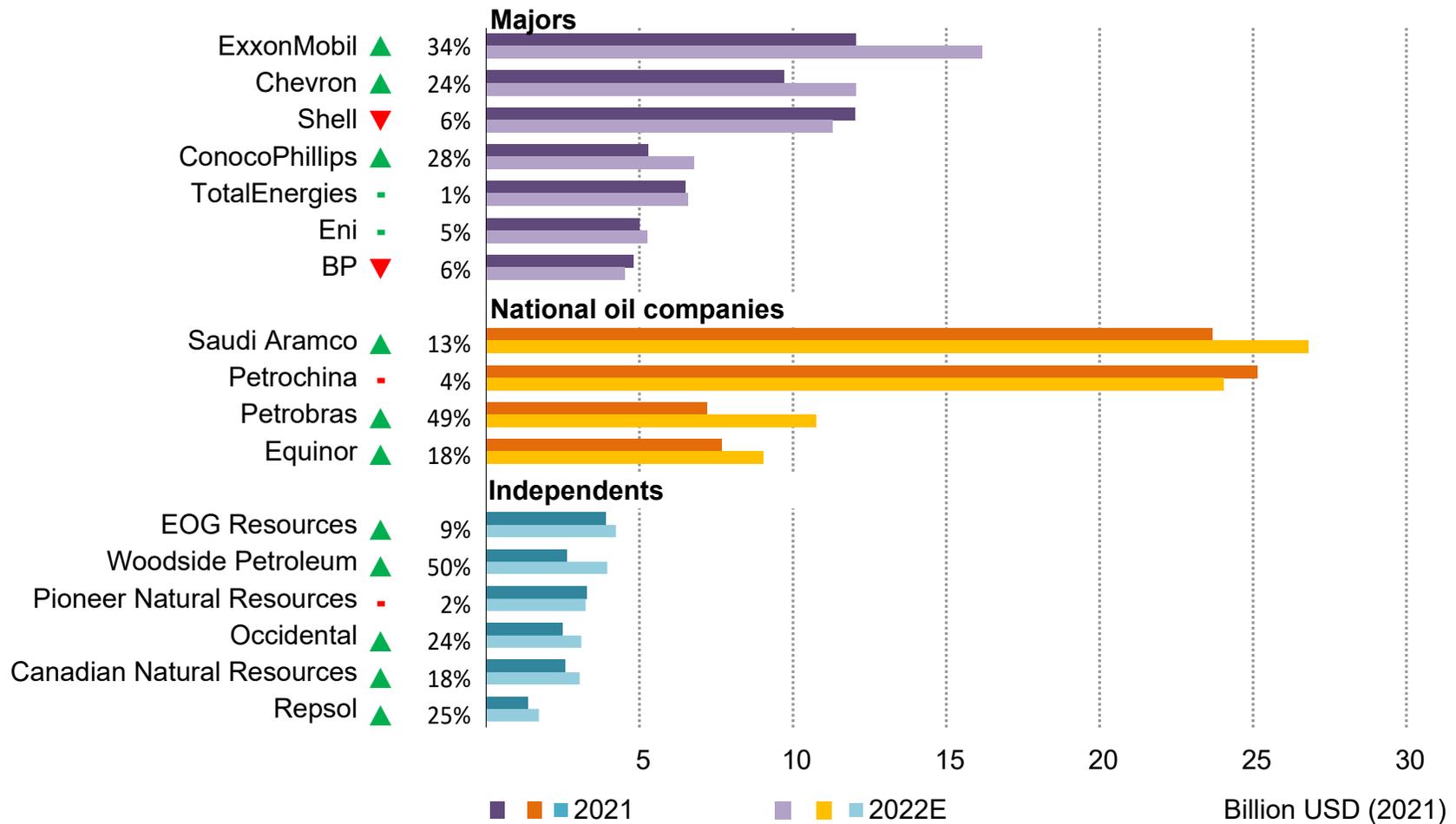
Sanctions affecting investment and technology transfer were imposed on Russia after its annexation of Crimea in 2014, and these put a halt to collaboration in the Arctic and on Russian shale. Restrictions have now tightened considerably. Many international energy companies have announced that they will stop or curtail operations in Russia and with Russian entities, with the impact likely to be felt this time on the pace of expansion of Russian LNG and on the longer-term prospects for production growth for all hydrocarbons in the country.

Prior to the invasion, Russian oil and gas players had signalled large year-on-year increases in planned investment for 2022, but these are now under review. A number of planned projects to expand LNG liquefaction and install steam crackers have been delayed or cancelled. Banks headquartered in Europe and North America have withdrawn, limiting the availability of finance, and oilfield service and international oil companies have limited their operations or announced that they will make no new investments. In recent years, an increasing share of investment in Russia has been in projects looking to export to Asia; this share is likely to increase further.

Upstream oil and gas

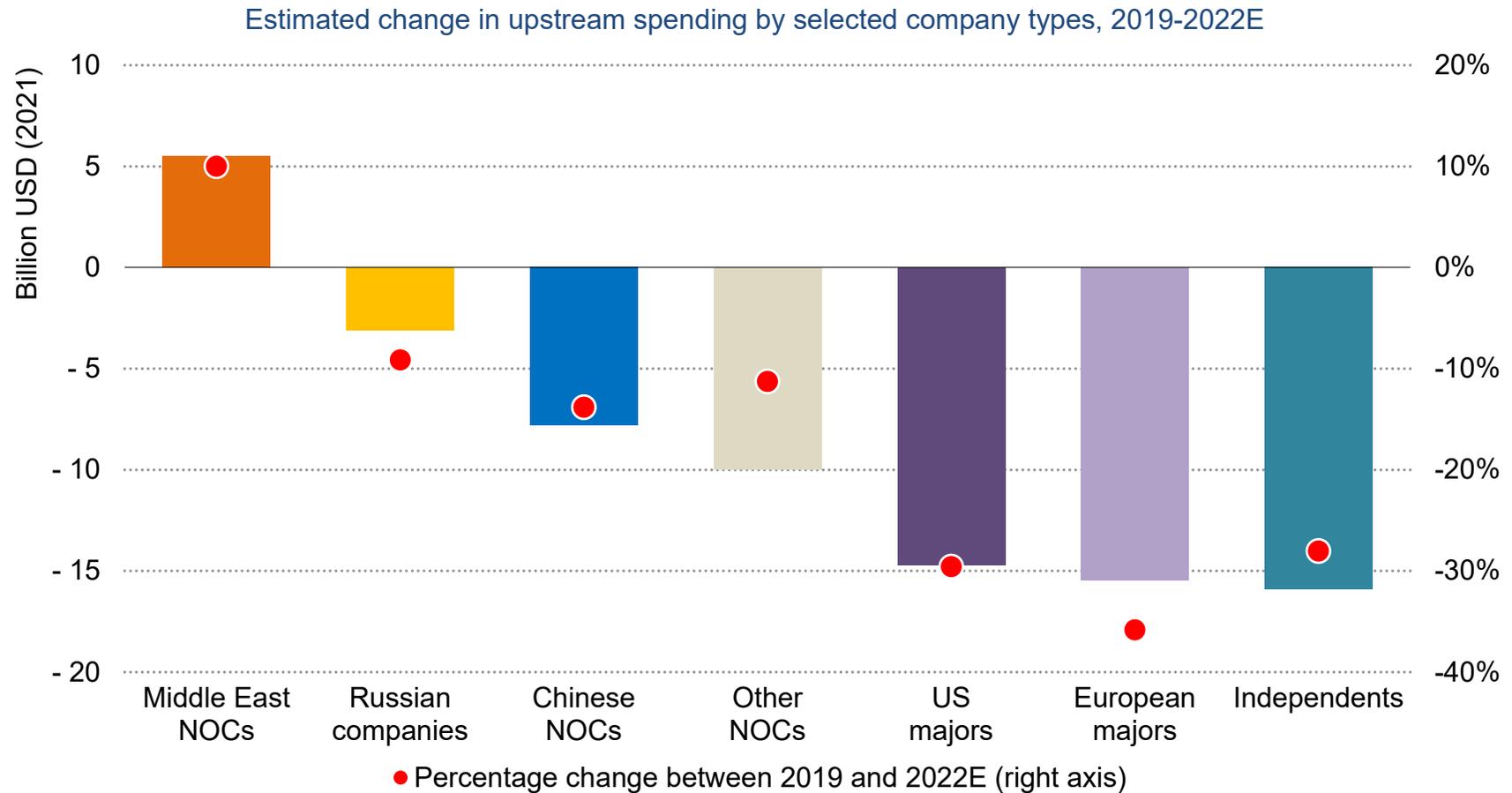
Total upstream oil and gas investment is set to rebound by around 10% in 2022, led by the US majors, independents and NOCs in the Middle East...

Upstream investment by selected oil and gas companies, 2021 and expected in 2022



IEA. All rights reserved.

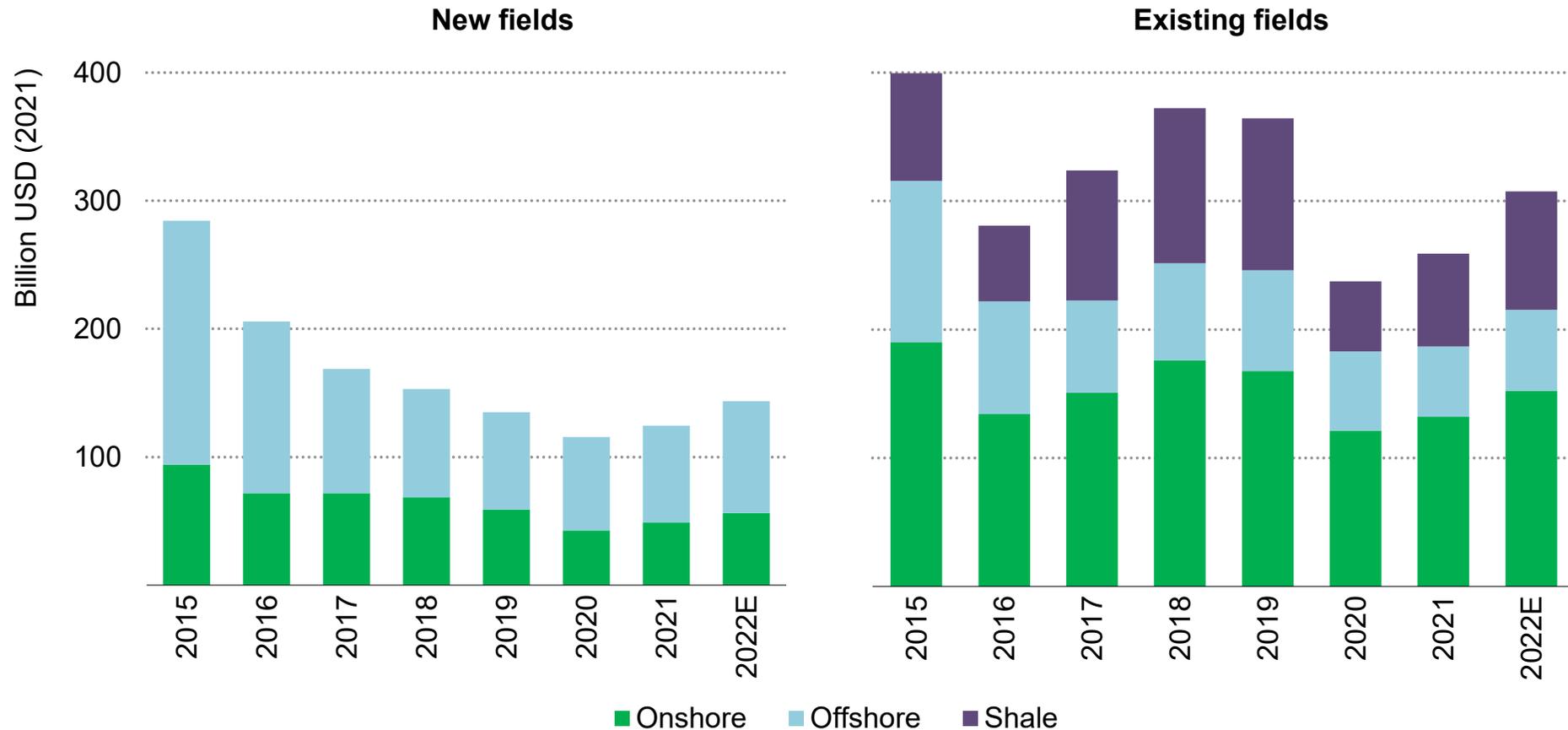
...but only Middle Eastern NOC spending has risen above pre-pandemic levels. Spending by majors and independents is still well below average levels seen in the last decade.



IEA. All rights reserved.

Investment in new fields is back on a rising trend but most upstream capital spending is still on existing fields and shale plays

Upstream investment in new and existing oil and natural gas fields



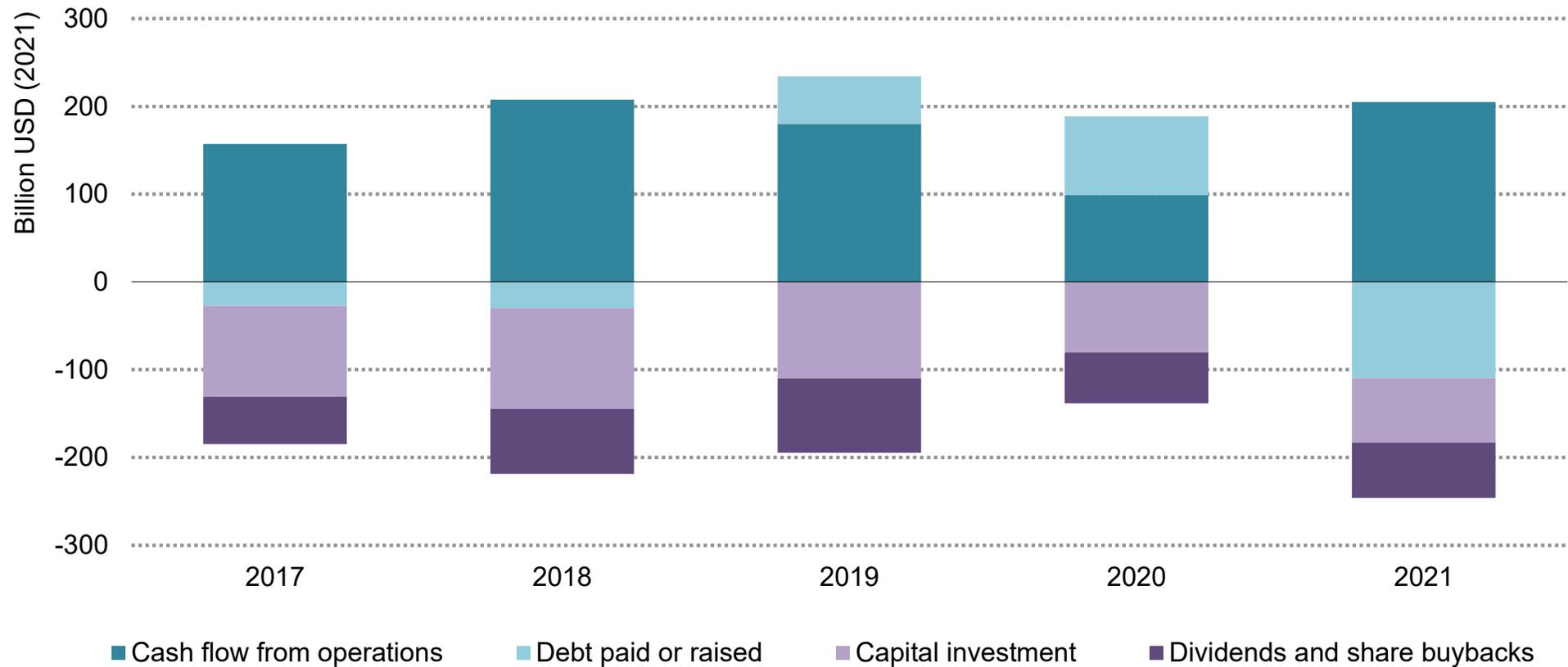
IEA. All rights reserved.

Note: "Shale" includes tight oil and shale gas, primarily in the United States, and is classified here as "existing".

Sources: IEA analysis based on Rystad (2022), company reporting and publicly available data.

The majors generated much larger profits in 2021; most of this was used to pay down debt and return money to shareholders, but it also allowed for expanded 2022 investment plans

Evolution of cash generation and spending of the majors, 2017-2021



IEA. All rights reserved.

Note: Comprises BP, Chevron, ConocoPhillips, Eni, ExxonMobil, Shell and TotalEnergies.

Sources: Bloomberg terminal (2022), company annual reports.

Despite an expected rebound in 2022, upstream oil and gas investment remains about 20% below levels seen before the Covid-19 pandemic

At USD 380 billion, upstream investment in 2021 was nearly 10% greater than in 2020 but still less than 20% below pre-pandemic spending levels. Higher prices are expected to underpin a further 10% increase in 2022 on 2021 levels (although some of this is being absorbed in practice by higher costs, as discussed below). The focus in many cases has been on short-cycle investments that bring new supply to market as quickly as possible, for example via tie-backs to existing projects and increased infill drilling.

The shift in overall spending towards NOCs is a well-established trend and is set to continue. Middle Eastern NOC spending is now well above pre-crisis levels. Saudi Aramco and ADNOC are looking towards aggressive growth following the 2020 downturn, and have announced plans to increase investment spending by about 15-30% in 2022. Aramco's spending is split roughly equally between its twin goals of increasing oil production capacity and domestic gas supply. Petrobras has announced plans to increase its spending by about 50% in 2022, after years focused on debt repayments.

Some Russian producers are reviewing their investment programmes due to sanctions and the announced exit of companies that have supported Russian supply growth since the 1990s. Rosneft's spending will be watched closely as the ambitious strategy it laid out

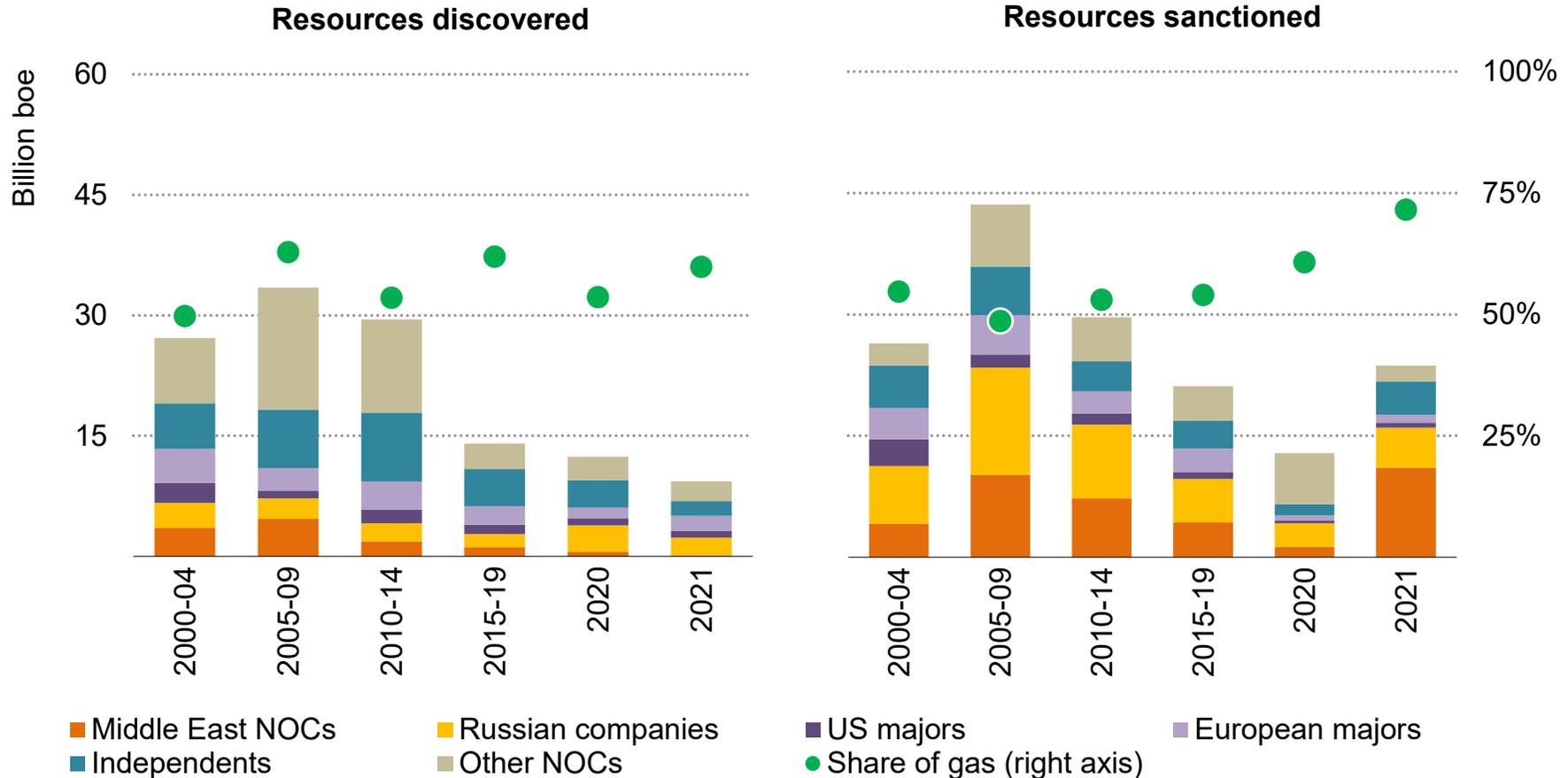
in 2021 so far remains in place with plans to increase overall oil and gas production by more than 20% to 2030 from 2021 levels.

Some of the largest increases in upstream investment in 2022 are expected to come from the US majors, which are looking to increase spending by more than 30% in 2022. Meanwhile, planned upstream capex is essentially flat for the European majors in 2022, underscoring that their investment plans are driven more by long-term strategy commitments than by short-term prices. Independent US shale operators cut investment by around half in 2020, but announced activity levels indicate something of a rebound since then. Nonetheless, investment in this area in 2022 is still expected to be around 30% below 2019 levels, given the focus on profitability and capital discipline rather than production expansion.

The upstream oil and gas industry has seen extreme volatility over the past decade. Investment reached its highest level in 2014 (at nearly USD 890 billion), but fell by over 45% between 2014 and 2016 as a result of the oil price crash, and by a further 30% between 2019 and 2020 as a result of the pandemic. Many companies saw a strong rebound in cash flow from operations in 2021 and used it to pay down debt raised during the pandemic and return money to shareholders. Almost half of the cash generated by the majors has been used to pay down their debt.

Conventional discoveries are falling but still significant, while decisions to sanction new developments picked up in 2021, with a focus on natural gas

Conventional oil and gas resources discovered and sanctioned, 2000-2021



IEA. All rights reserved.

Notes: Data for the four-year periods between 2000 and 2019 are annual averages.
 Sources: IEA analysis with calculations based on Rystad (2022) and company reporting.

Could worries over security of supply prompt an upturn in exploration and project approvals?

High fuel prices and the drive to diversify away from Russian imports could underpin a more accommodating stance towards exploration in some countries, despite concerns about the incompatibility of new resource developments with climate goals. For the moment, exploration activity remains well below levels prior to the 2015 oil price downturn; just under 10 billion boe were discovered in 2021, with exploration spending down 35% from 2019 levels.

Three discoveries account for about 40% of all announced oil and gas volumes discovered in 2021: Zinichev in the Russian Arctic (discovered by Rosneft and BP); Baleine in Côte d'Ivoire (Eni); and North Sakarya in Turkey (TPAO). The extension of the Guyana-Suriname basin by ExxonMobil, Hess and CNOOC in Guyana and TotalEnergies and APA Corporation in Suriname brought around 1.8 billion boe discovered volumes in 2021, with exploration success continuing in 2022 in [Guyana](#) and with Krabdagu in Suriname. The Shafag Asiman discovery in Azerbaijan was announced by BP and SOCAR, but few details on volumes were made public.

The total volume of oil and gas achieving FID increased by nearly 85% in 2021 to around 24 billion boe, reverting to the pre-pandemic level, with NOCs responsible for more than 75% of the total. This was

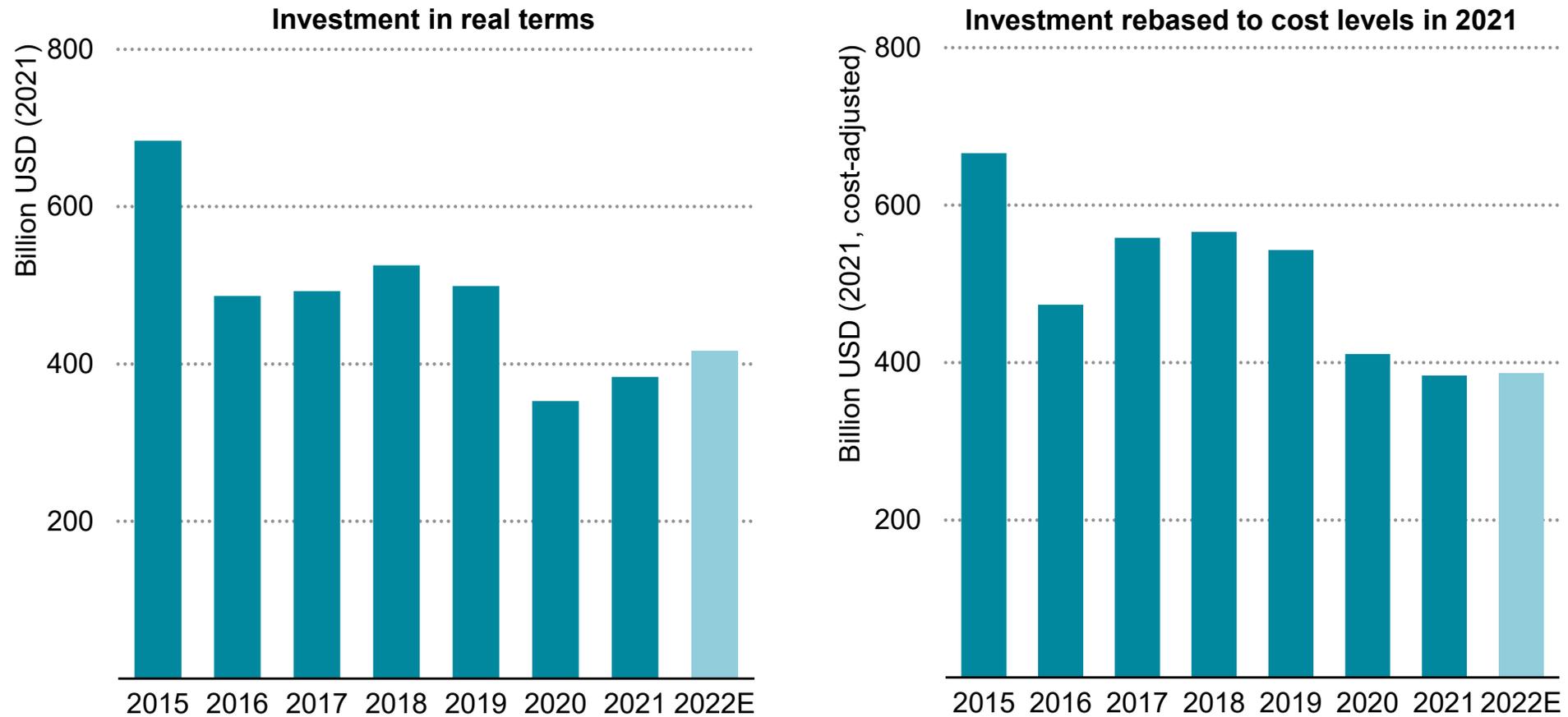
underpinned by a push in the LNG export market, notably QatarEnergy's North Field East project and Gazprom continuing to progress Baltic LNG (although the future of the latter project is now in doubt).

Other development strategies have focused on projects with a short gap between investment and first production, that can make use of existing infrastructure and that can employ replication to lower costs. For example, Shell announced FID on its deepwater Whale field, and aims to begin production within two years; Eni announced plans to begin production from its 2021 discovery Baleine by 2023; and in April 2022 ExxonMobil, Hess and CNOOC sanctioned the Yellowtail field in Guyana, which is expected to produce 250 kb/d by 2025. In many parts of the world, without a strong exploration funnel, FID opportunities will be increasingly limited in the future.

As regards US tight oil and shale gas, the number of rigs in operation is around 60% higher in Q1 2022 than in Q1 2021, but levels are still around 30% lower than in 2019, reflecting companies' focus on capital discipline and returning more revenue to shareholders. Private capital has grown from about one-quarter of investment in US shale between 2015 and 2019 to about one-third in 2021.

The increase in upstream oil and gas spending in 2022 is largely a reflection of higher costs....

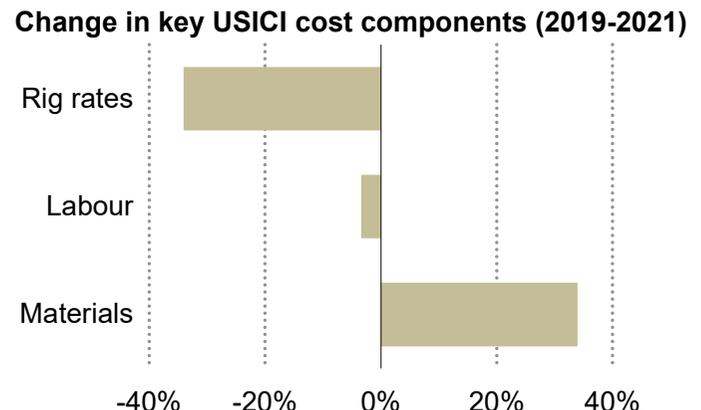
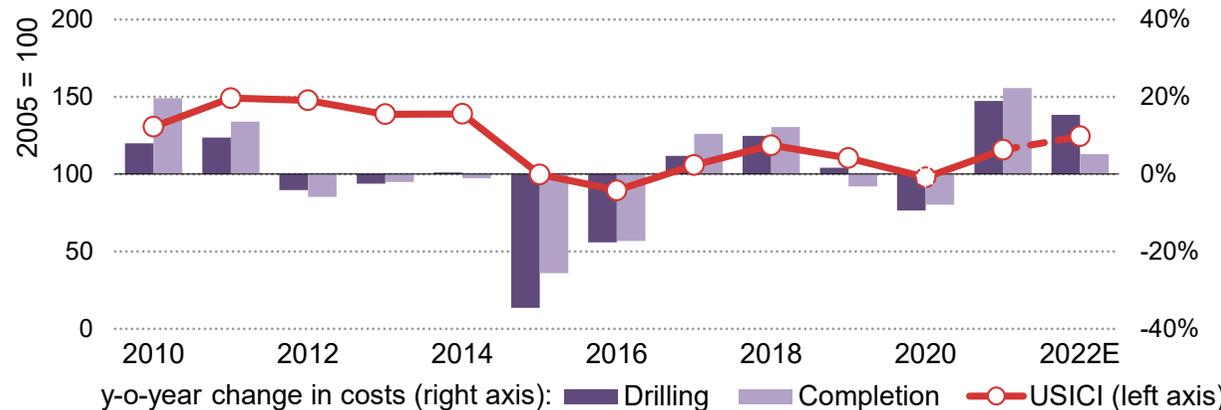
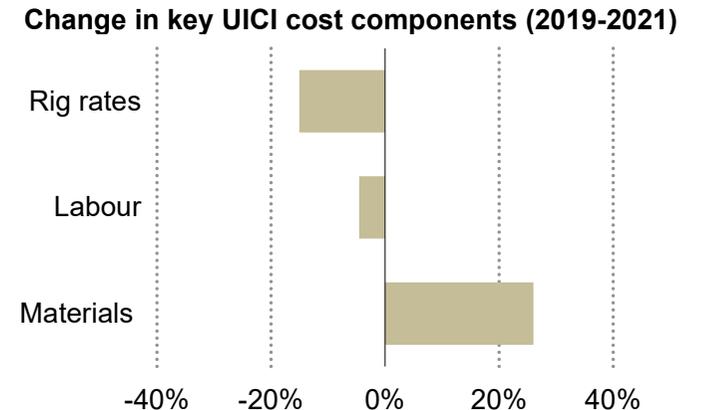
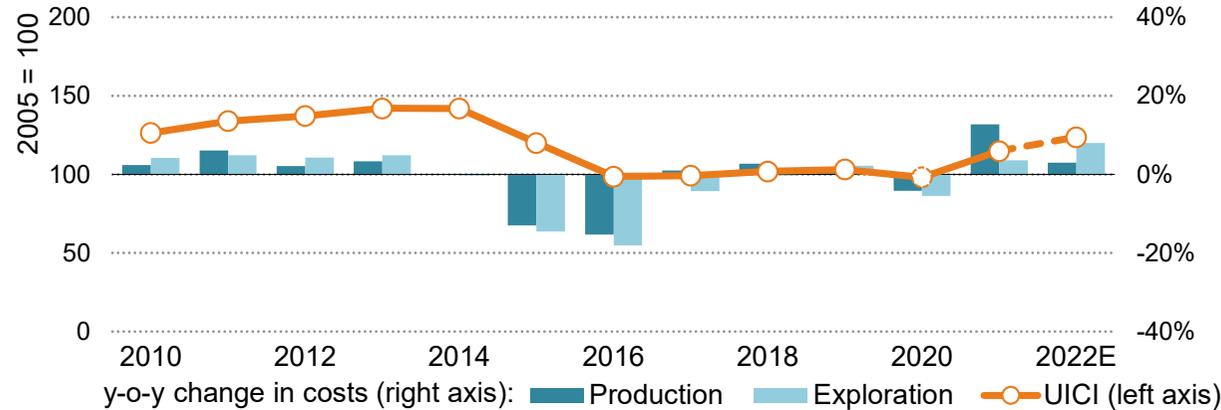
Global investment in upstream oil and gas in 2021, real terms (left) and rebased at constant 2021 costs (right), 2015-2022E



IEA. All rights reserved.

... as, after years of relative stability, cost inflation has pushed upstream costs up by over 25% since 2020, largely due to the increased cost of input materials.

Upstream cost index (top charts) and upstream shale cost index (bottom charts) and key changes in cost components, 2019-2021



Notes: UICI = upstream investment cost index; USICI = upstream shale investment cost index. Materials comprises steel, steel products, cement, aluminium, copper, concrete and high-density polymers.

IEA. All rights reserved.

Supply and logistics constraints are global and the upstream oil and gas industry is now seeing increased costs across the board

Oil and gas production costs increased by around 40% between 2005 and 2014 due to high oil prices and activity levels. This rise came to an abrupt halt after the 2014-2015 oil price crash as companies tightened their belts and implemented a host of strategic changes to ensure greater capital discipline and improve efficiency. As a result, by 2016 our cost index had returned to 2005 levels and remained around this level for a number of years. Cost inflation has now returned and so while investment levels are expected to rise in nominal terms in 2022, nearly all of this increase is simply because the industry is paying more to achieve the same results.

The Covid-19 pandemic severely impacted global supply chains, including the cost of key materials, equipment and talent needed to drill, engineer and build oil and gas supply projects. Since 2020 upstream and shale production costs have grown by over 25% as lockdowns affected supply chains for steel and raw materials (such as aluminium, nickel, copper and high-density polymers). Russia's invasion of Ukraine has further exacerbated supply chain impacts, as Russia provides 10% of global nickel supply, over 5% of global aluminium supply, and is a major steel exporter.

Many larger oil and gas operators and oilfield service providers have some level of material stock or locked-in contracts that are likely to limit cost increases in the near term. Volatility in supply chains may

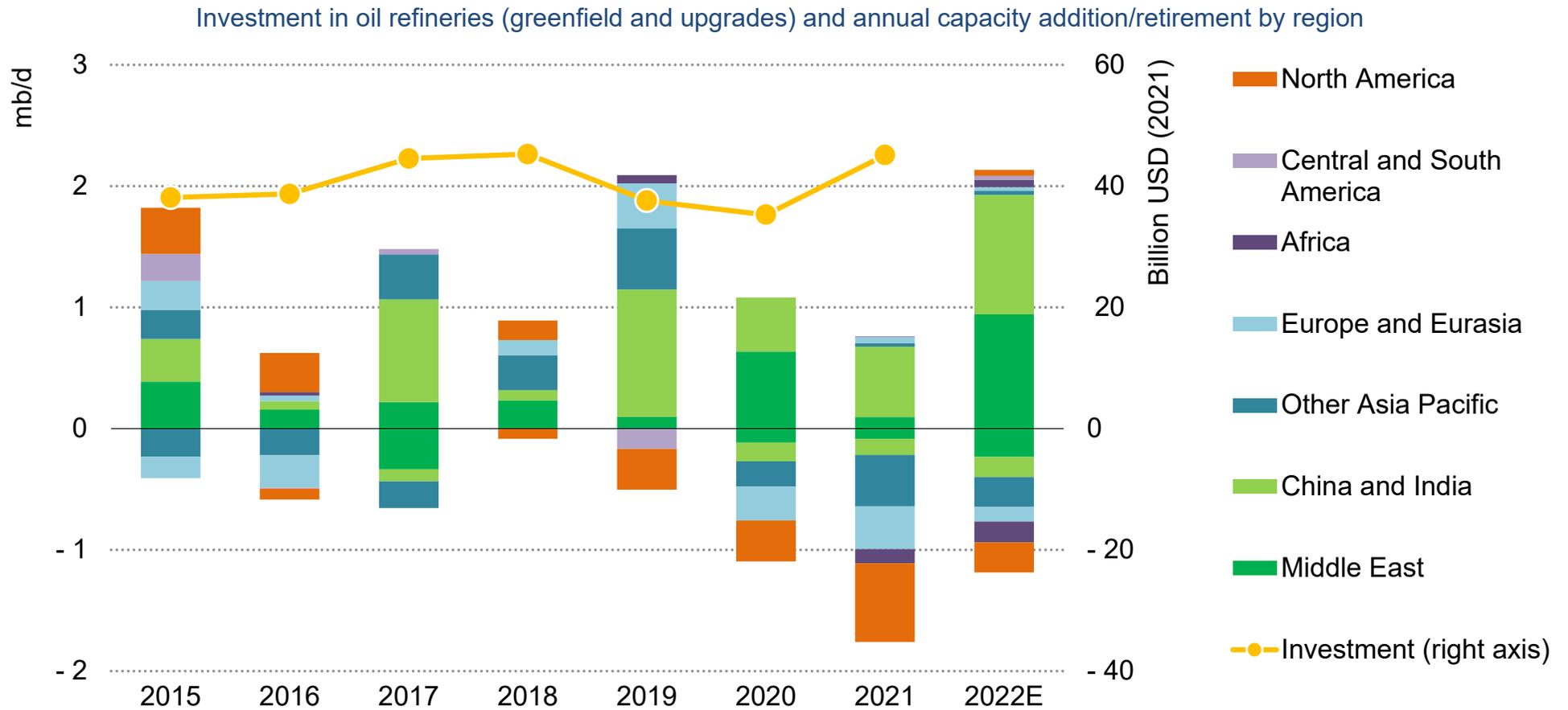
serve to delay investment decisions that would otherwise move ahead in the current higher oil and natural gas price environment. Service companies, both large and small, have noted supply chain constraints translating into lower revenues, while some producers have yet to feel the full impact on major project delivery times.

Oilfield service providers have moved towards increasing local content in supply chains to improve resiliency in delivery models, while efficiency improvements and cost reduction efforts are helping to limit supply chain impacts. Nonetheless, bottlenecks, particularly for materials and minerals, are likely to become more difficult to avoid over time.

The industry is also facing increased cost pressure from the lack of new and experienced workers. US shale producers have [highlighted difficulty recruiting and retaining staff](#) as a key obstacle to delivering new volumes. Much of the workforce that left the industry during recent downturns has not returned and workers are [not enticed by the offer of higher wages](#). Low intake numbers and societal pressures have led to cuts in some programmes offering oil and gas engineering.

Midstream and downstream oil and gas

Investment in new refineries and upgrades increased by 30% in 2021, but a near-record level of refining capacity was retired



IEA. All rights reserved.

Note: Investment figures reflect estimates of ongoing capex, excluding maintenance capex.

Despite the recent increase in margins, refiners continue to explore options to maintain long-term competitiveness

The level of refining capacity additions was noticeably lower in 2020 and 2021 than in 2019, when a record amount of new capacity came online. Most of the new capacity additions in 2021 occurred in China and the Middle East. A growing amount of refining capacity has also been retired in recent years: in 2021 around 1.8 mb/d of refining capacity was retired in North America, Europe and Asia together, resulting in a net reduction in global refining capacity for the first time in 30 years.

In 2022 several large-capacity projects are expected to come online, including the Al-Zour refinery in Kuwait and the Jieyang and Shenghong refineries in China. The scale of capacity additions may be larger if the 650 kb/d Dangote refinery in Nigeria starts operation this year (currently assumed to come online in early 2023). Reflecting this activity, investment in new refineries and upgrades (excluding maintenance spending) increased by nearly 30% in 2021, primarily in the Middle East and developing economies in Asia. Just over 1 mb/d of capacity is expected to be retired in 2022, but there is still set to be a net 1 mb/d increase in capacity globally. After 2022 the pace of new capacity additions is likely to slow, which could lead to a reduction in refining investment in the coming years.

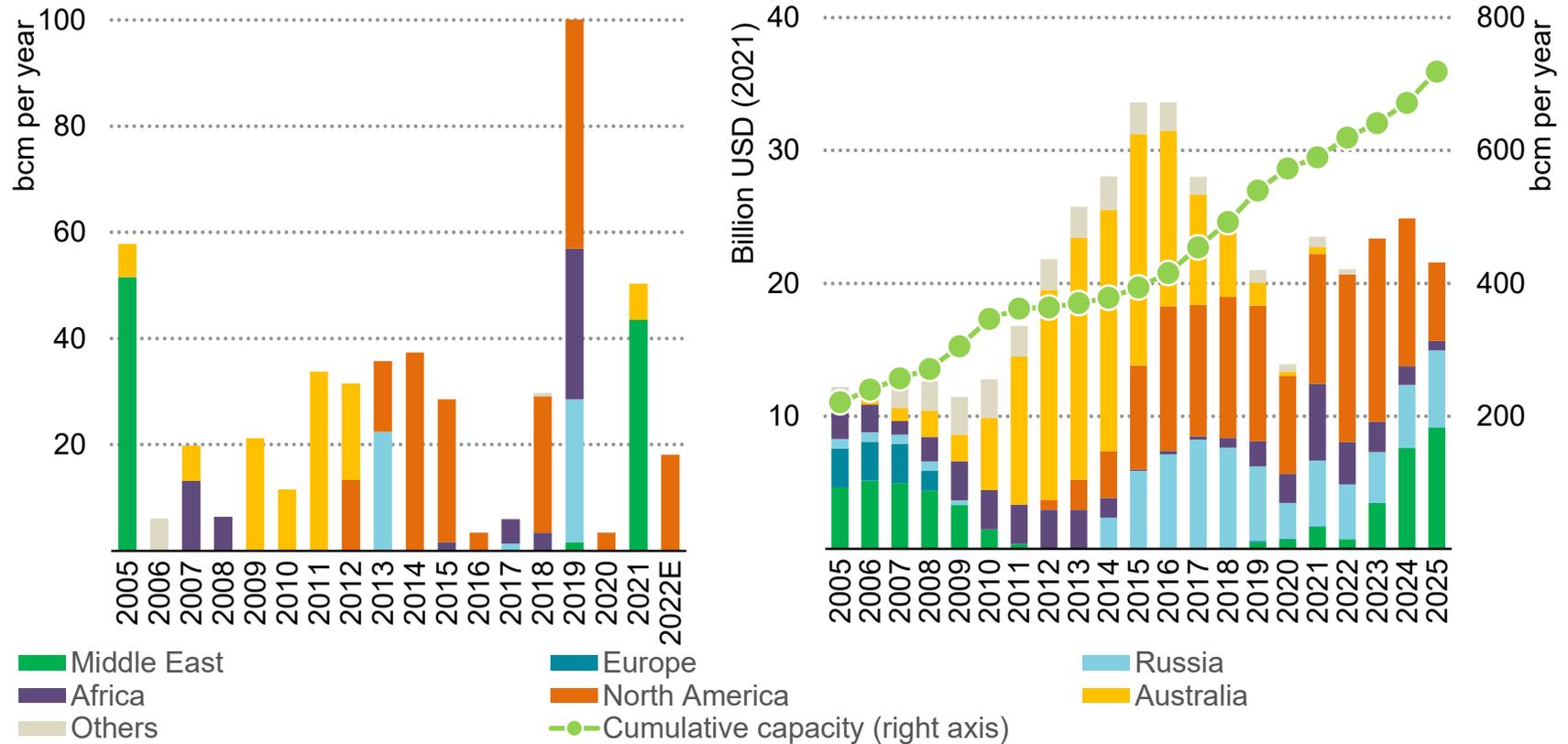
Refinery margins were elevated in 2021 thanks to higher crack spreads for lighter products such as gasoline and naphtha. In the first

few months of 2022 the crack spreads for diesel and kerosene – which had been relatively weak in 2021 – also skyrocketed due to Russia's invasion of Ukraine. In 2021 Russia exported [2.8 mb/d](#) of oil products (mainly diesel and fuel oil), of which 1.5 mb/d was sent to Europe. The disruption of Russian exports, capacity constraints and low inventories are making it challenging to fill the product gap, which points to continued tightness in global product markets.

The strong financial performance and high utilisation rates seen recently may not necessarily translate into higher investment levels in the years ahead given lingering uncertainty around the long-term outlook for oil demand. Less competitive traditional refiners continue to face mounting pressures to adapt to the new market environment set to be created by energy transitions. Many refiners are looking to expand low-carbon businesses such as renewable biofuels, plastic recycling and low-carbon hydrogen. TotalEnergies is investing over EUR 500 million to convert its Grandpuits refinery into a zero-crude platform for biofuels and bioplastics. Neste has teamed up with Marathon Oil to invest USD 1 billion to build a renewable biodiesel plant in California. A number of European refiners have announced plans for plastics recycling projects. At the end of 2021 OMV in Austria took the FID to expand its pilot plastic waste-to-crude recycling plant at its Schwechat refinery.

LNG capital spending and project approvals recovered in 2021 from historic lows, mostly as a result of a new wave of projects in Qatar

Sanctioned LNG export capacity (left graph) and annual investment spending on sanctioned projects (right graph)



IEA. All rights reserved.

All eyes are on the tight global LNG market, but where, how and when will new supplies arrive?

Global LNG demand grew by 6% in 2021, faster than the 4.5% increase in total natural gas demand. Capital spending on LNG liquefaction projects exceeded pre-pandemic levels to reach USD 23 billion in 2021, with the United States accounting for nearly half of the total. Around 90 bcm worth of term LNG contracts were signed in 2021 – 60% higher than levels in 2020. Around a third of these contracts underpinned new liquefaction capacity, while the rest were mostly Qatari and Russian marketed gas volumes.

Compared with 2021, an additional 30 bcm of LNG export capacity is expected to come online in 2022, providing some small relief to the currently tight LNG market. However, delays to projects sanctioned in recent years, notably Mozambique LNG, Golden Pass, and LNG Canada, mean that anticipated capacity growth in 2023 and 2024 is only 20 bcm each year. The next large wave of LNG projects is due from 2025, led by 50 bcm of new Gulf Coast projects in the United States and Qatar's 45 bcm North Field expansion. However, there is significant uncertainty around the commissioning of Trains 2 and 3 of Novatek's Arctic LNG project, worth an estimated USD 15 billion, as sanctions on Russia complicate the work of service companies and limit access to suppliers and shipyards.

The European Union's plan to rapidly diversify fuel supplies away from Russia has set the stage for competition between Europe and Asia for incremental LNG volumes, upturning the conventional wisdom of Europe acting as a "balancing market" for global LNG supply. Some European gas buyers are seeking to maximise LNG supplies to existing facilities as well as expand terminal capacity (with

announced plans totalling an extra 20 bcm per year), and are also chartering FSRU capacity.

The outlook for new LNG supply remains uncertain. Qatar's FID on the 45 bcm North Field expansion in early 2021 was the largest of its kind. Since July 2021 as gas prices began climbing, two LNG projects reached financial close as of May 2022 (the 11 USD billion Pluto expansion in Australia and the USD 13 billion Plaquemines project in Louisiana). A further 900 bcm of projects lie in waiting, with long-run costs in the range of USD 5-10 MBtu – well below today's spot gas prices. The United States leads the pack, with projects totalling 250 bcm annual capacity approved by the Federal Energy Regulatory Commission (FERC).

However, many are unlikely to be realised; sponsors are contending with inflationary pressures, supply chain bottlenecks and labour shortages, and most projects face a 3-4-year construction period and a 30-year operating lifetime, with payback periods for invested capital that go well beyond the tight LNG balance that is expected over the next 2-3 years. Players able to offer fast-track LNG solutions, for example the expansion or de-bottlenecking of existing terminals, or supply chain innovations such as modular liquefaction, are likely to thrive in this market. An example of the latter is New Fortress Energy self-financing a 4 bcm offshore project in the United States combining the use of drilling rigs with prefabricated medium-sized liquefaction modules, at a reported cost of around USD 1.5 billion. The company has also partnered with Eni to develop a 4.5 bcm LNG project in the Congo. Both projects are slated to come online in 2023.

Oil and gas industry transitions

Diversification plans by oil and gas companies are more ambitious than the underlying clean energy investments

Current diversification options by selected international oil companies and NOCs

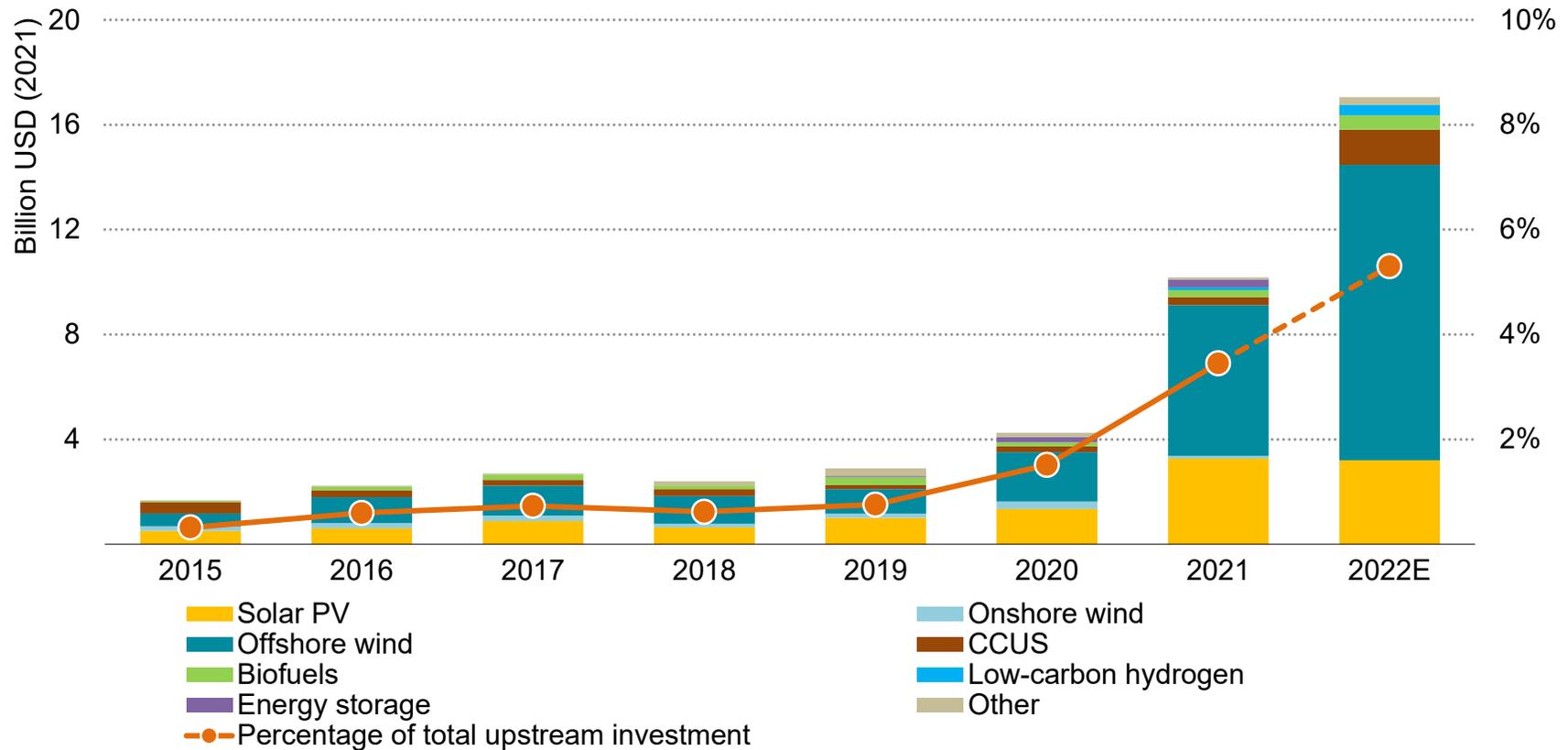
Company	Activity and investment in selected alternative businesses						
	Solar PV and wind generation	Geothermal	Electricity services	Bioenergy	CCUS	Low-carbon hydrogen	Nature-based solutions
BP	●	●	●	●	●	●	●
Eni	●		●	●	●	●	●
Shell	●	●	●	●	●	●	●
TotalEnergies	●		●	●	●	●	●
Chevron		●		●	●	●	
ExxonMobil				●	●	●	
ConocoPhillips					●		
Saudi Aramco	●				●	●	
ADNOC	●				●	●	
CNPC	●	●		●	●	●	●
Sinopec	●	●			●	●	
CNOOC	●				●	●	

Notes: ● = growth supported by strategic investments (M&A), project FIDs and/or spending on commercial-scale activities; ● = announced strategy with minor investments, venture capital and/or R&D spending; ● = announced strategy but with limited evidence of investment activity or no announced strategy but minimal investments. Electricity services include battery storage and EV charging. Bioenergy includes advanced biofuels and biomethane.

Sources: Company reported strategies, publicly disclosed investments and interviews with Chinese NOCs.

Spending by oil and gas companies outside “traditional” supply continues to grow, but only to an expected 5% of the total in 2022; European oil and gas majors dominate the field

Capex by selected oil and gas companies on clean energy technologies



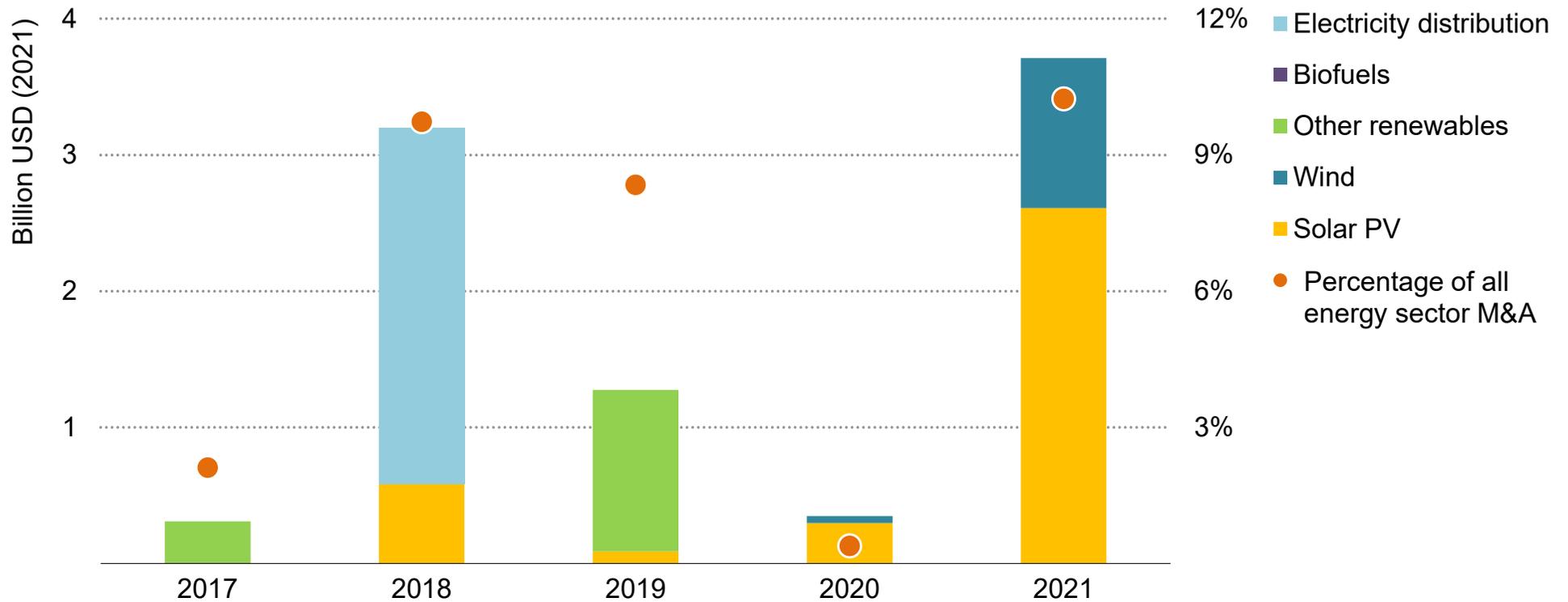
IEA. All rights reserved.

Notes: Includes the majors, ADNOC, CNPC, CNOOC, Equinor, Gazprom, Kuwait Petroleum Corporation, Lukoil, Petrobras, Repsol, Rosneft, Saudi Aramco, Sinopec and Sonatrach. The estimated clean capex in 2022 is based on investment spending announced to 31 March 2022 and assumes that this pace of investment is maintained throughout the year.

Sources: IEA calculations based on BNEF (2022); Clean Energy Pipeline (2022); company reports and websites.

Oil and gas companies have increased their M&A activity as they seek to diversify their portfolios with clean energy technologies

M&A spending by oil and gas companies on clean energy technologies



IEA. All rights reserved.

Notes: Includes the majors, ADNOC, CNPC, CNOOC, Equinor, Gazprom, Kuwait Petroleum Corporation, Lukoil, Petrobras, Repsol, Rosneft, Saudi Aramco, Sinopec and Sonatrach. "Other renewables" comprises combined deals for solar, wind and hydro.

Sources: Bloomberg (2022); BNEF (2022).

Oil and gas industry investment in clean energy technologies is set to almost double in 2022, with offshore wind projects dominating growth

Oil and gas companies are undertaking a wide variety of approaches to respond to energy transitions. The majors, especially in Europe, have taken a broad view of potential value chains outside oil and gas and are looking to reposition themselves as “energy companies”, developing positions in solar PV, wind, electricity services, bioenergy, low-carbon hydrogen, CCUS, and other CO₂ removal technologies. The North American majors have collectively dedicated a much smaller fraction of their capital budgets to alternative technologies than their European peers. They have expressed a preference to focus on areas most closely aligned with existing company strengths, including bioenergy, CCUS and low-carbon hydrogen.

Among the NOCs, Saudi Aramco and ADNOC have indicated a desire to develop CCUS and low-carbon hydrogen and hydrogen-based fuels. The Chinese NOCs have highlighted that they intend to focus mostly on enhancing energy security, and so are looking to expand natural gas production, with some initial steps into clean technologies such as CCUS and offshore wind.

The oil and gas companies included in our analysis invested around USD 10 billion in clean energy technologies in 2021, more than double the level in 2020, but still less than 4% of their total upstream spending. These companies’ investment is on track to almost double again in 2022, which would increase the share of clean energy to just

over 5% of upstream capital investment. The majors and Equinor have led this growth, accounting for about 90% of total clean energy investment by the oil and gas industry in 2021 and almost all of the investment tracked so far in 2022. If growth continues according to recent trends, the companies in our sample would be spending around 15-20% of their upstream capital on clean energy by 2030, or around USD 50-60 billion per year at current rates. This is equivalent to 4-5% of total global spending on clean energy in 2021.

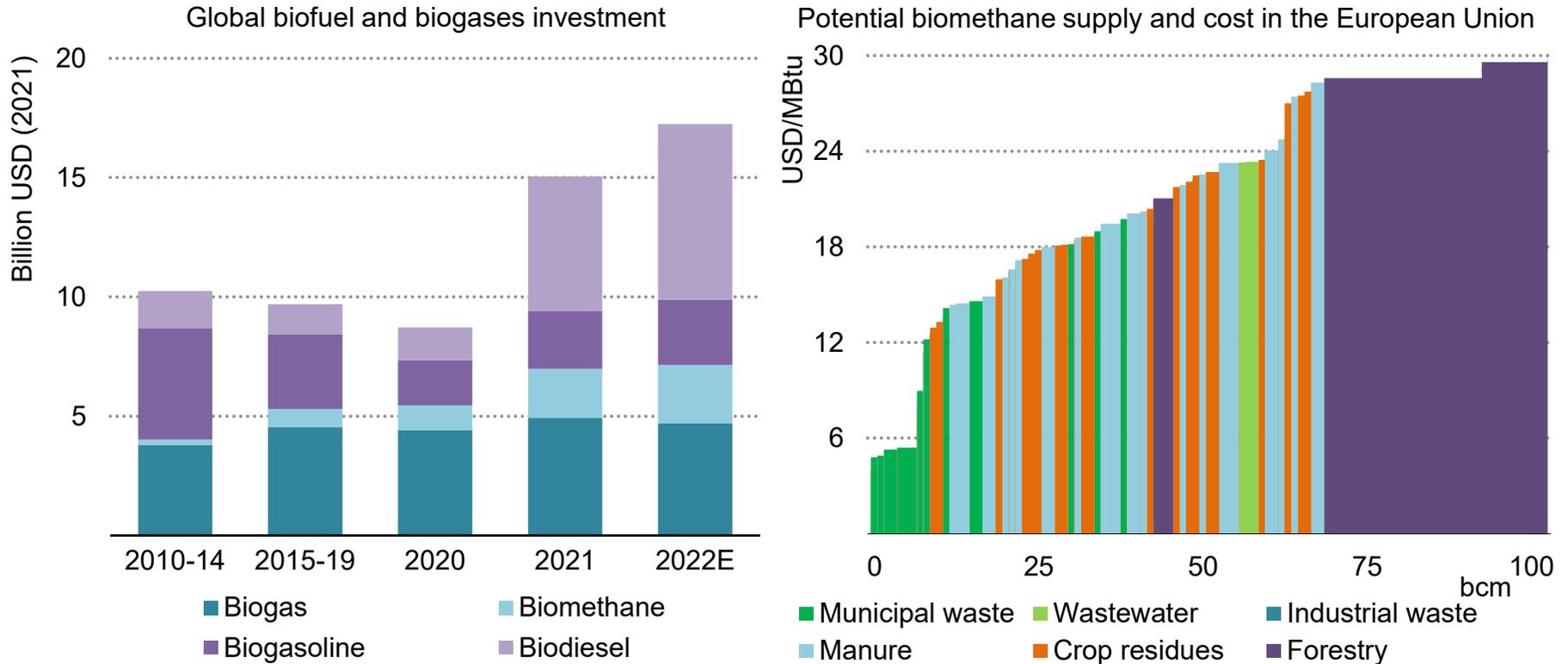
Solar PV and offshore wind accounted for nearly all the clean energy technology investment by oil and gas companies in 2021, as companies focus spending on areas where demand markets, business models and technology risks are best understood. Shell, Eni, Equinor and BP have been especially active in North Sea offshore wind projects, leading to an expected doubling of investment by the oil and gas industry in 2022 to USD 11 billion.

Strategic investment in clean energy accounted for around 10% of the analysed companies’ total M&A in 2021, and this share is set to increase in 2022. Several large deals have been agreed to enter fields such as electricity distribution (e.g. TotalEnergies Electricité et Gaz), electric vehicle charging (e.g. BP with Chargemaster), and solar and wind (e.g. TotalEnergies with Adani Green Energy, BP with Empire Wind & Beacon Wind assets, and Eni with Dogger Bank).

Low emissions fuels

Investment in liquid biofuels and biogases nearly doubled in 2021 and are set to grow in 2022

Biofuel and biogas investment and the biomethane cost curve based on sustainable feedstocks in Europe



IEA. All rights reserved.

Note: Biomethane supply costs exclude onward transport costs, e.g. grid connection or injection costs or CNG bottling.

High commodity prices are incentivising investment in biofuels and biogases, but food crop-based production pathways are adding strain to global food supply chains

Global investment in liquid biofuels more than doubled in 2021, reaching just over USD 8 billion. Two-thirds of this growth was in biodiesel, spurred by rising investment in renewable diesel (also known as hydrotreated vegetable oil, or HVO), although ethanol investment also nearly doubled. The United States and Brazil each contributed around 30% to global investment in 2021. The planned expansion of capacity at HVO and sustainable aviation fuel (SAF) projects, such as Neste's USD 1.5 billion investment in Singapore, is likely to create further supply in the near term.

Food supply chain disruption and soaring prices due to Russia's invasion of Ukraine are casting a shadow over the availability and use of grains employed in ethanol production, as well as vegetable oils and waste-based oils for biodiesel production. In April 2022 Indonesia announced a ban on exports of palm oil, and other countries are considering freezing biofuel blending mandates; large markets such as the United States and India, however, have recently raised blending targets. Higher oil prices typically encourage more investment in biofuels, but the parallel squeeze on grain and vegetable oil supplies is likely to redirect investment towards food production. Capital spending on biofuels in 2022 is likely to rise in aggregate, pushed up by significant growth in HVO and SAF projects. Pressures on food supply chains, caused in part by soaring costs at fertiliser plants reliant on expensive natural gas, are an acute

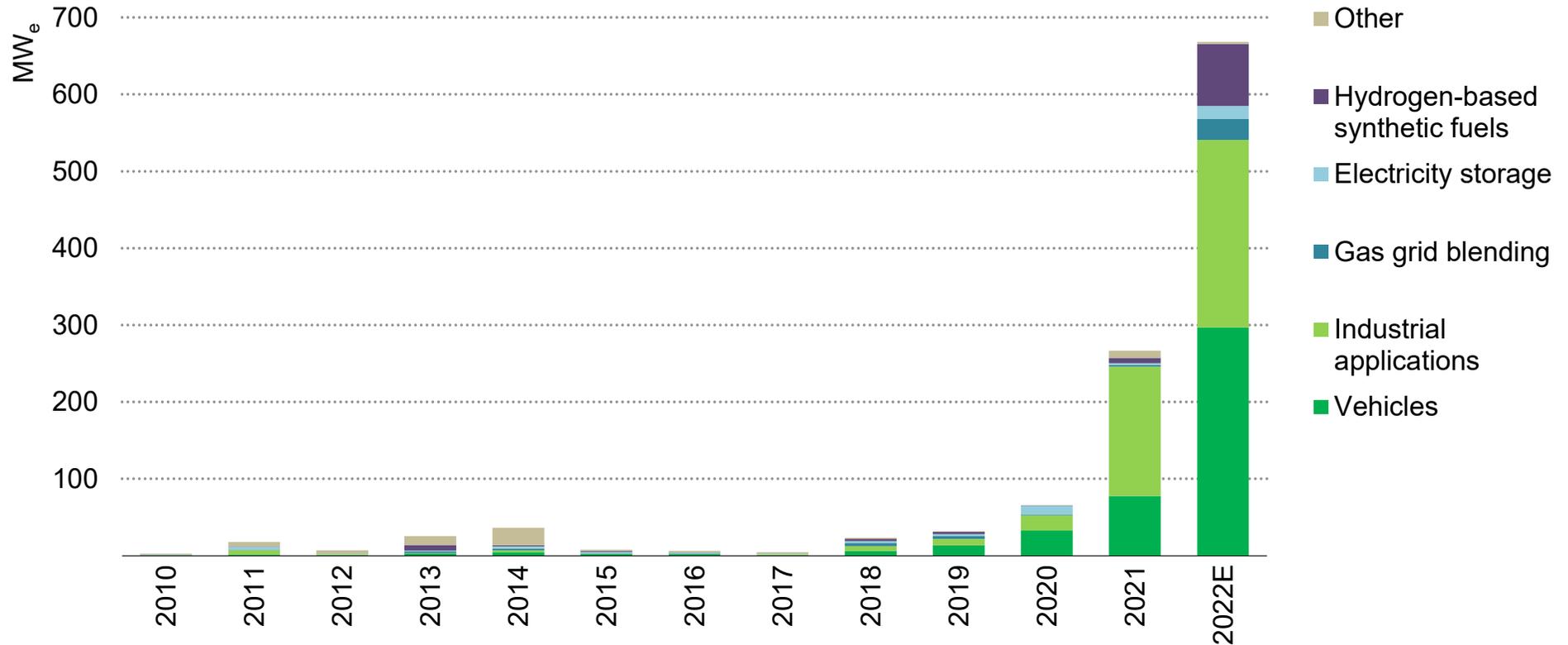
reminder of the need to ensure that biofuels are produced sustainably.

Global investment in biogases was just under USD 7 billion in 2021, a 30% rise on 2020 levels. Most of this came in the form of new biomethane investment in the European Union, and 2022 is set for further growth. The European Commission announced a target to double biomethane production by the end of 2022 from the current level of around 3 bcm per year, and eventually reach 35 bcm by 2030. Several small gas markets in the European Union, including Denmark and Sweden, already have a 20% biogas share of total gas demand. France is emerging as a major market for biomethane, having doubled injections in 2021 compared with 2020.

Today's high gas prices provide a new context for assessing the competitiveness of biomethane. Our bottom-up estimate of sustainable feedstocks that do not compete with food production in the European Union reveals a potential production capacity of up to 100 bcm per year, virtually all of which can be produced at costs below average EU spot prices between October 2021 and May 2022. Around 160 TWh of biogas is produced in the European Union, and by investing in upgrading equipment this can be converted to biomethane, which can then be injected into natural gas grids and displace imported gas.

The hydrogen project pipeline continues to grow and projects are increasingly likely to achieve FID; over USD 0.5 billion will have been spent on supply projects coming online in 2022

Capacity of electrolyzers for hydrogen production by commissioning year, by intended use of hydrogen, 2010-2022E



IEA. All rights reserved.

Notes: 2022E values represent estimates based on successful completion of all projects publicly stating a 2022 commissioning data as of the start of 2022. MW_e = megawatts of electricity input; in some cases, this is calculated from hydrogen output volumes where otherwise not stated. Includes electrolyzers for the supply of hydrogen for energy purposes or as an alternative to fossil fuels in industry, such as chemical production and oil refining.

Europe's quest for alternatives to Russian energy could supercharge hydrogen investment and – if achieved – could lead to USD 1 trillion of new projects globally by 2030

The momentum behind the global [low-carbon hydrogen](#) sector has been given a major boost by Russia's invasion of Ukraine. In 2021 the sector was already converting more of its bulging project pipeline into investment decisions, and hydrogen-focused companies were raising more money than ever before. Now, with the [REPowerEU](#) objectives of the European Union to increase low-carbon hydrogen use, coupled with higher formal targets in the United Kingdom and other European countries, it is much more likely that major projects around the world will enter construction in the near future.

The EU targets in the Fit for 55 package and REPowerEU plan call for 20 Mt of hydrogen produced from renewable energy sources to be consumed in the European Union in 2030, half of which is to be imported. To supply the additional hydrogen targeted in the REPowerEU plan (i.e. that which is on top of the existing *Fit for 55* policy target of 5 Mt in 2030), we estimate that capital investment of around USD 600 billion globally would be needed, with 60% of this for infrastructure outside the European Union. This rises to USD 1.3 trillion when including the cost of capital to fund the investments. If the hydrogen is primarily produced using new, dedicated renewable electricity generation facilities, the wind and solar projects would represent around 40% of total costs. Infrastructure for hydrogen transport – including port facilities, ships and storage – would represent a further 25%.

There are already signs of mobilisation towards this target. In 2022 [RWE](#), [TES](#) and [Uniper](#) announced separate intentions to integrate ammonia or hydrogen import terminals into LNG import terminal projects in Germany by 2026. The USD 0.5 billion RWE project foresees a facility to “crack” ammonia to hydrogen. A similar project in the Netherlands was [announced](#) in April 2022. In Egypt, a project worth up to USD 5 billion for making and exporting ammonia from renewable electricity was [approved](#) in March 2022.

Just under 270 MW of electrolyser capacity that can produce hydrogen from water came online in 2021, more than in any previous year. We estimate this new capacity to be equivalent to investment of around USD 0.2 billion, a near-fourfold rise from 2020. The 670 MW due to be commissioned in 2022 would represent investment of over USD 0.5 billion. Much of this relies on government funding, support that continues to underpin project viability, which would otherwise have been harder hit by market uncertainties since 2020.

The world's largest electrolyser [began operating](#) in 2022 to supply a methanol plant in China. The plant's expansion from 30 MW to 150 MW makes it seven and a half times bigger than the next largest facility, and it will run on a combination of grid-sourced and solar electricity. A larger 260 MW plant is due to be completed in Xinjiang

in 2023 to supply a refinery, and 120 projects to produce hydrogen from renewables are [reportedly](#) in development in China.

Electrolyser manufacturing could be a key value chain bottleneck this decade. Existing factories that can manufacture electrolysers currently allow for hydrogen production to grow by around 0.7 Mt each year at full capacity. This includes a plant in the UK that can manufacture 1 GW of new electrolyser capacity each year and a 500 MW/yr plant in Bangalore (both of which started operation in 2021). New manufacturing facilities have been announced since the beginning of 2021 in Australia (Plug Power, 2 GW/yr), China (John Cockerill, 2 GW/yr; Cummins, 500 MW/yr), India (John Cockerill, 2 GW/yr), the United Kingdom (ITM Power, 1.5 GW/yr), France (McPhy, 1 GW/yr), Germany (Siemens, 1 GW/yr; Sunfire, 0.5 GW/yr) and Spain (Cummins, 500 MW/yr) and. Collectively, these factories represent around USD 0.5 billion of announced investment. Planned expansions and additions could lead to around 25 GW/yr of manufacturing capacity globally by 2026. This would be enough to add 2 Mt of new hydrogen production around the world each year from 2026 onwards, but still insufficient for the EU REPowerEU goals.

Alkaline electrolysis continues to dominate global capacity additions, especially in China. In Europe, factories are more varied, as much polymer electrolyte membrane (PEM) production in planning as alkaline. Recent designs for large low-carbon hydrogen supply projects indicate synergies between the two technologies, rather than direct competition. For example, the load-following benefits of PEM

can be realised even if it only represents a share of the total capacity at a given facility, with a proportion of cheaper alkaline operating under more stable conditions. Manufacturers offering a variety of technologies may be well-positioned, fuelling further partnerships and M&A between developers.

The use of natural gas to produce low-carbon hydrogen domestically would not contribute to reducing EU natural gas demand, but several projects to produce hydrogen using CCUS are making progress. In spring 2022 Shell and Uniper [announced](#) a UK project to produce over 0.1 Mt of low-carbon hydrogen per year by 2030 and Exxon [announced](#) a plan to build a plant to produce 1 Mt of hydrogen per year in Texas, United States. Globally, there are around 40 projects looking to produce low-carbon hydrogen from natural gas. These are mostly in Europe, but new initiatives to make ammonia with CCUS have been launched in the Middle East, including a [project](#) for over 1 Mt of hydrogen per year in Abu Dhabi.

A number of shipping companies have recently contracted to buy ships that can run on hydrogen-based fuels. Maersk has [ordered](#) thirteen methanol-powered ships for delivery in 2024, after starting design work in 2017. The first ammonia-ready ship was [delivered](#) to Avin International in January 2022, and MAN and Mitsui [revealed plans](#) to commercialise dedicated ammonia-powered ships by 2023. These investments reflect rising confidence that hydrogen-based fuels will be a key emissions reduction option for shipping, but with different views on which fuel will be preferred.

A portfolio of 33 firms focused on low-carbon hydrogen has outperformed markets since 2020; their market capitalisation has increased dramatically on expectations of near-term revenues

Monthly returns (left) and market capitalisation (right) of hydrogen companies, hydrogen funds and relevant benchmarks



IEA. All rights reserved.

Notes: ETFs = exchange traded funds. Portfolio member tickers: 288620 KS, 336260 KS, ACH NO, ADN US, AFC LN, ALHRS FP, BE US, BLDP CN, CASAL SW, CIB SS, CWR LN, F3C GY, FCEL US, GREENH DC, H2O GY, HTOO US, HYON NO, HYPRO NO, HYSR US, HYZN US, HZR AU, IMPC SS, ITM LN, MCPHY FP, NEL NO, NXH CN, PCELL SS, PHE LN, PLUG US, PPS LN, SPN AU, VIHD US, VYDR US.

Source: IEA calculations based on Bloomberg terminal (2022)

The valuation of the portfolio of hydrogen firms is now four times higher than in 2019

Unprecedented levels of investment in hydrogen companies have been mobilised as near-term expectations for hydrogen projects have risen. To track this trend, we assembled a portfolio of 33 publicly traded companies whose success depends on demand for low-carbon hydrogen growing. These companies span a range of sectors, including electrolyser and fuel cell manufacturing, low-carbon hydrogen and ammonia project development, hydrogen distribution infrastructure and hydrogen-fuelled vehicles. We believe it to be a near-comprehensive set of “pure play” low-carbon hydrogen firms.

At USD 40 billion, the portfolio is worth around 20 times more than five years ago in nominal terms and four times more than at the end of 2019. The monthly investor returns and revenues of this portfolio are three times higher than five years ago. By comparison, the returns of comparable technology and clean technology indices only doubled over the same period. However, the hydrogen portfolio and clean technology indices have significantly f0.5altered since the start of 2021. In the case of hydrogen, this reflects: market corrections after the previous year’s investor exuberance; a reallocation of capital away from long-term growth stocks in search of more short-term value; and rising competition from large, diversified energy companies.

In late 2019, four fuel cell manufacturers – Bloom Energy, Ballard Power Systems, Ceres Power and Powercell Sweden – represented

around half of the capital value of the portfolio. Today, the value of three companies active in electrolyser manufacturing – Plug Power, ITM Power and Nel – represent half of the total. Plug Power, which also makes fuel cell systems, is responsible for most of this, having increased its market capitalisation by USD 11 billion since the start of 2020.

As a signal that capital may start flowing into large projects for low-carbon hydrogen supply, Aker Clean Hydrogen, a project development company that only began trading in March 2021, raised USD 0.3 billion in a share issue, a sign of appetite among investors for exposure to hydrogen projects as well as technology developers. In total, eight of the 30 firms in the portfolio started trading since the beginning of 2020, and 13 started since the beginning of 2016.

The portfolio of 30 firms represents only a subset of all the companies active in low-carbon hydrogen. Other key players include larger, diversified companies and some that are in private hands, many of which are in China. One large, diversified company that has been active in hydrogen M&A is Fortescue Metals Group, which bought into Sparc Technologies, HyET Hydrogen and Williams Engineering to build a hydrogen business from scratch.

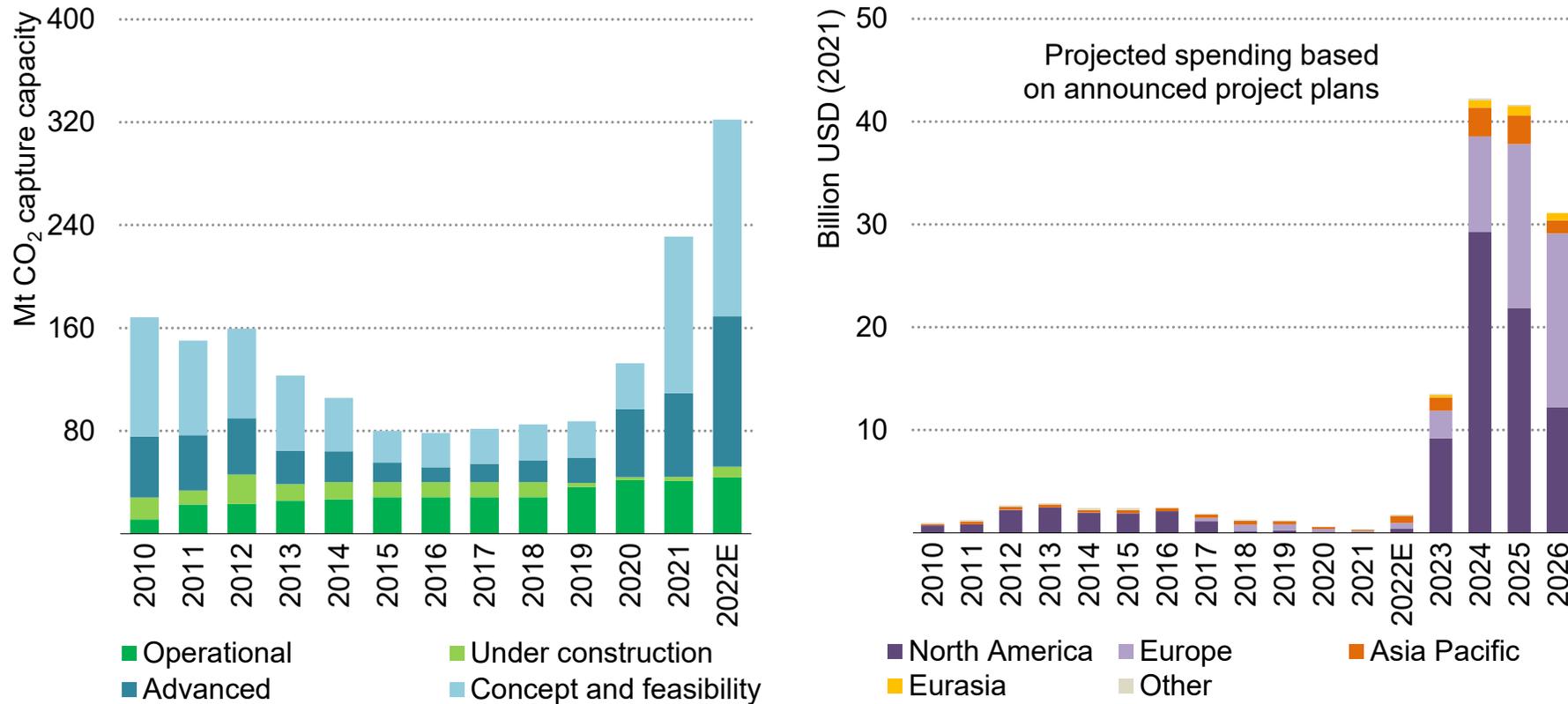
While most of the investment into our hydrogen portfolio originates from companies and diversified venture capitalists, dedicated

hydrogen funds have also entered the market. Six such funds are traded publicly and all have been launched since the start of 2021. They are already worth over USD 0.9 billion, including the HydrogenOne Capital fund, which is backed by Ineos and has invested in Doosan Fuel Cell and unlisted companies Sunfire and NanoSUN. 2. A larger fund, the Clean Hydrogen Infrastructure Fund, which is not publicly traded, closed its first round of fundraising at

USD 1.1 billion in January 2022 and has since raised a further USD 0.4 billion, including from the Japan Bank for International Cooperation, France's public reinsurer (CCR), Air Liquide, TotalEnergies and VINCI. It has so far invested around [USD 0.2 billion](#) in start-ups such as Hy2gen and two hydrogen projects.

Net zero pledges and anticipated low-carbon hydrogen have led a wave of CCUS project announcements that could push annual investment up to USD 40 billion by 2024

Commercial-scale CO₂ capture projects in development (left) and annualised historical and potential project spending (right)



IEA. All rights reserved.

Note: Includes commercial capture and full-chain CCUS projects with a capacity of over 0.1 Mt CO₂ per year. Projects shown in development in 2022 are correct as of May 2022. Projected spending represents the capital costs of projects with announced capacities based on their planned FID and operational dates. Spending is estimated where project-level cost data is unavailable. Other includes Africa, South and Central America and the Middle East.

Sources: IEA analysis and tracking based on [Global CCS Institute Global CCS Facilities Database](#); company reports/websites.

Governments announced nearly USD 18 billion in new public funds for the development and deployment of CCUS in 2021, most which needs to be spent by 2030

Selected CCUS public funding announcements since the start of 2021

	Government	Value	Note
New public funds	United States	USD 12 billion	US Infrastructure Investment and Jobs Act .
	Denmark	USD 2.4 billion	A new CCUS development fund up to 2048.
	Canada	USD 2.1 billion	CCUS tax credits included in the 2022 budget for the next five years.
	Korea	USD 1.2 billion	To develop CO₂ storage .
Existing funds allocated to projects	Netherlands	USD 2.3 billion	Announced funding to four CO ₂ capture projects proposed by refiners and hydrogen producers to cover the predicted shortfall between revenues and the costs of capturing and storing CO ₂ . However, projects delays have since put the funding timeline in doubt. The CO ₂ will be stored in the offshore Porthos facility, for which FID is targeted for 2022.
	European Union	A share of USD 1.2 billion	Four of the first seven large-scale projects to receive EU Innovation Fund support feature CCUS. The projects, in cement, chemicals, hydrogen production, and heat and power, need to take FID by 2026.
	United Kingdom	USD 225 million	UK Industrial Decarbonisation Challenge funding five clusters of projects, including the HyNet and East Coast Clusters that aim to be online by the mid-2020s. A USD 1.4 billion CCS Infrastructure Fund is available to these two projects subject to pending negotiations.

Renewed private-sector commitment to CCUS is reflected in six FIDs for projects in 2021

Plans for around 130 commercial-scale CO₂ capture projects in 20 countries were announced in 2021. They aim to capture CO₂ from a range of applications, including hydrogen and biofuel production, which combined account for almost half of newly announced projects. This project pipeline could raise global CO₂ capture capacity from around 40 Mt/yr today to over 300 Mt/yr, but would still be well short of the 1 700 Mt/yr in the NZE Scenario in 2030.

The CCUS investment landscape is evolving as net zero commitments and related policies increase investor confidence, and new business models emerge. In 2021 Santos, an oil and gas company, became the first company to include CO₂ storage resources in its [annual reserves statement](#); it is among several firms targeting market growth in CO₂ capture, transport or storage services.

Investment is rising, to around USD 1.8 billion in 2022 as six CCUS projects took FID last year. In China, Sinopec took FID in July on its 1 Mt CO₂ per year Qilu refinery project, which was completed just seven months later. Qatar Petroleum [took FID](#) on the North Field East LNG Liquefaction Project, where [around USD 200 million](#) will be spent on facilities to capture and store 2.9 Mt CO₂ per year from 2025. In Australia, Santos [announced](#) FID for its USD 165 million Moomba CCS Project to capture and store 1.7 Mt CO₂ per year by 2024, with the project awarded a grant from the Australian government for 7% of the cost. Investment decisions were also taken on three smaller projects: the partial retrofit of the [Taizhou Power Plant](#) in China; a Dutch [waste-to-energy plant](#) from which Twence will

sell CO₂ to greenhouses from 2023; and a [biofuels project](#) from which Shell intends to send CO₂ to a large CO₂ storage facility from 2024, also in the Netherlands. 2021 also saw notable announcements of public funding for advanced projects to further their progress towards FID, as well as new funds announced in several countries. Based on the rising number of projects aiming to reach operation by mid-decade, capital spending on CCUS could exceed USD 40 billion by 2024. However, this depends on having the right conditions for investment in the near term, which for some projects may have been impaired by high fossil fuel prices. Policy support will be essential to ensure that momentum is maintained beyond 2024 and that announcements are translated into realised projects.

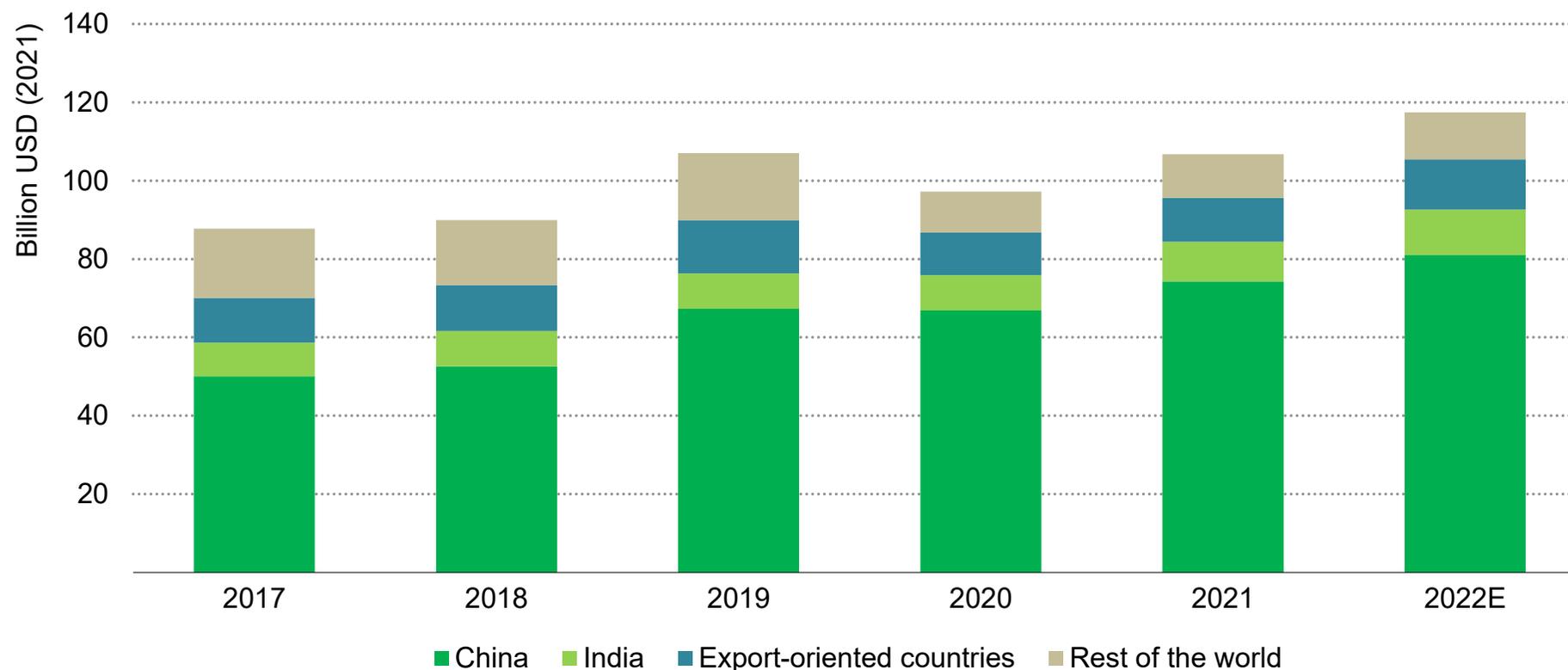
Private capital is starting to flow to young companies with costly technologies to remove CO₂ from the air. Direct air capture (DAC) with storage is considered to be among the most robust types of CO₂ offsetting, with potential for cost reductions. This is attracting capital from firms outside the energy sector. In April 2022, Climeworks [raised](#) USD 650 million, while investors including Alphabet, Meta and Stripe launched a USD 925 million [fund](#) for DAC. The fund will cover upfront project costs in exchange for certificates for future CO₂ removals.

CCUS-related technology start-ups raised around USD 400 million in funding in 2021. They include Svante, Carbon Clean, Carbon Capture Inc. and Verdox, which offer new means of CO₂ capture, and Prometheus Fuels, which aims to make fuels with CO₂ from DAC.

Coal

Coal investment rebounded slightly in 2021, led mainly by developments in China, and tight markets are expected to prompt a further increase in 2022

Coal supply chain investment by geography, 2017-2022E



IEA. All rights reserved.

Note: Export-oriented countries are Australia, Colombia, Indonesia and South Africa.

Strains on domestic and global markets have accelerated China's investment in coal

Around USD 105 billion was invested in the coal supply chain in 2021, an increase of 10% from 2020 and returning to levels seen in 2019. China, which represents half of the world's production and two-thirds of investment in the coal supply chain, drives the global trends. In 2021 investment in coal in China grew by just over 10%, a larger increase than expected. Strong economic growth and associated industrial output, along with low hydropower output, pushed up coal power generation, especially in the first half of 2021. This led to a significant coal shortage and related power shortages from May to September. These shortages prompted power restrictions to industrial consumers across 20 provinces, including the northern provinces of Heilongjiang, Jilin and Liaoning, where restrictions also affected households.

The coal shortages in China had an important knock-on effect on investment in coal mining, as the government quickly reacted by increasing production in the short term. Coal mining capacity grew by around 370 Mtpa in the second half of 2021. Together with 140 Mtpa opened in the first half of 2021, this means that over 500 Mtpa of coal mining capacity was put into operation in China in one year. Net capacity growth was lower, however, as part of the new capacity was commissioned under a capacity exchange scheme involving mine closures.

India, the world's second largest consumer and producer of coal, is seeking to increase coal production as its energy needs grow and the

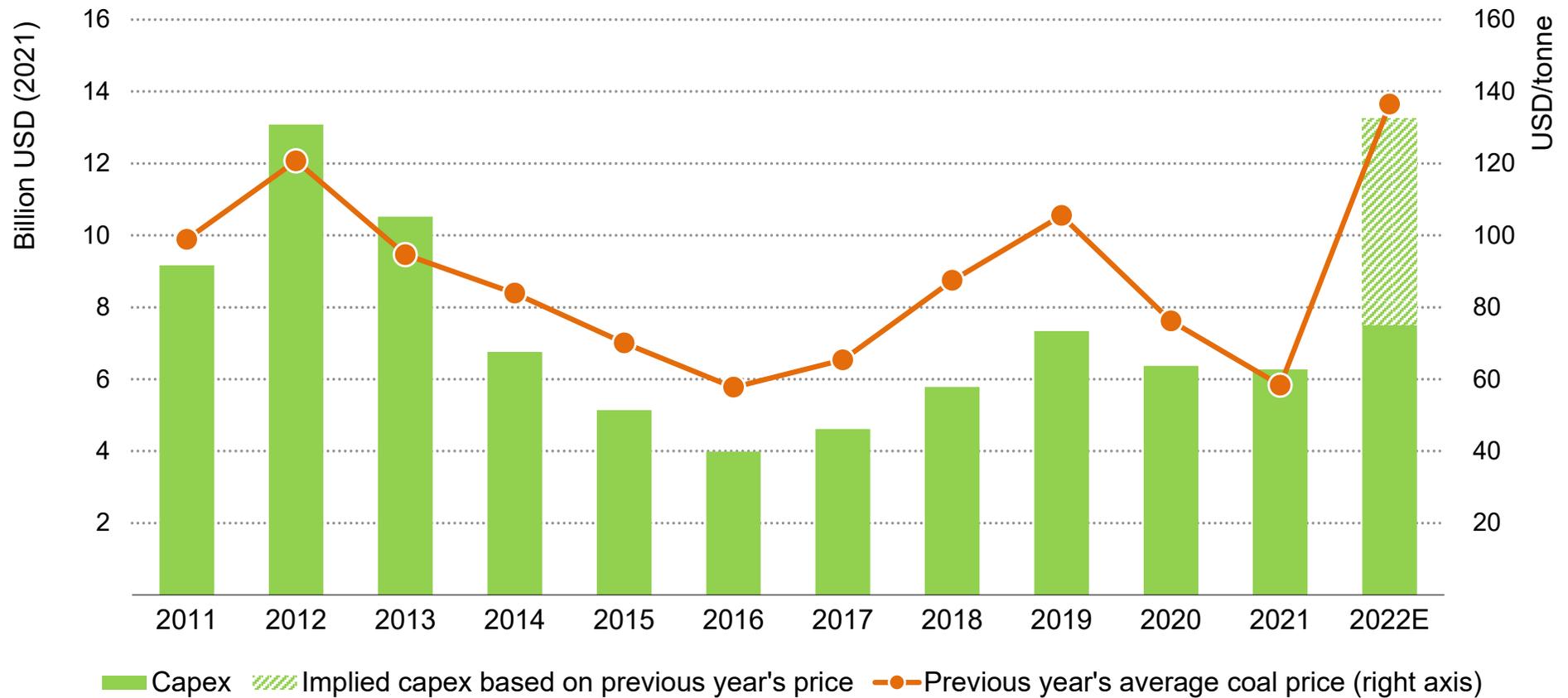
government looks to decrease imports. This is particularly the case because a supply squeeze in 2022 increased the use of more expensive imported coal. Coal India, the central government-owned monopoly that accounts for over 80% of national output, has a target to reach 1 000 Mtpa production in the coming years, while also investing in washing plants and rail corridors. Other players include public companies (e.g. SSLC and NLC), captive producers and mine developer-operators who are increasingly working for Coal India.

Under the Indian government's Coal Mines (Special Provisions) Act, merchant producers are allowed to sell coal at free-market prices outside Coal India's monopoly. The first auction for commercial mining blocks was awarded in November 2020, with 19 mines allocated, representing over 3 billion tonnes of coal reserves and a peak capacity over 50 Mtpa. A number of additional auction rounds have been launched since. There is uncertainty about how rapidly private producers can navigate the approval process and the pace of development of the production capacity, but current high coal prices are likely to provide a strong incentive.

Global coal supply investment is expected to grow by another 10% in 2022 as tight supply continues to attract new projects. At over USD 80 billion, China and India are anticipated to make up the bulk of global coal investment in 2022.

The link between coal prices and upstream investment may be weakening...

Thermal coal price and coal mining investment in Australia (2011-2022E) and capital spending implied by the previous year's coal prices



IEA. All rights reserved.

Note: Implied capital spending is calculated as the level of capex that would be expected solely on the basis of the historical relationship between lagged average annual coal prices and capex.

...with implications for the long-term availability of coal outside China and India

Given the unprecedented rise in coal prices in 2022, a key question is whether this will trigger a new wave of investment in the coal supply chain. Outside China and India, it is not clear that such an increase in investment will take place. Investment in new “greenfield” coal mines follows long development cycles, meaning investors require a long-term view on demand beyond the current price cycle. However, higher prices can stimulate near-term investment in existing capacity. For example, Australia saw a correlation between lagged coal prices and investment spending during 2011-2019. Each 10 USD/tonne upward increment in the previous year’s coal price increased operating cashflow and encouraged additional capital spending to sustain mining activities, in the order of around USD 1.5 billion. If this relationship were to be applied to the situation in 2022, we would expect capital investment in Australia of around USD 13.5 billion, a level last seen in 2012. However, estimated spending in Australia in 2022, at USD 7.5 billion, is around half of this level.

The mismatch between coal prices and additional investment is in part a product of a financial and regulatory environment that has become increasingly restrictive toward further investment in coal supply. Prices are in strong backwardation and major mining companies are focused on using profits to reduce debt, diversify investment (for non-pure coal players), or optimise portfolios (for pure players). With high investment requirements as a percentage of

EBITDA to keep existing mines operating, there are few incentives to pursue new projects, which have economic lifetimes that far exceed the current high price cycle.

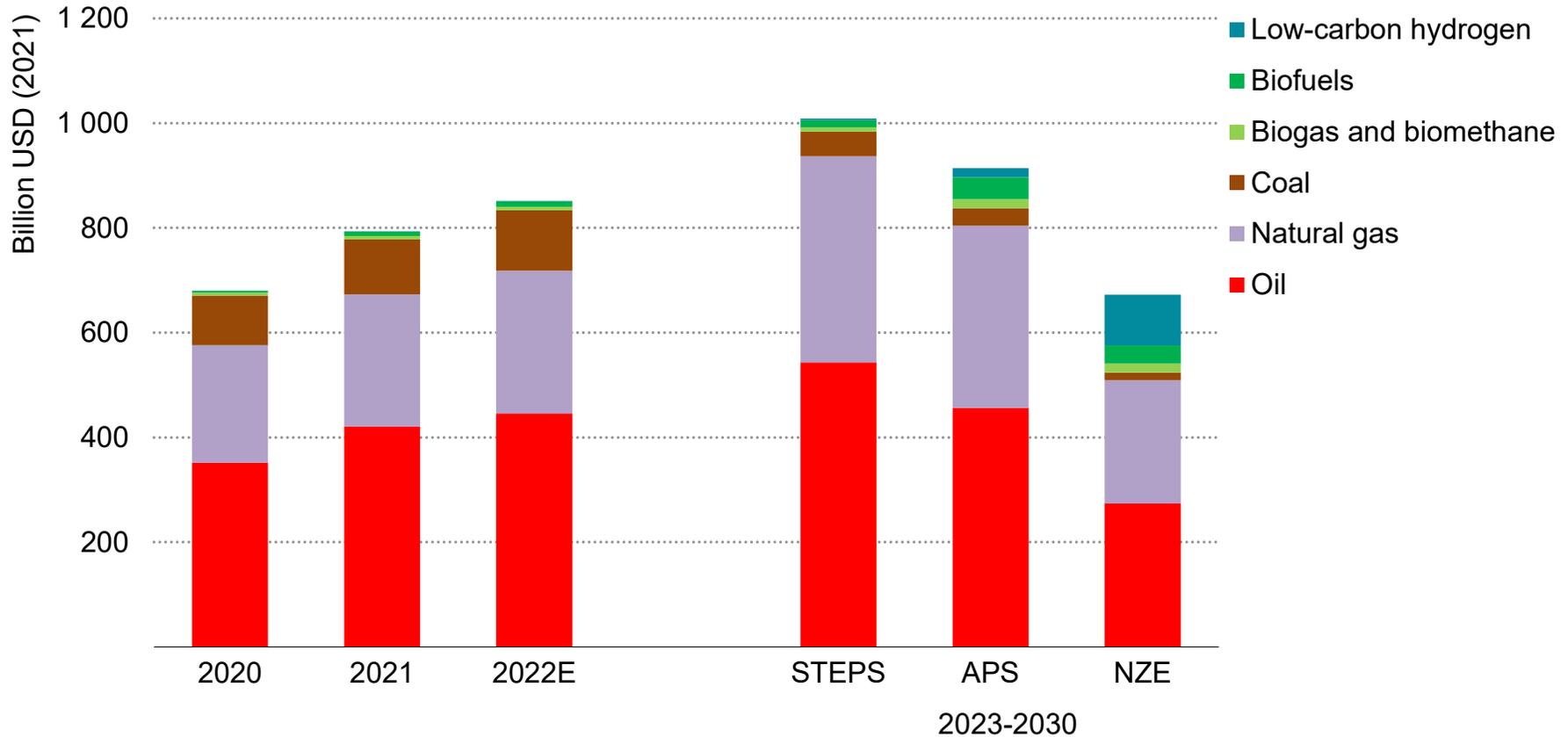
In recent years there has been a gradual process in which coal mines are sold by big listed corporations to smaller companies. These smaller, private players tend to have more limited access to financial markets and raising capital is more challenging, but they are also not subject to the same level of scrutiny on climate and emissions by their shareholders.

These trends continued in 2021 and during the first half of 2022. In South Africa, Anglo American spun off the remains of its thermal coal business to a new company in 2021 (the company had already sold its Eskom-tied coal mines to Seriti in 2018). Also in 2021, Anglo American and BHP sold their stakes in the El Cerrejón mine in Colombia to Glencore, which already owned one-third of the company. With this asset disposal, Anglo American has exited thermal coal operations, involving the transfer of more than 50 Mtpa of thermal coal mining capacity in less than five years. BHP, which also sold its stakes in El Cerrejón to Glencore, is following a similar path. Glencore has disposed its La Jagua and Calenturitas mines, which are expected to have a new owner later in 2022. In 2022 Vale, the Brazilian mining giant, sold its coal assets in Mozambique (including mines, a railway and Nacala port) to Vulcan Resources.

Implications

Energy security concerns and high prices are set to boost fuel investment, but investors remain caught between different visions of the future

Global investment in fuel supply and annual average investment, 2023-2030, by scenario

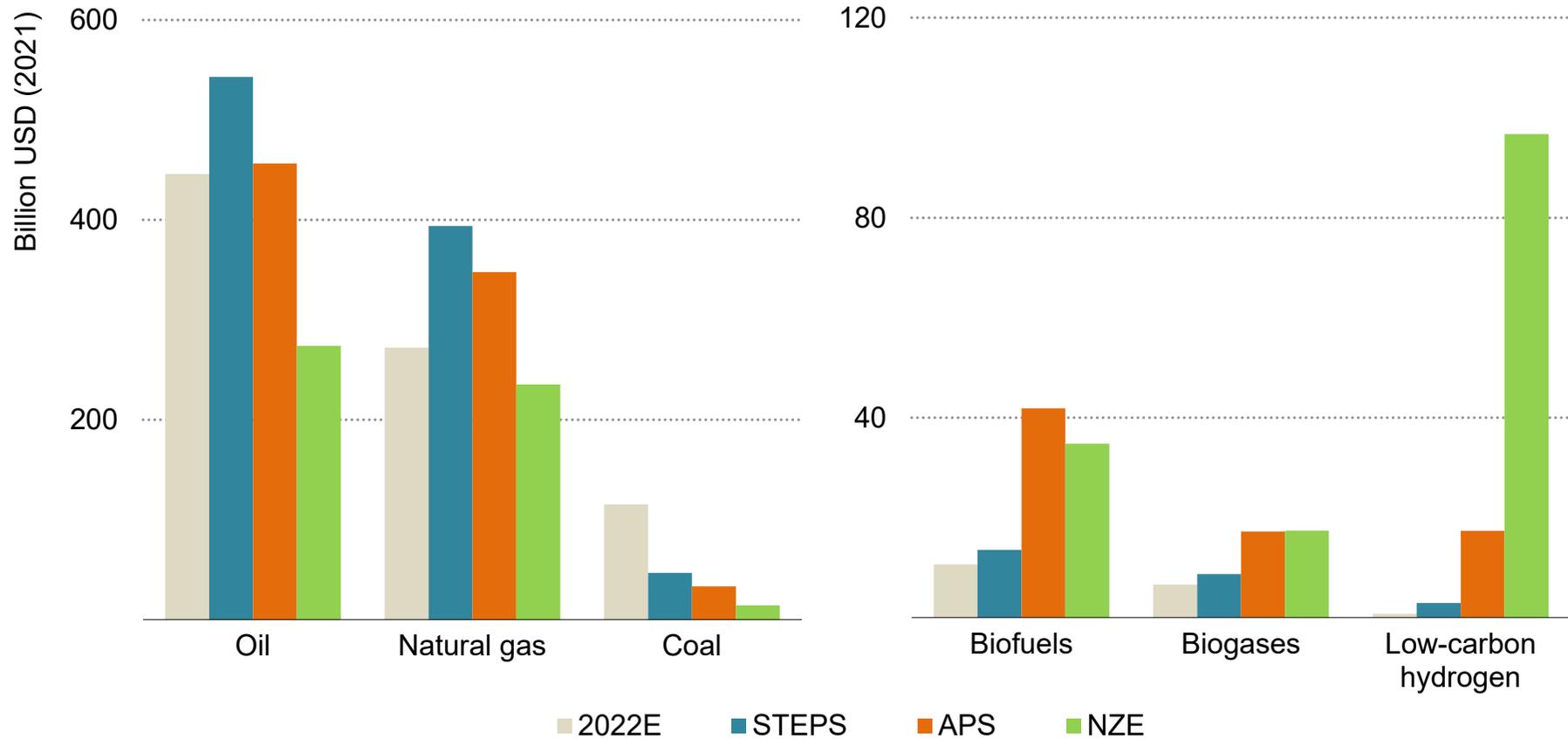


IEA. All rights reserved.

Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.
Source: IEA (2022).

Investment in oil supply remains short of levels implied by today's market outlook, while spending on clean fuels needs to grow fast to meet the world's net zero ambitions

Expected investment in 2022 and annual average investment needs, 2023-2030, by scenario and by fuel



IEA. All rights reserved.

Source: IEA (2022).

What is the “right” level and mix of investment in fuel supply?

Whichever way the world evolves, investment in the production, handling and distribution of fuels will be a pivotal part of a well-functioning energy system. But the types of investment required vary substantially across different scenarios, and current trends are caught between different visions of the future.

In the STEPS, oil and gas demand rises until 2030 and major investment is needed in both new and existing sources of fossil fuel supply to balance the market. The approximate USD 720 billion of oil and natural gas investment expected in 2022 is around 25% below the annual average levels needed in this scenario over the period to 2030. Almost 90% of investment in the STEPS is to compensate for declining output at existing fields, rather than to meet extra demand. As a result, investment under the APS is not far from that of the STEPS, even though oil and gas demand peaks in the mid-2020s.

In the NZE Scenario, the policy-driven surge in clean energy investment dramatically reduces demand for fossil fuels. Declines in demand are sufficiently steep that they can be met without supply from any new oil and gas fields. Around USD 340 billion is still spent in existing oil and gas fields on average per year under the NZE Scenario in the second half of this decade. This is to maintain production at the levels required in the scenario, involving some low-cost extensions of existing fields, and to minimise the emissions intensity of production.

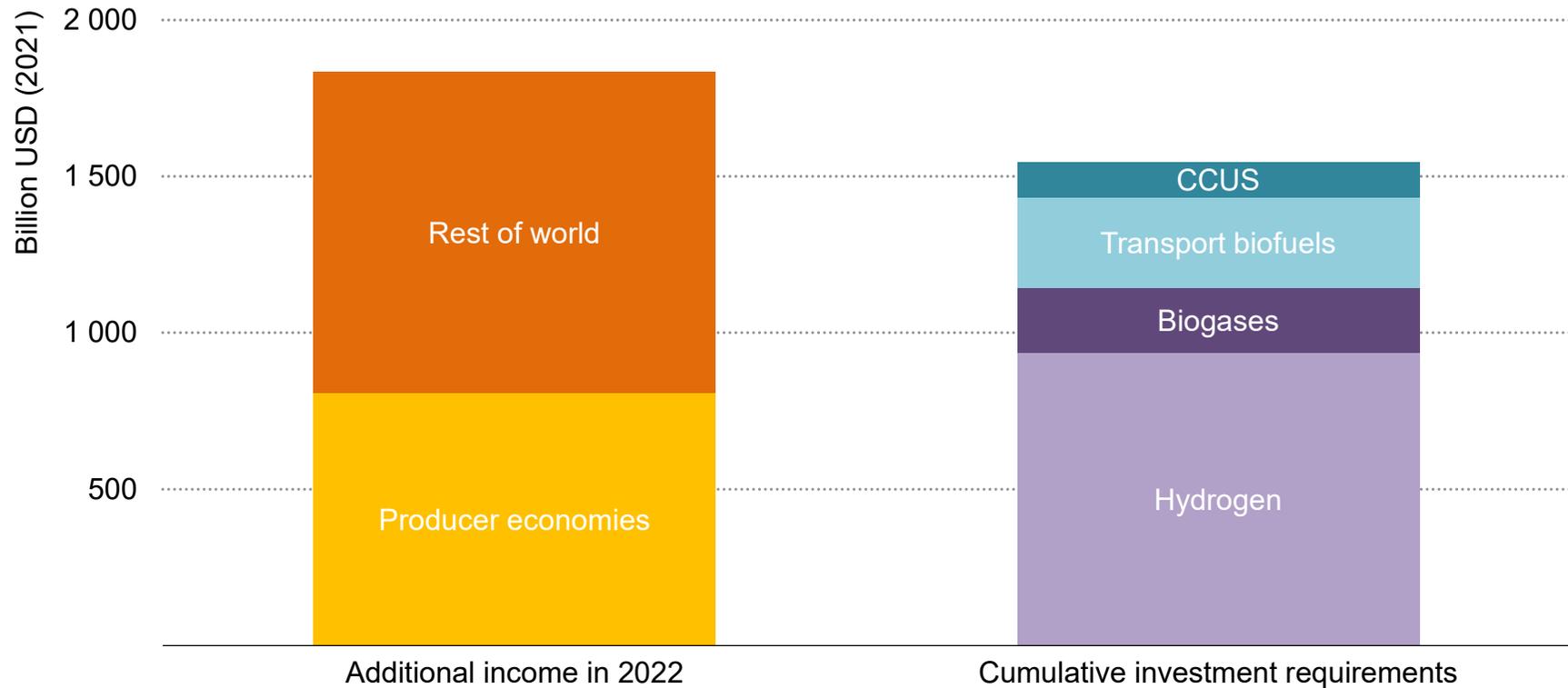
A key way to reduce the emissions intensity of fuels is to tackle methane emissions, requiring investment of around USD 11 billion per year, but bringing an additional 80 bcm of gas to global markets and net income of about USD 20 billion based on gas prices in 2022. Such a strong alignment of cost, reputational and environmental considerations should push the oil and gas industry to take a zero-tolerance approach to methane leaks.

Simply curtailing investment in fossil fuel supply in line with the NZE Scenario will not lead to the long-term emissions reductions and energy transition objectives of this scenario. Higher prices would trigger some reductions in demand, but they tend to do so in an undifferentiated manner and most negatively impact lower-income households. This can lead to social backlashes and short-term policy responses that are not aligned with longer-term emissions reduction, security and affordability objectives. To achieve sustained and deep reductions in emissions while reducing future risks of tight markets, policy makers need to set stronger targets and send stronger signals that they will reduce fossil fuel demand.

Investment in low emissions fuels such as biogases, biofuels and hydrogen remains below the levels required in any scenario, and would need to rise from an expected level of USD 18 billion in 2022 to an average of USD 150 billion per year over the remainder of this decade to be in line with the NZE Scenario.

The additional income expected for the oil and gas industry in 2022 would be enough to fund nearly a decade of investment in low emissions fuels and CCUS under the NZE Scenario

Estimated additional net income from global oil and gas production, 2022 compared with 2021, and cumulative investment requirements for low emissions fuels and CCUS, 2022-2030, in the NZE Scenario



IEA. All rights reserved.

Notes: Low emissions fuels comprises hydrogen, hydrogen-based fuels, transport biofuels and biogases. CCUS comprises end-use industry, while gas-based hydrogen production using CCUS is included in the hydrogen category. Producer economies comprise Angola, Azerbaijan, Iran, Iraq, Kuwait, Nigeria, Oman, Russia, Saudi Arabia, Trinidad & Tobago, Turkmenistan, United Arab Emirates and Venezuela.

A huge windfall for the oil and gas industry can be used to kickstart a low-carbon fuel economy

The decline in fossil fuel investment in the NZE Scenario is accompanied by a parallel ramp-up in investment in low emissions fuels. These fuels – including low-carbon hydrogen and advanced biofuels and biogases – are essential to decarbonise sectors where emission reductions through direct electrification are more challenging. The vast majority of the oil and gas industry's capital spending on clean energy at present goes towards renewables, most notably offshore wind and solar PV. Investment by these companies into bioenergy, hydrogen, and CCUS over the last three years is less than 0.2% of their total capex. Nonetheless, the industry's financial heft means even small shares translate into large spending commitments: the oil and gas sector has been responsible for over 75% of investment in CCUS in 2021.

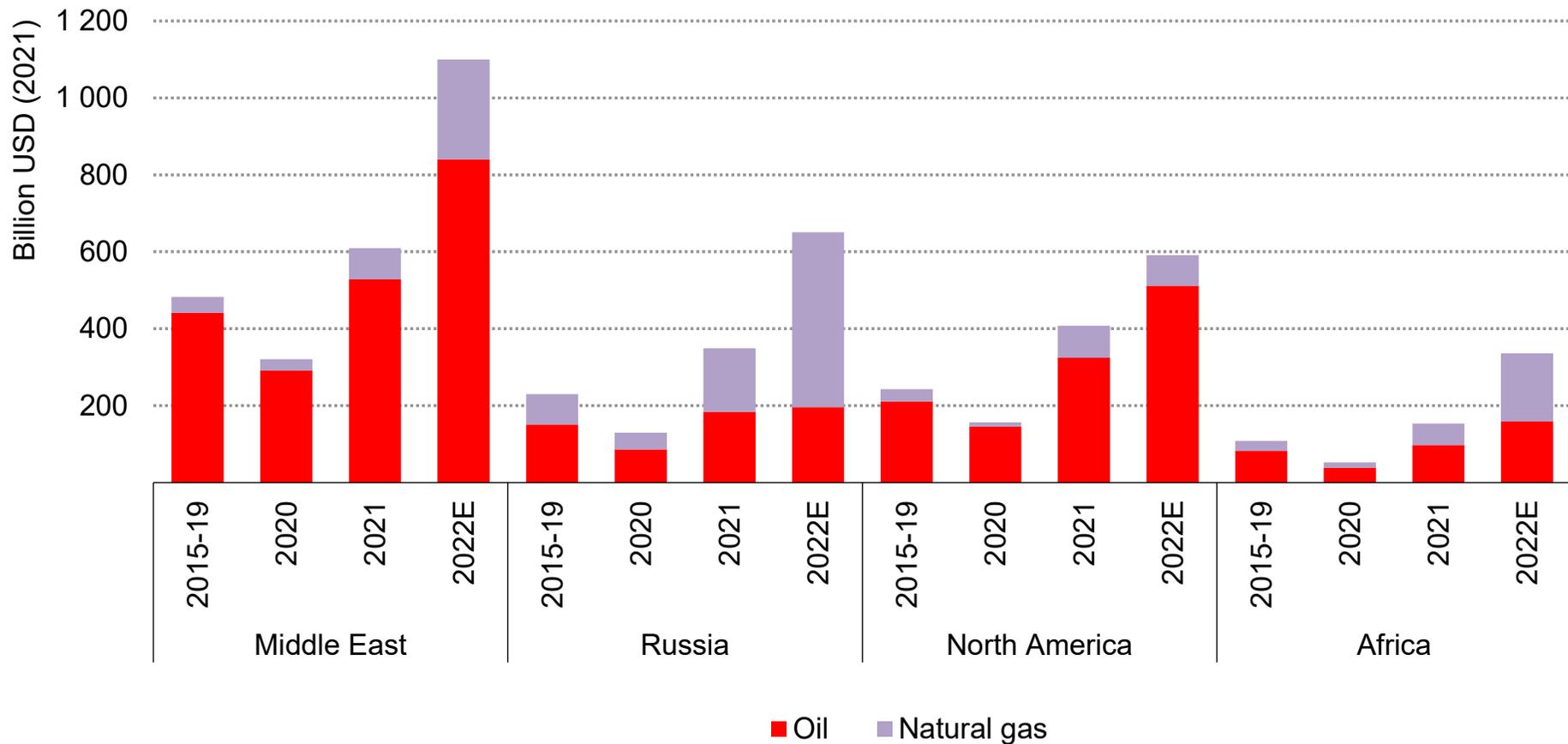
Global net income from oil and gas production is anticipated to reach nearly USD 4 trillion in 2022, double 2021 levels, presenting an extraordinary windfall to oil and gas companies. If the industry were to spend on low emissions fuels the additional USD 2 trillion received in 2022 above the amount earned in 2021, this alone would fund all of investment needed in low emissions fuels under the NZE Scenario for the remainder of this decade. The windfall could go even further if used to catalyse spending by both private and public sources on clean energy more broadly.

The windfall in 2022 represents a once-in-a-generation opportunity for producer economies to fund diversification activities and for the major oil and gas companies to deliver on their net zero pledges. It would enable countries and companies to strategically position themselves for a future in the production and transport of low-carbon hydrogen and the production and marketing of biogases and advanced biofuels. Developing the supply chains of complex and capital-intensive technologies such as CCUS and hydrogen play to the oil and gas industry's strengths.

There are other demands on the oil and gas industry's earned income, such as funding government expenditure, returning revenue to shareholders, reinvesting capital into oil and gas developments, and undertaking near-term actions to improve security of supply. Strong policy signals are needed to balance these demands with investment in low emissions fuels, particularly in cases where there is a need for capital-intensive, long-lived infrastructure that may take several years to come online and which carries multiple commercial, regulatory and technological risks. For example, putting in place a market for internationally traded hydrogen may require state-guaranteed supply and offtake contracts. For bioenergy, a concerted effort is needed to co-ordinate agricultural, environmental and energy policies so that together they incentivise a sustainable scale-up in supply.

Higher prices triggered a record increase in revenues for oil and gas producers in 2021, and there is even greater potential upside in 2022

Annual average net income from oil and gas production in selected regions



IEA. All rights reserved

Note: Net income is revenue from oil and gas sales minus capital and operating costs.

High prices are providing a windfall for oil and gas producer economies, but the need for economic and energy diversification remains strong

The 2015-2020 period of relatively low oil and gas prices was extremely challenging for producer economies. Average annual income from oil and gas was around USD 1.4 trillion, 50% lower than levels during 2010-2014. The rise in prices in 2021 triggered a reversal in fortunes, with revenues jumping by more than USD 1 trillion in a single year; revenues from natural gas nearly tripled and oil revenues more than doubled. Russia was one of the main beneficiaries of recent high prices. It earned USD 150 billion selling oil, gas and coal to the European Union in 2021, around 50% more than the average over the period 2015-2019. The European Union provided around 60% of Russia's total revenue from energy exports in 2021.

In 2022, if prices remain at the elevated levels seen so far this year, revenues of the producer economies would increase by a further USD 800 billion, reaching nearly USD 2 trillion, a level among the highest ever seen. Revenues from natural gas sales would be responsible for 40% of the total, a near record high share. A key uncertainty is Russia: sanctions, cuts in cross-border deliveries and efforts by EU countries to reduce their reliance could mean that energy flows are much lower than in 2021. Because of higher prices, the European Union would need to reduce Russian imports by 35%

in 2022 (oil by 20%, gas by 55% and coal by 40%) just in order to keep Russian revenues from EU sales at 2021 levels.

Recent price trends and record revenues offer relief to producer economies buffeted by the period of low revenues since 2015, but they cannot afford to relax entirely. The risks of future market volatility, long-term policy uncertainty – especially demand signals in importing regions – and the need to create employment opportunities for a large and youthful population means structural changes in their economic and energy systems are still essential.

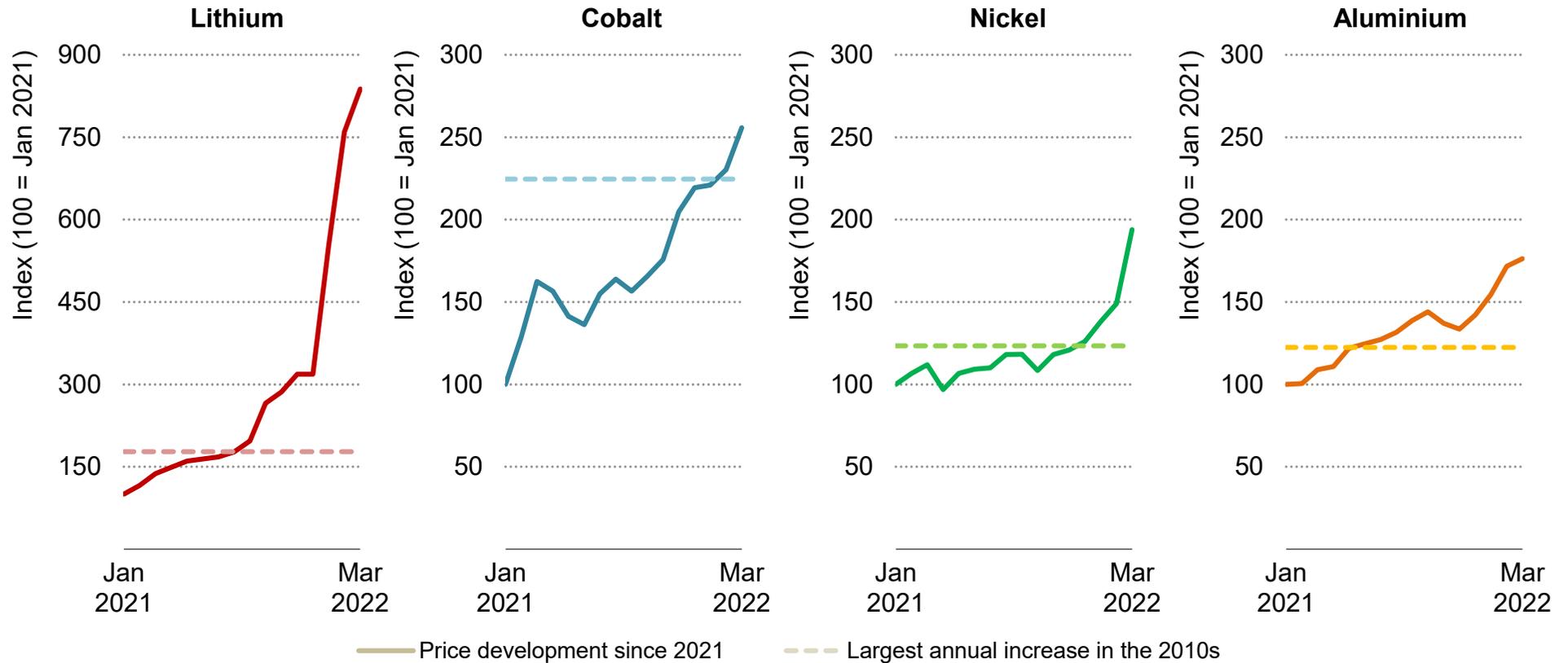
Growth in non-hydrocarbon sectors is not simple to nurture, especially in countries where fossil fuel consumption subsidies underpin energy affordability. Low fuel prices in 2020 presented an opportunity to reform fossil fuel subsidies, but the uncertain economic recovery put pressure on policy makers to limit significant interventions. Total oil and gas subsidies rebounded in 2021, in lockstep with rising energy prices and recovering energy use. Even higher prices in 2022, along with downside risks to global growth, have made the prospects for subsidy reform even more challenging, despite offering longer-term dividends in the form of greater energy efficiency and additional funds for investment in more productive sectors of the economy.

Critical mineral supply

Overview

Prices for important energy transition minerals and metals have been on a sustained upward march since the start of 2021

Price development for selected energy transition minerals and metals



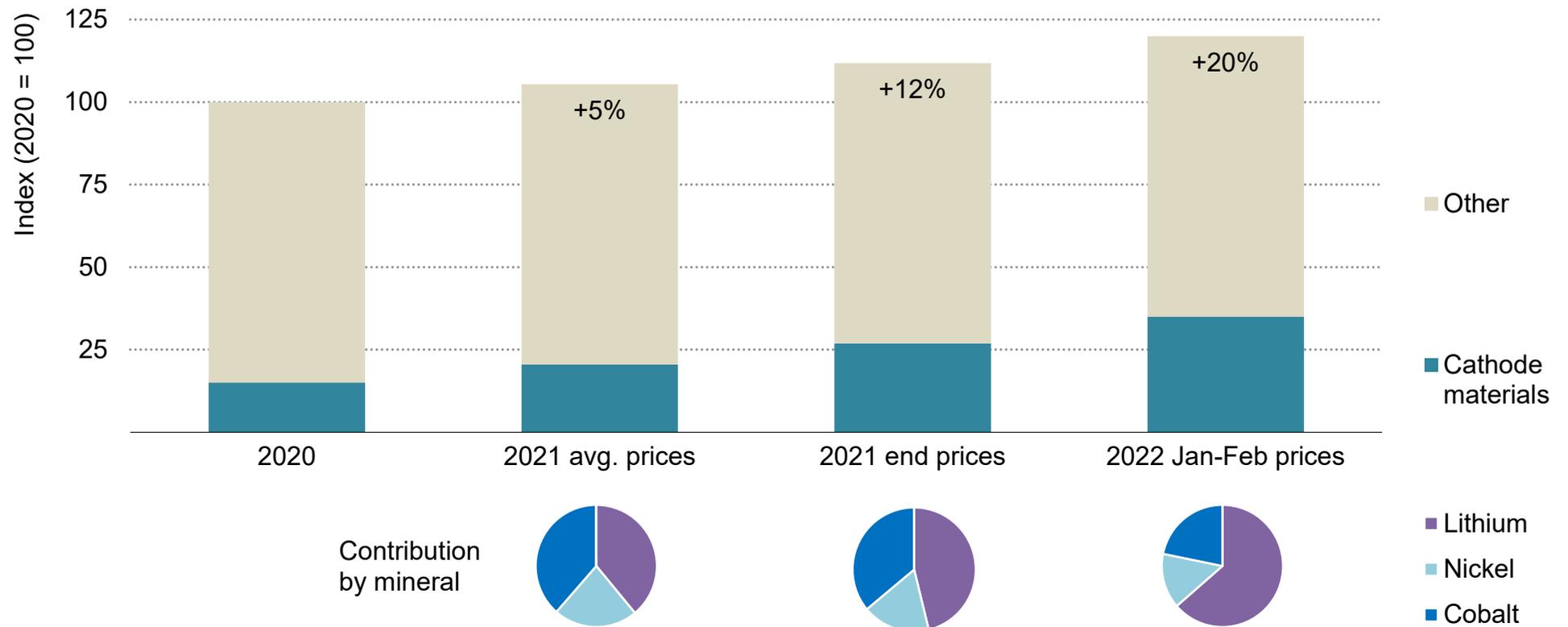
IEA. All rights reserved.

Note: Assessment based on Lithium Carbonate Global Average, LME Cobalt Cash, LME Nickel Cash and LME Aluminium 99.7% Cash prices.

Source: IEA analysis based on S&P Global (2022).

The surge in material prices threatens a decades-long trend of falling costs for clean energy technologies

Increases in the cost of EV battery packs caused by higher cathode material prices



IEA. All rights reserved.

Notes: Cathode material costs include lithium, nickel, cobalt and manganese. Other cost elements are fixed for this analysis, and include costs for the anode, electrolytes, separator and other components as well as costs associated with labour, manufacturing and capital depreciation.

Sources: IEA analysis based on BNEF (2022) and S&P Global (2022).

Efforts to reduce clean energy technology costs face an uphill battle with rising material prices

In 2021 many of the minerals and metals that are essential for clean energy technologies registered broad-based price increases due to a combination of rising demand, disrupted supply chains and concerns around tightening supply. Prices for lithium and cobalt more than doubled in 2021 and those for copper, nickel and aluminium all rose by around 25-40%.

The trends have continued into the first few months of 2022. The situation for lithium has been particularly astonishing, with another two and a half times increase in prices between January and March. Prices for nickel and aluminium – for which Russia is a key supplier – have also sustained their upward march, driven in part by Russia's invasion of Ukraine and a short squeeze on nickel. For most of the minerals and metals that are vital to energy transitions, the observed price increases since the start of 2021 have outpaced the largest annual increases seen in the 2010s by a wide margin. Prices are likely to remain elevated in 2022 due to supply chain imbalances, inflationary pressure and low stock levels at major exchanges. They may moderate in the latter part of the year as more supply comes online and weakening economic growth affects consumption.

The surge in prices for critical minerals is taking a toll on the cost of clean energy technologies, reversing a decades-long trend in cost declines. In 2021 prices for wind turbines and solar PV modules rose by 9% and 16% respectively. Prices for lithium-ion batteries are likely

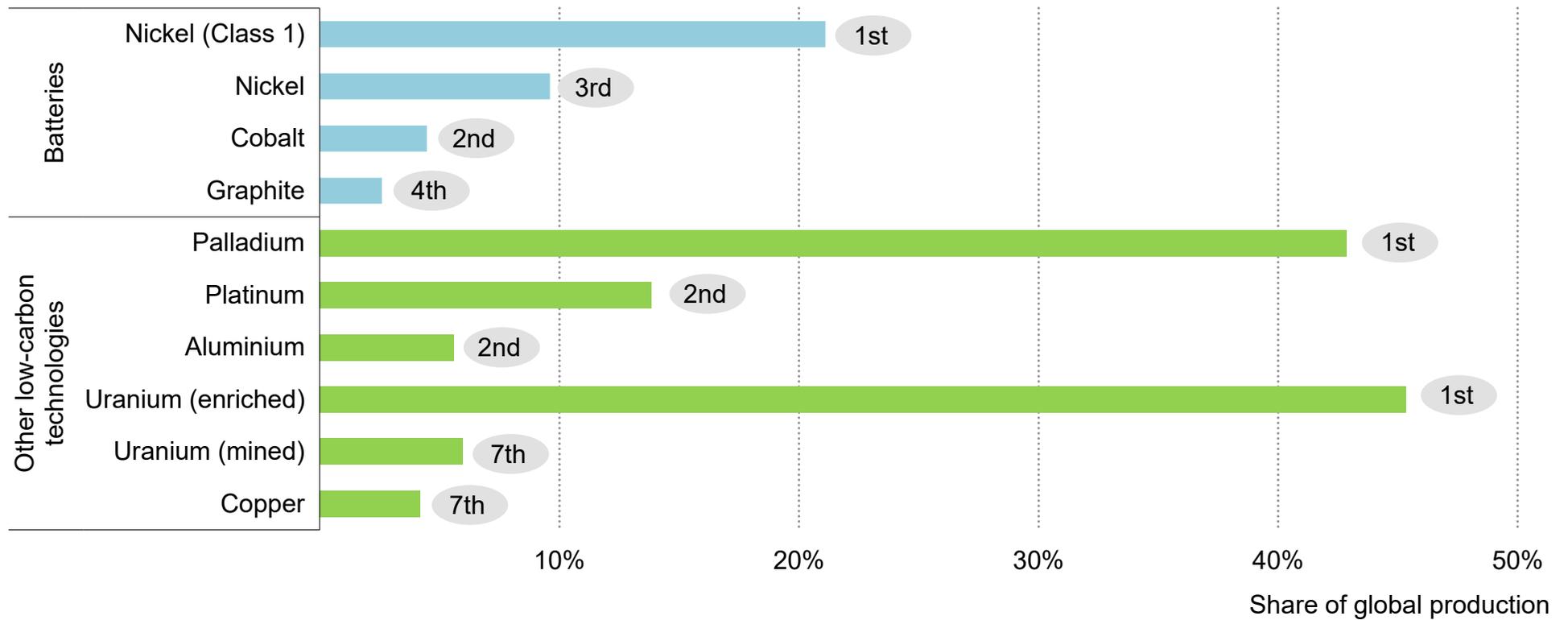
to see a major uptick in 2022 as the impact of rising raw material prices are reflected in final prices.

Taking one example, the share of cathode materials in the cost of lithium-ion battery packs was less than 5% in the middle of the last decade, when there were only three battery gigafactories in operation or under construction globally. The share has risen to over 20% today, when [some 300 gigafactories](#) are at different stages of planning and construction as of April 2022. The higher prices for cathode materials in early 2022 caused upward cost pressure on lithium-ion battery packs estimated at 20% compared with 2020 levels and [15% compared with 2021 levels](#). In China the relentless rise in lithium prices is already [translating into higher prices](#) for EVs, with Tesla and BYD announcing price hikes of 2-5% in March 2022.

This does not mean that further reductions in the cost of clean energy technologies are unattainable, but these efforts are increasingly facing an uphill near-term battle as raw material costs rise. High material prices require a redoubling of efforts to reduce costs by other means (e.g. technological innovation, efficiency improvements and economies of scale) to keep the overall costs on a continued downward trajectory. Otherwise, pronounced disruptions in supply chains and rising costs could increase the cost of clean energy technologies, potentially slowing their rollout and clean energy transitions more generally.

Russia's international isolation adds to the pressure

Russia's share of global production and rank, 2020



IEA. All rights reserved.

Notes: Class 1 nickel refers to high-purity, battery-grade nickel products. The value for Class 1 nickel is based on mined output.

Sources: IEA analysis based on [USGS \(2022\)](#); [S&P Global \(2022\)](#); [McKinsey \(2020\)](#); [WISE uranium project \(2021\)](#).

Russia's invasion of Ukraine underscores the need to diversify critical mineral supply

Russia is a major producer of many minerals and metals that are vital for energy transitions, and increasing international isolation following its invasion of Ukraine places additional pressure on the already tight market. For example, Russia is the world's second largest producer of aluminium (6%) and accounted for 8% of EU imports in 2020. As aluminium production is highly electricity-intensive, high gas and electricity prices in Europe have already [reduced the region's production capacity by nearly half](#) since September 2021. Combined with supply cuts in China, aluminium prices rose to record highs in the aftermath of the invasion. High aluminium prices are adding stress to many end-use industries, including the automotive sector.

The impacts of the war are also apparent in the battery metals market. Russia is the largest producer of battery-grade Class 1 nickel, accounting for 20% of the world's mined supply. It is also the second and fourth largest producer of cobalt and graphite respectively. The frenzy in nickel prices on the London Metal Exchange (LME) in March 2022 brought the potential perils into sharp relief. Triggered by concerns around Russian supplies and a short squeeze involving a major Chinese company that had anticipated a price drop, prices more than doubled in a single day in March. Although the price spike was not driven by market fundamentals, the event has been a wake-up call on the importance of diversifying supply. There are also concerns that the recent extreme price

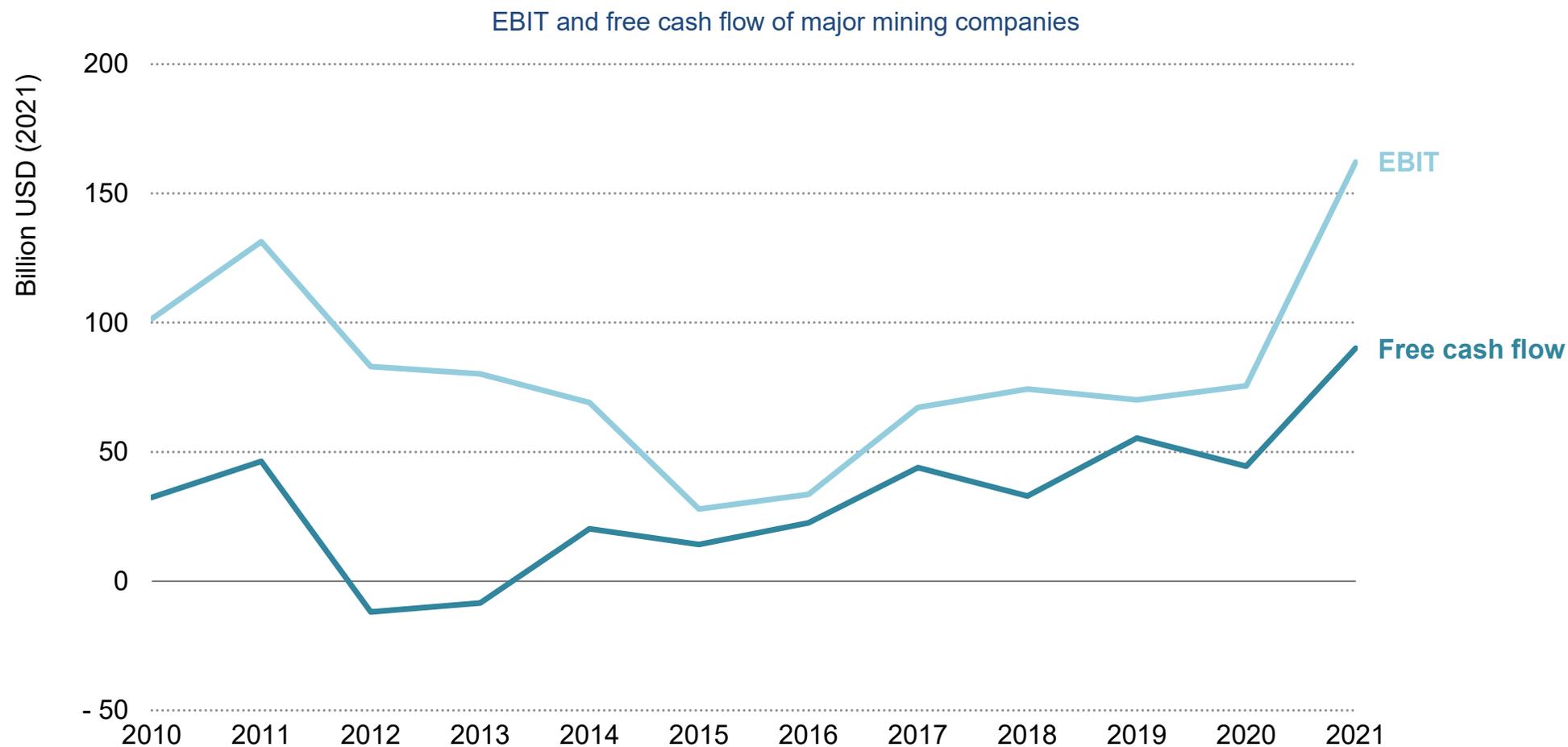
volatility could undermine investor interest in new projects and reduce trading liquidity at a time when greater investment and liquidity are needed.

Russia is the world's leading producer of palladium (43%), a precious metal used for catalytic converters in cars. Europe accounts for over half of Russia's palladium exports. As in the case of aluminium, palladium supplies had already been tight before the invasion, with low stock levels. Automakers could switch to platinum, but Russia is also the second largest producer of platinum with a 14% share.

Uranium for nuclear fuel is another element of concern. Russia accounts for only 6% of global production of mined uranium, but [over 40%](#) of global enrichment capacity is located there. Prices for uranium were already high at the end of 2021 due to tightening supplies, and climbed by a further third in March 2022 to its highest levels since the Fukushima accident in 2011. While a number of conversion and enrichment plants exist in Canada, China, France and the United States, many of them have been operating at low utilisation rates or idled due to low profitability. In light of renewed interest in nuclear power's role in clean energy transitions, the war has underscored the need to explore options for diversifying enriched uranium supplies, including investment in new facilities as well as the reopening of existing conversion plants.

Investment trends

The operating profits and cash flows of mining companies increased significantly in 2021



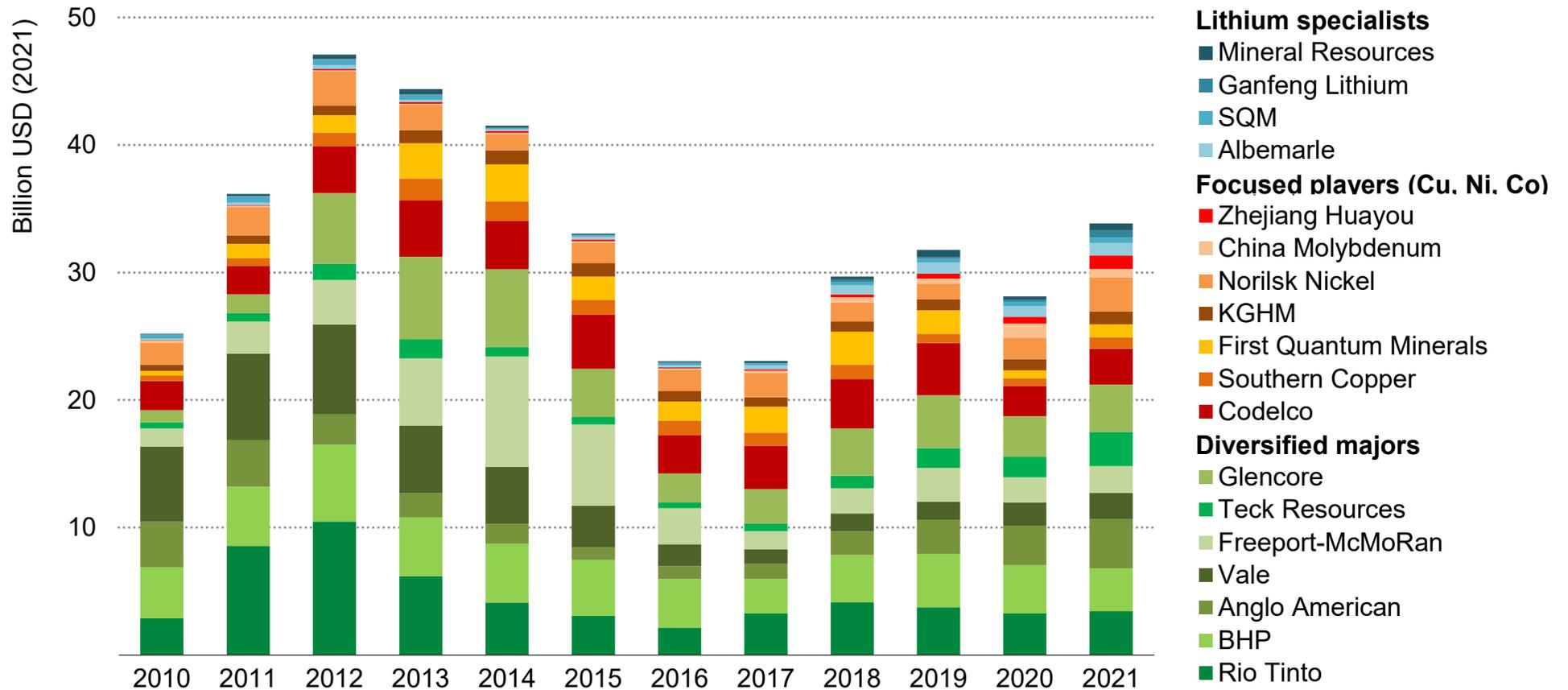
IEA. All rights reserved.

Notes: EBIT = earnings before interest and taxes. See next page for the full list of 18 companies included in the assessment.

Sources: IEA analysis based on company annual reports.

Investment in critical mineral mining registered a notable uptick in 2021, and soaring commodity prices are expected to maintain investment momentum in 2022

Capex on non-ferrous metal production by major mining companies



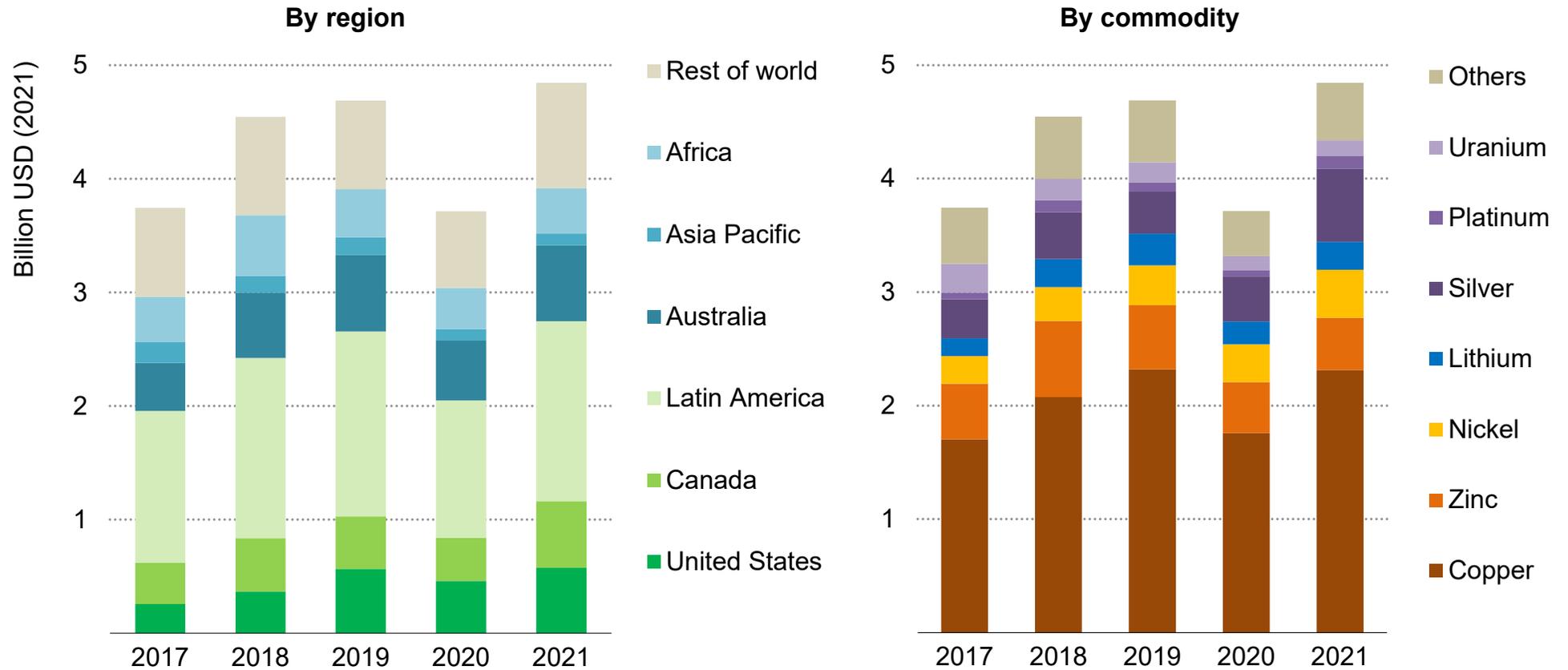
IEA. All rights reserved.

Notes: Co = cobalt; Cu = copper; Ni = nickel. For diversified majors, capex on the production of iron ore, coal and other energy products was excluded.

Sources: IEA analysis based on company annual reports and S&P Global (2022).

Exploration spending for mineral resources rebounded strongly in 2021, led by the Americas

Exploration spending for selected non-ferrous mineral resources



IEA. All rights reserved.

Notes: Excludes budgets for iron ore, coal, aluminium, gold and diamonds. Others comprise rare earth elements, potash/phosphate and many other minor metals.

Source: IEA analysis based on S&P Global (2022).

Strong cash flows and the momentum behind energy transitions are driving investment growth

The surge in mineral prices in 2021 contributed to a major improvement in mining companies' profitability and cash flows. We have assessed the aggregate operating profit and free cash flow of 18 major mining companies that have a strong presence in developing energy transition minerals. The list consists of diversified mining majors and specialised developers for specific minerals. The combined operating profit of these 18 companies more than doubled in 2021, surpassing the previous high seen in the early 2010s. Free cash flows showed similar trends, hitting record levels in 2021.

Thanks in part to record cash flows, investment spending in non-ferrous metal production registered a notable increase of 20% in 2021, although it is still lower than the levels seen in the early 2010s. While diversified mining majors accounted for the largest share of absolute growth, the pace of increase was faster among those focusing on specific minerals. Companies specialising in lithium development increased their spending by 50% to record highs.

Exploration spending also recorded a strong uptick in 2021, up by 30%. The United States, Canada and Latin America drove the bulk of the growth. Although it takes time for exploration spending to translate into production growth, the increase in spending should help diversify sources of supply in the years ahead. However, spending levels in Africa and developing Asia saw limited growth, leading to a reduced share in global exploration activities for these regions.

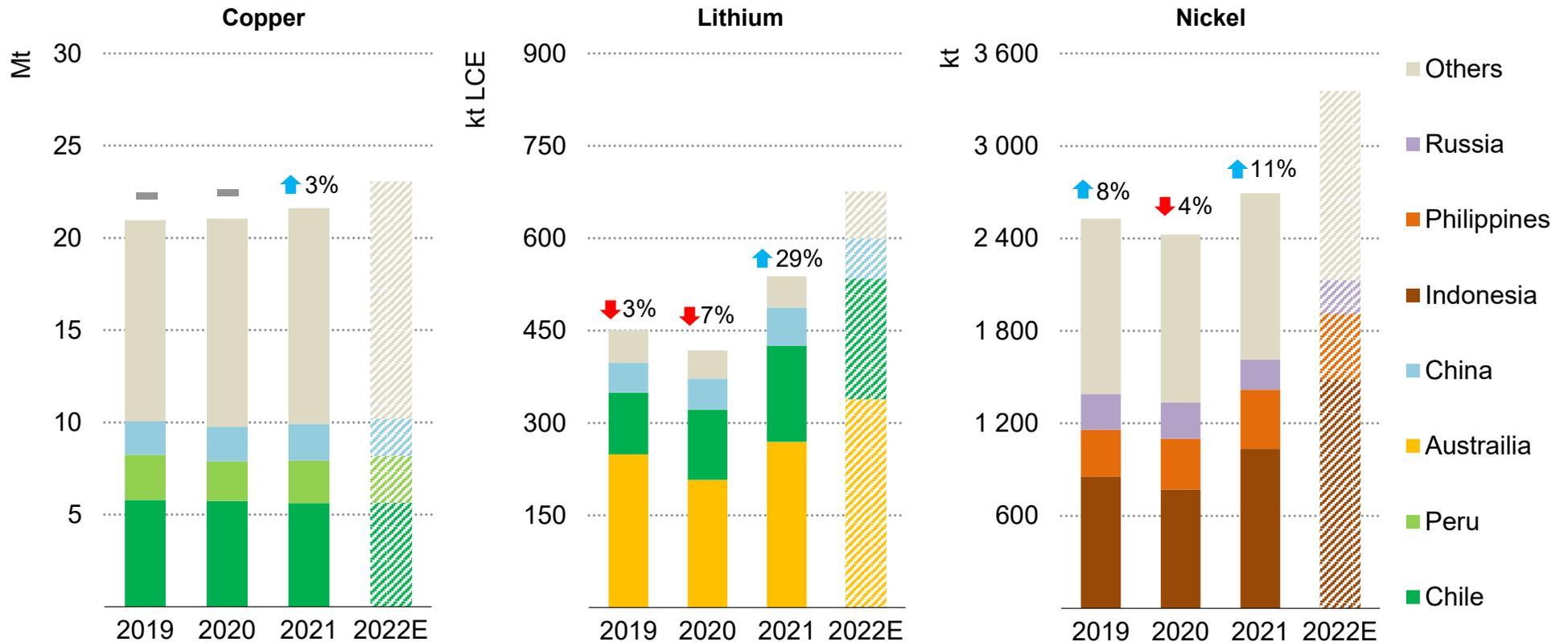
There are signs of the pool of investors widening and of increasing vertical integration of supply chains. With strains along supply chains and rising raw material costs, vehicle and battery manufacturers are increasingly involved directly in the mining and processing of critical minerals in order to safeguard their production pipelines. For example, Volkswagen intends to begin nickel and cobalt refining in China and Tesla plans to build its own nickel chemical and lithium hydroxide plants in Texas. CATL, the world's largest EV battery maker, has taken stakes in several lithium mining companies. A consortium led by LG Energy Solution, the world's second largest EV battery maker, announced [plans to invest USD 9 billion in the entire EV battery value chain](#) in Indonesia, including smelting and refining of nickel, and manufacturing cathode materials.

Many governments are also supporting investment activities with the aim of ensuring secure mineral supplies for their domestic clean energy supply chains. In March 2022 the United States [invoked the Defense Production Act](#) to rapidly boost US production of critical minerals for EV and storage batteries (lithium, nickel, cobalt, graphite and manganese). In 2022 the Canadian government [allocated CAD 3.8 billion \(USD 3 billion\)](#) to support the development of the critical mineral supply chains in the country. In September 2021 the government of Australia released a [USD 2 billion loan facility](#) to stimulate the development of critical minerals in the country.

Trends by individual commodity

Production bounced back strongly in 2021 and growth is expected to continue in 2022

Production trends for copper, lithium and nickel

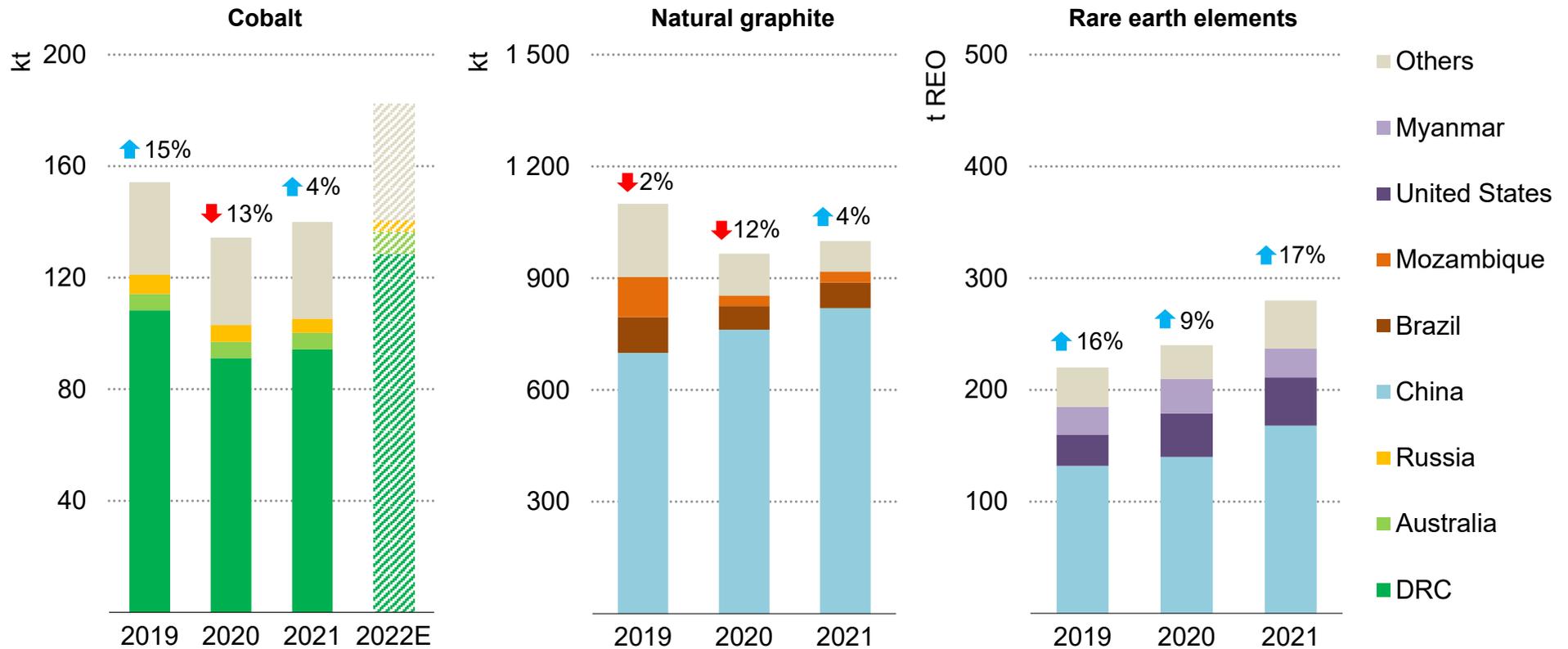


IEA. All rights reserved.

Notes: Based on mined output. Percentage figures show change on previous year. LCE = lithium carbonate equivalent.
Source: S&P Global (2022).

Production bounced back strongly in 2021 and growth is expected to continue in 2022

Production trends for cobalt, natural graphite and rare earth elements



IEA. All rights reserved.

Notes: Based on mined output. DRC = Democratic Republic of the Congo; REO = rare earth oxide.

Sources: S&P Global (2022); [USGS \(2022\)](#).

Trends by individual commodity

After a downswing caused by the pandemic, production of many energy transition minerals and metals picked up strongly in 2021, fuelled by healthy demand and heightened prices. The growing momentum behind energy transitions is also providing a tailwind for companies that produce copper, battery metals, rare earth elements and others, although the pace of recovery varies by commodity.

Copper

Copper is widely used in a broad range of electronic and industrial applications due to its superior electrical and thermal attributes. Copper production increased by 3% in 2021, following two years of no production growth in 2019 and 2020. The first phase of operation has begun at Kamo-a-Kakula in the DRC and is due to produce 200 kt of copper per year.

Production is likely to see a further uptick in 2022 and 2023 if new projects come online as planned. Anglo American is about to begin the operation of Quellaveco in Peru, which is expected to produce 300 kt of copper per year. There are also several brownfield mine expansions underway, such as Grasberg (Indonesia), Chuquicamata (Chile) and Oyu Tolgoi (Mongolia). These projects should moderate prices if they come online as scheduled. However, beyond 2023 supply growth is likely to slow as output from existing operations

begins to subside and there are not enough late-stage projects to offset the declines at existing mines.

However, the elevated prices seen in recent years, along with expectations of rapid demand growth, are triggering the advancement of new projects. Chile's Codelco announced investments of USD 1.2 billion in El Teniente and USD 1.4 billion in Andina Transfer. Grupo México is planning to invest USD 8 billion in Tia Maria (Peru) and other projects. Zijin Mining plans to invest USD 770 million in a smelter for Kamo-a-Kakula. Aurubis AG, a Germany-based copper producer, announced plans to build a new multi-metal recycling plant in the United States, with EUR 300 million of investment.

It remains to be seen how quickly all the planned projects advance. Importantly, new projects will need to manage their environmental and social impacts carefully to ensure social acceptance, which will have major implications for market balances in the medium term.

Lithium

Lithium is one of the most prominent critical minerals for clean energy transitions. The leading source of lithium demand is the lithium-ion battery industry, which has expanded at an unprecedented pace in the past decade thanks to the rise of e-mobility. While demand for

nickel, cobalt and manganese can be affected by the choice of cathode chemistry, lithium is the backbone of lithium-ion batteries of all kinds, including lithium-ion phosphate (LFP) batteries. Even as technological innovation is accelerating progress in commercialising the much more energy-dense and thermally safe all-solid-state battery (ASSB), these also come with lithium metal anodes. Supply of lithium therefore remains one of the most crucial elements in shaping the future decarbonisation of light passenger transport and energy storage.

Ranging from mined spodumene to high-purity lithium carbonate and hydroxide, the price of every component of the lithium value chain has been surging since the start of 2021. The previous boom in lithium prices was observed in 2017 following an unprecedented demand for EV batteries stemming from China's subsidy-driven rollout of EVs. This was followed by a period of overproduction and low prices between 2018 and 2020, when new mines were mothballed and expansion projects were deferred. This left producers unprepared for the growing momentum behind electric mobility that emerged globally after the onset of the Covid-19 pandemic. Global sales of vehicles powered by lithium-ion batteries are mirrored in lithium's exponential usage curve. A record high of 270 kt of LCE were consumed in EVs in 2021, double the 140 kt in 2020. Lithium production increased by 30% in 2021 (based on mined output), driven by Australia and Chile. However, the major increase in consumption tipped the lithium balance from a surplus of 69 kt LCE in 2020 to a

deficit of 7 kt LCE in 2021, which supported the surge in prices in 2021. Prices have continued to soar in 2022.

Helped by rising prices, lithium production is set to increase further in 2022. Several projects are beginning production in 2022, including Cauchari-Olaroz (Argentina, 40 kt LCE), Sal de Vida (Argentina, 11 kt LCE), Manono (DRC, 104 kt LCE) and Finniss (Australia, 25 kt LCE). Other major projects slated to begin production in 2023 or 2024 include Thacker Pass (United States), Mt Holland Lithium (Australia), James Bay (Canada), Authier (Canada) and Keliber (Finland). The announced expansion of the Silver Peak project in Nevada, the only active lithium operation in the United States, would double production by 2025 to 10 kt LCE per year. While prices may moderate in 2023 as new supplies come online, the security of lithium supply will remain important given the rapid pace of demand growth and restrained refining capacity to produce battery-grade products.

Nickel

Most of the world's nickel is used in the manufacture of stainless steel and other industrial alloys, with clean energy technologies accounting for 10% of overall demand. Mined nickel output increased by 11% in 2021, almost entirely driven by Indonesia and the Philippines. Refined output increased by 10% due to major growth in Indonesia.

Since Indonesia's ban on nickel ore exports in 2020, several Chinese companies have made major investments in refining projects in Indonesia, most notably the projects in the Morowali and Weda Bay

industrial parks. Output from Indonesia has mostly been used in the steel and industrial sectors in the past, but the country is increasingly targeting the burgeoning EV sector, with high-pressure acid leaching (HPAL) being the main method of converting its laterite resources into battery-grade products. The first two HPAL projects in Indonesia began shipments in June 2021 ([USD 1.1 billion project by Lygend and Harita](#)) and February 2022 ([USD 1.3 billion joint venture between Huayou, Tsingshan and China Molybdenum](#)). Their combined production capacity is 100 kt nickel and 12 kt cobalt. Also in Indonesia, Tsingshan started producing nickel matte – an intermediate nickel product that can be processed into chemicals for EV batteries. In April 2022 two major battery value chain projects were announced, including nickel mining and processing: a [USD 6 billion project led by CATL](#) and a [USD 9 billion project led by LG Energy Solution](#).

In 2021 the Philippines lifted its nine-year ban on new underground mines as well as its four-year ban on new open-pit mines. The country's nickel production increased by 16% in 2021 and is poised for further growth as [10 nickel mines are set to open in 2022](#), adding to the 32 mines currently in operation.

While the overall nickel market may not face a significant deficit in the coming few years, there are concerns of growing market tightness for battery-grade Class 1 nickel due in part to the war in Ukraine. Although sanctions to date have not included nickel, the fallout from Russia's invasion, including shipping disruption, has compelled

consumers to seek other sources of supply, driving nickel prices up by 10% in the week following the invasion on 24 February.

Nickel prices made global headlines in early March, when a short squeeze more than doubled prices within 24 hours on the LME before trading was suspended on 8 March. While prices have since fallen by around 40% from peak values, they remain elevated as of end-May at around 20% higher than average prices in February.

Developments in other countries could also provide additional nickel supplies for EV batteries. Australia's first nickel sulphate plant, at BHP's Nickel West project (Kwinana refinery), produced its first nickel sulphate crystals in October 2021. Once fully operational, the plant could produce [100 kt of nickel sulphate per year](#) (20 kt nickel-equivalent), enough to supply around 700 000 EV batteries. The AUD 2.4 billion Sunrise Battery Materials Complex was granted Major Project Status in December 2021, with expected annual average output in its first decade of [21 kt nickel and 4 kt cobalt](#). Several companies in Canada are also mobilising investment to develop nickel targeted at the EV sector. In early 2022 Stellantis and LG Energy Solution announced a plan to [invest over CAD 5 billion](#) to build a large-scale battery production plant in Canada, aiming to leverage the country's abundant raw material resources.

Despite all this activity, the volatility of nickel prices could motivate OEMs to accelerate the adoption of nickel-lean or nickel-free chemistries, such as LFP. While this could help stabilise commodity prices, the lack of valuable metals in LFP batteries poses a challenge

for battery recycling economics using conventional methods. [Direct recycling](#) could be well suited to LFP, although this technique is still an emerging process and faces its own challenges.

Cobalt

Lithium-ion batteries are an important consumer of cobalt, and how their cathode chemistries evolve will play a key role in determining the pace of cobalt demand growth, especially in the near term. However, even if the adoption of high-cobalt chemistries slackens, cobalt demand for use in clean energy technologies is still set to grow in climate-driven scenarios due to the sheer growth in EV sales.

Cobalt prices more than doubled in 2021 and continued to increase in early 2022, driven by geopolitical tensions, Africa's logistical challenges and reduced cobalt refinery production in China. The war in Ukraine and associated fallout have further tightened cobalt availability, with prices up by 15% in the month following the invasion. The severe flooding in South Africa also disrupted export routes from the DRC, the largest raw material producer, to China, the largest refiner.

Several new projects and expansions have been announced in the past year, which could lead to notable production growth in the years ahead. Huayou, EVE Energy and others announced a USD 2.1 billion smelter in Indonesia (Weda Bay), with target annual production of [15 kt cobalt and 120 kt nickel](#). In the DRC, the announced USD 2.5 billion expansion of the Tenke Fungurume mine could [boost](#)

[annual cobalt production by 17 kt](#), while the USD 600 million expansion of the Kinsevere project could [boost annual cobalt hydroxide production by 4-6 kt](#). The Sunrise project in Australia could produce an [additional 4 kt cobalt](#). In Canada, Electra Battery Materials Corporation plans to build cobalt sulphate production plants, together with a lithium-ion battery recycling facility.

Graphite

Battery cathode materials have traditionally received more attention than their anode counterparts due to the various challenges linked to cathode supply chains. Nevertheless, the importance of securing graphite for anodes will also increase as it is the leading choice for anode materials for most lithium-ion battery chemistries. The situation could gradually evolve as silicon-doped graphite gains popularity and ASSBs with lithium metal anodes enter the phase of commercial deployment. However, these are unlikely to affect graphite's decisive share in the near term.

The primary challenge with graphite is a lack of sufficient mining projects rather than a shortage of resources. S&P Global estimates that for higher-cost mining projects to come online, the small flake graphite price would need to stay at its current highs of around USD 800 per tonne compared to the much lower historical average of around USD 500 per tonne.

The balance between the use of natural and synthetic graphite will depend on processing capacity and pricing. Natural graphite has

environmental benefits compared with synthetic graphite. The latter is made from a special grade of petroleum coke, a by-product of the oil-refining process. China mines almost 70% and processes almost all of the world's natural flake graphite, and it is estimated that 95% of the world's synthetic graphite battery anodes are also currently produced in China.

To ensure that supply meets rapidly growing demand, greater investment and diversification in graphite mining and processing are needed. Efforts on this front have begun with both graphite exploration and the development of processing facilities in [eastern Africa](#), Scandinavia, the United States, Canada, India and Australia. For example, in early 2022 the [Australian government backed two graphite projects with USD 171 million](#) in loans as a part of its wider effort to support domestic mining and diversify mineral supplies for battery production. The US Department of Energy [offered a loan of USD 107 million](#) to Syrah Technologies to expand natural graphite-based active anode material production in Louisiana.

Rare earth elements

Rare earth elements (REEs) are used to make the permanent magnets found in some EV motors and wind turbines. REEs are among the most geographically concentrated minerals in terms of extraction and processing, with China representing 60% of global mining operations and 90% of processing operations. In December 2021 the merger of three Chinese state-owned rare earth mining

companies [consolidated nearly 70% of China's heavy REE output](#) into a single entity.

Many countries and companies are seeking to diversify their REE supplies. Several projects are under development outside China, including in the United States, Canada, Greenland, Sweden, Australia, Namibia, Angola, Tanzania and South Africa. These projects are at various stages of government approval, permitting, fundraising and construction. Production began at the Nechalacho Mine (Canada) in 2021, with several other projects anticipating initial production in the next few years, including Kvanefjeld in Greenland, Steenkampskraal in South Africa, Strange Lake in Canada, and Bokan Mountain and Round Top in the United States. However, these projects face strong competition from China's vertically integrated and dominant supply chain, and may require further policy and investment support, such as favourable trade policies and offtake agreements.

REE prices surged in 2021, including a doubling of prices for neodymium oxides. Driven by supply and environmental concerns, manufacturers of clean energy technologies are increasingly looking to develop REE-free EV motors and wind turbines. Recycling is another pathway to boost supply security, but less than 5% of rare earth magnets are recycled today due to the lack of economies of scale. The availability of larger magnets from end-of-life wind turbines and EVs after 2030 could provide a strong basis to further develop the recycling industry.

Aluminium

Aluminium is used in a wide range of clean energy technologies due to its light weight and high electrical conductivity. Aluminium metal is produced through three steps: mining companies mine bauxite ore, alumina refineries process it to produce alumina, and lastly aluminium smelters produce aluminium metal from alumina by electrolysis.

Electricity prices, a major cost factor in smelting, have risen sharply over the past year in key markets including the European Union. As a result, [nearly half of the aluminium smelters in Europe suspended or curtailed production](#) in the last three months of 2021. Aluminium stock levels on the LME fell by two-thirds between April 2021 and 2022, which pushed up aluminium prices to record highs in March 2022.

China is a major producer of bauxite ore (20% of global production), alumina (55%) and aluminium metal (60%). It has increased its imports of bauxite ore as domestic sources have been depleted following decades of rapid exploitation. Old alumina refineries are being replaced with new, high-efficiency and low-emitting facilities. Bosai Minerals Group, Jingxi Tiangui Aluminum Industry, and Hebei Wenfeng Iron & Steel are starting up new facilities in 2022, and bauxite imports into China are expected to increase by 20% in 2022.

At the same time, bauxite exporting countries are encouraging companies to build alumina refineries in their own territories. Guinea,

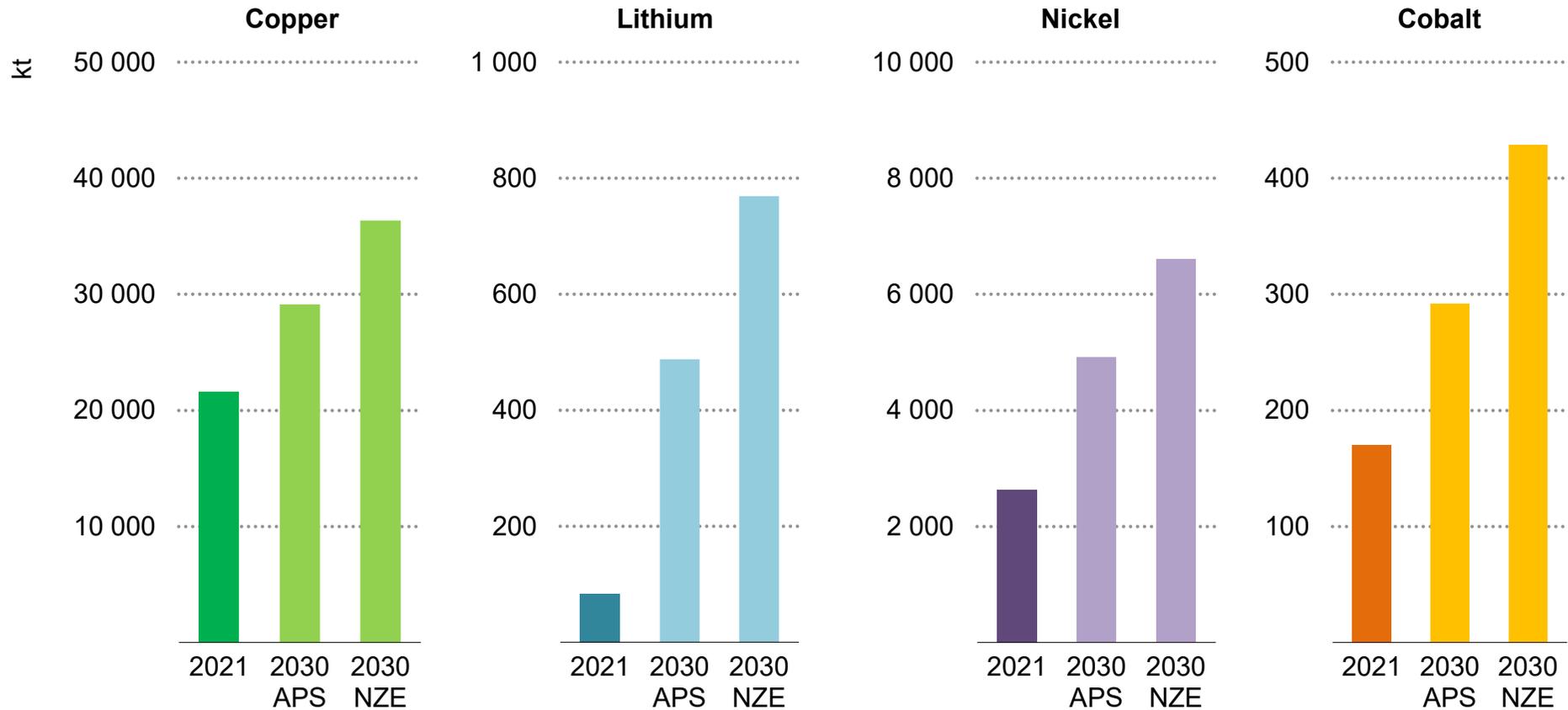
which accounts for 20% of global bauxite production, exports nearly all of its ore, and accounts for nearly half of Chinese imports. Chinese companies have invested heavily in bauxite mines in Guinea, but following a coup in September 2021 the new interim administration requested mining companies to propose plans to build domestic alumina refineries. Indonesia, the sixth largest bauxite producer in the world, announced its intention to cease bauxite exports by the end of 2022. It is estimated that around USD 1.3 billion of additional investment would be required to expand the number of refineries from Indonesia's current two to seven, to refine all the bauxite ore that is produced in the country.

In Australia, Canada and Brazil, high aluminium prices have helped to stimulate project expansions and the reopening of suspended facilities. Rio Tinto announced a USD 87 million investment in smelters at Saguenay-Lac-Saint-Jean (Canada) to expand production. Alcoa announced plans to restart its Alumar smelter (Brazil) and the Portland Aluminium smelter (Australia). These projects are planning to use renewable electricity for smelting in response to growing demand for low-carbon aluminium. The Australian government also announced AUD 10 million in funding support for Alcoa's pilot project to trial an electric calcination process powered by renewable energy to reduce emissions from alumina refining. With CAD 20 million of Canadian government support, [ELYSIS](#) is working to commercialise by 2024 a new smelting technology that eliminates all greenhouse gas emissions from the process.

Implications

Despite production growth in 2021, a further scale-up in investment is necessary to meet rising demand for minerals in climate-driven scenarios

Production in 2021 and projected demand in 2030 in climate-driven scenarios for selected minerals and metals



IEA. All rights reserved.

Notes: APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.

Investment, innovation and recycling are critical to meet growing demand for clean energy

Although the production of many key minerals and metals increased in 2021, current supply and investment plans remain well short of meeting the growing demand from clean energy technologies if the world is to achieve the goals in the Paris Agreement. Greater investment to bring new mines and refineries online with high ESG standards is essential to bridge this gap. Enhanced collaboration between mineral producers and users and strategic funding support can help. Investment in geological surveys is also needed to better understand resource potentials, particularly in developing countries which remain vastly underexplored.

Technological innovation can play an important role in alleviating strains on supply while also reducing costs. For example, newer low-cobalt EV batteries contain 75-90% less cobalt compared with earlier generations, albeit using twice as much nickel. There is also renewed interest in LFP batteries, which do not contain nickel or cobalt, but have lower energy density and face challenges with recycling. Lithium supply is of particular concern because there are currently no lithium-free alternatives available at scale that meet the performance of lithium-ion batteries. Sodium-ion batteries could offer a promising low-cost alternative, if successfully commercialised. Reducing overall mineral demand could also be achieved by reducing material intensity through innovation, shifting to smaller batteries and encouraging higher utilisation of assets (e.g. ridesharing of vehicles).

Innovation in production technologies can also unlock sizeable new supplies. Emerging technologies – such as direct lithium extraction or enhanced metal recovery from waste streams or low-grade ores – offer the potential for a step change in future supply volumes. Extracting metals from mine wastes could be an important source of secondary supply to boost production relatively quickly (Box 4.1).

Reuse and recycling can also relieve pressure on primary supplies while reducing adverse environmental and social impacts associated with mineral extraction and processing. For example, spent EV batteries could be repurposed for grid storage applications. Better collection systems and investment in new recycling plants and supporting infrastructure are needed to extract critical minerals from spent batteries and other clean energy technologies that reach the end of their life in the coming decades.

At the [IEA Ministerial Meeting](#) in March 2022, Ministers from IEA member countries asked the IEA Secretariat to expand its work on critical minerals as part of the new mandates to enhance energy security. Building on the six key recommendations for a comprehensive approach to mineral security presented in the [special report](#) in 2021, the IEA will expand its work programme in the coming years to strengthen activities on market monitoring, technology innovation, supply chain resilience, recycling, environmental and social standards and international collaboration.

Box 4.1. Re-mining: Extracting value from mine waste

The long lead times for new mining projects pose a serious challenge to scaling up production fast enough to meet growing mineral demand for clean energy technologies. Between geological surveys, environmental assessments, permitting processes and construction, major new projects can take as long as 10-20 years from exploration to production.

Extracting metals from mine wastes, particularly in the form of waste rocks and tailings, could be an important untapped source of secondary supply to complement recycling and boost production relatively quickly. “Re-mining” has not received much attention in the past, but rising mineral prices and new technologies are raising interest from companies and governments. In addition, many advanced economies hold large sources of mine waste, providing the additional benefit of securing domestic supplies to support clean energy technology value chains. [The US Defense Production Act](#), invoked in March 2022, mentions reclaiming valuable materials from existing mines and mine waste as one of the key measures to step up domestic production of critical minerals.

The most direct way to boost production from wastes is to use new technologies. For example, solvent extraction and electrowinning (SX/EW) in the 1980s helped to recover copper from rocks that had been discarded as waste. SX/EW has played a key role in meeting growing copper demand, and now represents 20% of global supply.

In 2021 Rio Tinto demonstrated the [production of battery-grade lithium from waste rock at a borate mine](#) in the United States, following a successful small-scale trial in 2019. It also [began to produce scandium oxide](#) – used in fuel cells and aluminium alloys – from the waste streams of titanium production. The company plans to [launch a start-up](#) that will use the re-mining and processing of waste from legacy mine sites to extract valuable minerals and metals, support rehabilitation activities and restore natural environments. E3 Metals is trying to [extract lithium from oilfield wastewater](#).

The sheer volume of waste implies significant potential – the total amount of mine tailings globally is estimated to be more than 200 km³. In Western Australia alone, one study estimates that 720 kt of nickel (a quarter of current global demand) could be recovered from more than 240 Mt of tailings containing 0.5% nickel.

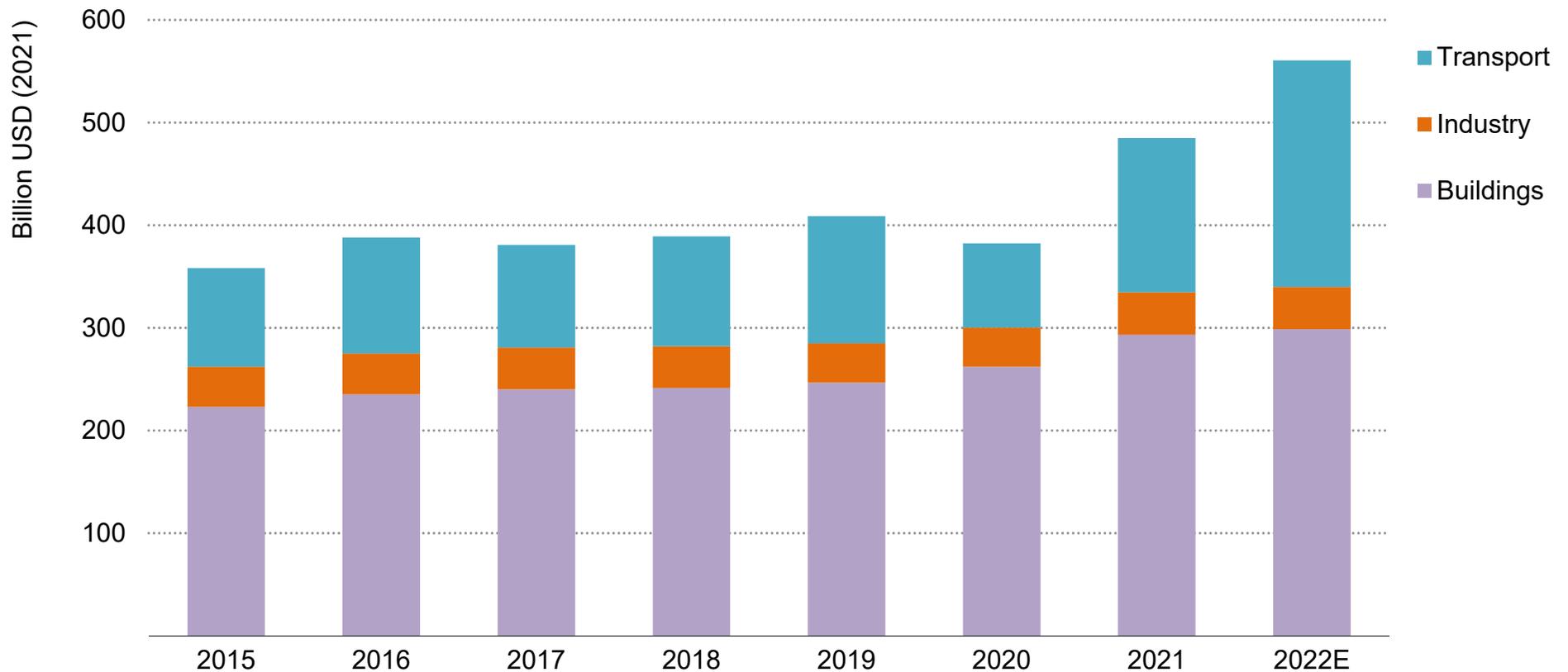
While there is considerable potential for re-mining and a strengthening economic case, there remain challenges with new technologies and processes, including high costs and energy inputs. Strong and clear policy messages can play an essential role in promoting the ramp-up of supply from waste while limiting negative impacts. For example, government support for assessing the economic value of existing tailings and R&D for efficient metal recovery may help.

Energy end use and efficiency

Overview

Global energy efficiency investment reached record levels in 2021, driven by spending in the buildings sector and the doubling of EV sales

Global investment in energy efficiency, electrification and renewables for end uses by sector

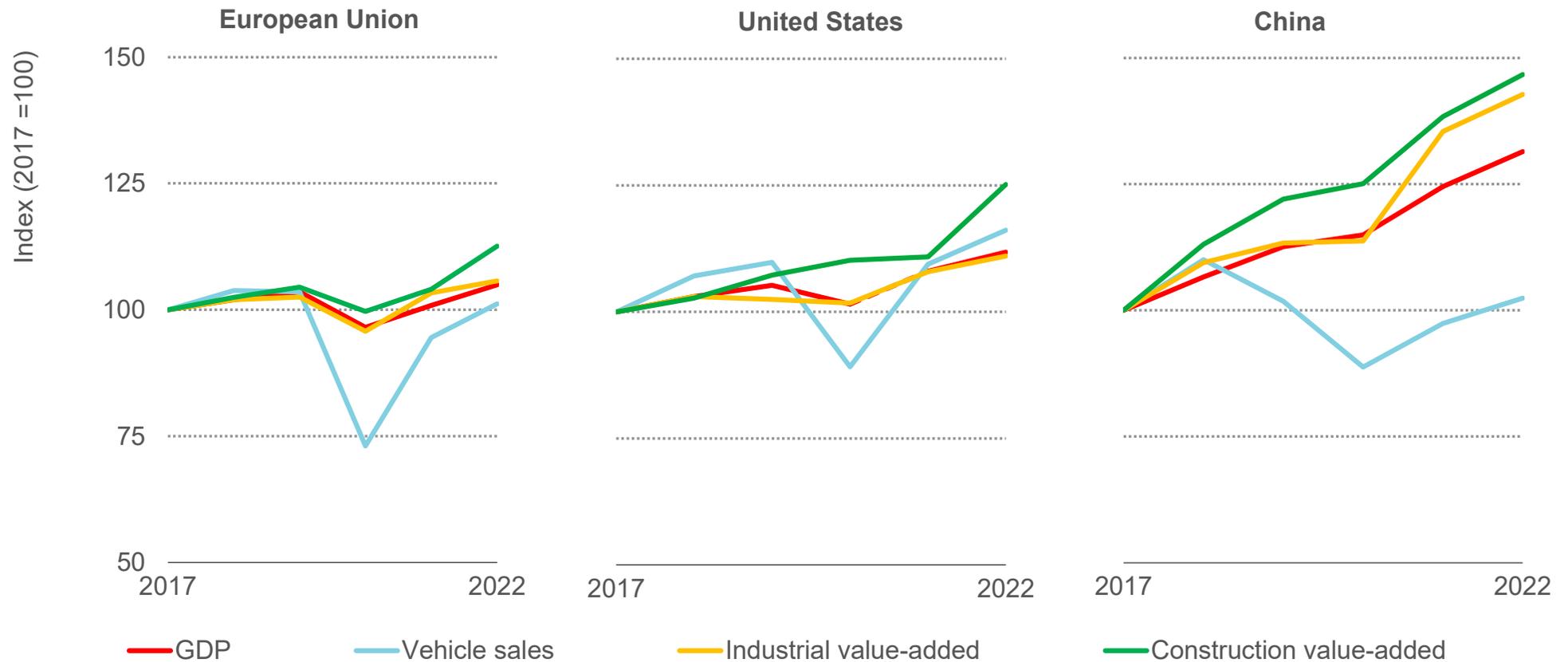


IEA. All rights reserved.

Notes: An energy efficiency investment is defined as the incremental spending on new energy-efficient equipment or the full cost of refurbishments that reduce energy use. The intention is to capture spending that leads to reduced energy consumption. The total in all years is slightly higher than that shown in World Energy Investment 2021 due to the inclusion of additional national-level data in the buildings sector.

Indicators affecting investment in energy efficiency are just returning to pre-pandemic levels in Europe, while growth is stronger in the United States and China

Trends in sectoral indicators for three major economies that are relevant to key sectors for energy efficiency, 2017-Q12022



IEA. All rights reserved.

Sources: IEA calculations based on [BEA \(2022\)](#); [Eurostat \(2022\)](#); [NBS \(2022\)](#).

Despite rising costs and supply chain disruptions, spending on energy efficiency is set to further expand in 2022, albeit at a slower rate than in 2021

After continued stagnation during the previous few years, global investment in energy efficiency, electrification and renewables for end uses reached new highs in 2021, with a 27% increase from 2020 levels.

Energy efficiency investment in buildings received a boost from stimulus-related government programmes, newly enacted regulations and record sales of heat pumps; it also benefited from the rebound in construction around the world. In transport, annual sales of battery EVs have doubled, driving up electrification numbers. Investment in energy efficiency in the industrial sector also increased in 2021 as recovery proved strong, notably in the United States, and materials production output grew substantially. New announcements of investment in initiatives to decarbonise industrial processes in advanced economies also contributed to the growth.

However, progress differs across regions. Investment in buildings has not been as strong in emerging markets and developing economies, where construction activity was impaired by the resurgence of Covid-19 cases and new lockdowns or has been structurally slower to recover. The adoption of energy performance standards, building codes and stimulus packages continue to be geographically disparate. EV sales reached all-time highs in Europe

and China, but have been slower in the United States and Japan, and still account for a very limited market share in other large EMDEs. Industrial energy efficiency investment has rebounded rapidly past pre-pandemic levels in North America and from a relatively lower base in India and Europe, but investment increased only modestly in China and remained stable in other parts of the world.

Trends for efficiency spending in 2022 remain highly uncertain and will hinge on continued government support and enabling policies to shape consumer and corporate demand. Indicators that usually correlate with energy savings-related investment (construction, vehicle sales, industrial value-added) and the recent spikes in fuel prices should be conducive to renewed interest in efficiency measures, but there are powerful headwinds in the system.

Inflation has been at its highest since 1980, and the cost of construction and industrial materials has skyrocketed. In response, central banks are expected to rapidly raise interest rates, which will increase the cost of debt for governments, consumers and corporates, potentially delaying decisions to invest in energy efficiency measures. Disruptions in the supply chain, new lockdowns and labour shortages are other worrisome signs for 2022.

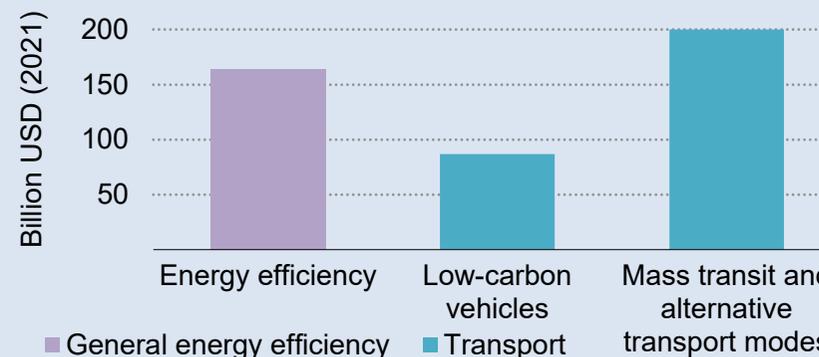
Box 1.1. Covid-19 crisis recovery plans included USD 450 billion for end-use sectors, a welcome boost but one that has revealed implementation challenges

As of March 2022 governments worldwide had earmarked over USD 710 billion in direct spending for long-term clean energy and sustainable recovery measures in Covid-19-related recovery plans, as identified in the [IEA Sustainable Recovery Tracker](#). This is the largest ever clean energy recovery effort, 40% higher than the green element of the fiscal stimulus disbursed after the 2008-2010 global financial crisis. We estimate that over 90% of the spending will occur in advanced economies, as EMDEs focus their fiscal capacity on health measures and emergency support for vulnerable households and businesses. This trend is likely to be further compounded by the current energy price spikes, which may further restrict EMDEs' room for manoeuvre.

Covid-19-related recovery packages have placed increased focus on end-use sectors. These packages are set to direct over USD 450 billion towards energy efficiency in buildings and industry, developing mass transit and supporting the switch to EVs. This amount comprises around 60% of recovery spending earmarked for sustainability. While a similar percentage of all sustainable recovery funds is available for spending prior to 2023, tensions in the global supply chain and concerns over energy security and affordability may hinder actual and timely disbursement in the real economy.

Buildings efficiency support disbursed through direct subsidies and tax rebates are particularly at risk of under-delivery, as complex funding application processes hold back wider uptake. Supply chain constraints, labour shortages and price hikes are also delaying construction projects, causing budgets to overrun or contractors to shelve projects in several sectors, from housing retrofits to large mass transit infrastructure. Addressing these non-financial barriers is necessary to increase direct investment by consumers and thereby leverage public funding for maximum impact.

Government recovery spending earmarked for specific end uses as of March 2022.



IEA. All rights reserved.
Source: [IEA Sustainable Recovery Tracker](#).

Update on the ESCO market: A key enabler of efficiency investment

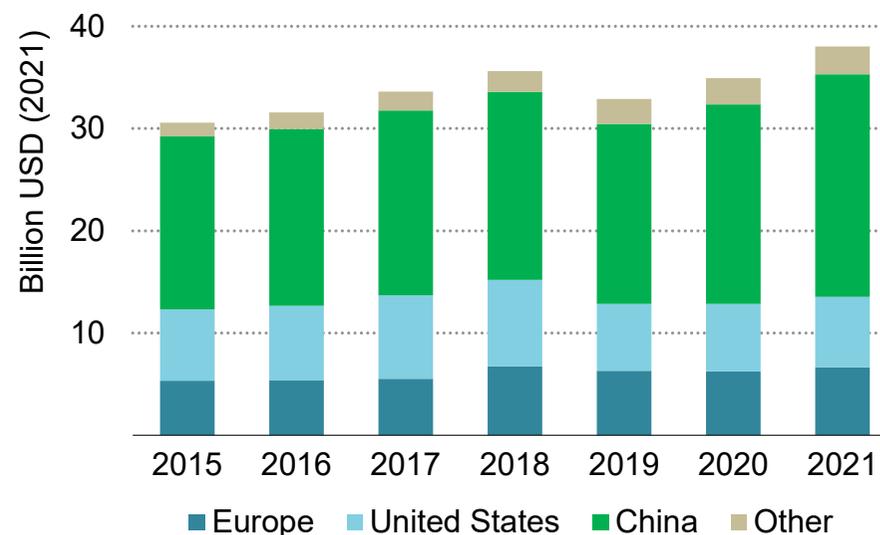
Energy service companies (ESCOs) are important enablers of investment, delivering energy efficiency improvements for their customers, financed through the cost savings realised. ESCOs and their clients enter into energy performance contracts with guaranteed or shared savings, or a similar contractual arrangement. ESCOs then support their clients in identifying, financing and implementing projects, thereby lowering the burden of upfront capital investment and facilitating access to commercial financing.

2021 was a positive year for the global ESCO market, reaching an estimated USD 38 billion based on a 9% increase year-on-year. Although the definition of an ESCO can vary from country to country, China remains the main market, with close to USD 22 billion of cumulative investment in ESCO projects and a 12% increase in 2021 alone. Driven by the government's commitment to achieving carbon neutrality by 2060, increased decarbonisation efforts show their effects on the ESCO market. China is piloting a new green financing programme that provides carbon reduction insurance and carbon reduction loans to finance building efficiency improvements.

Investments in Japan increased in 2021, whereas some other Asian markets such as the Philippines were still affected by the pandemic. The US market is on an upward trend as well, with some ESCOs reporting growth rates between 10% and 15% in 2021, and a positive business outlook for 2022. A new [Energy Efficiency and Conservation Block Grant Program](#), with an overall budget of

USD 550 million, allows states, local governments and tribes to benefit from performance contracts for the first time. Canada saw fewer public-sector ESCO projects implemented as smaller projects aggregated. Europe as a whole exhibited slight growth, while some markets such as the Czech Republic were still negatively affected by the pandemic. The ESCO market in Mexico experienced a shift in government focus and funding towards renewable energy, whereas the Turkish ESCO market grew in 2021.

Total investment by ESCOs



IEA. All rights reserved.

Sources: IEA calculations and estimates based on IEA annual ESCO market surveys (2022) in collaboration with the Global ESCO Network.

Higher energy prices could fuel demand for ESCO services

The share of ESCO projects in the public sector is typically larger in Europe, North America and China, whereas private-sector projects dominate in large parts of Asia.

The buildings sector is traditionally the strongest for ESCO projects in many markets in Europe and Asia. In China the buildings sector reached a share of over 50% for the first time, driven by changes in policy orientation (e.g. the introduction of a new carbon assessment framework for buildings) and a contraction of industry projects due to ongoing effects of Covid-19. Industrial-sector projects dominate in Turkey, and form the majority of projects in both financial terms and number of projects in Japan. With the overall reduction in ESCO projects in Mexico, energy efficiency projects in municipalities (mainly lighting retrofits) acquired a considerably higher significance. Municipal services accounted for about 10% of projects in several Asian markets. No notable projects in the transport sector were reported, although EV fleet acquisitions are categorised under energy performance contracting in Canada.

Contract structures

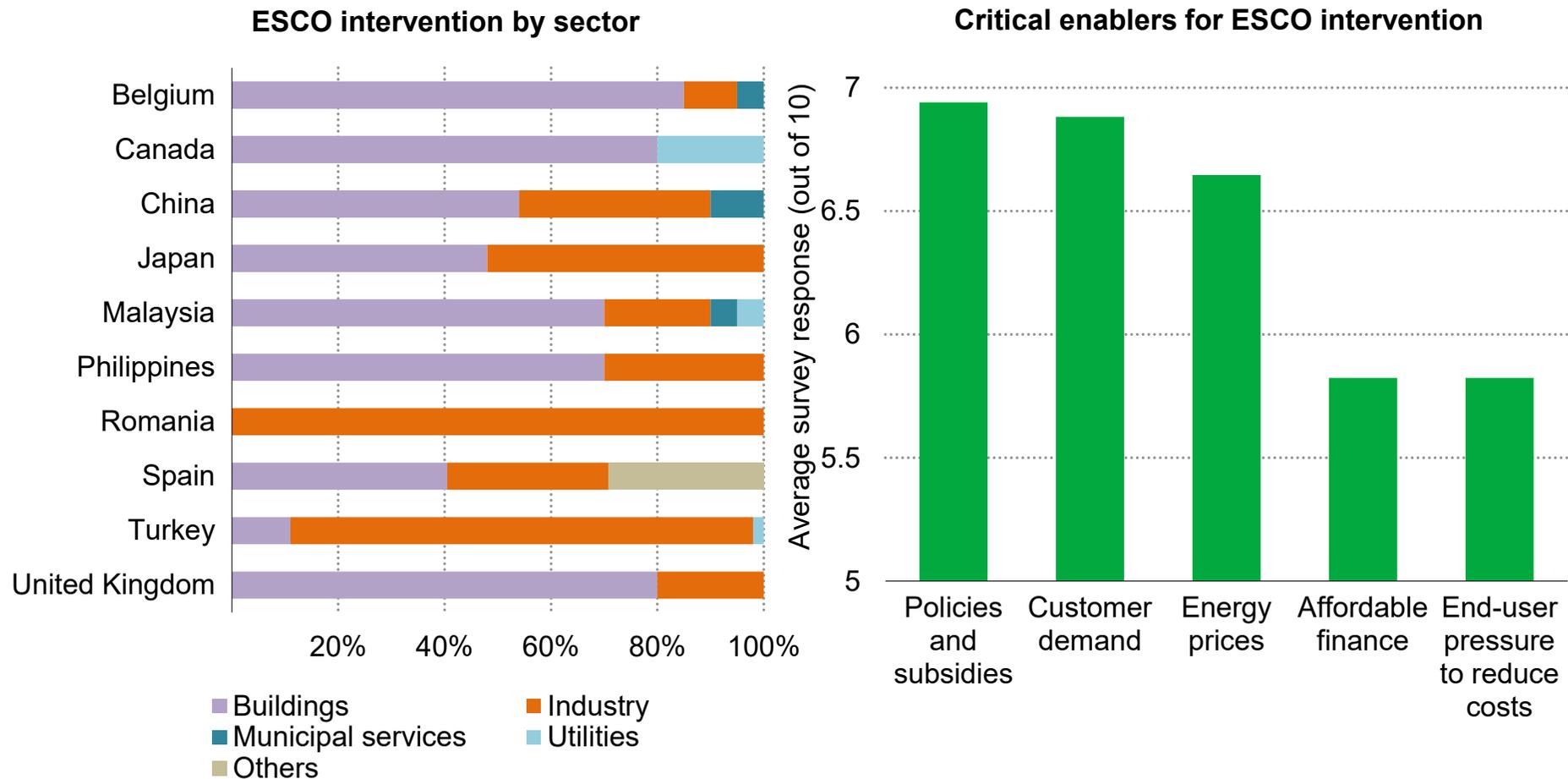
Contractual arrangements with guaranteed savings continue to dominate in established ESCO markets, whereas shared savings

contracts are more widely used in some Asian markets including Japan and Malaysia. Besides energy performance contracts, other contract types are increasingly being used, such as contracts for energy supply, facilities management and leasing, BOOT (build, own, operate and transfer) models and others. Contract types like engineering, procurement, construction and management, and power purchase agreements account for about 20% of the Spanish market. Chinese ESCOs are striving to transform their businesses into a “one-stop shop” comprehensive service model, providing energy-saving consultations, diagnosis, financing and transformation services.

Market barriers and enablers

Financing challenges persist in 2021, with credit risk on the client side, lack of demand and trust in the ESCO industry ranking highest among the most important barriers, followed by administrative barriers and challenges with aggregation and securitisation of projects. The most influential enablers of ESCO projects include supportive government policies and subsidies, customer demand for ESCO projects, high energy prices, access to affordable finance and end-user pressures to reduce costs.

ESCO interventions predominantly focus on the buildings sector and require policy predictability, transparent prices, strong customer demand and access to affordable finance



IEA. All rights reserved.

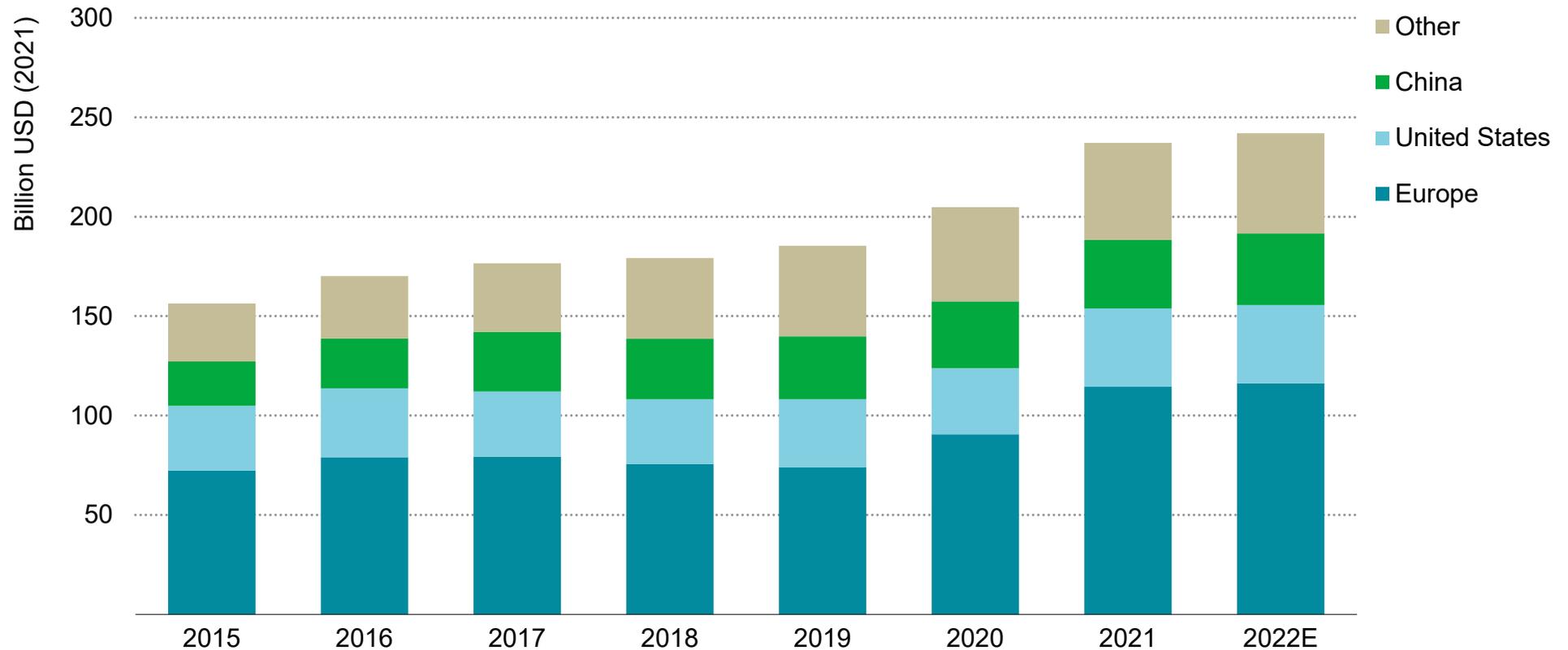
Notes: Share of ESCO projects based on number of projects; ranking of enablers based on annual ESCO market survey.

Source: IEA calculations and estimates based on IEA annual ESCO market surveys (2022) in collaboration with the Global ESCO Network.

Buildings

Energy efficiency spending on buildings rose by more than 15% in 2021, but is set to stabilise in 2022 as the continuation of stimulus packages remains uncertain...

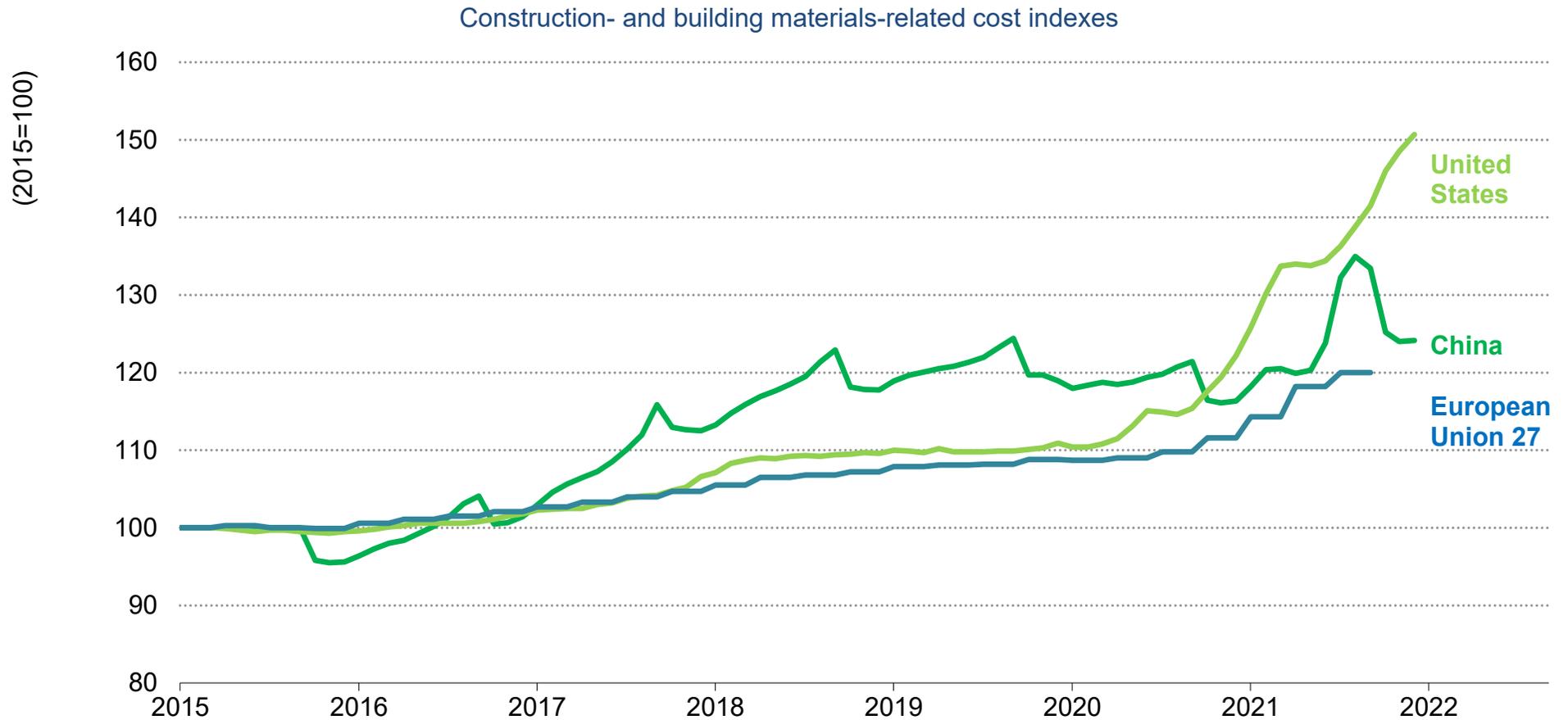
Investment spending on energy efficiency and electrification by region in the buildings sector, 2015-2022E



IEA. All rights reserved.

Note: Includes electrification (e.g. heat pumps).

... while construction and material costs have reached all-time highs in the first quarter of 2022



IEA. All rights reserved.

Notes: China = Producer price index – Building materials industry non-seasonally adjusted; US = Producer price index – Materials and components for construction seasonally adjusted; EU27 = Construction cost index seasonally adjusted.

Sources: IEA calculations based on Bloomberg terminal (2022); [Eurostat \(2022\)](#); [NBS \(2022\)](#).

Investment in buildings energy efficiency continued to rise as a result of direct stimulus and a turnaround in the construction sector

In 2021 global buildings sector investment in energy efficiency increased by an unprecedented 16% from 2020 levels to a total of approximately USD 237 billion. This marks the single largest increase in investment in buildings energy efficiency since the first World Energy Investment report in 2014.

This increase in efficiency investment in 2021 reflects the recovery of construction investment in Western European countries (e.g. the United Kingdom, France and Italy) and a continued incremental growth in construction in several large markets (e.g. Germany, the United States and China). Some of these countries, for example Germany and Italy, have also benefited from large public spending programmes that have resulted in substantial increase in global buildings efficiency investment.

However, investment in energy efficiency among developing economies in South and Southeast Asia and Africa has struggled with the continued impact of the pandemic, with continued disruption to construction activities and limited public programmes of investment. Despite some recovery in 2021, efficiency investment remains below 2019 levels in these regions.

Stimuli related to pandemic recovery have made a major contribution to energy efficiency investment in Western Europe. The

United Kingdom, for example, committed GBP 1 billion of spending between 2020 and 2022 through the Public Sector Decarbonisation Scheme, while the French Recovery Plan provides up to EUR 4 billion in loans for the renovation of schools, hospitals and local and state buildings.

Several countries have programmes that take advantage of the tax system to support energy efficiency investment by encouraging building owners to invest and receive tax refunds or repayments. The French MaPrimeRénov offers a grant of up to EUR 15 000 to all owners according to the type of energy efficiency work, with additional amounts for those in the low-income segment in order to combat energy poverty. In addition, the Italian Superbonus provides a tax credit that is worth up to 110% of the cost of the energy efficiency work undertaken and already has already seen more than EUR 25 billion spent under the programme as of March 2022.

There remain several major public programmes for investment in energy efficiency, with the German development bank KfW investing nearly EUR 37 billion in 2021 on improving the energy performance of existing and new buildings and accounting for 18% of the global estimate. However, major initiatives in the country were paused in early 2022 as funds had been exhausted. Some have since been

resumed with a smaller budget and a focus on retrofits and more ambitious efficiency standards for new builds.

Other major OECD economies have provided more restrained levels of energy efficiency investment. The United States has seen a minor increase in energy efficiency investment via the federal government weatherisation programmes, increased to USD 377 million in 2021, although a funds appropriation of more than USD 800 million has been requested from Congress in 2022. Canada's Green Homes Grant offers a modest CAD 5 600 to support households' investment in improving building energy performance, with a total budget of CAD 2.6 billion over the coming seven years.

Some economies have seen a marked increase in high-performance construction. Japan's Zero Energy Housing accounted for over 16% of the private housing market in 2021, up from around 3% in 2014. Likewise, China's commitment to green buildings construction has a target for more than [50% of urban development to meet a green standard](#) as part of the country's previous 13th Five Year Plan. In 2021 energy efficiency investment in China was estimated at about USD 35 billion, and total green building floor space in China is estimated to be around [6.6 billion m²](#), while total residential floorspace amounted to around 52 billion m².

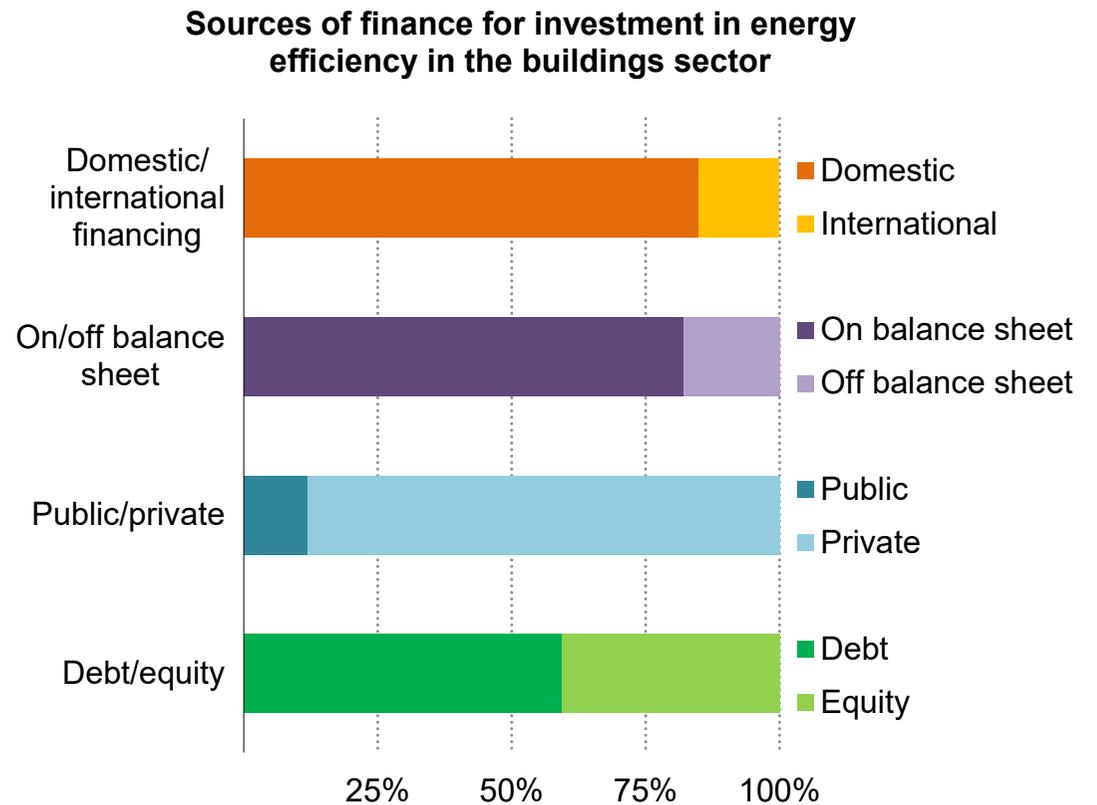
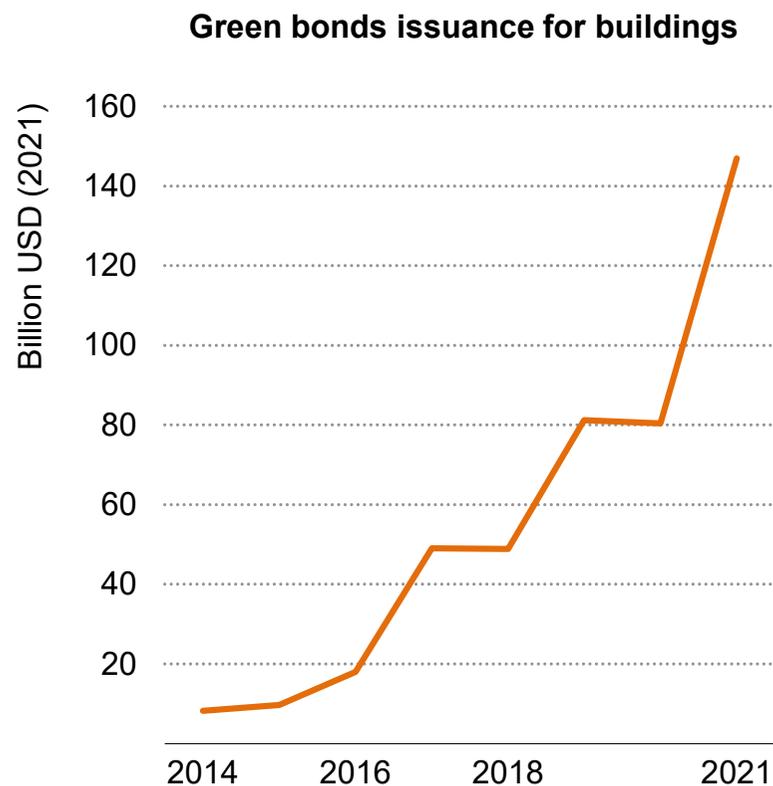
While the global economy continues to focus on recovery from the pandemic, stimulus programmes are likely to be tapered during 2022 as governments focus on addressing inflation. Substantial increases in demand for construction and rising interest rates, combined with raw material and labour supply constraints, are likely to push costs up in the buildings sector. If and when supply chains resume normal conditions, consumer interest in housing investment may well wane without continued directed programme support.

Private financing schemes are starting to pick up in several places. Green mortgage products, which offer discounted interest rates to buyers of energy-efficient houses or to homeowners who invest in retrofits, have been launched at an increasing pace, for instance in the [United Kingdom](#) and [Australia](#). Other schemes, such as the [Property Assessed Clean Energy Programs](#) in the United States, allow homeowners to fund energy efficiency improvements through a loan to be repaid through property "assessments", where the repayment is attached to the property tax bill. Green mortgage refinancing and securitisation also experienced a strong year in 2021, and Fannie Mae was the [largest single issuer of green bonds](#), where the use of proceeds are earmarked for green buildings.

Based on these early trends, our estimate for global investment in energy efficiency is a modest increase of 2% in 2022.

Green debt financing for energy efficiency investment in buildings is on the rise, with record green bond issuances in the sector in 2021

Green bonds earmarked for the buildings sector, 2014-2021, and sources of finance, 2021



IEA. All rights reserved.

Note: Left graph shows data for bonds that identify energy efficiency in the buildings sector as one of the intended uses of proceeds.

Source: IEA calculations based on [Climate Bonds Initiative](#).

Heat pump sales are trending upwards, while the use of renewable energy for buildings is stagnating

The annual rate of building retrofits around the world remains at around 1% of the existing building stock. Despite efforts to ramp up public policy support for renovations, as described above, the uncertainty about the availability of funds for stimulus packages beyond 2022 in the European Union's major markets (Germany and France) puts at further risk these countries' ambitious objectives to support and generalise building renovations. While broad in their eligible scope, these packages tend to be used to fund specific one-off renovations such as heating systems upgrades (accounting for 72% of the budget in France under MaPrimeRénov) and fall short of the spending levels required in the Net Zero Scenario. Stringent new policies, as seen in some European countries where home sellers are required to obtain energy performance certificates that entail retrofitting properties up to the accepted efficiency level, may boost retrofit levels in the few coming years. Similarly, owners in France will not be able to rent properties in the three least-efficient categories from 2025, which could affect one-third of the housing supply.

Geothermal projects for district heating and cooling suffered from the pandemic, but a rebound is expected in the next five years with 232 projects under development, mostly for district heating in Europe. Renewed interest in the technology is anticipated in the United States and China where the market remains broadly untapped. This capital-

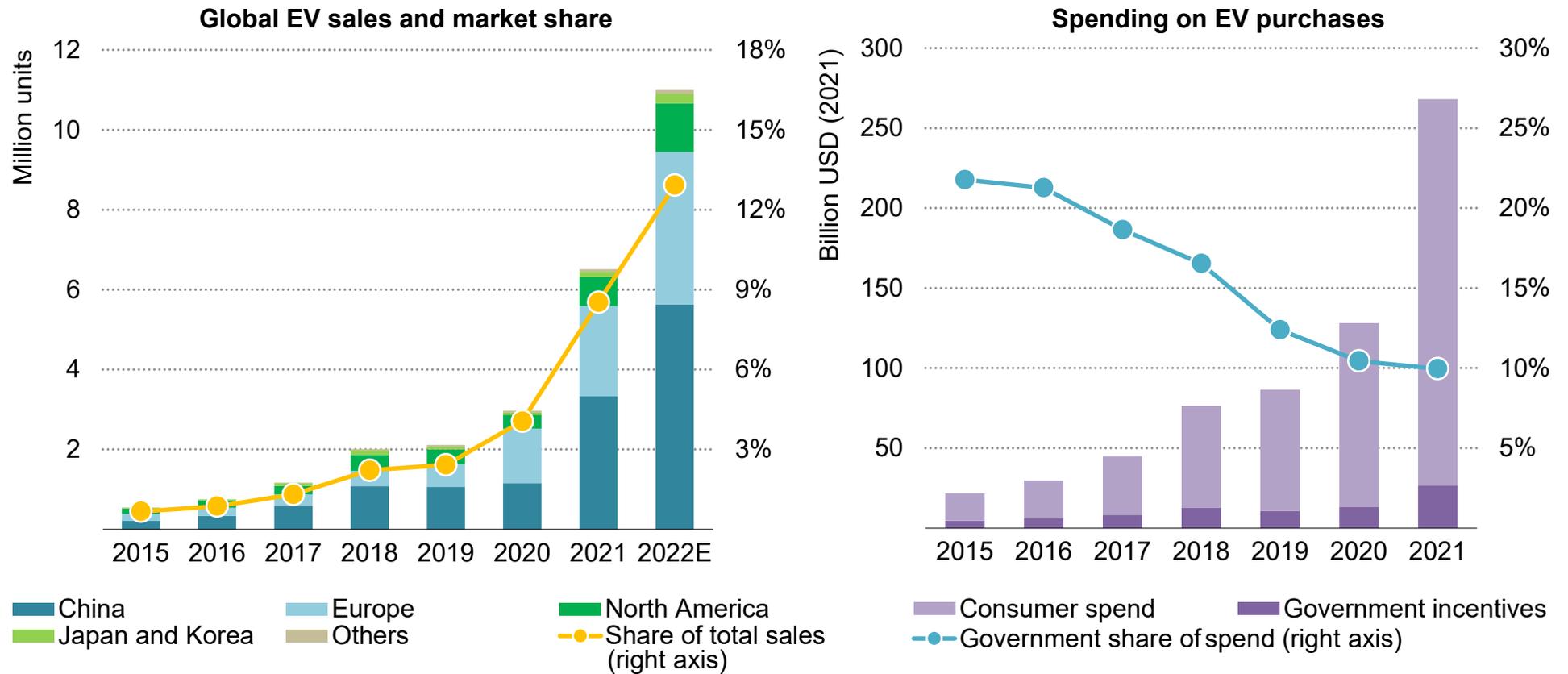
intensive technology is, however, suffering from the same inflationary pressures seen elsewhere in the energy system, although studies in the United States have demonstrated that investment in [geothermal heating and cooling has been strongest following spikes in the price of fossil-based heating fuels](#). The markets for solar heaters and bioenergy remained broadly stable in 2021.

Global sales of heat pumps grew by more than 15% in 2021, achieving a global market value of about USD 60 billion, with the strongest growth in Europe, Japan and the United States. Annual sales in Europe have passed 2 million units for the first time, while figures in Asia remained robust. Investment is driven by policies such as that in Germany where a national cap and trade system was adopted to effectively put a carbon tax on heating fuels, among other sectors. As highlighted in the [IEA 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas](#), speeding up the replacement of gas boilers by doubling heat pump installations in Europe would save 2 bcm of gas use in the first year and require a total additional investment of EUR 15 billion. The REPowerEU plan, which aims to reduce EU demand for Russian gas by two-thirds before the end of 2022, could also provide a powerful catalyst for heat pump deployment. [The lifetime cost of heat pumps is now cheaper than oil and gas for heating in several countries](#).

Transport

Global EV sales jumped to over 6.5 million in 2021, reaching 8% of global passenger car sales

Global trends in the electric passenger light-duty vehicle markets, 2015-2022E



IEA. All rights reserved.

Notes: EV includes battery electric vehicles, plug-in hybrids and fuel cell vehicles. ZEV = zero-emission vehicle. ZEV includes battery electric vehicles and fuel cell vehicles for passenger cars.

Sources: [IEA Global EV Outlook \(2022\)](#); MarkLines (2022).

Despite supply chain disruptions and lockdowns, EV sales are set to cross the 10 million unit mark in 2022...

EV sales

Global EV sales more than doubled in 2021, with most of the growth in China and Europe where for the first time EVs surpassed diesel vehicle sales. All the net growth in global car sales in 2021 was from EVs. Renewed interest in EVs was also seen in the United States, where sales recovered the ground lost during the pandemic. Together China and Europe accounted for more than 80% EV sales. The market grew more slowly in Japan as the automotive industry has taken a more cautious approach towards shifting to zero-emission vehicles (ZEVs) and has tended to focus on plug-in hybrid models. The market for EVs remained small even in large emerging economies such as Brazil, India and Indonesia, where EV sales accounted for less than 0.5%, albeit showing sizable growth in 2021. EV sales doubled in developing Asia, Central Europe and the Middle East. Globally, the ZEV share of total sales has grown from 3% to 9% in the past two years and sales are expected to pass the 10 million threshold (or more than 12% of the total car market) in 2022 as manufacturers widen their offerings, further increase range and keep prices in check.

Consumer spending on EVs increased in 2021...

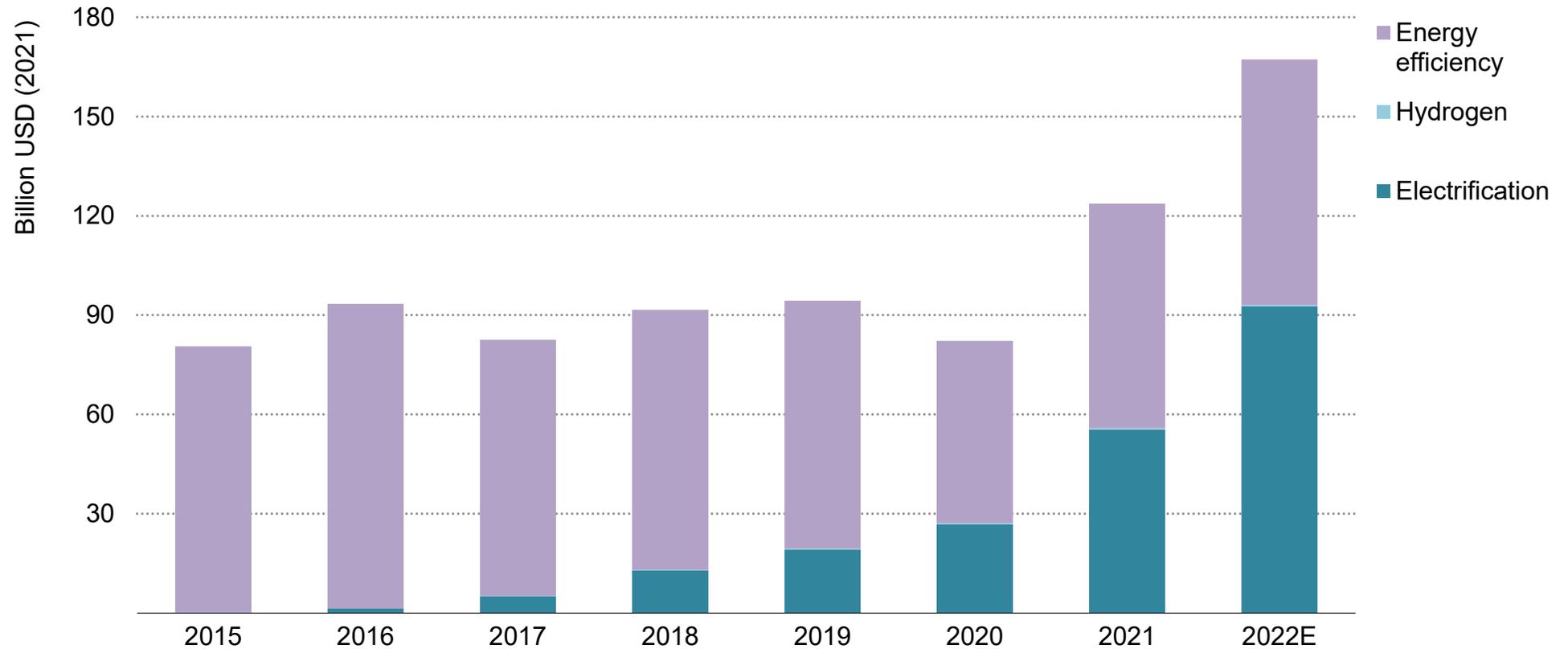
As a result, direct spending on EVs increased to over USD 270 billion in 2021. While government subsidies for EV purchases have decreased over time, sales growth remained strong, suggesting that the market is maturing and that EVs are becoming more competitive compared to their conventional peers as the price differential narrows. According to [GEVO2022](#), the median price of an EV in China was only 9% above that of the overall fleet, while it remained about 50% higher in Europe and the United States. Model availability in EMDEs (outside China) is still limited and prices are high.

...but SUV sales largely offset efficiency gains

The average price of battery EVs slightly increased in 2021, largely due to the high demand for higher-end vehicles. Outside China, two-thirds of available ZEV models were large cars or SUVs, even in EMDEs, despite large purchasing power disparities with Europe and the United States. Global sales of SUVs (both ICE and EV) [have set another record in 2021](#), driving up demand for electricity and critical minerals as battery-powered SUVs tend to require larger batteries. However, the selling price per unit of range (km or miles) decreased by 7% for battery EVs around the world.

...resulting in a surge in energy efficiency and electrification spending

Energy efficiency, electrification and hydrogen spending in the transport sector



IEA. All rights reserved.

Electrification becomes the main source of investment in energy-efficient transport

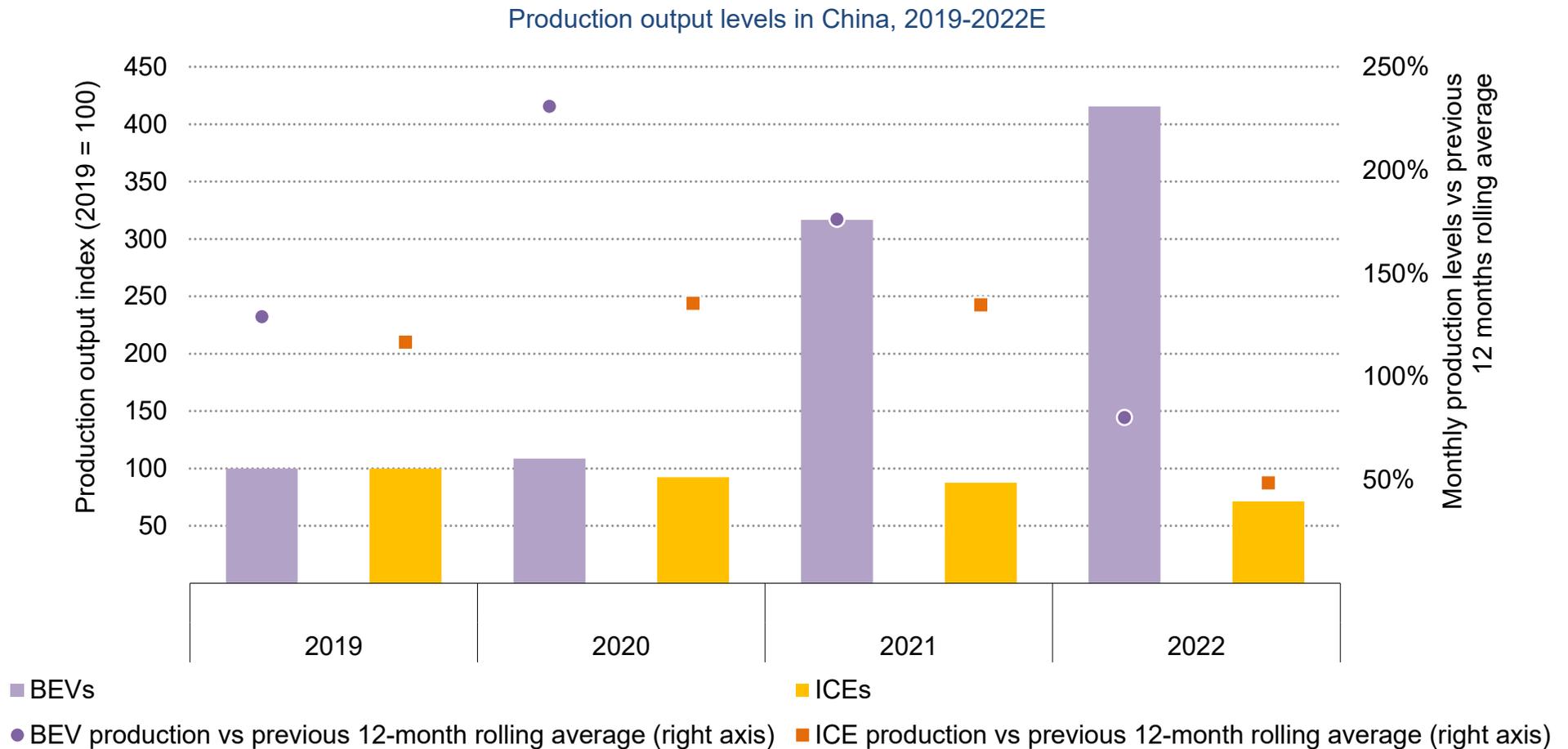
The growth in EV sales is driving investment in electrification, which represented more than 45% of overall end-use investment in the transport sector in 2021. We estimate that share to increase to more than 55% in 2022. Investment in the electrification of buses and heavy-duty vehicles also increased in 2021. In early 2022 India ran a tender for the purchase of more than 5 000 electric buses in five major cities. The contract was awarded for half the price reached in previous tenders. [A public-private joint venture in Chile](#) is also seeking financing to fund a 1 000-strong electric bus fleet in Santiago. Sales of fuel cell EVs remained low in 2021 (USD 0.4 billion), with only two commercial models currently in production and limited charging infrastructure. However, countries such as Korea are starting to invest in fuel cell manufacturing capacity. With the market share of ICE vehicles anticipated to decline, energy efficiency investment in the transport sector is growing at a slower pace than electrification, but has showed some signs of recovery since the pandemic as new fuel efficiency mandates are implemented around the world.

Demand for electrification is expected to grow stronger in 2022, but some uncertainty remains on the ability of automakers to keep up with orders. The forced shutdown of factories in China in response to surging Covid-19 cases and subsequent lockdowns are delaying production, as is the global semiconductor shortage that started in 2021. Car manufacturers in Europe and the United States were

forced to temporarily halt production at several plants in early 2022. However, even without these shortages, automakers were straining to meet demand, with lead times for delivery of a car at more than six months to a year for popular models. The median chip inventory held by industrials fell from 40 days in 2019 to less than 5 days during 2021. The shortage is anticipated to ease in the second half of 2022, but manufacturers have warned that a return to normality is not in sight even as record high investment has been announced in new production capacity, notably in the United States. EV manufacturers, which are heavy users of microchips, have found ways to manage supply and demand imbalances through increased delivery lead times, delayed customisation where non-essential elements of the car are retrofitted once available, and software updates to allow for use of different chips already in inventory.

The global production capacity of batteries is set to increase from below 200 GWh in 2019 to over 1 200 GWh in 2024, following massive capital expenditure in 2021 by listed battery manufacturing companies, rebounding from a large dip during the pandemic. These companies are now investing three times as much as they did in 2020. In 2021 China led global battery manufacturing capacity by controlling around 75% of the world's total, followed by the United States, Hungary and Germany. In 2024 China is expected to control two-thirds of the total, followed by the United States (10%), Germany (5%), Norway (2%) and France (2%).

Despite lockdowns and chip shortages, BEV production in China is at 80% of last year's average and is proving more resilient than production of conventional cars



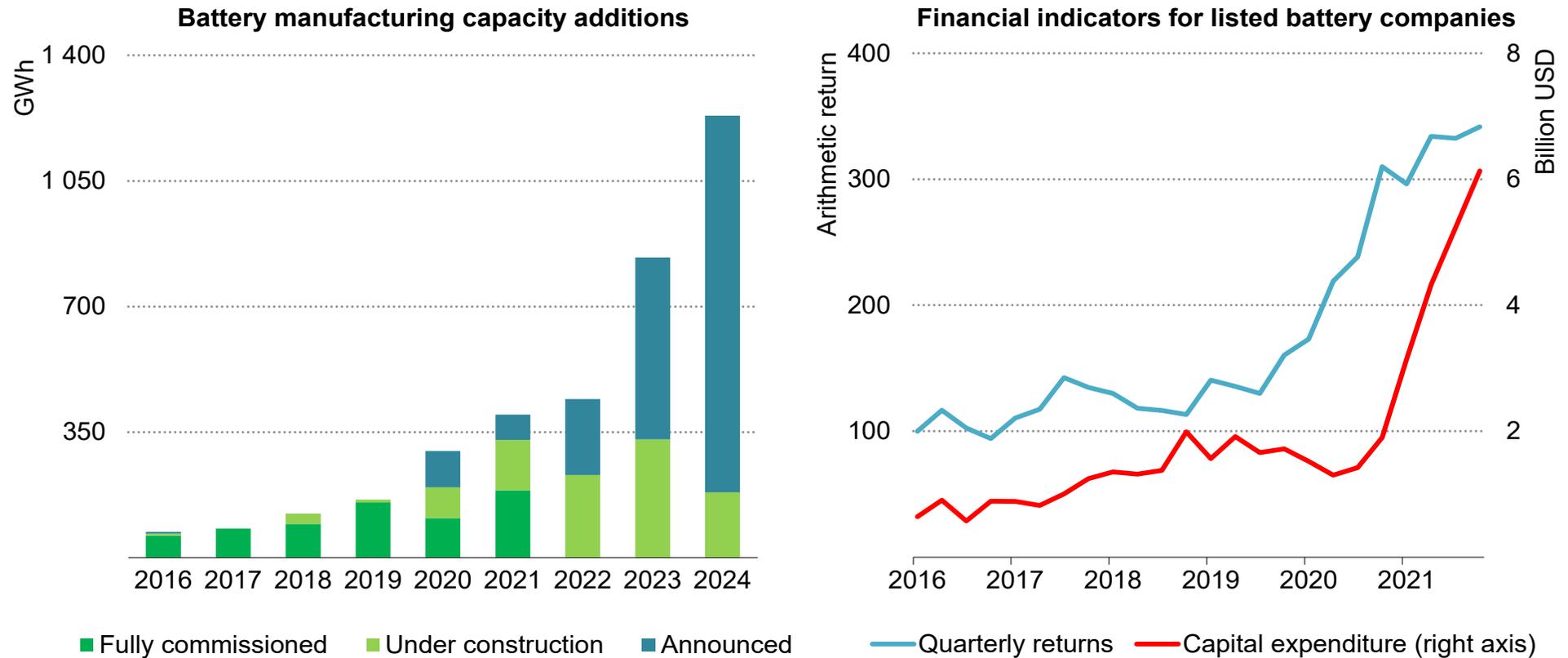
IEA. All rights reserved.

Notes: BEV = battery electric vehicle. Data as of 30 April 2022.

Source: IEA analysis based on Bloomberg terminal (2022).

Capital expenditure by listed battery manufacturing companies surged to 6 billion USD in Q4 2021, with a steady growth in production capacity expected by 2024

Global trends in battery manufacturing industry, 2016-2024



IEA. All rights reserved.

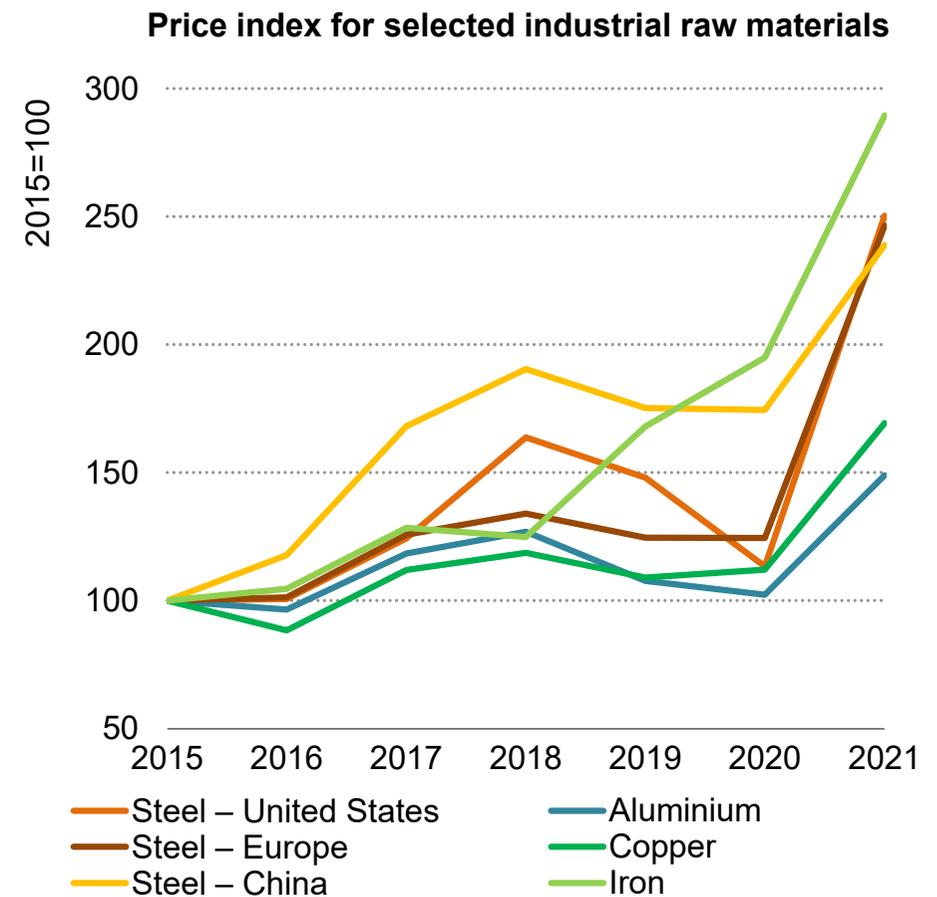
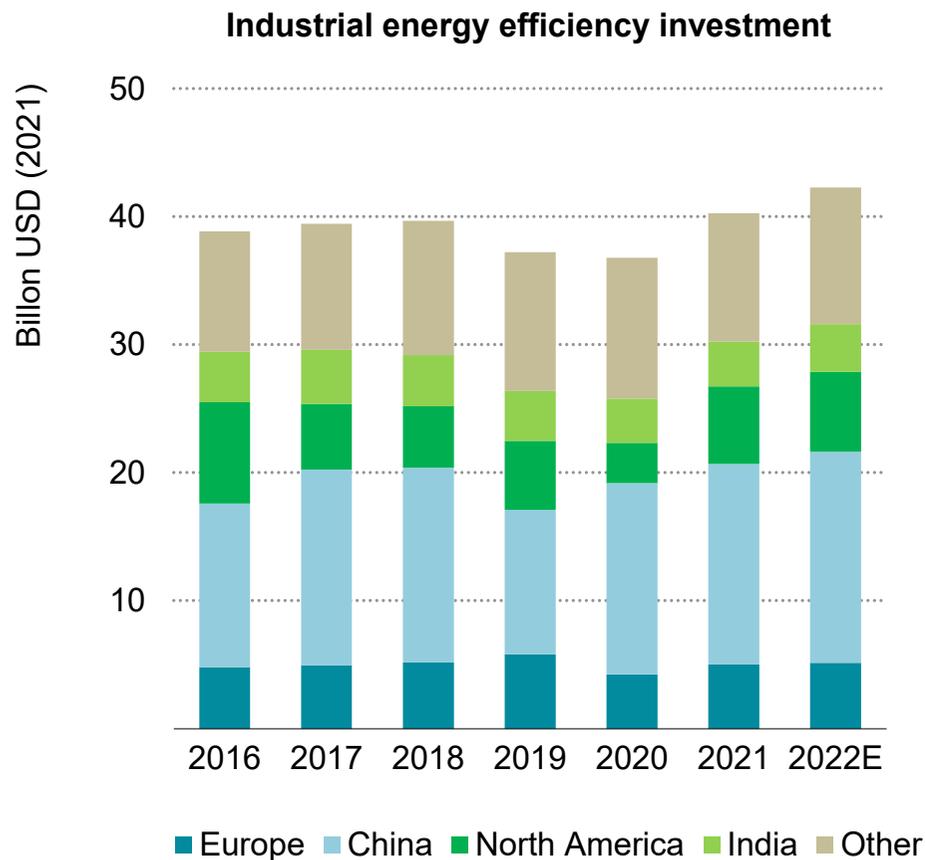
Notes: Listed battery companies comprise LG Energy Solution, BYD, Contemporary Amperex Technology, Samsung SDI, Gotion High-tech, Eve Energy and Farasis Energy Gan Zhou. 2021 values based on fully commissioned capacities. 2024 values based on announced, under construction and fully commissioned capacities.

Sources: IEA analysis based on BNEF (2022) and Bloomberg terminal (2022).

Industry

Industrial-sector energy efficiency investment rebounded in 2021, but new Covid lockdowns, record raw material prices and supply chain bottlenecks present challenges

Energy efficiency investment in the industrial sector, 2016-2022, and cost index for selected raw materials, 2015-2021



IEA. All rights reserved.

Source: IEA calculations based on [Oxford Institute of Economics and Statistics](https://www.oxfordinstitute.com/).

Economic recovery has been stronger and faster than expected, leading to rising industrial production and investment in energy efficiency

Investment in energy efficiency rebounded strongly in 2021 at about 10% growth, surpassing pre-pandemic levels as the recovery proved stronger, especially in North America and China, where Covid-19 impacts were lower than expected in 2021. Worldwide industrial material production grew by around 10% for crude steel and cement and 5% for aluminium. Chemicals remained stable.

Several recovery measures were introduced around the world that led to the rebound in industrial energy efficiency investment in 2021. This was especially so in the United States, where the Infrastructure Investment and Jobs Act and Build Back Better plans sent a very strong signal to invest and are driving energy efficiency improvements in industrial production. Better prospects for chemical production in 2022 (up 10% for propylene and aromatics so far this year) are also driving efficiency investment upward in North America.

In China the 14th Five-Year Plan has an objective to reduce the energy intensity of the economy by 2.6% per year by improving energy efficiency and accelerating the low-carbon transition. It implies revised production peaks for crude steel in 2025 of 1.16 Gt (or 14% more than in our previous estimates). Cement production levels are also rising and set to surpass 2.5 Gt in 2022.

The overall restructuring of China's industrial sectors means large-scale efficiency gains and renewed investment can be expected from efficient technologies, such as heat pumps for low-temperature heat.

Massive recovery packages targeting energy efficiency in Europe also sustained investment levels in 2021, compounded by new national laws, support packages (e.g. the climate change and energy transition law in Spain) and [green procurement commitments](#). In France, the decarbonisation roadmap for the chemicals sector was adopted and [Arcelor-Mittal announced a series of investments with public support to replace coal-fired furnaces with electric and hydrogen-based furnaces in Europe](#). Sustainable and transition finance is increasingly being considered to help decarbonise the sector. In exchange for Paris-aligned commitments, the Japanese government has published basic guidelines and roadmaps to help industrials access sustainability-linked debt funding. In H1 2022 Baowu Steel Group, the world's largest steelmaker, issued China's first transition bond (USD 70 million) to fund hydrogen-based iron production.

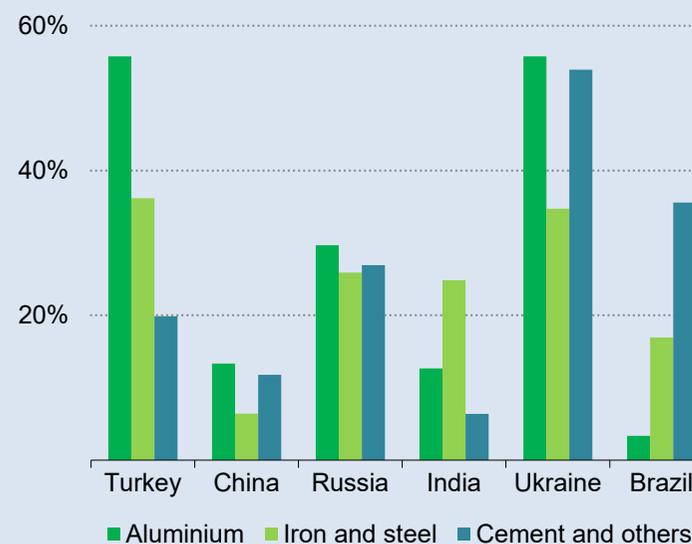
Box1.1 Potential impacts of the Carbon Border Adjustment Mechanism on trade

In March 2022 the European Council agreed on the principles of setting up a Carbon Border Adjustment Mechanism (CBAM) as part of its Fit for 55 package, which has a target to reduce emissions from the bloc by at least 55% by 2030 compared to 1990 levels. The CBAM's objective is to avoid carbon leakage from goods and services imported into the European Union by applying a carbon levy on imports from emission-intensive industries by mirroring the fees that European companies are required to pay as part of the EU Emissions Trading Scheme (ETS). In a first phase set to start in 2026, the CBAM would apply to sectors deemed at high risk of leakage such as iron and steel, aluminium, cement and electricity generation. The mechanism will exempt products imported from countries where a carbon price is in place at levels similar to those in the ETS. The aim is to encourage trading partners to consider either decarbonising their production process or implementing equivalent emission pricing schemes.

Currently, 21.5% of global emissions are covered by carbon pricing instruments and only 3.76% at a price above the USD 40-80 range recommended to keep warming below 2°C. The CBAM poses risks for countries with a high level of exports to the European Union and some are already working on implementing instruments to price emissions (e.g. China, Turkey). However, matching price levels seen in the EU ETS (~USD 90/tCO₂-eq) will prove difficult.

The United States and European Union are also discussing a [Carbon-Based Sectoral Arrangement on Steel and Aluminium Trade](#), showing how bilateral agreements might pre-emptively address the impacts of the CBAM. Other countries have indicated their intention to challenge it under World Trade Organization rules. Yet initially [only 3.2% of the value of EU goods imports](#) would be covered by the CBAM.

Share of total exports to the EU for selected countries and materials relevant for CBAM



IEA. All rights reserved.

Source: IEA calculations based on [UN Comtrade](#) data (based on cumulative 2017-2021 USD value of exports)

Industrial clusters

Industrial clusters are geographical areas where businesses, either similar in scope (e.g. chemical parks), or at various stages of a sector's value chain (e.g. port terminal next to a steel plant) are co-located. Because of their large scale and significant share of an area's carbon footprint, existing clusters provide an opportunity to focus decarbonisation efforts on large emitters in concentrated areas.

A study by the [World Economic Forum and Accenture](#) has shown that these clusters can aim for net zero emissions by leveraging their size, proximity and complementarity of infrastructure to pool resources and implement measures. These span energy efficiency, electrification, renewables for heat and cooling, investment in hydrogen fuels and CCUS. Together with EPRI, they launched the “Transitioning Industrial Clusters towards Net Zero” initiative at COP26, which was joined by four global clusters.

Through grants and contracts for difference, governments are allocating funds to “legacy” clusters focused on decarbonising existing industries. But several funding facilities have also been launched to support the establishment of new clusters centred on renewable energy generation, hydrogen production and CCUS. The United Kingdom has announced that two industrial hubs are to receive a USD 1.5 billion grant for CCUS activities. France has launched four [calls for proposals](#) to support companies planning new

production of green products or investment in more mature technologies like low-carbon heat and energy efficiency, while the United States announced the provision of USD 8 billion for [Regional Clean Hydrogen Hubs](#).

The size of the investment needed in such major infrastructure projects means that the private sector is not ready to invest alone – steady government support will be necessary, especially in EMDEs. For instance, issues around land planning and permitting will need to be co-ordinated to make sure that sufficient levels of infrastructure can be built on time to meet decarbonation goals.

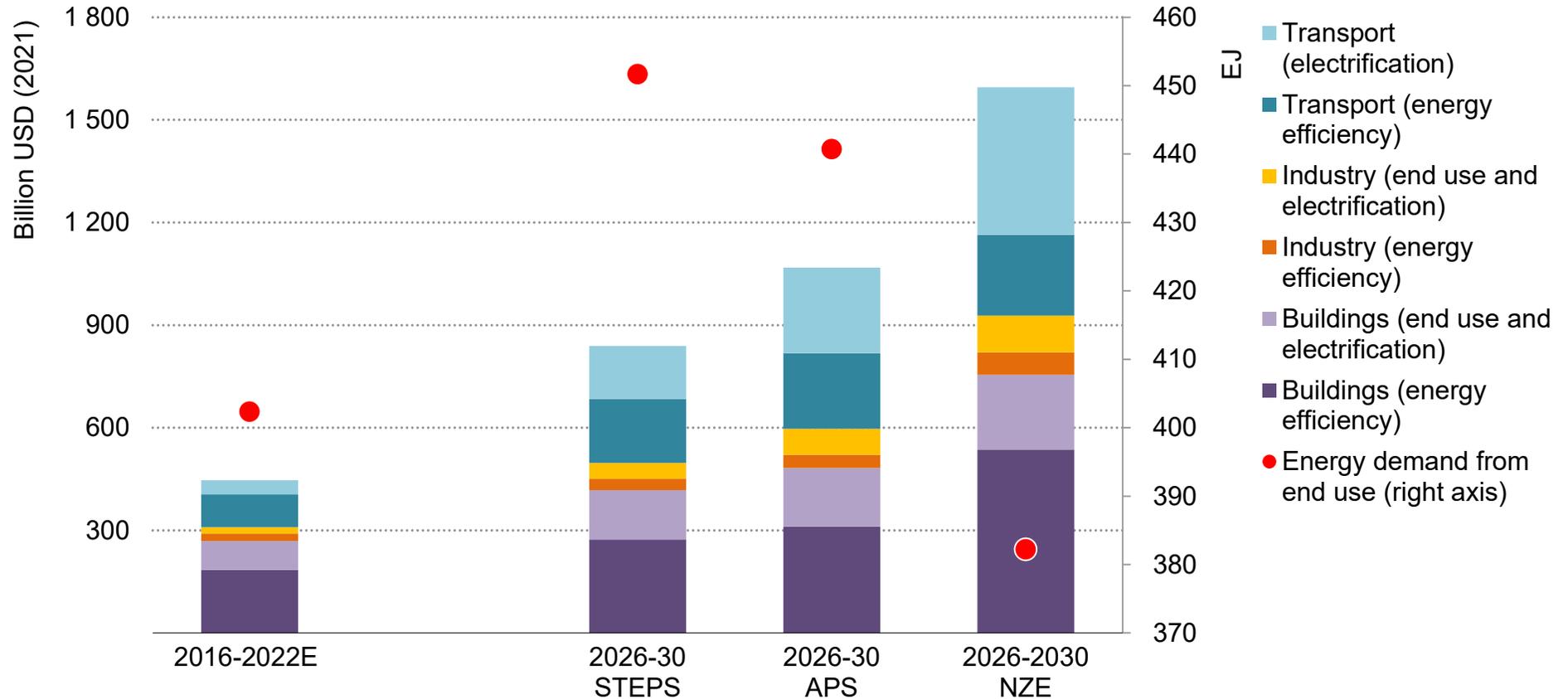
As in other sectors, carbon pricing and high fuel prices can constitute an incentive to invest in efficiency and abatement technologies, but prices will need to reach much higher levels than those seen today before industry chooses to invest in expensive low-carbon enabling infrastructure and CCUS on their own balance sheet.

While government support will continue to be required in the medium term, other new shared-ownership mechanisms among existing industrial companies or public-private partnerships could be established to ease the burden of up-front investment costs for private companies.

Implications

Spending on energy efficiency and electrification has surged in recent years...

Global investment in end-use and energy efficiency compared with annual average investment needs, by scenario, 2026-2030



IEA. All rights reserved.

Notes: APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario.

...but annual investment needs to almost quadruple by 2030 to keep climate goals in sight

Keeping the door open to achieving the objectives of the Paris Agreement requires an unprecedented acceleration in the pace of efficiency improvements and a drastic reduction in energy intensity across the entire economy. While levels of investment are set to rise in the coming years under the Stated Policies Scenario, sustained by sizable gains in the buildings and transport sectors, they still fall short of the requirements of the Announced Pledges Scenario and the Net Zero Scenario, which see a rapid uptake of electrification of transport, heating, cooling and industrial production, and a massive wave of retrofits and spending on new and energy-efficient buildings. By 2030 annual spending on energy efficiency, electrification and end uses is almost four times higher in the Net Zero Scenario than today. Even in the less ambitious Announced Pledges Scenario, investment is set to almost triple by 2030.

This year marks a decisive point for energy efficiency, as the world's geopolitical situation, the high price cycle of fuels and ultimately [the urgency of curbing GHG emissions](#) call for an urgent acceleration in reducing the carbon intensity of the economy and in some cases dependence on foreign energy imports. Examples of well-designed incentive packages, accommodating fiscal policies and increasingly ambitious regulations abound, notably in Europe, but most countries still lack the basic enabling environment for energy efficiency investment.

Overall, the drivers for continued investment in energy efficiency lie in the presence of long-term, predictable and ambitious signals from policy makers. Carefully designed regulations and roadmaps that set mandatory building codes, retrofit mandates, gradual elimination of internal combustion engine sales, and green public procurement of industrial materials are all sending long-term messages that enable proper planning and decision making from private-sector investors, especially as energy-efficient systems tend to involve high purchase costs and long lifetimes.

Broad access to affordable financing will also remain pivotal, as energy improvements increasingly rely on debt. Ensuring the long-term sustainability of incentive mechanisms will be vital, especially as the fiscal space tightens for some countries. The use of capital markets and innovative burden-sharing contracts are still in their infancy, but will prove decisive in unlocking access to broader pools of finance for energy efficiency investment.

Not only is investment in energy efficiency necessary to achieve climate goals, but it can also be a formidable driver of growth and job creation. The Superbonus scheme in Italy, for example, is estimated to have [created jobs and GDP growth](#). Countries need to roll out tailored programmes widely to enable investment in energy efficiency at the pace and scale required to reach net zero emissions by 2050

R&D and technology innovation

Overview

The strategic importance of energy innovation, including research and development (R&D) and demonstration, remains as high as ever: without a significant increase in energy innovation spending, climate goals and long-run economic prospects are at risk. But the market uncertainty that has resulted from the Covid-19 pandemic and the destabilising war in Ukraine is affecting spending on energy innovation, just as it has affected investment in other energy assets. Policy support for clean energy innovation counteracts this uncertainty by bolstering public and private efforts while directing them towards long-term sustainable outcomes. This shifting balance of factors colours our outlook for investment in the near term.

Uncertain economic times typically lead to a decline in R&D, especially in the business sector. As a labour-intensive and intangible area of investment, R&D spending cannot usually be recovered simply by selling resulting assets. Delaying new R&D projects is thus a common response to growing revenue risks. The uncertainty caused by Covid-19 – with the expectation of a rapid bounceback in market demand – produced only short delays in project launches and therefore a relatively mild dip in spending. Indeed, surveys during 2021 of corporate R&D spending intentions for 2022 showed plans for growth after two years of stagnation. While some innovative smaller firms' R&D plans did not survive, acquisitions will have helped others to be realised.

In the energy sector, some of the uncertainty has been tempered by expectations that the market will be increasingly receptive to new low-carbon products, partly due to stimulus spending on infrastructure. However, questions remain about the pace of energy transitions and the design of climate policies, and these uncertainties have now been exacerbated by war in Ukraine and high, volatile energy prices in 2022. In the short term, technologies that are not yet market-ready will do little to ease prices or increase energy security.

In WEI 2022 we bring together multiple indicators of investment in the development of tomorrow's energy technologies, including public R&D, private R&D, fundraising by start-ups and corporate venture capital (CVC). A picture emerges of rising public funding support for energy innovation, totalling USD 38 billion. This is the backbone of energy innovation spending, providing a vital guide to priority technology areas and, under higher interest rates, reducing private-sector exposure to more costly sources of capital. However, the high expectations of governments' recovery plans for infrastructure-led demonstration projects are yet to be translated into operational programmes. Furthermore, some of these plans carry objectives linked to national technology sovereignty and building less globalised value chains. While bigger budgets and greater interest in equitable outcomes are very welcome, these approaches are likely to be less effective at accelerating innovation and driving down the costs of

achieving net zero emissions compared with more rapid exchange of ideas through trade, cross-border investment and intergovernmental co-operation.

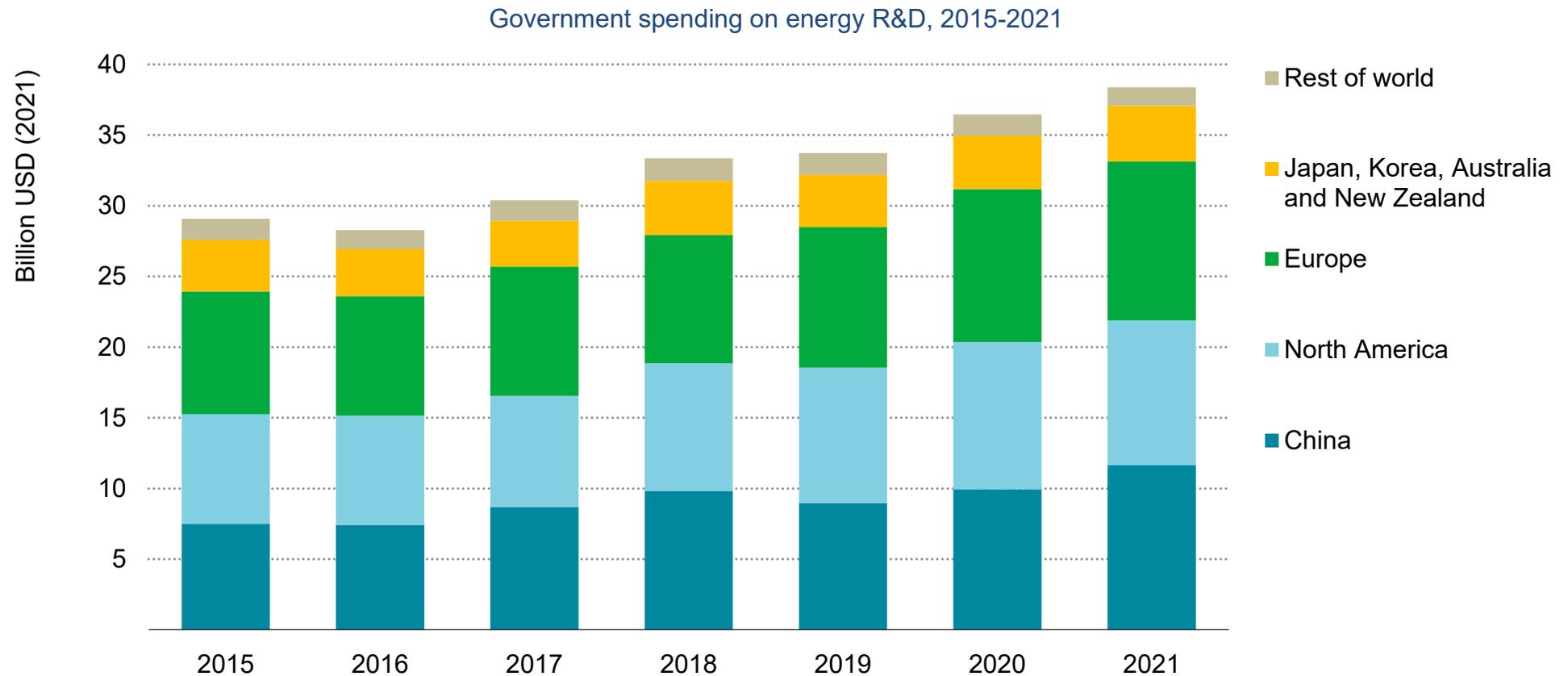
Recovery programmes may now face new challenges of navigating an evolving trade and knowledge exchange landscape, and compensating for lost time: in 2021 outside China, growth in government energy R&D spending was slower than the previous four years and corporate energy R&D spending stagnated. However, in the data on heavy industry and early-stage venture capital two bright spots appear: the iron and steel and cement sectors' R&D budgets seem to be responding actively to the decarbonisation challenge. While clean energy continued to attract record amounts of early-stage equity funding in 2021 – reinforcing investors' willingness to

take risks on “asset-heavy” hardware companies – headwinds now face start-ups trying to raise venture capital in 2022: uncertainty, inflation and higher interest rates are reorienting investors from long-term growth to less risky investments.

A further trend in the private sector is to minimise risks and prepare for diverse technology futures through greater collaboration in research alliances and partnerships and by investment in innovative start-ups. The growth in CVC, whereby funds are generally pooled by a group of investors who enter after the basic research stage, is an example. These trends are supported by [new public policies](#) that target clean energy start-ups and unprecedented equity investment in potentially disruptive energy technology companies.

Spending on energy R&D

Government spending on energy R&D increased in 2021, but Covid-19 uncertainties slowed growth



IEA. All rights reserved.

Notes: Includes spending on demonstration projects (i.e. RD&D) wherever reported by governments as defined in [IEA documentation](#); 2021 is a preliminary estimate based on data available by mid-May 2022; state-owned enterprise funds comprise a significant share of the Chinese total, for which the 2021 estimate is based on reported company spending where available; the IEA Secretariat has estimated US data from public sources.

Source: [IEA Energy Technology RD&D Budgets: Overview](#) (forthcoming).

Major new R&D programmes to support economic recovery and net zero ambitions promise a stronger steer towards priority technologies, but their financial impacts are yet to be felt

In 2021 public spending on energy R&D rose to USD 38 billion, nearly 90% of which was allocated to low-carbon energy R&D. However, at 5% the increase was slower than the annual average of 7% from 2017 to 2020. In IEA countries, a rare decrease in energy efficiency R&D funding in several countries was partly offset by more money for hydrogen and fuel cell R&D, the only technology category whose budget has systematically increased since 2015. While it remains too early to draw firm conclusions on the impacts of Covid-19, there are signs that it has not been a significant setback, and may be followed by a major boost in spending as economic recovery takes effect. Funding increases were earmarked by governments around the world in 2021 as part of stimulus packages, much of it for hydrogen, CCUS and energy storage.

In Europe new funding programmes have been launched. Among these, [Breakthrough Energy Catalyst](#) is a novel approach to public funding in tandem with a private entity, Breakthrough Energy. In total, USD 1 billion of public and private funds could be available for EU demonstration projects in clean hydrogen, long-duration energy storage, sustainable aviation fuel and DAC. In January 2022 the [first call](#) invited [projects](#) to apply for co-funding via the [InvestEU](#) economic recovery framework, alongside grants, equity and offtake agreements facilitated by the private partner to stimulate demand.

Italy is one of several European countries that made stimulus funding available for clean energy R&D: it [assigned](#) EUR 30 million (USD 33 million) from the Recovery and Resilience Plan to private-led hydrogen research projects and EUR 20 million (USD 22 million) to

projects at public research institutes. The United Kingdom has [announced](#) its largest-ever public R&D budget for 2022-2025 and a GBP 1 billion (USD 1.3 billion) [Net Zero Innovation Portfolio](#), nearly all the funds from which are already committed to 10 technology themes covering energy supply, storage and end use, and carbon dioxide removal.

In addition, EU programmes launched in previous years selected recipient projects in 2021, including the flagship Horizon Europe programme. The [first 37 projects](#) to be awarded Innovation Fund grants totalling EUR 1.2 billion (USD 1.4 billion) were announced, including [seven large-scale projects](#) in CCUS, PV manufacturing waste-to-energy and industrial decarbonisation. Another mechanism, Important Projects of Common European Interest (IPCEI), confers first-of-a-kind and cross-border projects with exemptions from EU competition rules, exemptions that have only previously been conferred on two transport infrastructure projects, but are now promoted for battery and hydrogen assets. In 2021 [EUR 2.9 billion](#) (USD 3.2 billion) in national public funding for the battery value chain was unlocked through IPCEIs. Hydrogen IPCEI projects proposed by 22 countries are under consideration and look set to test the effects on EU internal market competition of a larger IPCEI role.

In 2021 the Australian government launched the first calls under its [Technology Investment Roadmap](#), through which it plans to invest over [AUD 22 billion](#) (USD 15 billion) in low-emission technologies in the decade to 2030 to support decarbonisation and economic recovery. In the year since the launch of the roadmap, AUD 2.5 billion

(USD 1.8 billion) has been [committed](#) to selected technology areas, including [hydrogen](#) and [CCUS](#). Australia and Germany each contributed around USD 37 million to a fund for hydrogen supply chain projects involving partners from both countries. This was not the only example of international co-operation on hydrogen in 2021, with new partnerships for project funding announced between Belgium and Oman, Belgium and Namibia, and Japan and the United Arab Emirates, plus private-sector agreements.

Japan's USD 18 billion ten-year [Green Innovation Fund](#) was announced in 2021 and launched its first calls the same year. Around USD 8.5 billion had been allocated to specific technology areas by January 2022. Of this, 29% is for hydrogen supply chains, 27% for CO₂ conversion to fuels and materials, 15% for batteries and motors, 12% for offshore wind, 7% for electrolysers, 5% for solar cells and 4% for CO₂ capture. Target technologies are at pilot stage or above and will be developed in Japan, with procedures to avoid technology leakage to other countries.

In the United States, the [Infrastructure Investment and Jobs Act](#), signed into law in November 2021 and fully funded in March 2022, represents a significant injection of stimulus funds into energy innovation. It creates an Office of Clean Energy Demonstrations to select, fund and manage demonstration projects, and co-ordinate government activities to bring them to market. The office is so far funded with USD 21.5 billion for the 2022 to 2025 period, [of which](#) 37% has already been allocated for hydrogen hubs, 22% for grids and energy storage, 16% for CCUS and 2% for industrial emissions avoidance. The US response to the Covid-

19 pandemic also includes an expansion of the ARPA-E SCALEUP programme to develop commercial-scale prototypes, for which it issued a USD 100 million call in December 2021. However, the [Build Back Better Act](#), which could add more than USD 10 billion in energy innovation spending, remains stalled in the legislative process.

We estimate that China was the largest source of public energy R&D spending growth in 2021 in absolute terms, as it entered the first year of its 14th Five-Year Plan (2021-2025), staying slightly ahead of the United States. For environmental and economic reasons, China emphasises clean energy innovation strongly in the plan, which includes [a planned increase](#) in energy R&D spending of 7% per year, among the measures to improve Chinese energy innovation performance. If realised, this could lead to China substantially outspending the European Union and United States by 2025. China also [announced](#) more open competitions for funds, national innovation centres for carbon neutrality, a hiatus for taxes on imported R&D equipment, and consolidation around five key areas (CCUS, hydrogen, industry, digital, and advanced biofuels).

A notable feature of recent energy technology funding announcements is the inclusion of critical minerals. Since September 2020 the United States has published calls for energy-relevant critical minerals research worth around USD 320 billion. In 2021 Korea [announced](#) support for large-scale R&D projects for novel batteries worth KRW 500 billion (USD 0.4 billion) by 2028 and a target of 100 firms to be engaged in rare metals supply chains by 2025.

IEA member countries more than doubled public spending on non-fossil energy R&D following the oil shocks of the early 1970s

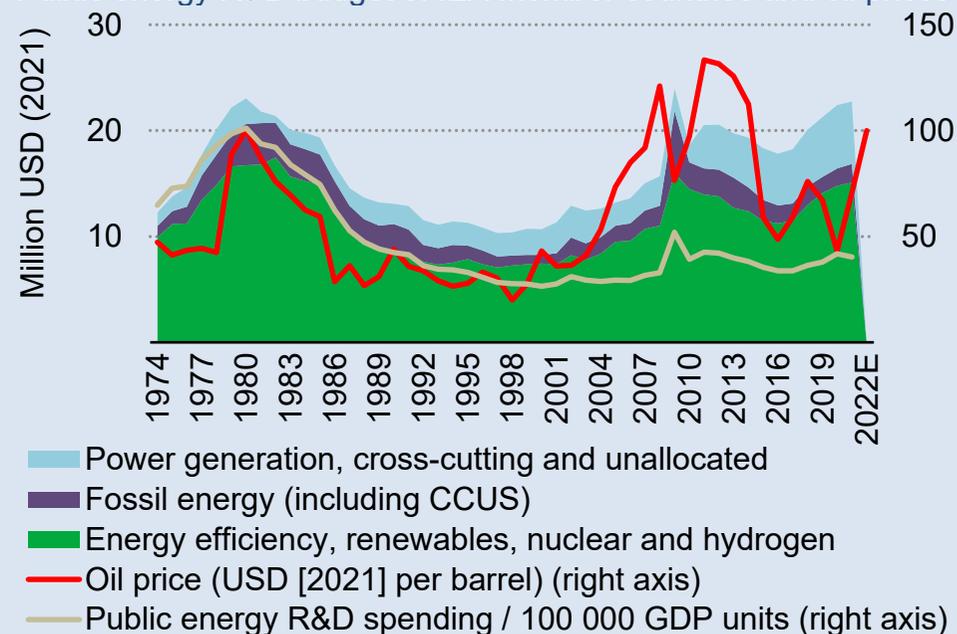
If history is any guide, today's elevated fossil fuel prices and energy security concerns could further bolster the priority governments are attaching to clean energy innovation. This was the case following the oil shocks of the early 1970s. Between 1974 and 1980 IEA member countries more than doubled their public spending on non-fossil energy R&D. Between the mid-1990s and early 2010s they increased it by over 70% as oil prices rose again.

When looking at the potential to raise spending today, the ratio of public spending on energy R&D to national income is instructive. While the current trend in public R&D spending has been steadily upwards even before the energy crisis this year, it represents a much lower share of GDP than in the 1970s.

In 2022 several countries and regions have set explicit targets for accelerating the substitution of fossil fuels with low-carbon energy sources and energy efficiency. While some of these targets are short term, and will require behavioural changes and rapid uptake of existing technologies, they will also be more achievable if the cost of low-carbon technologies falls across the spectrum. At a time of inflation and higher energy

costs, public spending can unlock private co-funding for R&D by modifying projects' risk profiles relative to other capital expenditure. Several governments – including China, Denmark, Germany, Japan, the United Kingdom and the United States – have announced increases in funding for clean energy R&D programmes for the period to 2030.

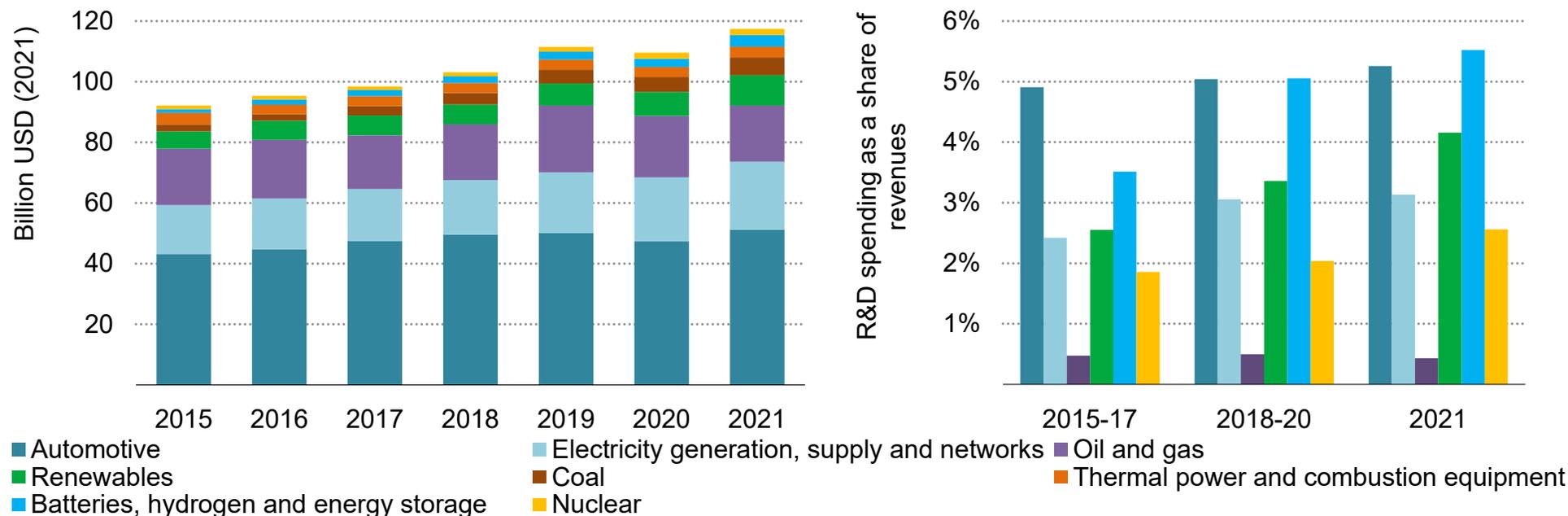
Public energy R&D budget of IEA member countries and oil prices



IEA. All rights reserved.

Corporate energy R&D spending returned to growth in 2021, with uplift in China and renewables compensating for tightened budgets elsewhere and among fossil fuel companies

Spending on energy R&D by listed companies (left) and R&D budgets as a share of revenues (right), by sector of activity, 2015-2021



IEA. All rights reserved.

Notes: Values for 2021 are estimates based on reported data at the time of drafting. Corporate energy R&D spending includes reported R&D expenditure by companies active in sectors that are dependent on energy technologies, including energy efficiency technologies where possible. Automotive includes technologies for fuel economy, alternative fuels and alternative drivetrains. Fuel cells are included with hydrogen. To allocate R&D spending for companies active in multiple sectors, shares of revenue per sector are used in the absence of other information. Classifications are based on the Bloomberg Industry Classification System. All publicly reported R&D spending is included, though companies domiciled in countries that do not require disclosure of R&D spending are under-represented. Depending on the jurisdiction and company, publicly reported corporate R&D spending can include capitalised and non-capitalised costs, from basic research to product development. Coverage has been expanded relative to previous editions. The right-hand figure considers the top 20 companies earning over half of their revenues in each sector, and represents average R&D spending as a share of revenues weighted by the sectoral R&D spending of each company.

Source: IEA calculations based on Bloomberg (2022).

Automotive companies maintained strong R&D spending in 2020 and 2021 despite a slump in revenues, as firms seek a technological edge in a fast-changing mobility sector

A dip in fossil fuel R&D spending was outweighed by continued growth in electric mobility and renewables

In 2021 energy R&D spending by listed companies reached around USD 117 billion, 5% higher than pre-pandemic levels in 2019. Among the technology areas, spending related to oil and gas fell for the second consecutive year to below USD 20 billion, back to levels comparable with the 2015-2018 period. Firms in this sector already had relatively low R&D spending per unit of revenue, and it dropped by over one-tenth to 0.4%. This was balanced by the largest single-year uptick in corporate spending on renewable energy R&D since 2015. At USD 10 billion, our estimate stands about 55% higher than five years ago.

Automotive, the largest area of energy-related corporate R&D spending, was up 8% in 2021 to USD 51 billion. This represents a return to 2018-2019 levels and a further rise in the sector's R&D spend per unit of revenue, which at over 5% has been joined by the batteries, hydrogen and energy storage fields. With most leading carmakers revealing new strategies and technology plans to accelerate electrification since 2020, the competitive pressures driving this trend seem resilient to short-term disruption. They are likely to be strengthened by additional government action to reduce oil demand and establish secure supplies of battery minerals while

managing high commodity prices, such as for steel. Since May 2020 the European Investment Bank has [extended](#) over USD 400 million in loans to support the cleaner mobility R&D programmes of eight European automotive firms.

Across all energy technology areas, much of the growth came from companies headquartered in China, which together accounted for 35% of the total in 2021. Had Chinese companies kept energy R&D spending at 2020 levels, the global trend would have been much flatter, with a 2% and not a 5% rise. Chinese companies are among the highest spenders in several fields (see table below).

R&D is rising in some hard-to-decarbonise sectors, but others do not yet match net zero ambitions

The heavy industry and long-distance transport sectors are in need of some of the most transformational changes in technology to realise net zero pledges. This turns the spotlight onto companies not typically classified as part of the energy sector. Only some of their R&D relates directly to energy efficiency or fuel switching.

Total R&D spending by companies in two segments – cement, and iron and steel – has risen markedly since 2015. In 2021 cement companies spent USD 2.3 billion on R&D, a sharp increase

compared with 2020 and up 170% from 2015. Similarly, iron and steel producers spent about USD 20 billion on R&D, and steady annual growth has delivered 110% more spending since 2015. These rates are faster than those in the energy supply and automotive sectors, but their R&D spending per unit of revenue nonetheless remains low. Large cement firms spend around 1% of their revenues on R&D, less than five years ago, while large iron and steel companies have raised this ratio to over 2.5%. Among major firms, HeidelbergCement is [planning](#) to open the world's first CO₂-neutral cement plant by 2030, and ArcelorMittal [borrowed](#) USD 330 million from the European Investment Bank for climate-related R&D for its steel production.

A similar increase has also been seen in chemicals, and pulp and paper, but not long-distance transport. Among these, chemicals remains the largest R&D spender, though its share of revenues spent on R&D has fallen from 4.3% in 2016 to 2.9% in 2021. Since 2021 [BASF](#) and [Mitsubishi Chemicals](#) have confirmed net zero emission targets for 2050, including aims for new technologies. Their spending beat the [expectations of budget-cutting](#) at the pandemic's outset.

In 2021 R&D spending by long-distance transport companies dropped: by 12% in shipping, 7% in aviation and 1% in rail, sectors badly hit by the pandemic. Aviation firms are investing more in start-ups focusing on electric and hydrogen-based powertrains, reflecting an evolving approach to innovation that complements in-house R&D. Airbus, for example, is pursuing several hydrogen options to meet its 2035 [target](#) for developing a zero-emission commercial aircraft.

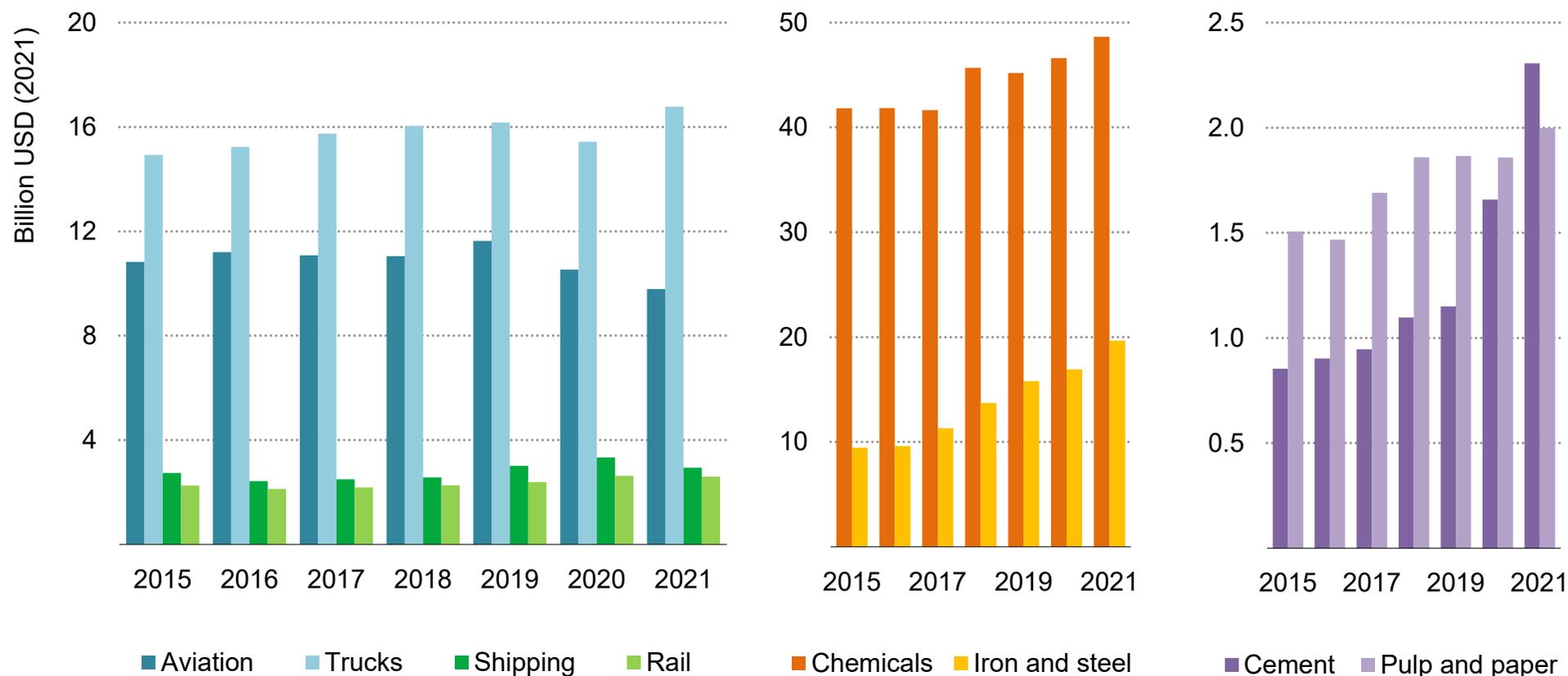
Corporate R&D budgets, inflation and fossil fuel prices

Today's high fossil fuel prices are likely to affect corporate energy innovation, although the duration and nature of the impact are hard to predict. Studies have [demonstrated positive correlations](#) between oil prices and patenting activity for renewable energy technologies, with stronger effects when the renewable energy knowledge stock is larger. Given the significant accumulation of knowledge on non-fossil and energy efficiency technologies in recent years, we might expect higher prices to induce focused strategic and policy responses that, in turn, raise R&D budgets and subsequently patents.

However, models are largely untested for high fuel prices together with inflation that squeezes profits for all firms. Higher interest rates [raise the cost of capital for R&D](#) and tend to reduce R&D in smaller firms and those that cannot mitigate risks with government grants and loans. Yet historical data are a poor guide to the responses of the major oil and gas producers that will benefit from higher prices and are presently engaged in significant low-carbon energy R&D. While spending is likely to be stimulated by 2024, if not before, much will depend on expectations about whether high prices are a temporary phenomenon or a more secular counterpart to geopolitical changes. Government measures can be used to offset some of this impact. In a move to stimulate R&D spending in the near term, the US [Infrastructure Investment and Jobs Act](#) delays the need to amortise corporate R&D expenditure until the end of 2025. Public R&D funding can also be mobilised to maintain clean energy R&D spending.

Corporate spending on R&D increases in cement and iron and steel, decreases in aviation

R&D spending by globally listed companies in heavy and long-distance transport (left) and industry (middle, right) by activity, 2015-2021



IEA. All rights reserved.

Notes: Values for 2021 are estimates based on reported data at the time of drafting; classifications are based on the Bloomberg Industry Classification System; trucks include recreational vehicles, but not industrial vehicles.

Source: IEA calculations based on Bloomberg (2022).

Chinese companies report the highest R&D spending in several key energy-related sectors

Top R&D spenders in 2021 among listed companies, by sector from which they generate over 50% of revenue

Sector	Companies	R&D (USD million)
Automotive	Volkswagen (Germany)	18 341
	Toyota Motor (Japan)	10 286
	Daimler (Germany)	9 101
	BMW (Germany)	8 126
	General Motors (United States)	7 900
Batteries, hydrogen, storage and fuel cells	LG Chemicals (South Korea)	1 215
	CATL (China)	1 193
	Tianneng Battery (China)	222
	EVE (China)	214
	Wuxi Lead Intelligent (China)	166
Coal	Shandong Energy (China)	776
	China Coal Energy (China)	703
	Shanxi Coking (China)	451
	Jinneng Holding (China)	410
	Huabei Mining (China)	257
Oil and gas	Petrochina (China)	2 594
	Sinopec (China)	1 780
	Saudi Aramco (Saudi Arabia)	1 033
	Exxon Mobil (United States)	843
	Total Energies (France)	824
Renewables	Siemens Energy (Germany)	1 381
	China Construction Engineering 8th Bureau (China)	963*
	Longi Green (China)	681
	Vestas Wind (Denmark)	525
	TBEA (China)	428

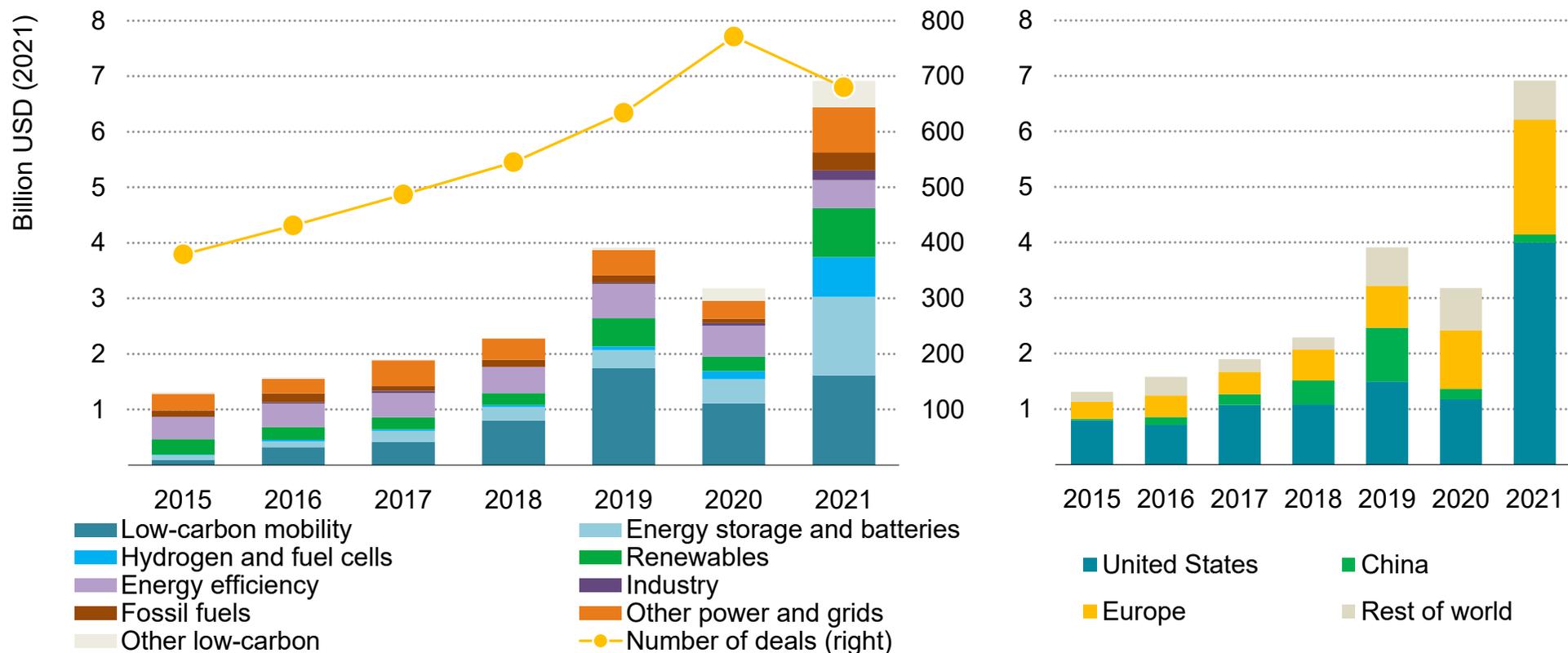
* Refers to a 2020 value in the absence of 2021 reported data.

Sources: IEA calculations based on corporate financial filings and Bloomberg (2022).

Venture capital funding of early-stage energy technology companies

Early-stage clean energy start-ups raised twice as much money in 2021, as deal size swelled

Early-stage venture capital investments in clean energy start-ups, by technology area (left) and start-up location (right), 2015-2021



IEA. All rights reserved.

Notes: Early-stage deals are defined as seed, Series A and Series B deals. Very large deals in these categories – above a value equal to the 90th percentile growth equity deals in that sector and year – are excluded and reclassified as later-stage investments. Low-carbon mobility includes technologies specific to alternative powertrains, their infrastructure and vehicles, but not generic shared mobility, logistics or autonomous vehicle technology. Within Renewables, bioenergy includes transport biofuels but not biochemicals. Other low-carbon includes CCUS, nuclear and heat generation. Fossil fuels covers fossil fuel extraction and use, fossil fuel-based power generation, and fuel economy for hydrocarbon combustion vehicles.

Source: IEA calculations based on Cleantech Group (2022).

Despite the pandemic, start-ups in the United States and Europe raised record funds, boosted by energy storage, hydrogen and renewable energy technologies

A new high was reached in 2021 as energy technology start-ups raised USD 6.9 billion of early-stage venture capital (VC) funds, a doubling of 2020 levels. While energy VC in 2020 was impressively resilient to the economic impacts of the pandemic, even maintaining year-on-year growth in the number of deals, the average amount invested in each deal dipped significantly. However, this reversed dramatically in 2021, reflecting a combination of continued investor confidence in energy transitions, recognition that the transitions present major market opportunities for disruptive new energy technologies and buoyant VC markets (as investors struggle to find similar returns in other asset classes). Across all sectors, VC funding [increased by over 90%](#) in 2021 and unlisted clean energy assets continued to [outperform](#) market benchmarks.

Early-stage VC funding supports entrepreneurs with technology testing and design, and complements the much larger amounts of money spent on energy R&D by governments and companies. It plays a critical role in honing good ideas and adapting them to market opportunities. This typically fits technologies with lower upfront capital needs, but data for 2021 shows more investor appetite for “asset-heavy” technologies, including in aviation and heavy industry.

Later-stage VC funding focuses on scaling up promising businesses to larger projects, factories and contracts. These funding rounds are

much larger. In 2021 later-stage energy VC funding also grew by 70%, led by energy storage, batteries, hydrogen and fuel cells, with a doubling of investment in US-based start-ups.

However, in early 2022 VC markets were rocked by turmoil in stock markets and changing risk perceptions among investors, favouring near-term value over potential growth. Data for 2022 do not yet signal scarcity of capital for clean energy start-ups, but it is unclear if policy will partly insulate climate-related technologies from a downturn that looks set to seriously affect other early-stage technology firms.

EVs, aircraft and batteries lead the way

The increase in 2021 was led by low-carbon mobility and battery start-ups, which together accounted for about 35% of year-on-year growth and 40% of the early-stage total. However, this share is lower than in 2017-2019, as growth in 2021 was more evenly shared among technology areas. The most notable trend in early-stage mobility investment is a shift away from companies developing EVs and associated technologies.

Encouragingly, early-stage investors have turned attention to riskier mobility concepts, such as small electric aircraft. [Beta Technologies](#) raised USD 368 million to develop vertical take-off electric aviation

with the US Air Force, United Parcel Service and Amazon, one of its investors; it subsequently raised [a further USD 375 million](#) in April 2022. After a seed round in 2020, [AutoFlight](#), a German-Chinese competitor, raised USD 100 million in 2021. [Heart Aerospace](#), a Swedish start-up developing an all-electric short-haul plane with a 400 km range using today's lithium batteries, secured USD 35 million from investors including United Airlines and Mesa Air Group.

Meanwhile, there has been a rapid progression of EV start-ups through early-stage funding rounds in recent years and, as the market consolidates around a smaller number of major players, their presence in later-stage funding has risen. About USD 24 billion of late-stage VC was channelled into electric mobility and batteries in 2021, more than half of all capital raised by clean energy start-ups. In China, [new EV manufacturers](#) have moved quickly from early to later stages, including Leap Motor, Zeekr and Hozon, which together have raised over USD 2.5 billion since 2021.

As near-term market expectations for EVs are revised upwards, boosted by concerns about high oil prices and energy security, their batteries remain an area of technology uncertainty and competition. While early-stage VC supporting EV manufacturers has decreased since 2019, funding for battery manufacturers is booming, providing crucial capital to alternative chemistries and emerging concepts for critical mineral extraction, processing and recycling (see next page). Late-stage VC for energy storage and batteries also jumped in 2021

to over USD 12 billion, accounting for 45% of total year-on-year growth.

In China, battery developer [Svolt](#) raised over USD 3 billion, and in Chinese Taipei, solid-state EV battery maker [ProLogium Technology](#) secured USD 326 million to expand production overseas. In the United States, after raising USD 160 million from investors including [BMW](#), [Ford](#) and [SK Group](#), solid-state battery manufacturer Solid Power listed through [a merger with a special-purpose acquisition company](#) (SPAC), raising over USD 500 million. [Form Energy](#) raised USD 240 million to develop long-duration iron-air battery storage, including funds from ArcelorMittal. In Europe, French battery developer Verkor raised USD 118 million, including from the French government, Renault, Schneider Electric and Arkema, to build an R&D and pilot production facility. It had already [secured](#) USD 1.4 billion of project finance in 2020 towards a 50 GWh per year factory by 2030, as Europe expands public financing for the rapid scale-up of manufacturing by start-ups.

Hydrogen and heavy industry applications on the rise

Another notable trend is rising early-stage funding for innovative approaches to avoiding fossil fuel use in heavy industry. Boston Metals raised over USD 60 million to help move electrolytic steelmaking from the laboratory to prototype. Investors included a mix of iron ore producers and steel users, rather than steelmaking companies. [ElectraSteel](#), a competitor, raised USD 30 million in its

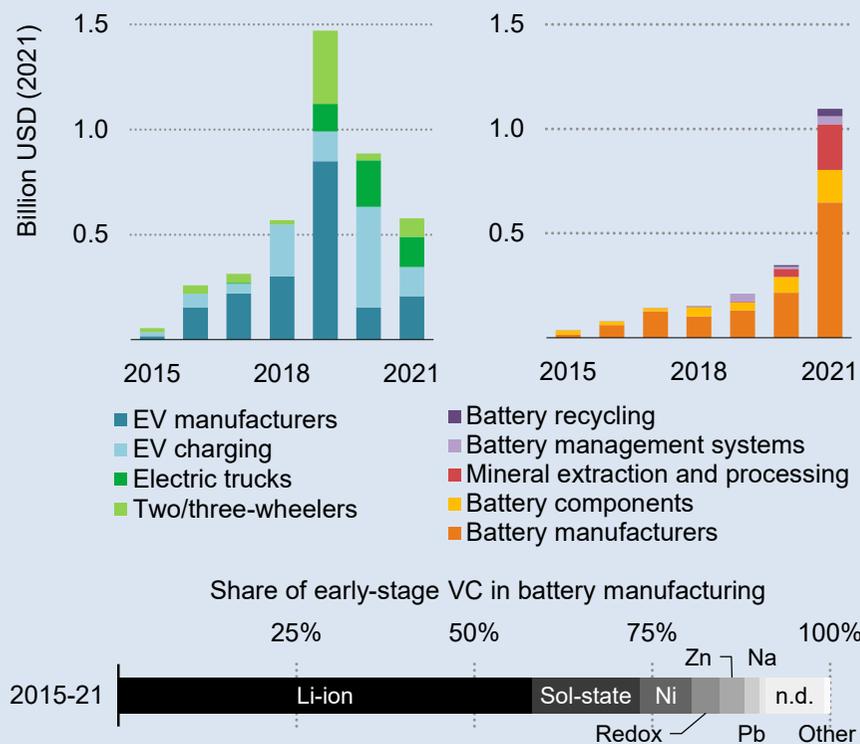
very first funding round. In the cement sector, [Fortera](#) raised USD 30 million to develop a process for converting CO₂ to cement.

One indication of how fast the sector is moving comes from large deals for project developers that do not own proprietary technology. Swedish company [H2 Green Steel](#) raised over USD 100 million for its plans to develop several hydrogen-based steel plants this decade by purchasing and integrating other companies' equipment. In general, hydrogen continued to attract large amounts of early-stage risk capital. Start-ups developing hydrogen and fuel cell technologies

raised nearly four times more early-stage VC in 2021 than in 2020, reaching about USD 800 million. In China, Weishi Energy, established by carmaker Great Wall Motors, [raised](#) nearly USD 150 million to advance fuel cell trucks and maritime transport. In Germany, Sunfire raised over USD 200 million for electrolyser development and manufacture, while HTEC in Canada [raised](#) USD 170 million to expand deployment of its refuelling technology.

Early-stage VC investment shifts from EV to battery manufacturing and critical minerals

Early-stage VC investment in EVs and batteries by type (top) and in battery manufacturing start-ups by chemistry (bottom)



Notes: n.d. = non-disclosed chemistry; Redox = redox flow batteries, including vanadium-based chemistries.

Source: IEA calculations based on Cleantech Group (2022).

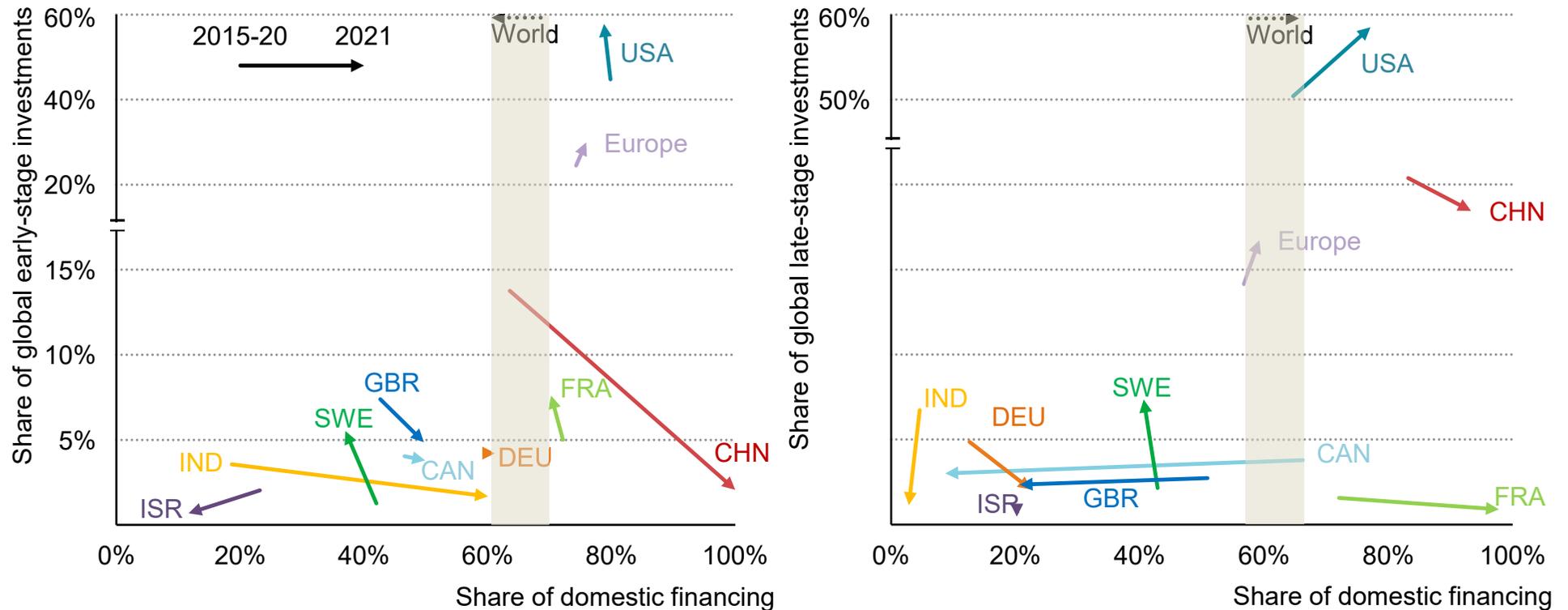
Early-stage VC investment in EVs and battery technologies exceeded USD 1.5 billion in 2021. As EV markets mature and major car manufacturers commit to electrification, EV-related investors and start-ups are focusing more on components and battery value chains, including for stationary applications. The opportunities for innovators in this area are large: for low-carbon electricity to displace unabated fossil fuels across the economy, battery performance must be improved while slashing costs and supporting secure supplies of certain [critical minerals](#), including via recycling, repurposing and new mineral sources.

Manufacturing (including components) accounted for 75% of early-stage battery VC in 2021, mainly for lithium-ion or solid-state designs (e.g. [Verkor](#), [BritishVolt](#), [Mitra Chem](#)). However, capital is increasingly flowing to chemistries with nickel or zinc (e.g. [EnerVenue](#), [e-Zinc](#), [Aesir](#)), vanadium redox flow (e.g. [VRB](#), [VFlow](#)), sodium (e.g. [Tiamat](#), [LiNa](#), [Altris](#)) and bipolar lead acid (e.g. [Advanced Battery Concepts](#)).

In 2021 local and more sustainable mineral extraction and processing start-ups (e.g. [Lilac Solutions](#), [Cornish Lithium](#), [EnergyX](#), [Mangrove Lithium](#)) raised over USD 200 million in early-stage VC, a big jump from previous years, and battery recycling start-ups raised USD 30 million (e.g. [Ascend Elements](#), [Green Li-ion](#), [Moment Energy](#), [betteries](#)). Some companies (e.g. [Lohum](#)) are seeking to integrate vertically both battery manufacturing and recycling.

Early-stage clean energy VC investment has become more globalised

Share of global deal value by start-up location versus the share of these deals financed by domestic investors at early stages (left) and later stages (right), selected countries, 2015-2021



IEA. All rights reserved.

Notes: CAN = Canada; CHN = China; DEU = Germany; FRA = France; GBR = United Kingdom; IND = India; ISR = Israel; SWE = Sweden; USA = United States. Late-stage deals are defined as growth equity, private equity, buyouts and private investment in public equity. Seed, Series A and Series B deals larger than a value equal to the 90th percentile of growth equity deals in that sector and year are also included. Calculation of the share of global deal value is based on a larger sample than that for the share of domestic financing, which does not include deals for which investor data are unavailable. Where no investment splits are available, it is assumed that all investors in a deal round contribute equal capital.

Source: IEA calculations based on Cleantech Group (2022).

Outside major hubs like the United States and China, most countries do not have available local investment funds to match the needs of their clean energy start-ups, especially during scale-up

While the geographical spread of clean energy start-ups covers more countries than in 2015, with notable growth in Europe, the United States reasserted its dominance in 2021. US start-ups raised nearly 60% of total early-stage investment, up from 45% on average over the 2015-2020 period, and more than three times what they raised in 2020. US start-ups led in industry-related technologies, with 75% of global investment in the technology area, as well as leading in power and grids (70%) and electric mobility (60%). Companies established in Europe raised twice as much as in 2020, representing 30% of the 2021 total, up from 25% over 2015-2020. European start-ups accounted for 50% of VC investment in hydrogen and fuel cells, followed by electric mobility, and energy storage and batteries (each at 35%), and then renewables (30%).

Chinese energy start-ups have a higher presence in late-stage VC funding than early-stage. One-fifth of all later-stage energy VC went to companies in China in 2021. This largely reflects the ability of [young EV companies](#) to rapidly raise large sums in recent years (e.g. over USD 1 billion). Meanwhile, Chinese early-stage funding dipped in 2021: it represented just 2% of total investment compared with 14% over the 2015-2020 period. However, the 14th Five-Year Plan (2021-2025) is [set to target](#) hydrogen, energy storage and batteries with similar policy measures to those that supported EV

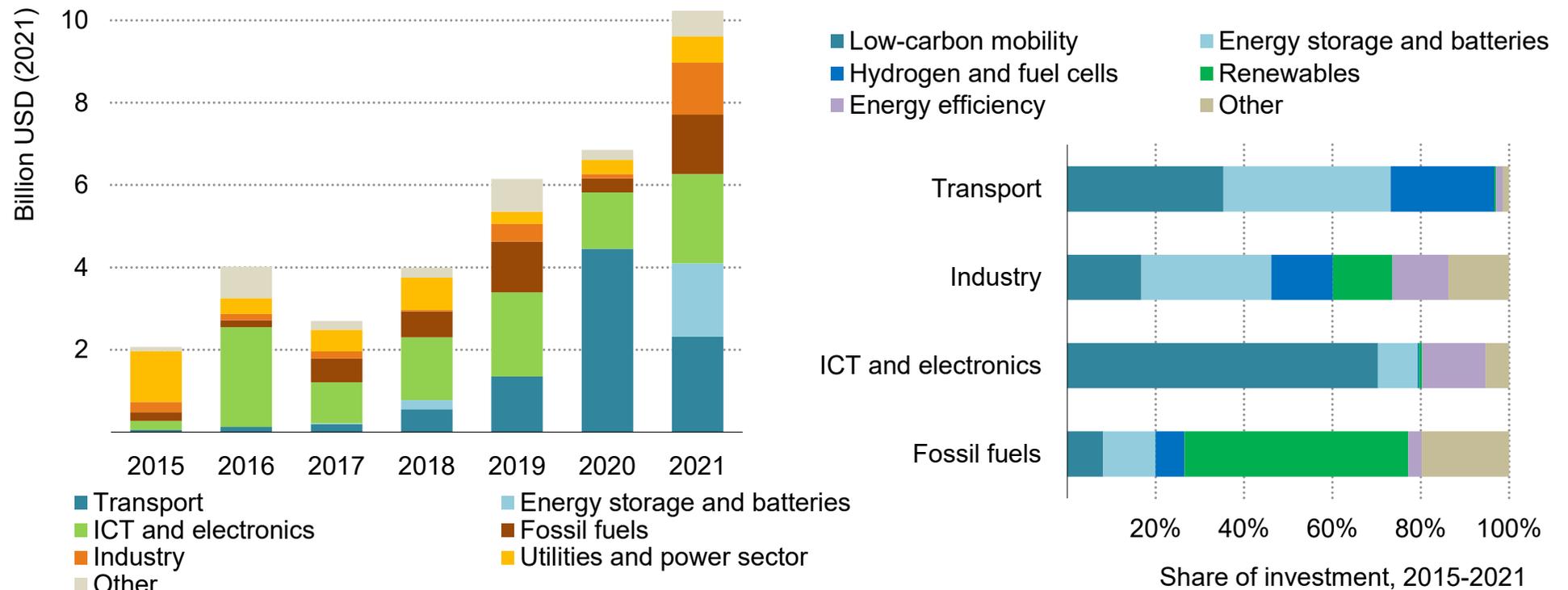
makers. These include direct VC investment with support from public banks, funds and enterprises.

In China and the United States, most start-ups raise money from investors in the same country. In the case of the United States, where 80% of early- and late-stage VC for energy technologies came from US investors in recent years, this reflects a mature ecosystem of entrepreneurs, investors and incubators. In China, which now attracts around 95% of its late-stage energy start-up funding from within its borders, it represents the dominance of a smaller number of large publicly backed funds and a more isolated ecosystem.

In Europe, early-stage energy VC is typically sourced from European investors – at around 75% – but entrepreneurs often need to [seek later-stage capital from overseas](#). This is positive if innovators, recognised for their quality, attract investors from around the world. However, a gap in funds for scaling up can make it harder to retain talent, especially if other markets (e.g. in North America) have [less fragmented regulation](#). In India and Africa most VC investors are from overseas. Overall, inward investment is growing there, but has not yet translated into robust interest in clean energy among local VC funds. A good match between local innovation and capital availability can help smooth the scaling-up process and place regional hubs on a more equal footing when co-operating or investing across borders.

Corporate VC investment in clean energy start-ups reaches an all-time high

Corporate VC investment in clean energy start-ups, by sector of corporate investor (left), and by technology area of start-up in which four of these sectors invest (right), 2015-2021



Notes: Includes early- and late-stage deals as defined in the previous figures. Includes only investment by private-sector investors. Where there are several investors, deal value is evenly split across them. ICT = information and communications technology. Left graph: Industry = chemicals, cement, commodities, construction (excluding real estate), iron and steel, and other equipment suppliers; Utilities and power sector = independent power producers, and electricity and renewables equipment and services.

Source: IEA calculations based on Cleantech Group (2022).

Strategic corporate investment in energy start-ups is surging, as firms vie to stay competitive in a fast-moving landscape or, increasingly, aim to break into the energy sector

A thriving strategy for corporate energy innovation

Corporate venture capital (CVC) investment in clean energy start-ups jumped by 50% in 2021 to over USD 10 billion, with deals more evenly spread across corporate sectors than in the past. With the technological landscape changing rapidly, companies increasingly use CVC investments in start-ups to enter new technology areas. The increase in 2021 was led by investors from the energy storage, battery, industry, fossil fuel, and ICT sectors. The presence of energy storage specialists among the top investors signals the sector's maturity and reflects the incumbents' goals to maintain a competitive edge and integrate the value chain.

While total CVC remains lower than R&D budgets, it has been growing quickly since 2015. Since Covid-19, CVC has become more attractive as a lower-cost and quicker means of acquiring knowledge, new technologies and business models. The “nimbleness” of start-ups and the “optionality” for investors can be particularly valuable under uncertainty, competition and budget pressures. For start-ups, CVC complements other sources of funding and can accelerate scaling up by providing access to corporate experience and resources, especially for manufacturing, as well as access to consumers around the world.

Non-energy players remain lead investors

As in previous years, companies outside the traditional energy sector were the primary source of CVC investment in clean energy start-ups in 2021. While the share of conventional energy actors – such as fossil fuel or power companies – increased to just below 20%, this remains below pre-Covid levels and continues a downward trend that started in 2015.

By contrast, ICT and electronics companies have been increasingly active. They account for 30% of cumulative CVC investment over the 2015-2021 period, compared with one-quarter for traditional energy firms. Nearly 80% of their investment went to transport, energy storage and battery start-ups. This supports a common view of the mobility sector as ripe for disruption by outsiders working with electrified and digital approaches, and a growing interest in energy storage to ensure company-level energy security and accelerate decarbonisation.

Transport companies – mostly in the automotive sector – spent less on clean energy CVC in 2021 than in 2020, but remained major players, accounting for 20% of the total, sometimes co-investing with ICT majors. For example, in 2021 US-based electric pick-up truck developer Rivian raised USD 5 billion from investors including

[Amazon](#) and [Ford](#), before its USD 12 billion [public offering](#), the largest since Facebook. Intel, CATL (a battery firm) and Bilibili (an online video firm) contributed to a USD 500 million funding round for EV brand [Zeekr](#). Chinese internet company 360 Security led a round of USD 625 million for EV developer [Hozon](#). In India, Softbank followed its USD 250 million pre-pandemic investment in electric two-wheeler maker [Ola Mobility](#) by joining a USD 200 million follow-on round.

Car companies have now been joined by aviation firms making notable CVC investments, including early stage investment by United Airlines and Mesa Air Group in Swedish start-up [Heart Aerospace](#). American Airlines and Rolls Royce took part in a USD 205 million round in [Vertical Aerospace](#) before it went public through a SPAC and raised another USD 300 million. United Airlines, Alaska Airlines and British Airways (as well as Amazon and Shell) all rank among key investors of [ZeroAvia](#), a hydrogen-based powertrain developer for aviation that raised USD 115 million in 2021. GE Aviation joined previous investors such as Airbus, JetBlue and Toyota in supporting [Universal Hydrogen](#) with USD 62 million.

Heavy industry players were more active in CVC in 2021, suggesting a strengthening role for start-ups in a sector usually dominated by large incumbents. Over 2015-2021 they invested more evenly across technology areas than corporations from other sectors, with a focus

on energy storage, batteries and mobility (46%), hydrogen and fuel cells (14%), renewables (14%) and energy efficiency (13%).

Alongside its investment in iron-air battery maker [Form Energy](#), ArcelorMittal reinvested in CCUS start-up [LanzaTech](#), which is involved in the company's flagship project SteeLanol producing bio-ethanol from steelmaking waste gases, and in concentrated solar start-up [Heliogen](#), which can deliver industrial heat. South Korean energy and chemicals conglomerate SK Group made a number of investments in 2021, including in batteries with [SES](#) and [Solid Power](#), mineral extraction with [Lilac Solutions](#), EVs with [Polestar](#), and hydrogen with [Plug Power](#) and [Monolith Materials](#).

Fossil fuel companies quadrupled CVC investment in clean energy start-ups in 2021 as they continue to diversify and seek opportunities in new segments. They accounted for the largest share of activity by traditional energy players. Between 2015 and 2019 most of their investment went to renewables companies, but in 2020 and 2021 there was more focus on hydrogen and fuel cells, batteries and electric mobility. Notable examples include BP's support for [FreeWire Technologies](#); Chevron's for [Hydrogenious LOHC Technologies](#), [Raven SR](#), [Malta](#) and [Infinitum](#); Equinor's for [Syzygy](#); Saudi Aramco's for [EnerVenue](#) and [Energy Vault](#); Shell's for [ZeroAvia](#); and TotalEnergie's for [Sunfire](#).

Implications

Governments are stepping up to accelerate clean energy innovation with multi-year R&D budgets, but flexibility will be needed to address evolving priorities and technologies

Ambitious government budgets for energy R&D and demonstration were announced in 2021, responding to national net zero pledges and the economic shock of the Covid-19 pandemic. If the new funds are spent on projects that are realised in the medium term, they will fund important demonstration projects and go a long way towards meeting the investment needs identified in the NZE Scenario and orienting research efforts towards critical clean energy challenges. However, accelerating innovation in line with such a scenario will require that these “stimulus” levels of capital become the new norm. And, to ensure the efficient use of resources, they should be accompanied by policy instruments, including those that encourage international co-operation, to help the private sector put more capital at risk in cutting-edge technology projects.

In 2022 a wider set of policy priorities has emerged that includes cutting fossil fuel imports more quickly, mitigating high domestic fuel prices and securing value chains for critical minerals (see Chapter 4). While these concerns are most pronounced in Europe, they resonate strongly elsewhere as well, notably in the United States, China, India and Japan. The higher prices and revenues that may yet spur higher investment in fossil fuels (see report section on fuel supply) can also drive innovators to develop clean, competitive substitutes more quickly.

One role of government will be to help private capital respond to new market incentives, and help local energy innovation ecosystems be resilient to changing technology and market conditions. Today, the market signals for low-carbon energy are stronger than ever before, and could drive major market opportunities by 2030 for innovators in areas including home heating, mobility, industry, hydrogen and more. However, governments today are spending just 0.04% of GDP on energy R&D, compared with 0.1% in 1980, when the world last responded to a fossil fuel supply crisis with more publicly funded non-fossil R&D. There is clearly more that can be done to increase funding and thereby stimulate private-sector co-funding of key R&D projects, in particular risky, large-scale demonstrations and field trials.

Another implication emerging from this year’s data is an expanded understanding of what constitutes energy innovation and who undertakes it. Whereas efforts to reduce oil demand in the 1980s focused on vehicle efficiency and supply-side technologies like nuclear and hydrogen, the options facing R&D funders today are far broader. Notably, critical minerals are becoming an established area of interest for both public R&D and climate tech investors, including for example new methods to extract lithium or nickel from alternative sources. Additionally, priority energy-relevant research is being conducted in the heavy industry, digital and consumer goods sectors.

A rise in military R&D spending could also generate new spillovers for mobility and energy storage. These all stretch the boundaries within which we need to track energy innovation progress.

Data from 2021 showed a continued trend towards more varied sources of finance and investor types. VC investors allocated more capital to early-stage energy technologies, and average deal sizes rose as they embraced more “asset-heavy” clean energy start-ups, previously considered too risky and long term. Corporations, too, are using CVC to enter new areas and learn quickly. Recognising the economic potential of dynamic new clean energy companies in the emerging energy economy, government funders of energy R&D are deploying [new policy tools](#) in support of these start-ups, including prizes, fiscal incentives and blended equity funds. However, higher interest rates and inflation in 2022 are driving a withdrawal of capital from VC markets that creates new risks for innovators. Whether clean energy technologies are perceived as less risky than technology start-ups in general, and therefore can continue to access sufficient investment, will depend on the credibility of climate policies and corporate commitments. Among the more radical ideas that have been floated is from Japan, which is considering whether sovereign debt could be issued to finance its Green Innovation Fund at a lower cost of capital.

In 2021 emerging economies represented a larger share of the energy innovation landscape than five years ago, led by China. India is more integrated into global energy VC ecosystems, and other

countries in Asia, Africa and Latin America look to follow its lead, including as hosts of international corporate R&D centres. Stronger local innovation capabilities hold the potential for these economies to accelerate their plans to develop hydrogen hubs, for example. However, the cost of capital for R&D remains higher in these countries than in advanced economies, and could be exacerbated by inflation and the absence of policy tools such as government loans for R&D, which are provided in the European Union by the European Investment Bank.

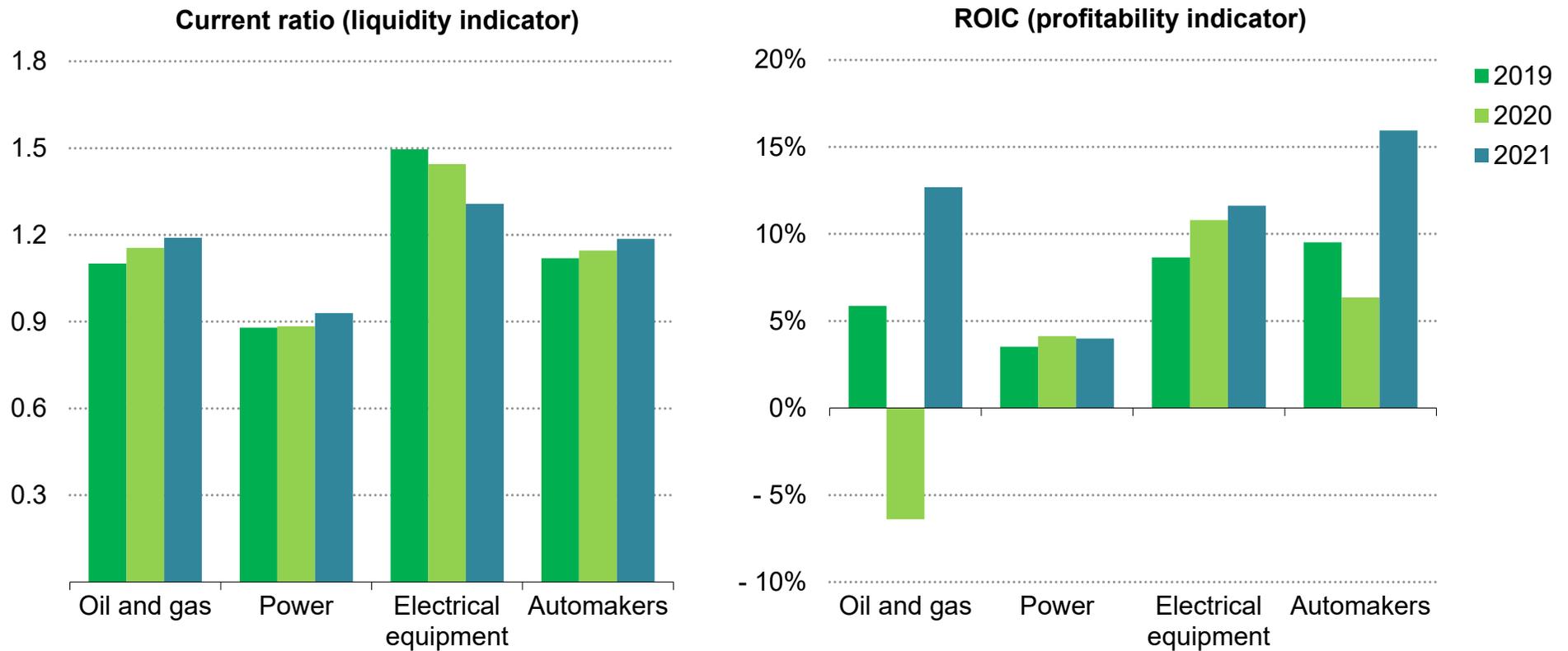
The world has the greatest chance of achieving net zero emissions and energy security goals if clean energy innovation is faster and more inclusive. Given the critical role of governments as enablers of innovation, they have a responsibility to share their experiences on a range of policy approaches and to co-operate internationally. Among other initiatives, the [Glasgow Breakthroughs](#) and [Mission Innovation missions](#) advanced this agenda in 2021.

Finance

Overview

Heading into 2022, profits and liquidity had generally returned to pre-pandemic levels across energy-related sectors...

Liquidity and profitability indicators of top companies by sector, 2019-2021



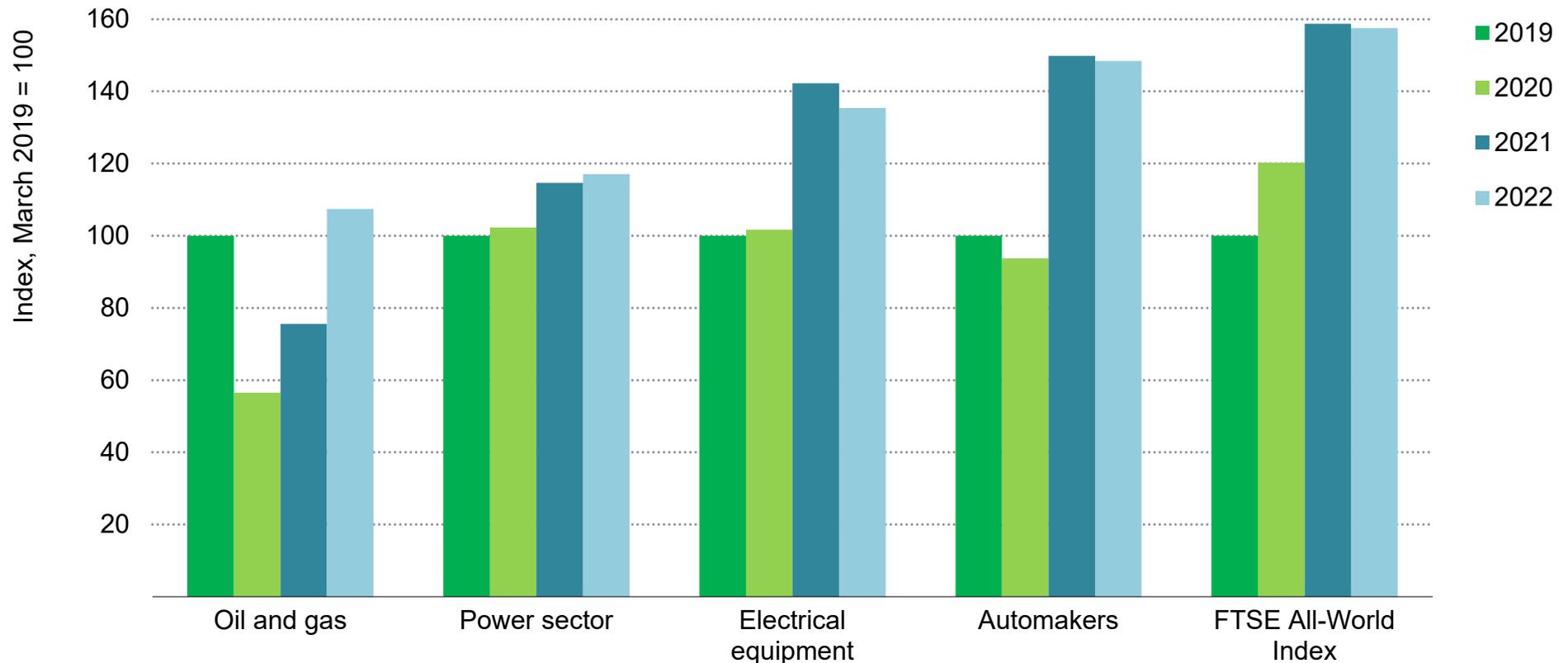
IEA. All rights reserved.

Notes: Current ratio = current assets divided by current liabilities; ROIC = return on invested capital. Comprises top 25 listed companies according to sales (top 10 for electrical equipment and automotive), but excludes those in China and Russia. Electrical equipment companies are involved in multiple sectors that can affect their financial performance.

Source: Refinitiv (2022) and IEA calculations.

... and equity market valuations returned to above pre-pandemic levels, although the slower rebound for oil and gas companies underlines concerns around price volatility

Indexed market capitalisation of top companies by sector, 2019-2022



IEA. All rights reserved.

Notes: Comprises top 25 listed companies according to sales (top 10 for electrical equipment and automotive), but excludes those in China and Russia. Electrical equipment companies are involved in multiple sectors that can affect their financial performance. 2022 figures are based on January-March data.

Sources: Refinitiv (2022); Bloomberg (2022) and IEA calculations.

The pandemic triggered volatility, particularly for oil and gas companies and automakers, but market confidence has returned, buoyed by improvements in key financial indicators

Oil and gas companies experienced the most market volatility during the pandemic, with a crash in revenues and profitability reflected in a fall in market capitalisation compared with equity benchmarks. A return to pre-pandemic demand levels and the rise in oil prices drove a massive improvement back to profitability in 2021 (see Fuel supply section). As cash flow improved, many players paid down debt and returned capital to shareholders, supporting improved liquidity. The slower rebound of market capitalisation despite the return of a leaner, more profitable sector, implies that investors remain concerned about price uncertainty and the risk of assets becoming stranded.

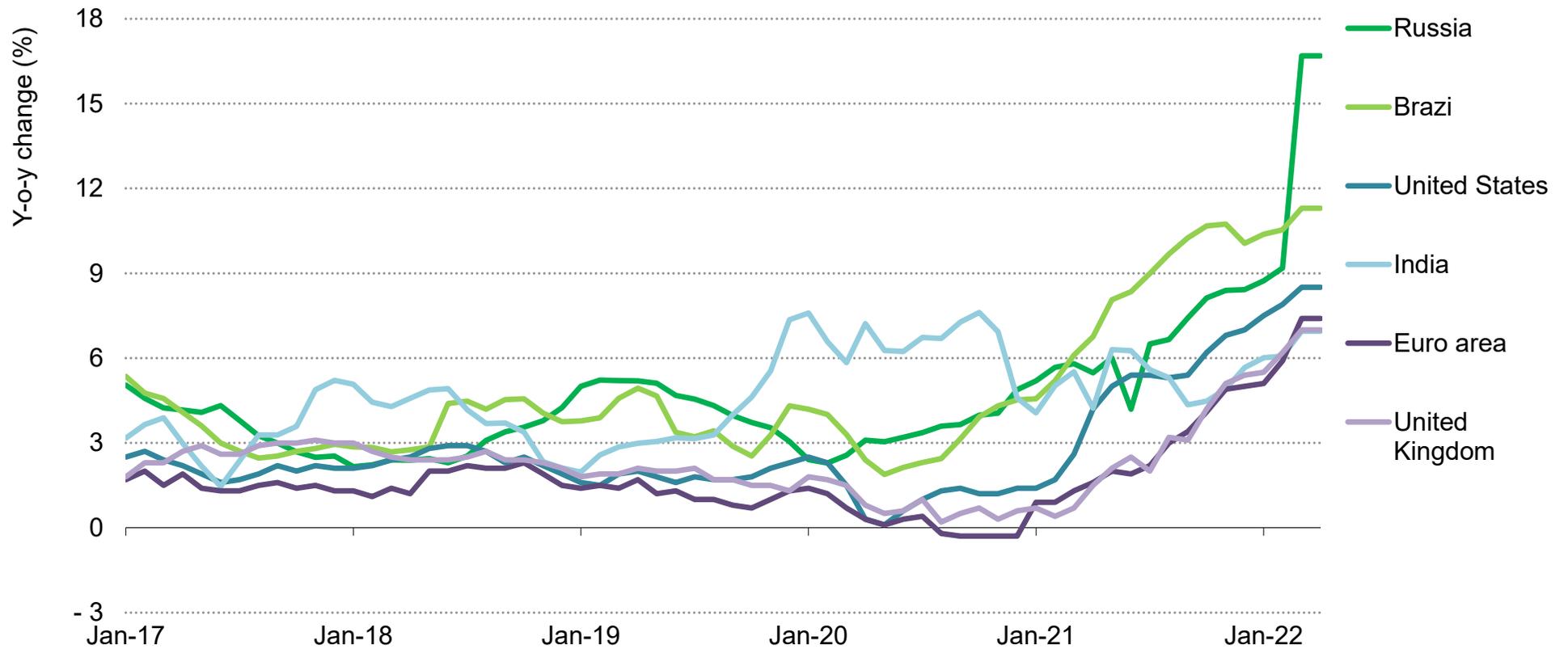
The impact on the power sector was more varied. Predictable revenues for utilities from regulated networks and renewables provide a buffer to market volatility. Renewables proved resilient during the pandemic, with market capitalisations holding steady in 2020 and increasing by more than the overall power sector in 2021. Investors were likely buoyed by governments' sustainable recovery plans emphasising the role of clean power. But regulations can also act as a brake, either due to long permitting and environmental processes, or restrictions on windfall profits or caps on allowed returns from grids keeping margins low. The sector is also sensitive to cost of finance, which will become more of an issue as debt costs rise from historic lows (see Power sector section).

The fortunes of electrical equipment manufacturers are often closely linked to those of the renewable power sector. During the pandemic equipment manufacturers experienced delays as tendering was paused or hit by capacity issues at permitting authorities. Since then demand has returned, pushing equity valuations above pre-pandemic levels. However, difficulties in the supply chain risk affecting the sector's growth and cash flow. While raw material costs can often be passed on to the customer, higher logistics and project management costs typically cannot. Equally, a shortage in skilled workforce and specialist part supplies risks creating a bottleneck.

After recovering from the temporary demand shock of 2020, automakers were faced with a global shortage of semiconductor chips in 2021. This resulted in lower inventories, although the return of demand reduced discounting practices and drove up industry profits. Automakers have stated their intent to continue tighter inventory practices, which will support higher margins. Meanwhile, pure-play EV makers (not included in the graphs above) continued to see [significantly higher valuations](#) per car produced than traditional automakers, despite being less profitable, which provides them with greater access to capital on public equity markets. They will need to translate high valuations into production and revenues in order to maintain investor confidence.

Supply chain difficulties as the world emerged from the pandemic, combined with high energy prices following Russia’s invasion of Ukraine, are driving a spike in headline inflation...

Consumer price index in key economies, 2017-2022

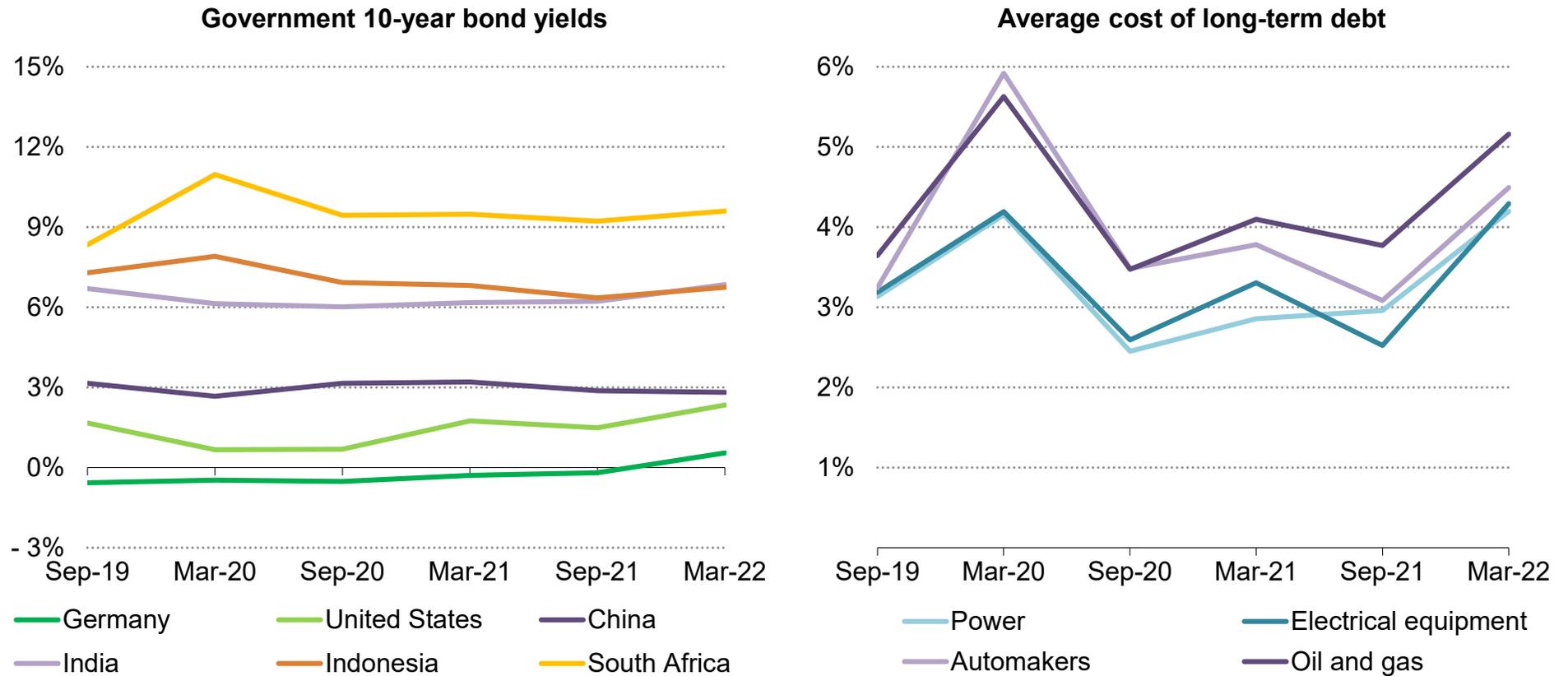


IEA. All rights reserved.

Source: Bloomberg (2022).

... leading governments to move interest rates back up from historic lows during the pandemic, but also pushing up the cost of debt

Key government bond yields and cost of long-term debt, 2019-2022



IEA. All rights reserved.

Source: Refinitiv (2022) and IEA calculations.

Inflation and interest rate rises put pressure on capital-intensive sectors and risk contributing to an economic slowdown, particularly in emerging markets and developing economies

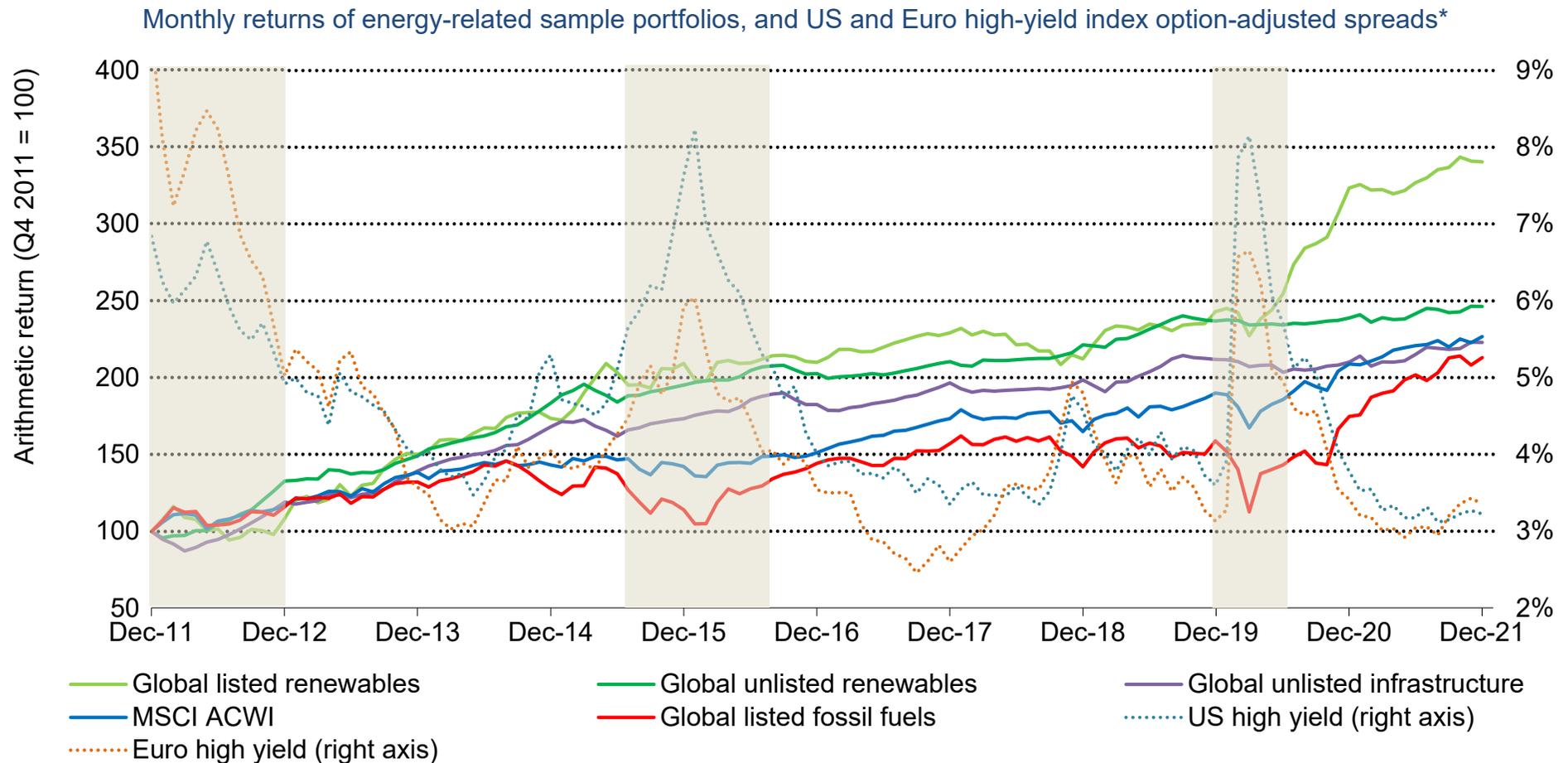
Inflation began to gradually rise during 2021 across markets, particularly as supply chains tightened in the latter half of the year. Since the start of 2022, rising commodity prices have pushed inflation to near 40-year highs in key economies, reaching 8.5% and 7.5% in the United States and the European Union respectively in March. In an effort to curb inflation, central banks around the world started raising interest rates and reducing the size of their balance sheets in spring 2022, with further tightening expected later in the year. For energy-related sectors, this has led debt costs to rise by over 30% from pre-pandemic levels and by an average of nearly 50% in the last year alone due to low rates during the pandemic. Combined with bottlenecks in international logistics, shortages and rising costs for raw materials, plus ongoing Covid-19 cases and lockdowns in China, the rising cost of financing could slow the global economy in 2022.

The risk is particularly acute in emerging markets and developing economies (EMDEs), whose room for manoeuvre is deteriorating with the combination of high levels of debt (especially that denominated in foreign currency) and traditionally low fiscal space (see Emerging markets and developing economies section). That said, the picture is quite different depending on where you look; for example, net producers of oil, gas or critical minerals stand to benefit from higher revenues as a result of high commodity prices. Equally,

countries with stronger currency reserves can use them to cushion the rise in import bills. But there are huge risks elsewhere in the system, compounded by the war in Ukraine. Global food supplies are under extreme pressure due to reduced wheat exports from Russia and Ukraine and high fertiliser costs; meanwhile, higher living costs risk triggering social unrest, particularly in already conflict-prone states.

How these economic forces affect the energy sector is likely to vary. Oil and gas companies stand to continue to benefit from high oil prices, although energy traders have expressed concerns over volatility in the market resulting in liquidity crunches due to their inability to hedge against changing prices. Meanwhile capital-intensive sectors are facing significant pressure, with the rising cost of financing and raw materials threatening already narrow profit margins. This is likely to affect earnings within the power sector, although the extent to which this occurs will vary by company according to a number of factors, including contractual arrangements around electricity pricing and the company's debt profile. Equally, margins at automakers are likely to be squeezed – as already seen in Q1 earnings reports from GM and Ford – due to the rise in material and electricity costs, plus continued semiconductor chip shortages affecting the supply chain.

Over a 10-year period, renewable assets have provided more stable returns than fossil fuels, including during periods of economic crisis



IEA. All rights reserved.

* High-yield index option-adjusted spreads are a measure of risk premium demanded for high-yield bonds.
 Sources: [IEA and Imperial College London](#) (2022).

Renewables have outperformed fossil fuels in listed and unlisted markets, but their smaller market capitalisations and lower margins reduce investors' willingness to reallocate capital

Reaching net zero targets requires a massive ramp-up of spending on clean energy, particularly by the private sector, which should account for 70% of all energy investment by 2030. Private-sector investor decisions to allocate capital towards different mixes of fuels and technologies depend primarily on financial performance, taking into account not only returns, but also the level of credit risk. Over the past two years the IEA has collaborated with Imperial College London to investigate the risk–return profile of renewable companies and projects in both listed and unlisted markets. Our findings demonstrate that across both markets, renewable assets provide attractive risk-adjusted returns to investors when invested in a long-term portfolio, outperforming the selected industry benchmarks and the broader public equity market index. This finding held true in both advanced economies and EMDEs.

To conduct this analysis we constructed hypothetical investment portfolios to compare fossil fuel and renewable power business segments across both advanced economies and EMDEs in listed markets. We tracked the portfolios over a 10-year period and in all cases listed renewables outperformed fossil fuel portfolios. They also demonstrated lower annualised volatility, except in China and EMDEs. In unlisted markets we compared renewable assets with

infrastructure assets and made similar findings of favourable returns and lower volatility over the 10-year period. This is particularly significant because up to 70% of renewable power assets are unlisted and, given their private nature, limited financial analysis is available.

Despite the generally favourable risk–return data for renewables portfolios, a number of key challenges still prevent a wholesale reallocation of investor capital away from fossil fuels. One major reason is the substantially different characteristics of renewables companies when compared to fossil fuel companies, which can affect investors' portfolio composition choices. Renewables companies tend to have smaller market capitalisations and lower margins, resulting in less liquidity and lower dividend payout ratios and also greater vulnerability to supply chain shocks. Equally, investing in renewables will often mean greenfield projects from companies with short trading histories, whereas investors have historically shown a preference for existing assets. Despite this, including renewables is shown to have a clear diversification benefit as they have also shown less correlation with the equity and fixed income markets. This can protect portfolios during times of economic uncertainty, when correlation falls even further.

Sustainable finance

Sustainable finance has taken an increasingly prominent role in climate policy discussions, driving environmental factors into investment decision-making

Meeting the Net Zero Emissions scenario requires changes in the financial sector's lending to and ownership of energy-related assets. Over the past five years several key initiatives, notably the [Task Force on Climate-Related Financial Disclosure \(TCFD\)](#), have driven the inclusion of carbon risk and emissions assessments in investment and lending decisions. The subsequent rise in net zero commitments from financial institutions culminated launch of the [Glasgow Financial Alliance for Net Zero \(GFANZ\)](#) in 2021, an alliance of 450 institutions with over USD 130 trillion of assets under management.

Industry-led initiatives vary in their methodologies and net zero target dates, so comprehensive sustainable finance regulation is vital to ensure the sector is moving at the necessary speed. European countries have led the way, introducing risk management and reporting requirements for companies and investors in relation to climate risks and sustainable activities (see table). Outside these markets, regulations have generally focused on improving the availability of carbon emissions data, which, although it has its limitations, is essential for decarbonisation strategies. Regulators are also striving to support green finance by introducing clear definitions of sustainable activities. Alignment of sustainable taxonomies – such as those between China and the European Union – is also underway in order to reduce the risk of greenwashing.

Key regulations introduced in 2021-2022, non-exhaustive

Regulation	Requirement
EU: Sustainable finance regulations*	From 2021 financial market participants must report on sustainability practices at the entity and product level. A new proposal introduced in 2021 will expand and tighten company reporting on non-financial metrics. From January 2022 in-scope companies must report eligibility with the EU taxonomy ; alignment reporting begins in 2023.
UK: Mandatory TCFD reporting	From April 2022 TCFD reporting became mandatory for the largest companies and financial institutions.
US: Proposed disclosure rules	In March 2022 the Securities and Exchange Commission proposed rules to require company climate risk and carbon emissions disclosures and to tighten fund naming requirements to prevent greenwashing.
China: Mandatory environmental reporting	From February 2022 listed companies and bond issuers must publish carbon emissions and other environmental data.

IEA. All rights reserved.

* Comprising the Sustainable Finance Disclosures Regulation, the Corporate Sustainability Reporting Directive and the EU Taxonomy for Sustainable Activities.

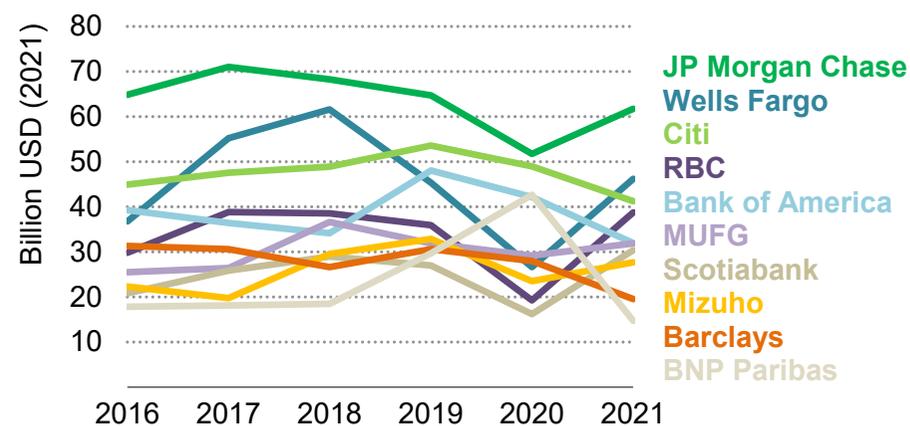
Notes: ESG = environmental, social and governance; TCFD = Task Force on Climate-related Financial Disclosures.

Banks are facing increasing pressure to reduce lending to fossil fuels, with European banks proving more responsive

The world's largest banks are among the financial institutions that have committed to net zero, forming the [Net-Zero Banking Alliance \(NZBA\)](#) (a member of GFANZ) in 2021. Banks play a particularly important role in the energy transition as fossil fuel companies tend to run highly leveraged balance sheets that rely on either public bonds or syndicated bank loans. Studies have found that bond yields for new fossil fuel company issuances [have proven more reactive](#) to climate policies than the yields on syndicated bank loans, demonstrating that banks are not yet pricing in stranded asset risk to the same extent as public market debt.

While banks have put in place some lending restrictions, they focus on projects in coal, Arctic exploration and oil sands. Outside multilateral development banks and development finance institutions, exclusions rarely cover either conventional oil and gas exploration or restrict company-level loans. Among the world's 60 largest commercial banks, lending to fossil fuels has [decreased from 2019 highs](#), falling 10% during 2020 and remaining static since. However, 10 banks account for roughly half of the lending and their financing of fossil fuels [increased by 5%](#) in 2021. Although all 10 banks are members of NZBA, the increased lending indicates that they remain bullish about the short-to-medium term prospects for oil and gas.

Bank lending to fossil fuels (top 10 largest lenders), 2016-2021

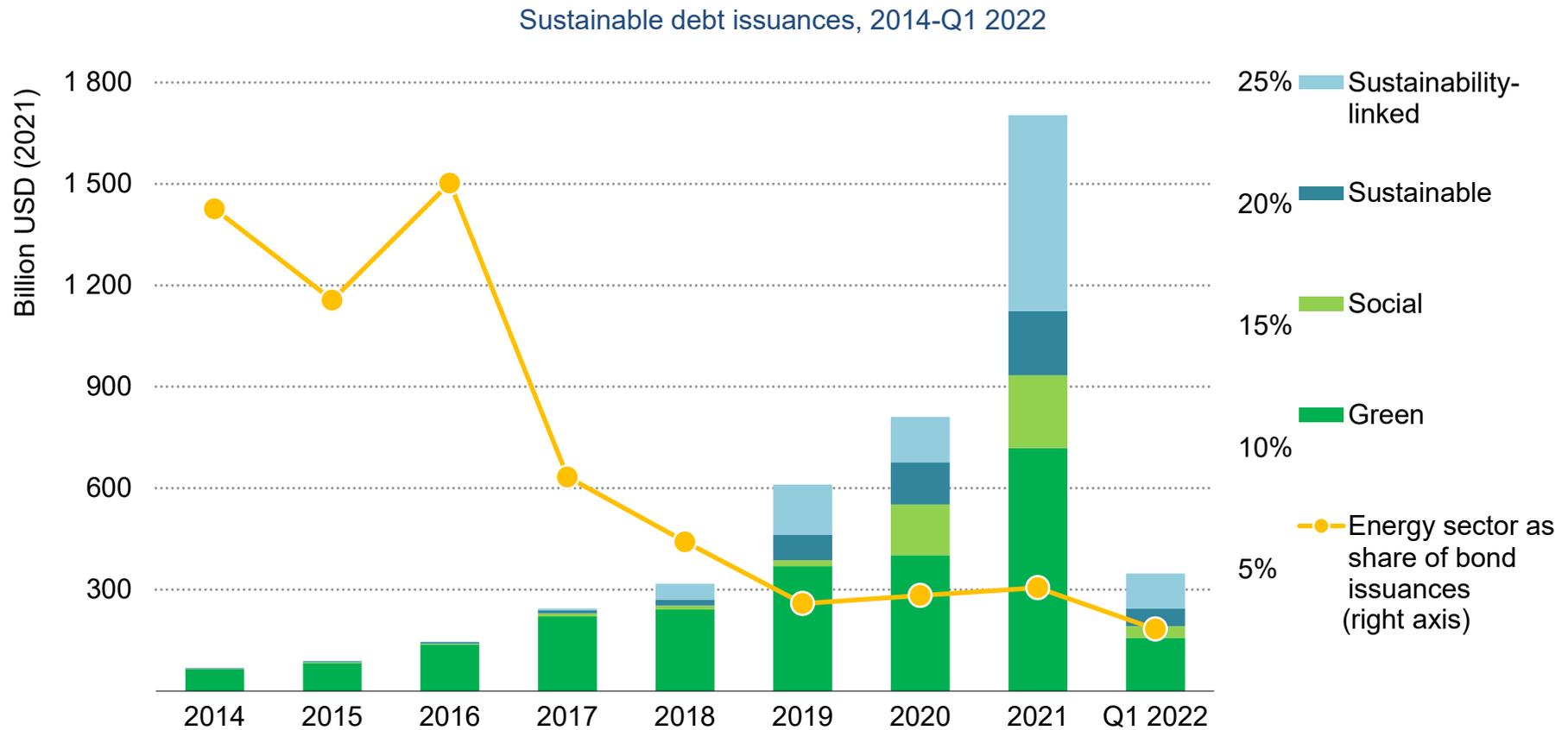


IEA. All rights reserved.

Source: [BankTrack](#) (2022).

The first impact of the NZBA is likely to be more detailed reporting from banks, which are encouraged to set emission reductions targets for all carbon-intensive sectors. Banks falling under the EU Taxonomy remit will also start reporting the taxonomy-aligned share of their balance sheets. This improved reporting, combined with stress testing by central banks and the European Banking Authority, can set a framework for the most efficient path for banks to drive net zero via a combination of reduced lending to fossil fuels, supportive transition activities and increased financing of clean energy.

Meanwhile companies are increasingly able to raise debt for sustainable activities, with the sustainable debt market booming in 2021 and showing only a marginal slowdown in 2022



IEA. All rights reserved.

Source: BNEF(2022), Refinitiv (2022).

Sustainable bonds are a particularly useful tool to fund renewables and transition projects that are vital to achieve net zero emissions, but they generally struggle to access capital

The sustainable debt market has boomed over the past 10 years, with issuances rising from USD 33 billion in 2012 to USD 1.7 trillion in 2021. Data from Q1 2022 show slightly lower issuance than the bumper 2021 figures, but the yearly figure is still on track to outpace 2020. Although the energy sector's share of bond issuances is decreasing, it issued nearly 35% more sustainable bonds in 2021 than 2020. Equally, within green bonds – which remain the largest category of sustainable debt – renewable energy also [still accounts for the largest allocation](#) (35%) of proceeds across all sectors. 2021 represented a particularly strong year for sustainable debt issuance, with the use of sustainability-linked debt more than quadrupling from 2020 levels. Unlike green, social and sustainable bonds that tend to be issued on a “use of proceeds” basis – whereby proceeds are earmarked for a particular project – sustainability-linked debt is performance-driven and allows the issuer to use proceeds to reach certain key targets, such as reducing emissions. This greatly expands the possible use of sustainable debt issuances from being project-focused to supporting broader organisational change.

Interest in sustainability issues remained high in European debt markets in early 2022, with [ESG targets present in 26%](#) of European corporate loans this year, up from 19% in all of 2021. This trend is

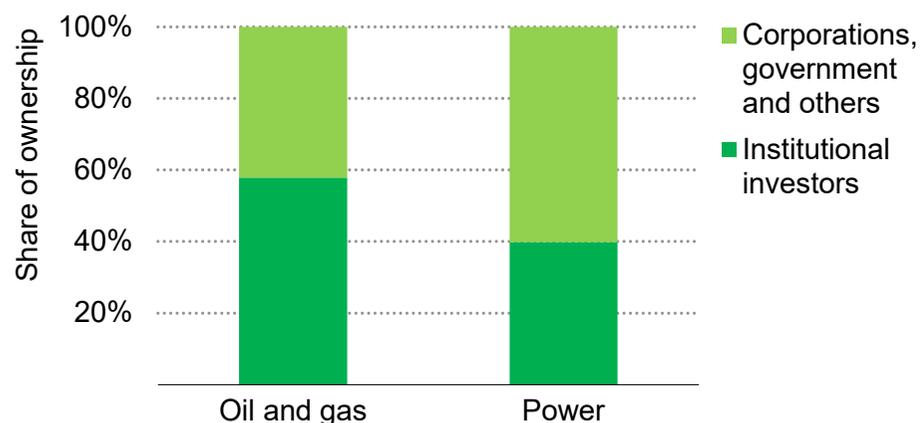
likely to continue as the Green Asset Ratio disclosure requirement – which requires banks to report the share of their balance sheet that is EU Taxonomy-aligned – comes into force over the next two years. However, 2022 will present a major test for the sustainable debt market, particularly bonds. The core rationale behind sustainable bonds is that they allow companies to raise finance at lower rates than non-sustainable bonds due to the expected impact of future sustainability regulations. This premise is relatively untested because the longer maturities of sustainable bonds mean there is little evidence of whether they outperform over a full credit cycle. Interest in sustainable bonds is therefore at risk of declining in the face of higher interest rates, particularly since returns on sustainable debt [have fallen by 6.7%](#) compared with the 6.1% fall in normal debt returns in 2022.

Even if growth rates do slow from 2021 highs, sustainable bonds will remain a particularly useful tool for funding transition at fossil fuel companies, utilities and hard-to-abate sectors. To achieve the Net Zero Emissions scenario, [around half of all energy investment](#) over the next decade goes to projects that do not immediately deliver zero-emission energy or energy services, for example switching from coal to oil or less polluting alternatives.

Beyond providing debt finance, institutional investors also wield significant influence over energy companies through ownership stakes

Institutional investors accounted for nearly 60% of the listed value of the largest oil and gas companies and 40% of the largest power companies as of April 2022. Asset managers represent about 80% of this, putting them in a strong position to influence company strategy.

Institutional investor ownership of oil and gas and power companies, Q1 2022



IEA. All rights reserved.

Source: Refinitiv (2022).

Asset managers offer actively managed funds and passive funds that track indexes. ESG strategies can be applied to both, but are more comprehensive in active funds as the asset manager controls the fund constituents. That said, whether passive funds implement ESG strategies is one of the key questions facing the industry.

Actively managed funds

Asset managers can select strategies to either increase their allocations to companies they consider sustainable or reduce their exposure to companies with higher ESG risks. The latter is generally achieved via exclusions and divestment or active ownership.

Divestment rose to prominence in the 1970s and proved successful in diverting capital from and exerting pressure on tobacco companies and companies dealing with the apartheid regime. Under this approach, funds are either created with exclusion criteria that remove fossil fuel companies from the investable universe, or fossil fuel assets held in existing funds are sold. Although popular with activists and increasingly environmentally conscious consumers, divestment has a number of limitations. Firstly, it can be hard for asset managers to implement without altering the risk–return characteristics of their portfolio, particularly in a high oil price environment. Secondly, while selling equity stakes can push down share prices and fixed income exclusions can drive fossil fuel companies to raise more funds via syndicated bank loans, divestment is only likely to have significant impact on companies' ability to raise capital if it is adopted by the majority of financial institutions. If this is not the case, companies can simply access capital from other, potentially less regulated, sources.

Given the limitations of divestment, asset managers are increasingly looking to remain invested in fossil fuels but to actively engage with companies to change their strategy. Owners encourage companies to set sustainability targets and use shareholder resolutions and proxy voting to drive company policy changes. If targets are not met, the owner will divest. Recent high-profile examples of this approach include activist hedge fund Engine No. 1's successful 2021 campaign to replace three of Exxon's board members, and resolutions at Shell and BP to increase emissions reporting and set binding reduction targets. Critics of active ownership argue that it allows the financial industry to continue supporting fossil fuels and that it is slow to drive change, but it is clear that a combination of both divestment and engagement will be needed to bring the scale of change necessary.

Passive funds

Active funds make up a decreasing share of asset manager business, with passive funds, such as exchange-traded funds (ETFs), growing in popularity due to their lower fees. This trend is most pronounced in the United States, where Bloomberg estimates that [passive funds will overtake](#) active ones within five years. As active funds reduce their stake in oil and gas, passive funds – which track major indexes that still include oil and gas companies – are at risk of becoming [“holders of last resort”](#).

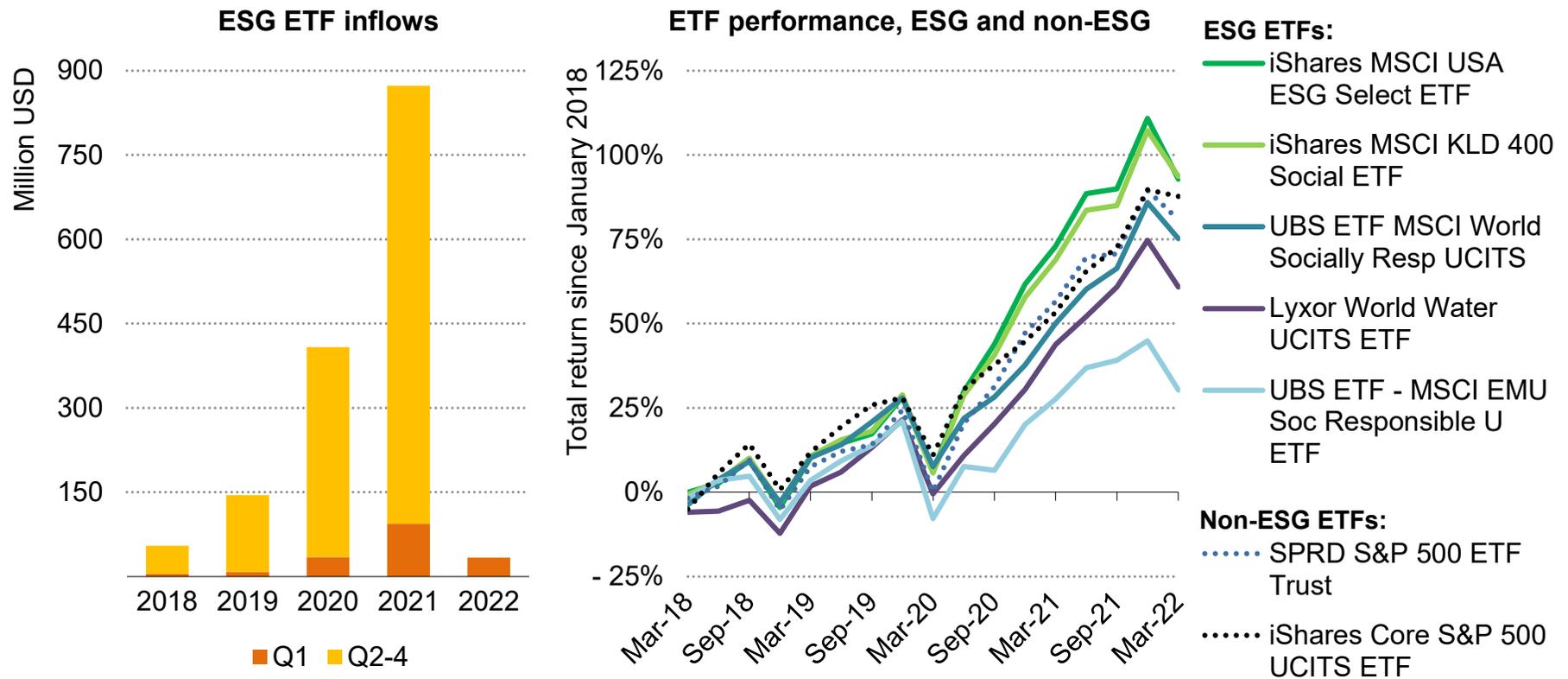
Whether this occurs will rest on the extent to which passive funds increase their stewardship role, particularly choices made by the

three largest index fund managers: BlackRock, State Street and Vanguard. These companies all have stewardship research teams that support their active funds, but generally have not used this research as part of their passive investing strategies and have been frequently criticised for failing to vote against shareholder resolutions. For example, a 2020 report by ShareAction found that BlackRock and Vanguard supported only [12% and 14% respectively](#) of ESG-related shareholder resolutions. Since passive investors act as permanent universal owners – i.e. they have a long-term view and are invested across the breadth of the market – they would benefit from removing systemic risks, such as those posed by climate change. The largest passive investors are therefore starting to increase their stewardship functions; for example, BlackRock has proposed introducing proxy voting rights for passive funds.

Separately, the role of financial index providers – who create indexes that passive funds track and which active funds use to benchmark their performance – is also starting to evolve. Sustainable finance regulations in the European Union include requirements for better labelling of indexes, which has otherwise been a relatively opaque space. Since 2021 index creators such as MSCI, S&P and FTSE Russell – who control an estimated 70% of the index market – have launched Paris-aligned benchmarks in Europe, in line with recent EU sustainable finance regulations. This allows passive investors to allocate their capital in a rules-based, carbon-conscious manner. However, this is a new space and how well it is monitored will be a key determinant of its success.

Early indications in 2022 show that interest has slowed in passive ESG funds, which risk underperforming compared to non-ESG benchmarks due to the global energy crisis

Inflows into ESG ETFs and performance of largest ESG ETFs vs non-ESG ETFs, 2018-2022



IEA. All rights reserved.

Notes: Although ETFs are only one element of the ESG investment space, they serve as an interesting bellwether for consumer sentiment. ETFs in the right graph are the five largest ESG ETFs by inflows in 2021 according to Refinitiv, plus the largest non-ESG ETFs in Europe and North America.

Sources: BNEF (2022); Refinitiv (2022).

ESG investing practices will need to more tightly align with climate targets in order to increase the capital going to energy transitions

ESG investing continued to grow during 2020 and 2021. For example, inflows into ETFs with an ESG focus more than doubled in 2021. But Q1 2022 results have seen a slowdown, likely because high oil prices increase the attractiveness of non-ESG funds. This is also reflected in sharper reductions in the returns from ESG ETFs when compared to non-ESG ETFs in Europe and the United States.

Carbon-related characteristics of 10 largest ESG ETFs

Metric	Detail
Weighted average carbon intensity	Of the 6 ESG ETFs with data, carbon intensities range across 45-97 t CO ₂ /USD million sales. This compares to 140 t CO ₂ /USD million sales for the iShares non-ESG ETF.
Implied temperature rise	Only 2 of 6 ESG ETFs with data are Paris-aligned.
Fossil fuel exclusions	9 of the ESG ETFs exclude thermal coal and oil sands companies, but only 3 do not include any oil- and gas-related companies.
Other carbon-related criteria	Only 4 of the ESG ETFs carry out additional screening based on emissions; 3 of these also screen according to carbon risk.

IEA. All rights reserved.

Sources: [iShares and MSCI \(2022\)](#), [UBS \(2022\)](#).

However, not all ESG funds are focused on climate and therefore do not always equate to lower carbon and the exclusion of all fossil fuels

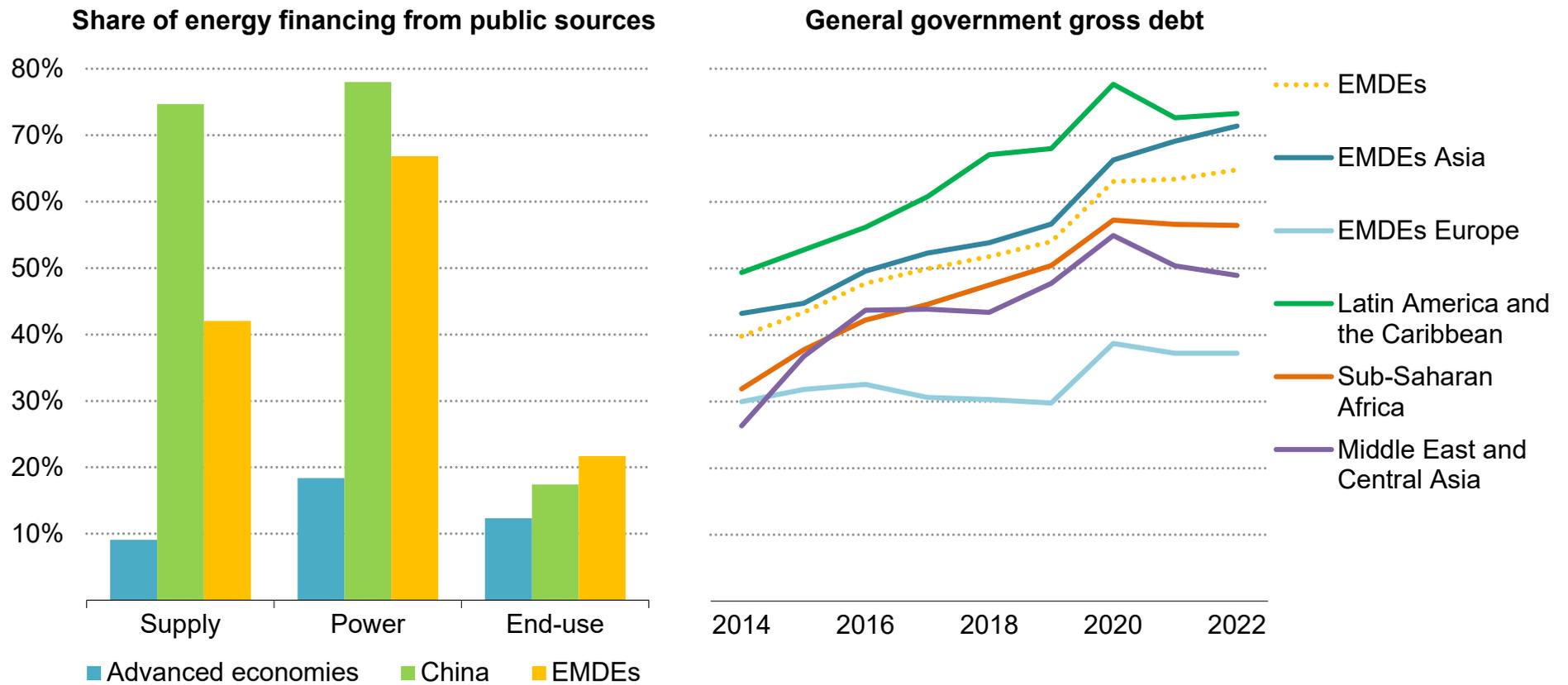
(see table). To meet the allocation of capital seen under the Net Zero Emissions Scenario, ambitious climate change strategies need to be more comprehensively integrated. There are signs of this evolution occurring, with the assets under management of climate-focused funds – both active and passive – [more than doubling between 2020 and 2021](#). These funds take a variety of different approaches, with the largest share being funds that select companies based on carbon transition risks and funds that invest in companies that provide solutions to climate change (including those outside clean energy). Morningstar also found China to be the second largest market for climate funds, overtaking the United States and reflecting the recent push in Chinese sustainable finance regulations.

The rapid expansion of climate funds bodes well for the allocation of capital to clean energy, but it may make it harder for carbon-intensive industries to finance transition. One of the goals of climate-conscious finance is to make it harder for non-Paris-aligned companies to raise capital. If this is applied too heavy-handedly, for example by focusing on a whole sector rather than company specifics, there is a risk that transitions will become more expensive for carbon-intensive industries. ESG investing and sustainable debt therefore need to continue to grow hand in hand, with financial institutions basing their choices on reputable net zero analysis.

Emerging markets and developing economies

State-backed financing plays a critical role in EMDE energy sectors, but government finances are facing significant strain due to pandemic-related debt pressures

Public-sector share of energy investment and government debt levels, 2014-Q1 2022



IEA. All rights reserved.

Sources: IEA and [IMF](#) (2022).

Slow growth, more costly debt servicing and rising inflation will limit governments' ability to finance new energy projects

The state plays an outsized role in the energy sectors of EMDEs when compared with their advanced economy peers. State-owned enterprises – the largest public providers of energy finance – account for 60% of energy investment in China and over 40% in EMDEs as a whole, with higher levels of involvement seen in Asia, Russia and the Middle East. State enterprises play a particularly prominent role in coal and fossil fuel power, and in grids and storage, especially transmission and distribution grids, where they account for just under 80% of spending across EMDEs.¹

Despite their prominence, state-owned utilities in developing markets are often highly indebted and worsening global economic conditions risk reducing governments' ability to fund energy projects. Debt levels have risen across EMDEs and debt repayment suspensions introduced during the pandemic have ended. Governments are therefore facing rising debt servicing costs, worsened by a strengthening US dollar (in which most EMDE debt is denominated) and surging bond yields. This is driving default risks: six countries defaulted during the pandemic, and the number of EMDEs with bonds trading at least 1 000 basis points above US treasuries [increased](#)

[from 6 to 13 in 2022](#).² Rising debt levels also severely reduce available public capital and limits governments' ability to provide guarantees to state enterprises or private investors. Meanwhile, the gap between the GDP growth rates of advanced economies and EMDEs is narrowing to a [level not seen since at least 2000](#). This indicates reduced revenues for EMDE governments and is also likely to slow investor interest since higher risk levels will not be offset by higher growth.

Meanwhile, emerging markets are also facing significant fallout from the Russian invasion of Ukraine, which has disrupted global oil, gas and wheat markets. Consequently, food and fuel prices are rising, and higher fertiliser costs risk reducing harvest yields. Central Asia also faces specific risks due to lower remittance flows from Russia, which are stymying growth and consumer spending. These issues are driving higher inflation, which also raises the prospects of social unrest. Producer economies, such as Brazil and countries in the Middle East, along with countries with good foreign exchange reserves, face lower risks as they have more fiscal space to respond.

¹ Private involvement in grids is higher in Latin America and India (distribution only) due to regulations that are more open. Excluding these regions, the average is nearer 90%.

² Defaulted during the pandemic: Argentina, Belize, Ecuador, Lebanon, Suriname and Zambia; countries facing severe risk of default in 2022 include Sri Lanka, Pakistan, El Salvador, Tunisia, Ethiopia, Ghana and Russia.

International concessional capital will be vital to support energy investment in EMDEs and mobilise greater private-sector involvement

As pressure on domestic public finance intensifies, international concessional funds can be used to bolster governments by funding capacity building or supporting debt restructuring at indebted utilities. Concessional funds also play a crucial catalytic role in energy transitions by de-risking new markets and new technologies, or by using grants to grow the pipeline of bankable projects or to fund non-profit-driven activities such as decommissioning fossil fuel plants.

Blending catalytic public capital with private capital can prove particularly effective since under climate-driven scenarios [70% of energy investment in EMDEs](#) comes from private sources by 2030. Blended finance gained traction in the 2010s, and since 2015 has averaged [approximately USD 9 billion annually](#) around the world. Transactions primarily focus on Africa, which attracted over 60% of blended finance deals in 2020. Multiple different blended approaches have proved successful, including:

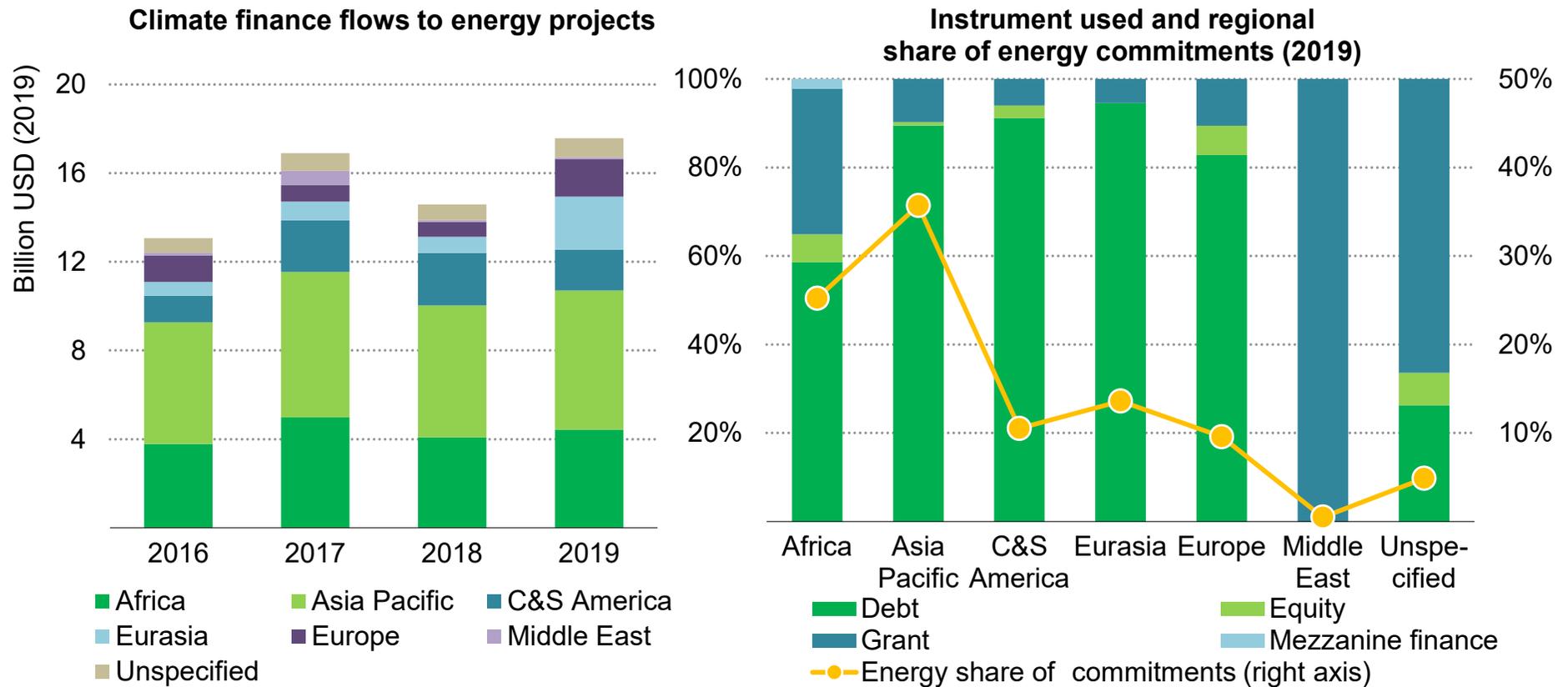
- **Project-level:** Initiatives like the International Finance Corporation's [Scaling Solar](#) programme provide individual projects with a mix of private and concessional public capital, such as senior debt.
- **Fund-level:** Specialist funds, such as FMO's [Climate Investor One](#), can mobilise commercial capital by using concessional funds for debt and equity financing according to the project development phase.

- **Institution-level:** Lending institutions can blend capital within their own equity base to maximise their lending capabilities, as seen at [Trade and Development Bank Group](#) (a development finance institution in east and southern Africa) and in the African Development Bank's [Room2Run](#) programme.
- **Specialised intermediaries:** Blended capital can also be used to create intermediaries, including guarantee providers such as [InfraCredit](#) in Nigeria, which supports domestic institutional investors' involvement in infrastructure projects.

Despite the clear potential for blended finance, it does not always “crowd in” private capital sufficiently. Mobilisation ratios are not widely reported and evidence shows that blending is often used by finance providers to de-risk their own capital. The requirement for investment returns can prevent these institutions from providing enough concessional capital to de-risk early-stage projects to a level the private sector is comfortable with, [particularly in least-developed countries](#). Equally, concern over returns means there is a preference for concessional loans when guarantees or grants to reduce costs may be better suited. Designing blended finance structures that are more in line with private-sector needs, and targeting less-commercial sectors or least-developed countries, would allow this to become an even more useful tool.

Climate finance from advanced economies represents a valuable flow of concessional capital to EMDEs...

Climate finance flows from advanced economies to EMDEs, 2016-2019, and nature of energy commitments, 2019



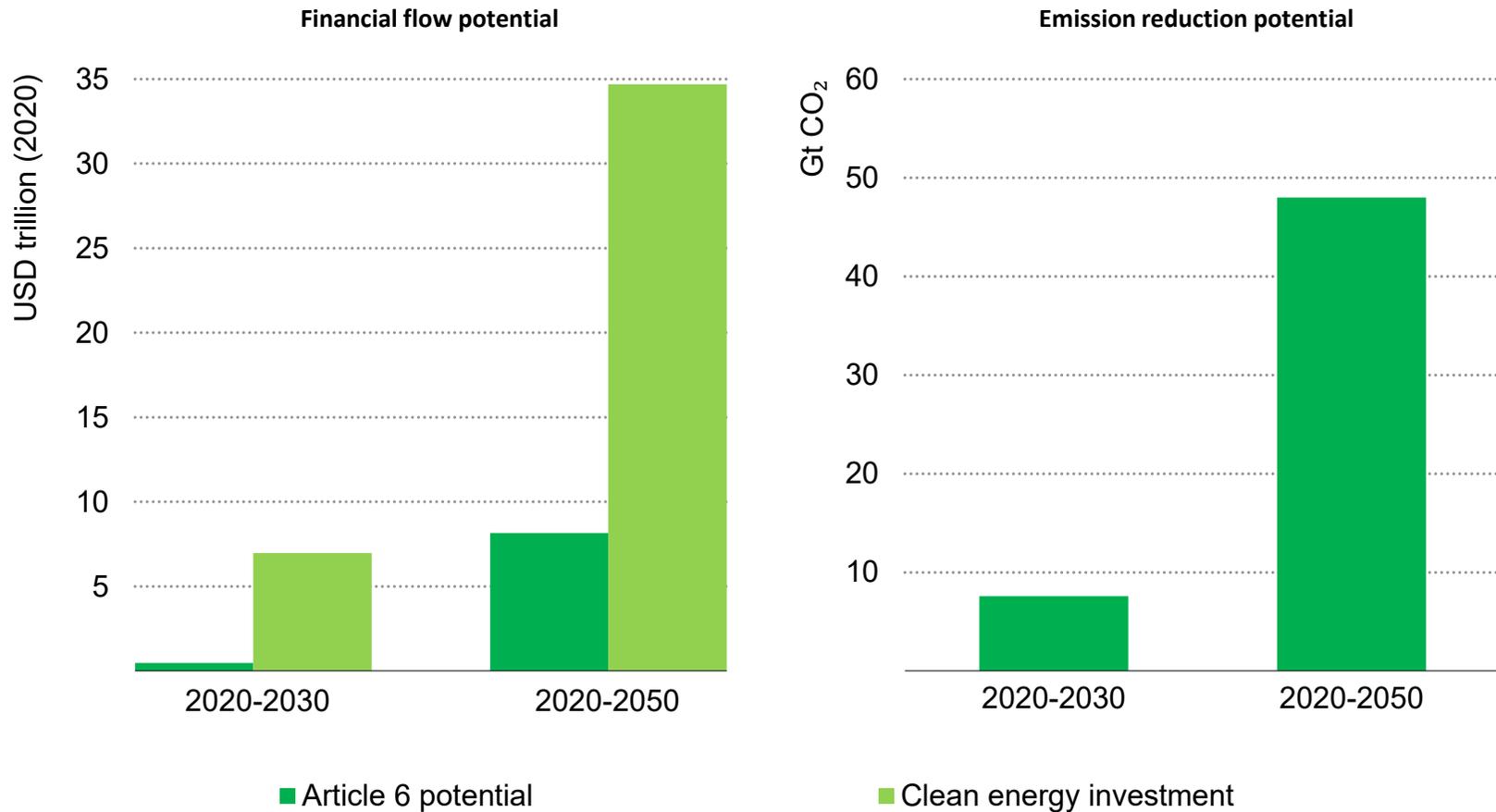
IEA. All rights reserved.

Notes: C&S America = Central and South America. 2019 is the latest available data; mezzanine finance is a hybrid of debt and equity that allows the provider to change debt to equity in the event of a default.

Source: [OECD DAC](#) (2022).

... which can also be supported by inflows from international carbon markets

Potential for carbon markets under Article 6 of the Paris Agreement in EMDEs



IEA. All rights reserved.

Notes: The investment and mitigation potential of Article 6 refers to African countries under a “staggered co-operative Net-Zero scenario” as per Yu et al (2021), where lower-income countries set a date later than 2050 for their net zero targets based on relative income differences, with co-operative implementation.

Source: IEA analysis based on data from [Yu, et al. \(2021\)](#).

Global efforts to fund climate mitigation and adaptation projects present a significant financing opportunity for EMDEs if properly harnessed

Increasing global co-operation on climate change can support clean energy investment via climate finance flows to EMDEs and the creation of new carbon markets. Advanced economies pledged to provide and mobilise USD 100 billion annually for climate mitigation and adaptation in EMDEs by 2020. Although this target was missed, the [OECD projects](#) it will be met this year. Energy-related projects accounted for a fifth of the USD 79 billion in climate finance reported to OECD's Development Assistance Committee³ in 2019 (latest available). These were concentrated in Africa and Asia Pacific, and focused on renewable energy and access projects.

As with international concessional capital more broadly, climate finance is well-suited to expand beyond renewables projects to support harder-to-commercialise activities and to de-risk new markets. However, it must do so without increasing country indebtedness while tightly focusing on mobilising private capital. This is likely to require a shift towards cost-reducing grants and equity finance, rather than the current over-reliance on debt instruments.

Following the [finalisation of Article 6](#) of the Paris Agreement rulebook at COP26, international carbon markets can help EMDEs receive

further foreign investment to develop mitigation projects. Countries can trade Internationally Transferred Mitigation Outcomes (ITMOs) under Article 6.2, and they can also issue carbon credits in a new international carbon market governed by the UN Framework Convention on Climate Change (UNFCCC), known as the Article 6.4 mechanism. [Estimations of Article 6 potential in EMDEs](#) indicate that by 2030 these mechanisms could generate USD 330-475 billion in net financial flows – up to 7% of clean energy investment needs – and prevent the emission of 5 030-7 590 Mt of CO₂ (up to 6% of total EMDE energy-related CO₂ emissions over the same period). The details for the implementation of the rules, modalities and procedures of Article 6 are still being finalised at the UNFCCC, and countries will need to translate them into legal frameworks to govern ITMOs and carbon credits.

Voluntary carbon markets are not regulated under the UNFCCC and are also expected to generate massive capital inflows to EMDEs. Uncertainty on the credibility of voluntary carbon credits can act as a barrier to entry for investors. Two initiatives ([VCMI](#) and [Carbon Credit Quality](#)) have recently been launched to address this issue.

³ OECD member countries and multilateral development banks report on public climate finance to DAC. The database does not track all the mobilised private finance and numbers can differ from the figures reported to UNFCCC as part of efforts to track the USD100 billion target.

Annex

Acknowledgements, contributors and credits

This report was prepared by the Energy Investment Unit in the Energy Supply and Investment Outlook (ESIO) Division of the Directorate of Sustainability, Technology and Outlooks (STO). It was designed and directed by Tim Gould, Chief Energy Economist, and Jonathan Coppel, Head of the Energy Investment Unit. Tanguy de Bienassis coordinated the report and led the section on end use and efficiency. Pablo Gonzalez and Lucila Arboleya led the analysis of the power sector. Christophe McGlade, Peter Zeniewski and Laura Maiolo were the main authors of the section on fuel supply; Tae-Yoon Kim led the work on critical minerals; Simon Bennett led the R&D and technology innovation section, and coordinated the hydrogen and CCUS analysis; Emma Gordon led the section on energy finance; Ryszard Pospiech, Charlène Bisch and Jérôme Hilaire co-ordinated modelling and data across sectors. Musa Erdogan contributed to data management and visualisation. Eleni Tsoukala provided essential support.

Internal contributors: The report benefited greatly from contributions from other experts within the IEA: Carlos Alvarez (coal), Heymi Bahar (renewables), Praveen Bains (bioenergy), Blandine Barreau (sustainable recoveries), Jose Miguel Bermudez Menendez (hydrogen), Stephanie Bouckaert (demand modelling), Clara Camarasa (buildings), Amrita Dasgupta (critical minerals), Chiara Delmastro (buildings), Tomás de Oliveira Bredariol (methane), Michael Drtil (power), Frank Gentile (sustainable recoveries), Ian

Hamilton (buildings), Louis Hennequin (venture capital), Paul Hugues (industry), Inchan Hwang (transport) Bruno Idini (transport), George Kamiya (critical minerals), Hyeji Kim (transport), Kevin Lane (buildings), Jean-Baptiste Le Marois (R&D and technology innovation), Suzy Leprince (R&D and technology innovation), Luca Lo Re (carbon markets), Yannick Monschauer (buildings), Rachael Moore (CCUS), Jeremy Moorhouse (bioenergy), Toru Muta (critical minerals), Leonardo Paoli (transport), Francesco Pavan (hydrogen), Apostolos Petropoulos (transport), Amalia Pizarro (hydrogen), Alison Pridmore (transport), Hugo Salamanca (industry), Cornelia Schenk (buildings), Rebecca Schulz (oil and gas), Seohee Song (buildings), Jacob Teter (transport), Monica Troilo (venture capital), Brent Wanner (power).

Internal reviewers:

Alessandro Blasi, Toril Bosoni, Laura Cozzi, Jean-Baptiste Dubreuil, Araceli Fernandez Pales, Carlos Fernandez Alvarez, Timur Guel, Samantha McCulloch, Gergely Molnar, Brian Motherway, Kristine Petrosyan, Uwe Remme, Masatoshi Sugiura and Daniel Wetzel.

Thanks also to Jad Mouawad, Astrid Dumond, Merve Erdem, Jethro Mullen, Rob Stone and Therese Walsh of the Communications and Digital Office. Justin French-Brooks edited the manuscript and Allison Leacu designed the cover.

The work could not have been achieved without the support and co-operation provided by many government bodies, organisations and companies worldwide, notably: European Commission and European Union's Horizon 2020 research and innovation programme funding under grant agreement No 952363; Ministry of Economy, Trade and Industry, Japan; Ministry of Foreign Affairs, Japan; and Ministry of Economic Affairs and Climate Policy, Netherlands.

Many experts from outside of the IEA provided input, commented on the underlying analytical work, and reviewed the report. Their comments and suggestions were of great value. They include:

Harmeet Bawa	Hitachi Energy
Vincent Berruto	DG Energy, European Commission
Rina Bohle Zeller	Vestas, Denmark
Barbara Buchner	Climate Policy Initiative
Mick Buffier	Glencore
Ryan Castilloux	Adamas Intelligence
Deirdre Cooper	Ninety-One
Jennie Dodson	Mission Innovation
Mili Fomicov	Imperial College
Masayuki Fujiki	MUFG, Japan
Charlotte Gardes	International Monetary Fund
Nili Gilbert	Carbon Direct
Francesca Gostinelli	ENEL

Giuseppe Grimaldi	EBRD
David Hart	Information Technology and Innovation Foundation
Emma Harvey	Green Finance Institute
Jim Henderson	Oxford Institute for Energy Studies, United Kingdom
Chris Heron	Eurometaux
Andrew Herscowitz	U.S. International Development Finance Corporation
Daniel Hill	Department of Natural Resources, Canada
Francisco Laveron	Iberdrola
Pierre-Laurent Lucille	Engie
Samson Masebinu	USAID
Antonio Merino Garcia	Repsol
Ylenia Meyer	Eni
Irene Monasterolo	EDHEC Business School
Peter Morris	Minerals Council, Australia
Arjun N. Murti	Warburg Pincus LLC
Nandita Parshad	EBRD
Vincent Petit	Schneider Electric
Davide Puglielli	ENEL
Filippo Ricchetti	Eni

Mark Richards	Rio Tinto
Simi Siwisa	ABSA Bank
Jonathan Stein	Hess Corporation
Martin Stuermer	International Monetary Fund
Adriana Maria	
Valencia Jaramillo	IDB Invest
Laszlo Varro	Shell
Kelvin Wong	DBS Bank

Abbreviations and acronyms

ADNOC	Abu Dhabi National Oil Company	GDP	Gross Domestic Product
APS	Announced Pledges Scenario	GFANZ	Glasgow Financial Alliance For Net Zero
ASSB	All-Solid-State Battery	GHG	Greenhouse Gas
CAGR	Compound Annual Growth Rate	HPAL	High-Pressure Acid Leaching
CBAM	Carbon Border Adjustment Mechanism	HVO	Hydrotreated Vegetable Oil
CCGT	Combined-Cycle Gas Turbine	ICE	International Combustion Engine
CCS	Carbon Capture and Storage	ICT	Information and Communications Technology
CCUS	Carbon Capture, Utilization and Storage	IPCEI	Important Projects of Common European Interest
CNG	Compressed Natural Gas	ITMO	Internationally Transferred Mitigation Outcomes
CVC	Corporate Venture Capital	LCE	Lithium Carbonate Equivalent
DAC	Direct Air Capture	LCOE	Levelized Cost of Electricity
DRC	Democratic Republic of Congo	LFP	Lithium Iron Phosphate
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization	LME	London Metal Exchange
EMDE	Emerging Markets and Developing Economies	LNG	Liquefied Natural Gas
EPRI	Electric Power Research Institute	LOHC	Liquid Organic Hydrogen Carriers
ESCO	Energy Service Companies	M&A	Mergers & Acquisition
ESG	Environmental, Social, and Governance	NOC	National Oil Companies
ETF	Exchange-Traded Funds	NZBA	Net-Zero Banking Alliance
ETS	Emissions Trading Scheme	NZE	Net Zero By 2050 Scenario
EV	Electric Vehicle	OCGT	Open-Cycle Gas Turbine
FERC	Federal Energy Regulatory Commission	OEM	Original Equipment Manufacturer
FID	Final Investment Decisions	OPEC	Organization of The Petroleum Exporting Countries
FSRU	Floating Storage Regasification Unit	PEM	Polymer Electrolyte Membrane
		PPA	Power Purchase Agreements

PV	Photovoltaic	UNFCCC	Un Framework Convention On Climate Change
R&D	Research and Development	VALCOE	Value Adjusted Levelized Cost of Electricity
RD&D	Research, Design, and Development	VC	Venture Capital
REE	Rare Earth Elements	VCMI	Voluntary Carbon Market Initiative
S&P	Standard & Poors	WACC	Weighted Average Cost of Capital
SAF	Sustainable Aviation Fuel	WEI	World Energy Investment
SDS	Sustainable Development Scenario	ZEV	Zero-Emission Vehicles
SES	Solid Energy Systems		
SPAC	Special-Purpose Acquisition Company		
STEPS	Stated Policies Scenario		
TCFD	Task Force On Climate-Related Financial Disclosure		
TTF	Title Transfer Facility		



This publication has been produced with the financial assistance of the European Union as part of the Clean Energy Transitions in Emerging Economies program.

This publication reflects the views of the International Energy Agency (IEA) Secretariat but does not necessarily reflect those of individual IEA member countries or the European Union (EU). Neither the IEA nor the EU make any representation or warranty, express or implied, in respect to the publication's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the publication.

The Clean Energy Transitions in Emerging Economies program has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 952363.

Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

This publication and any map included herein are 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.

IEA Publications

International Energy Agency

Website: www.iea.org

Contact information: www.iea.org/about/contact

IEA. All rights reserved.

Typeset in France by IEA – June 2022

Cover design: IEA

