World Energy Investment 2023

INTERNATIONAL ENERGY AGENCY

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Abstract

This year's edition of the *World Energy Investment* provides a full update on the investment picture in 2022 and an initial reading of the emerging picture for 2023.

The report provides a global benchmark for tracking capital flows in the energy sector and examines how investors are assessing risks and opportunities across all areas of fuel and electricity supply, critical minerals, efficiency, research and development and energy finance.

It focuses on some important features of the new investment landscape that are already visible, including the policies now in place that reinforce incentives for clean energy spending, the energy security lens through which many investments are now viewed, widespread cost and inflationary 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.

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Introduction

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A turning point for energy investment?

This new *World Energy Investment 2023* (*WEI 2023*) report is the eighth in our annual series where we provide the global benchmark for tracking capital flows in the energy sector. The last few years have been a period of extreme disruption for the energy sector. The new *WEI 2023* offers an opportunity to take stock of what this has meant for investment, and what those investments might mean in turn for the future security and sustainability of the energy sector.

The shock to the system from the global energy crisis has come at a time of increasingly visible impacts of a changing climate and has taken many forms. Price spikes created strong economic incentives to increase supply and to find alternative or more efficient ways to meet demand. Energy security shocks created powerful incentives for policy makers to reduce vulnerabilities and dependencies, while also – for many developing economies in particular – draining the financial resources available to address them.

In the new *WEI 2023* we provide a full update on the investment picture in 2022 and an initial reading of the emerging picture for 2023. Huge uncertainties remain over how events will play out. But some important features of the new investment landscape are already visible, including the policies now in place that reinforce incentives for clean energy spending, the energy security lens through which many investments are now viewed, widespread cost and inflationary 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 2023 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 deals with investment in **energy efficiency and the end-use sectors**, and Chapter 5 brings insights on energy **research and development and innovation**. The concluding Chapter 6 considers trends in **energy finance**.

While the focus of *WEI 2023* is to track investment and financing trends in 2022 and provide an early indication for 2023, the report also benchmarks today's trends against future scenarios from the IEA World Energy Outlook. 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 CO_2 emissions by 2050.

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Overview and key findings

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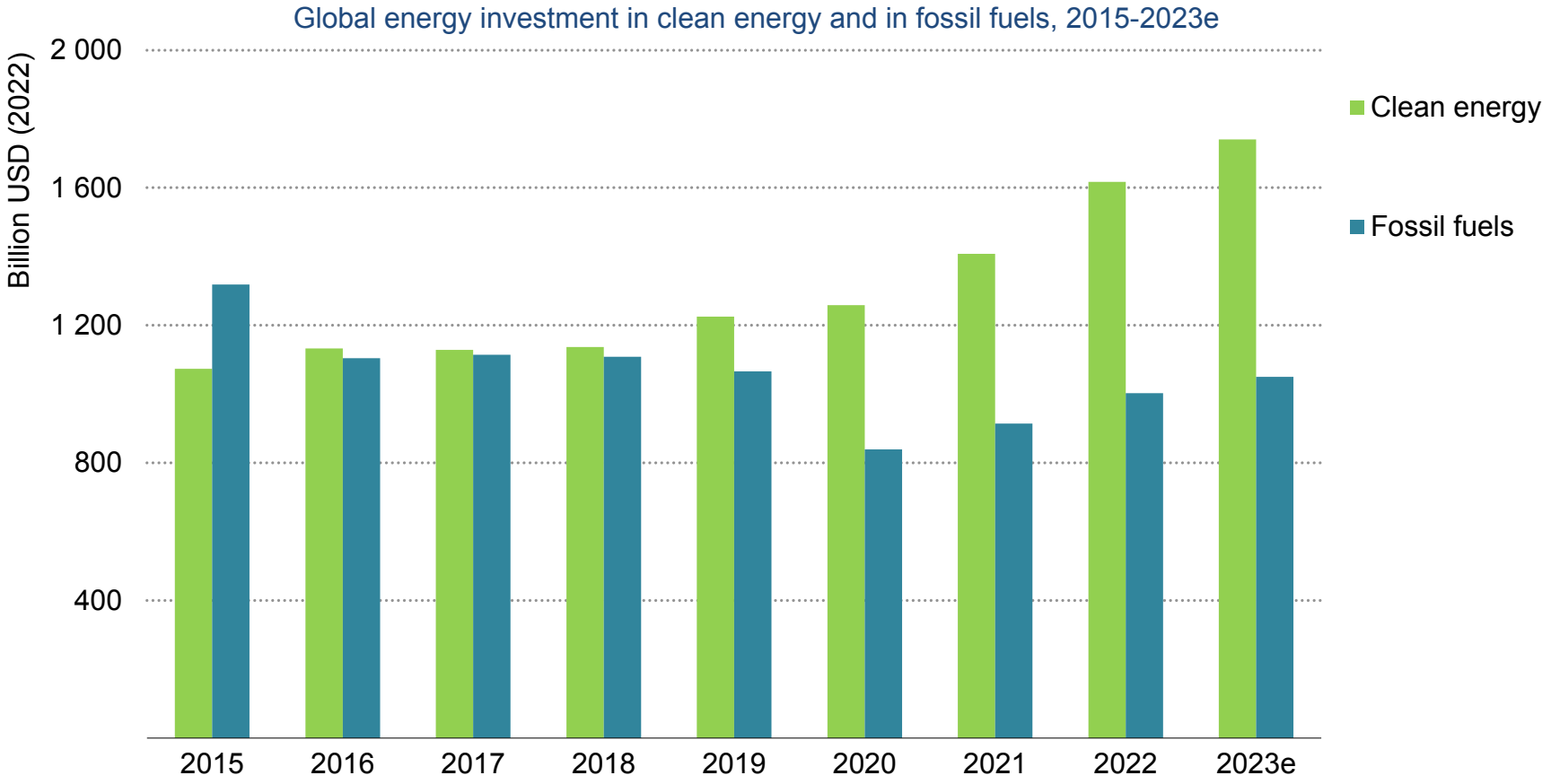
The recovery from the Covid-19 pandemic and the response to the global energy crisis have provided a major boost to global clean energy investment



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Note: 2023e = estimated values for 2023.

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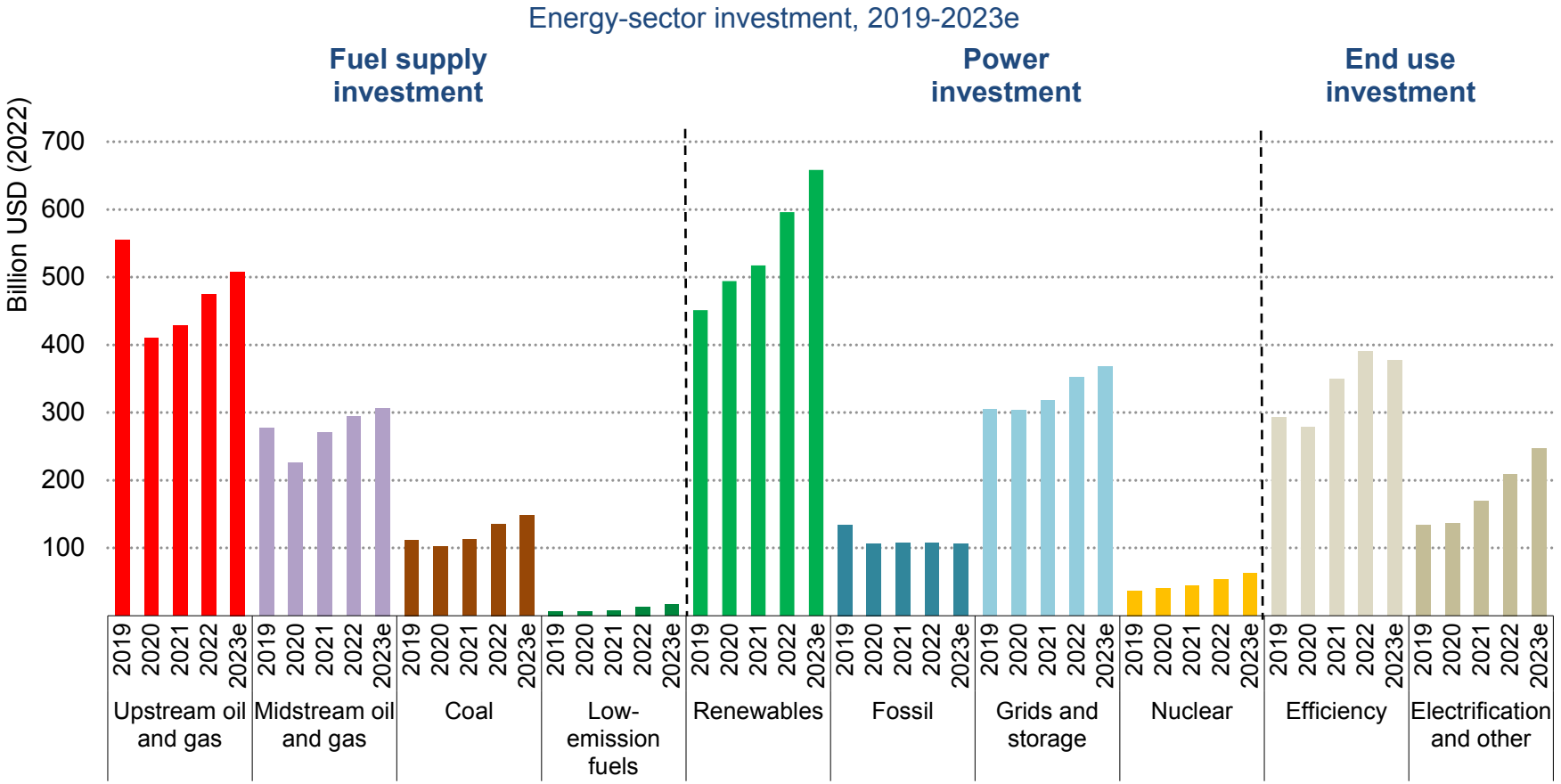
Increases across almost all categories push anticipated spending in 2023 up to a record USD 2.8 trillion



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Notes: “Low-emission fuels” include modern liquid and gaseous bioenergy, low-emission hydrogen and low-emission hydrogen-based fuels; “Other end use” refers to renewables for end use and electrification in the buildings, transport and industrial sectors. The terms grids and networks are used interchangeably in this report and do not distinguish between transmission and distribution; 2023e = estimated values for 2023..

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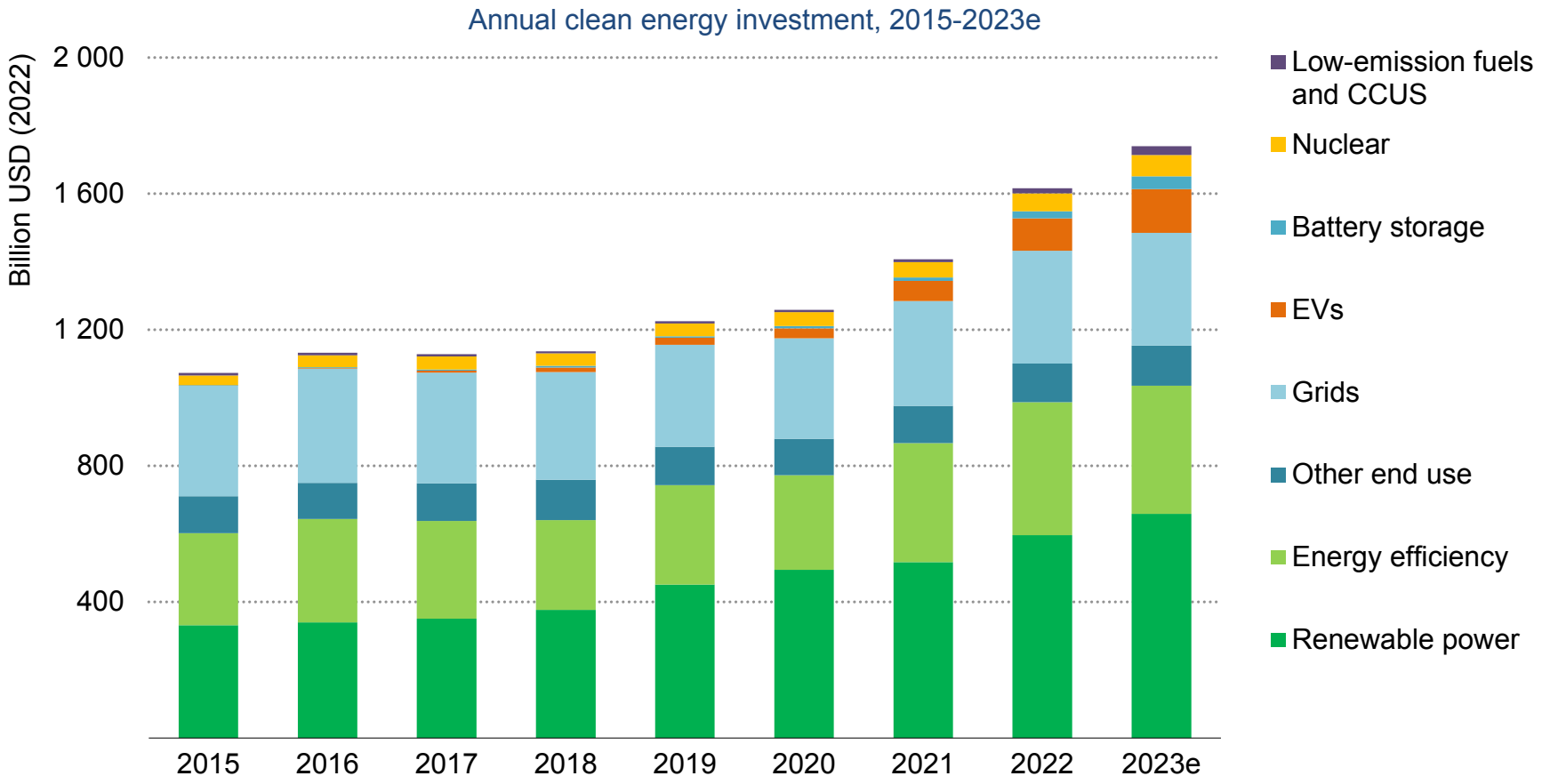
Renewables, led by solar, and EVs are leading the expected increase in clean energy investment in 2023



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Notes: “Low-emission fuels” include modern liquid and gaseous bioenergy, low-emission hydrogen and hydrogen-based fuels that do not emit any CO_2 from fossil fuels directly when used and emit very little when being produced; “Other end use” refers to renewables for end use and electrification in the buildings, transport and industrial sectors. 2023e = estimated values for 2023; CCUS = carbon capture, utilisation and storage; EV = electric vehicle.

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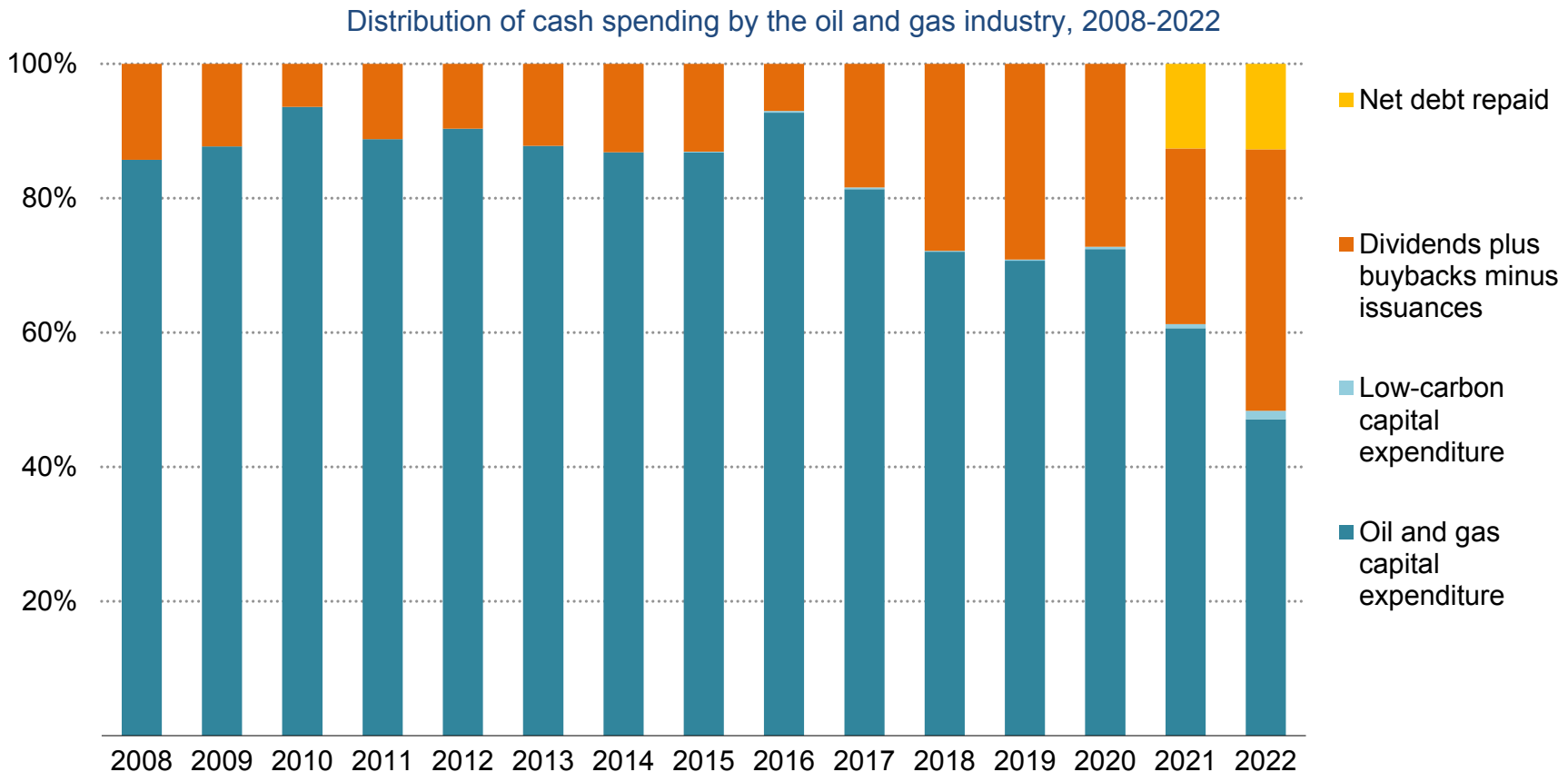
Less than half of the oil and gas industry's unprecedented cash flow from the energy crisis is going back into traditional supply and only a small fraction to clean technologies



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Source: IEA analysis based on data from S&P Capital IQ.

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The momentum behind clean energy investment stems from a powerful alignment of costs, climate and energy security goals, and industrial strategies

The recovery from the slump caused by the Covid-19 pandemic and the response to the global energy crisis have provided a significant boost to clean energy investment. Comparing our estimates for 2023 with the data for 2021, annual clean energy investment has risen much faster than investment in fossil fuels over this period (24% vs 15%). Our new analysis highlights how the period of intense volatility in fossil fuel markets caused by the Russian Federation's (hereafter "Russia") invasion of Ukraine has accelerated momentum behind the deployment of a range of clean energy technologies, even as it also prompted a short-term scramble for oil and gas supply.

We estimate that around USD 2.8 trillion will be invested in energy in 2023. More than USD 1.7 trillion is going to clean energy, including renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements and end-use renewables and electrification. The remainder, slightly over USD 1 trillion, is going to unabated fossil fuel supply and power, of which around 15% is to coal and the rest to oil and gas. For every USD 1 spent on fossil fuels, USD 1.7 is now spent on clean energy. Five years ago this ratio was 1:1.

Clean energy investments have been boosted by a variety of factors. These include improved economics at a time of high and volatile fossil fuel prices; enhanced policy support through instruments like the US Inflation Reduction Act and new initiatives in Europe, Japan, the People's Republic of China (hereafter "China") and elsewhere; a strong alignment of climate and energy security goals, especially in import-dependent economies; and a focus on industrial strategy as countries seek to strengthen their footholds in the emerging clean energy economy.

This momentum has been led by renewable power and EVs, with important contributions also from other areas such as batteries, heat pumps and nuclear power. In 2023 low-emissions power is expected to account for almost 90% of total investment in electricity generation. Solar is the star performer and more than USD 1 billion per day is expected to go into solar investments in 2023 (USD 380 billion for the year as a whole), edging this spending above that in upstream oil for the first time.

Consumers are investing in more electrified end uses. Demand for electric cars is booming, with sales expected to leap by more than one-third this year after a record-breaking 2022. As a result, investment in EVs (defined as the incremental spending on EVs vs the average price of vehicles sold in a given country) has more than doubled since 2021, reaching USD 130 billion in 2023. Global sales of heat pumps have seen double-digit growth since 2021.

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The increase in fossil fuel investment expected in 2023 is unevenly spread around the world; less than half the cash flow available to the oil and gas industry is going back into new supply

2022 was an extraordinarily profitable year for many fossil fuel companies, as they saw revenues soar on higher fuel prices. Net income from fossil fuel sales more than doubled compared with the average in recent years, with global oil and gas producers receiving around USD 4 trillion.

Our overall expectation, based on analysis of the announced spending plans of all the large and medium-sized oil, gas and coal companies, is that investment in unabated fossil fuel supply is set to rise by more than 6% in 2023, reaching USD 950 billion.

The largest share of this total is going to upstream oil and gas, where investment is expected to rise by 7% in 2023 to more than USD 500 billion, bringing this indicator in aggregate back to the levels of 2019. Around half this increase is likely to be absorbed by cost inflation.

Many large oil and gas companies have announced higher spending plans on the back of record revenues. But uncertainties over longer-term demand, worries about costs, and pressure from many investors and owners to focus on returns rather than production growth mean only large Middle Eastern national oil companies are spending much more in 2023 than they did in 2022, and they are the only subset of the industry spending more than pre-pandemic levels.

The headline rise in spending on new oil and gas supply represents less than half of the cash flow that was available to the oil and gas industry. Between 2010 and 2019, three-quarters of cash outflows were typically invested into new supply. This is now less than half, with the majority going to dividends, share buybacks and debt repayment.

Investment by the oil and gas industry in low-emissions sources of energy is less than 5% of its upstream investment. This indicator differs widely by company, with double-digit shares common among the large European companies. Investment by the industry in clean fuels, such as bioenergy, hydrogen and CCUS, is picking up in response to more supportive policies but remains well short of where it needs to be in climate-driven scenarios.

Investment in coal supply is expected to rise by 10% in 2023, and is already well above pre-pandemic levels. Investment in new coal-fired power plants remains on a declining trend, but a warning sign came in 2022 with 40 GW of new coal plants being approved – the highest figure since 2016. Almost all of these were in China, reflecting the high political priority attached to energy security after severe electricity market strains in 2021 and 2022, even as China deploys a range of low-emission technologies at scale.

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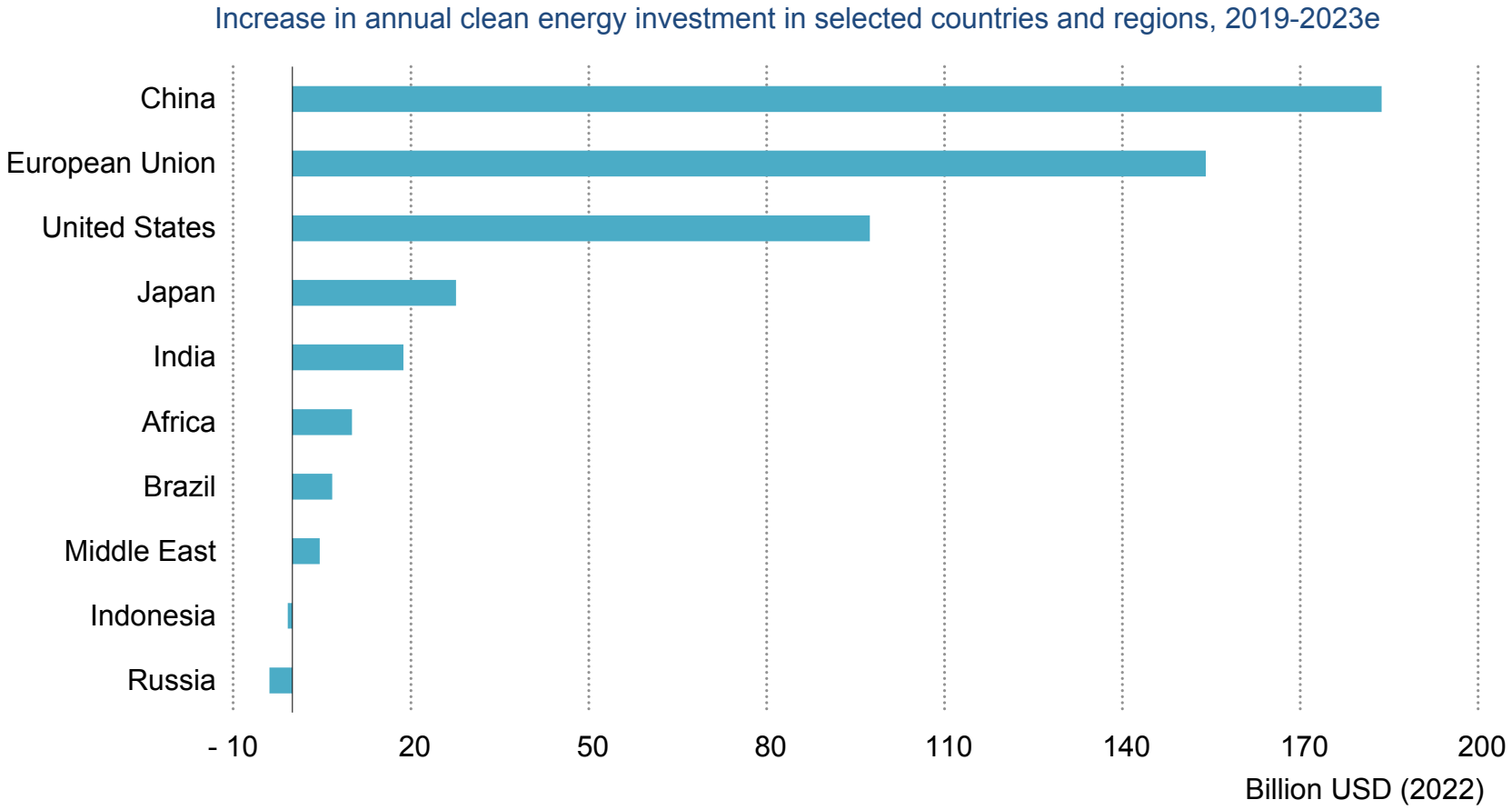
The increase in clean energy spending in recent years is impressive but heavily concentrated in a handful of countries



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Note: 2023e = estimated values for 2023.

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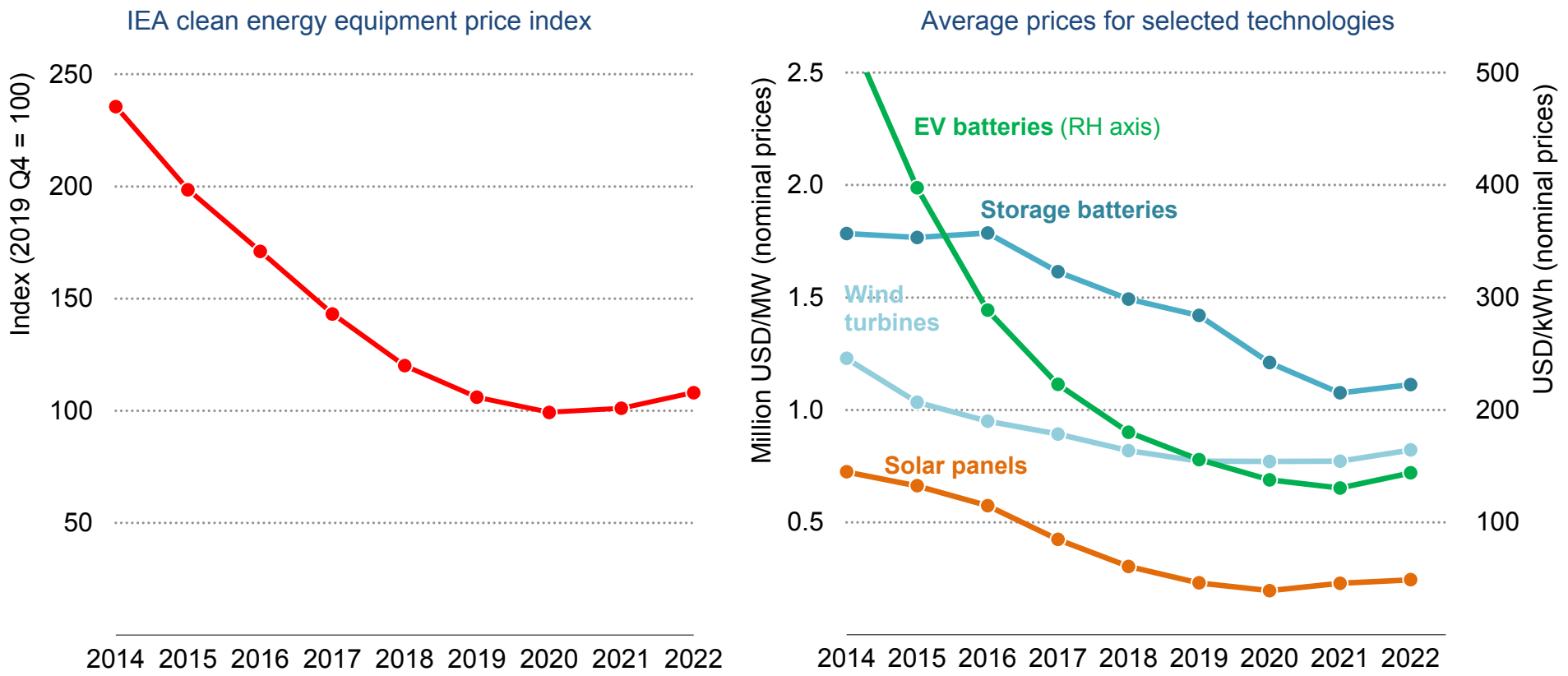
Clean energy costs edged higher in 2022, but pressures are easing in 2023 and mature clean technologies remain very cost-competitive in today's fuel-price environment



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Notes: The IEA clean energy equipment price index tracks price movements of a fixed basket of equipment products that are central to the clean energy transition, weighted according to their share of global average annual investment in 2020-2022: solar PV modules (48%), wind turbines (36%), EV batteries (13%) and utility-scale batteries (3%). Prices are tracked on a quarterly basis with Q4 2019 defined as 100.

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Notes of caution amid rising momentum behind clean energy transitions

The positive momentum behind clean energy investment is not distributed evenly across countries or sectors, highlighting issues that policy makers will need to address to ensure a broad-based and secure transition. The macroeconomic environment presents additional obstacles, with higher short-term returns for fossil fuel assets and rising borrowing costs and debt burdens. Clean energy investments often require high upfront spending, making the cost of financing a crucial variable for investors, even if this is offset over time by lower operating costs.

More than 90% of the increase in clean energy investment since 2021 has taken place in advanced economies and China. There are bright spots elsewhere: for example, solar investment remains dynamic in India; deployment in Brazil is on a steady upward curve ; and investor activity is picking up in parts of the Middle East, notably in Saudi Arabia, the United Arab Emirates and Oman. However, higher interest rates, unclear policy frameworks and market designs, financially-strained utilities and a high cost of capital are holding back investment in many other countries. Remarkably, the increases in clean energy investment in advanced economies and China since 2021 exceed total clean energy investment in the rest of the world.

After an unbroken run of cost declines, prices for some key clean energy technologies rose in 2021 and 2022 thanks largely to higher input prices for critical minerals, semiconductors and bulk materials like steel and cement. Solar PV modules were around 20% more expensive in early 2022 than one year earlier, although these price pressures have eased since. Wind turbine costs, especially for European manufacturers, remained high in early 2023, at 35% above the low levels of early 2020. Permitting has been a key concern for investors and financiers, especially for wind and grid infrastructure.

While solar deployment has been increasing year-on-year, the project pipeline for some other technologies has been less reliable. Investment in wind power has varied year-on-year in key markets in response to changing policy circumstances. Nuclear investment is rising but hydropower, a key low-emission source of power market flexibility, has been on a downward trend.

Weak grid infrastructure is a limiting factor for renewable investment in many developing economies, and here too current investment flows are highly concentrated. Advanced economies and China account for 80% of global spending and for almost all of the growth in recent years.

Our analysis presents a mixed picture on the prospects for energy efficiency and end use investments. They rose in 2022 thanks to the stimulus provided by new policies in Europe and North America, alongside exceptionally high energy prices. However, we expect spending to flatten in 2023 amid a slowdown in construction activity, higher borrowing costs and strains on household budgets.

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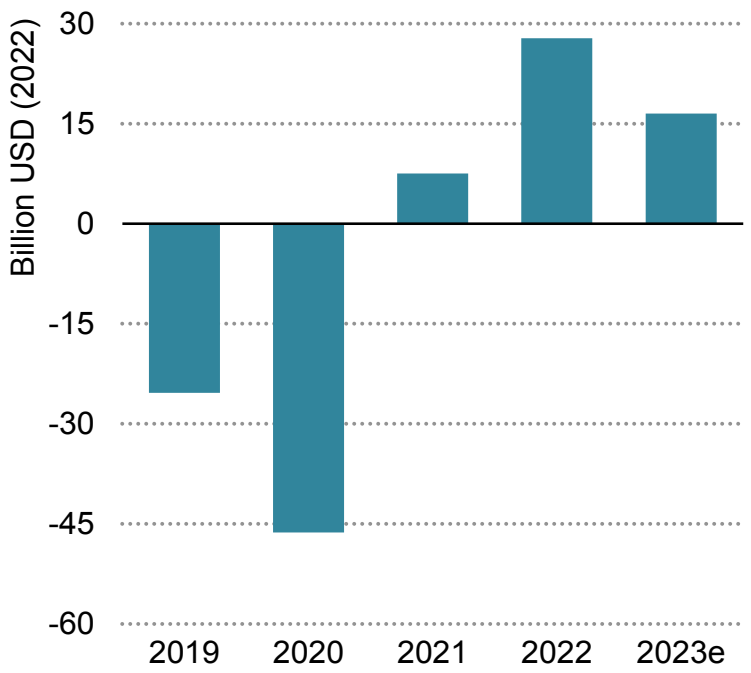
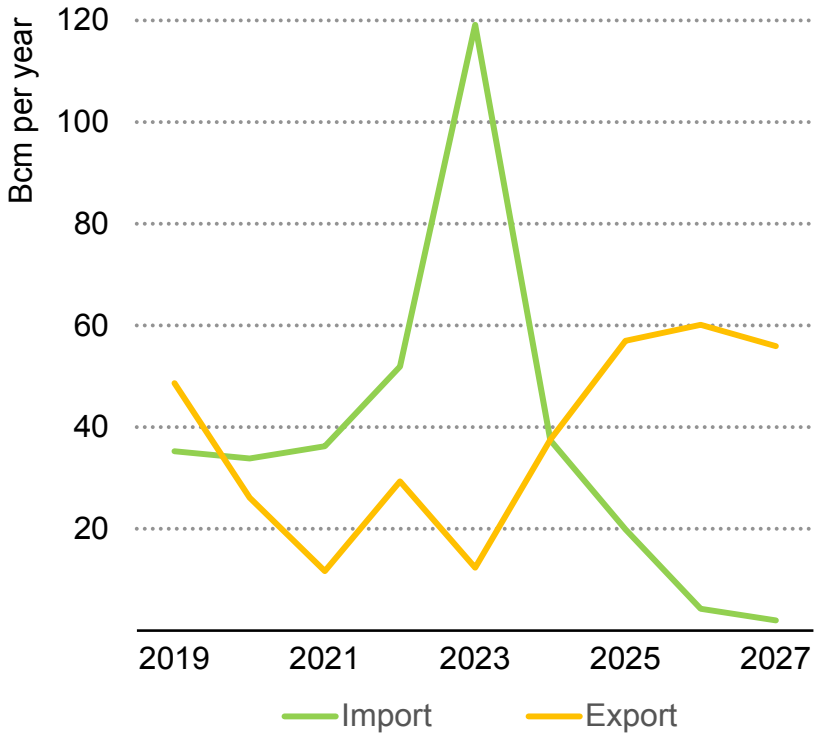
Cuts in Russian gas deliveries to Europe have prompted higher investment in alternative sources of supply and in LNG infrastructure

Change in global investment in natural gas supply



Annual LNG import and export capacity additions



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Notes: “Gas supply investment” includes upstream and transport (LNG liquefaction, shipping and regasification and pipeline transmission and distribution).
2023e = estimated values for 2023.

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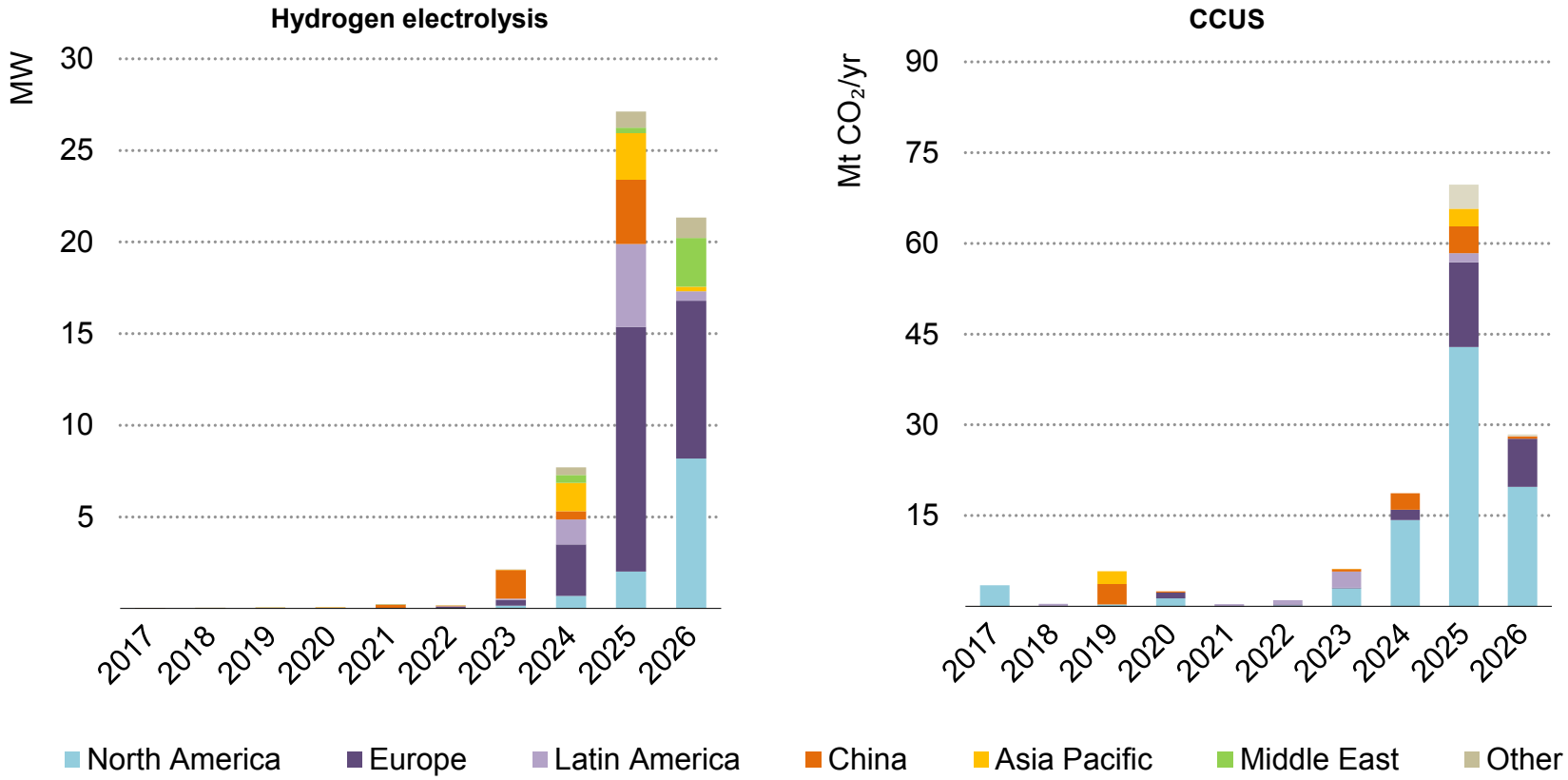
Strong policy signals and new support schemes have triggered a rapid expansion in the project pipelines for low-emissions hydrogen and CCUS

Capacity additions for hydrogen electrolysis and CO_2 capture projects by announced start date, 2017-2026



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Notes: GW = GW of electricity input; for years before 2023, actual start dates are shown; for 2023 onwards, scheduled start dates as announced by developers are shown; CCUS covers all sources of CO_2, including low-emission hydrogen projects using CCUS; data include projects at the "feasibility" stage and beyond.

Sources: IEA analysis based on IEA hydrogen project database, CCUS projects database and recent announcements.

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Gas investments are caught between immediate shortfalls and longer-term uncertainty, although low-emission opportunities are growing

Russia cut pipeline deliveries of natural gas to the European Union by around 80% in 2022, seeking leverage by exposing consumers to higher energy bills and supply shortages following its invasion of Ukraine. This led to strong price and policy incentives for investors to step up non-Russian gas supply, build up alternative delivery infrastructure, and scale up alternatives to natural gas. All of these effects are visible in our analysis.

The amount of new oil and gas resources approved for development in 2022 and 2023 has been below the average level seen over the past decade. However, 2023 is seeing a 25% increase in new approvals relative to 2022 and most of these are for natural gas, reflecting the push to substitute for the shortfall in Russian supply.

A wave of new regasification capacity is also underway as countries look to secure liquefied natural gas (LNG) imports. Europe's annual regasification capacity is set to increase by 50 bcm from 2022-2025, expanding the continent's overall LNG import capacity by one-fifth. Import projects are growing even more quickly in Asia, which is set to add over 100 bcm of LNG import capacity by 2025 (more than half in China).

The crisis has also prompted additional investment in liquefaction capacity, the most expensive part of the gas value chain. Around 60 bcm of capacity has been given the green light since Russia's invasion of Ukraine, nearly double the rate of new approvals compared with the past decade. Along with projects already under construction, this leads to an unprecedented 170 bcm of export capacity that could come into operation between 2025 and 2027.

A key dilemma for investors undertaking large, capital-intensive gas supply projects is how to reconcile strong near-term demand growth with uncertain and possibly declining longer-term demand. This is a particular issue for Europe, given the continent's strong climate goals. Many importers have been reluctant to commit to long-term contracts for gas supply. A preference for floating regasification terminals has been a way to avoid locking in future emissions.

Another avenue is to expand investment in low-emission fuels and in CCUS. New policies are swelling the project pipeline in these areas, driven by energy security and climate imperatives. Europe has a burgeoning number of electrolytic hydrogen projects, and reinforced US incentives in the Inflation Reduction Act have prompted a wave of investor interest in hydrogen and CCUS. After a number of false dawns, the number of large-scale projects and well-capitalised sponsors, along with a string of acquisitions by oil and gas majors (notably in transport biofuels and biogases), suggests that investment in low-emission fuels could grow strongly in the coming years.

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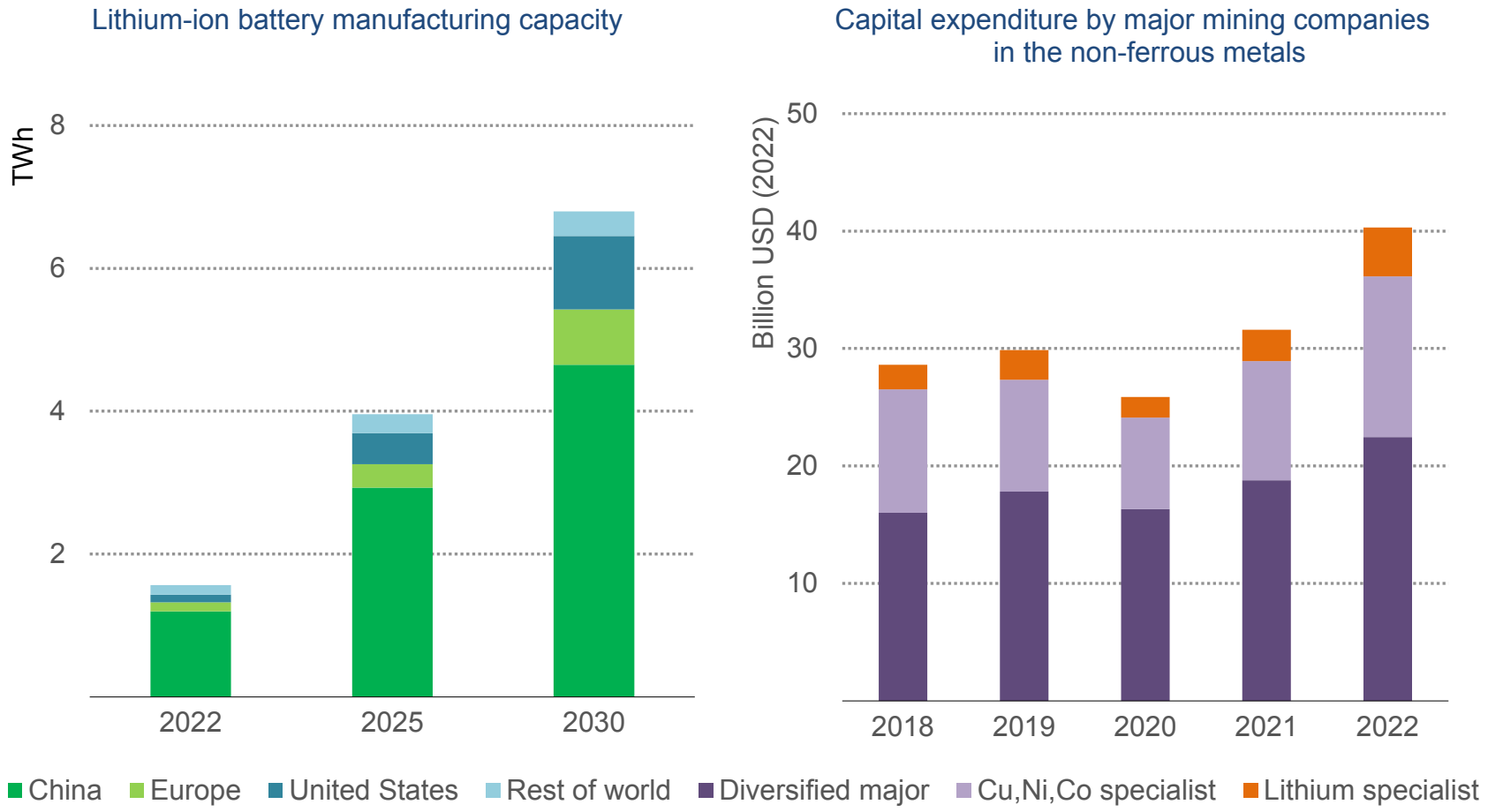
Investment is flowing to clean energy manufacturing and critical minerals, but ensuring well-sequenced growth of new supply chains will be a major task



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Notes: Cu = copper; Ni = nickel; Co = cobalt; the illustrative expansion of manufacturing capacity assumes that all announced projects proceed as planned.

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Competition for clean energy manufacturing and for supplies of critical minerals and metals is a major issue for the resilience of transitions

A secure transition to clean energy hinges on resilient and diversified clean energy technology supply chains. According to the IEA Energy Technology Perspectives, some USD 1.2 trillion of cumulative investment to 2030 is needed in clean energy manufacturing and in critical minerals supply to get on track for a 1.5°C scenario, in addition to the energy sector investments covered in this report.

Record sales of EVs, strong investment in battery storage for power (which are expected to approach USD 40 billion in 2023, almost double the 2022 level) and a push from policy makers to scale up domestic supply chains have sparked a wave of new lithium-ion battery manufacturing projects around the world. If all capacity announcements were to materialise, then 5.2 TWh of new capacity could be available by 2030.

For the moment, China is the main player at every stage of global battery manufacturing, with the exception of the mining of critical minerals. The announced manufacturing plans would somewhat erode this position. In 2022, over 75% of existing battery manufacturing capacity was located in China. However, despite accounting for two-thirds of yearly global capacity additions to 2030, China's share of global capacity could fall by nearly 10 percentage points by the end of the decade.

A key question for battery manufacturers is whether supplies of critical minerals will keep up with demand. Thanks to high prices and growing policy support, investment in critical mineral mining rose by 30% in 2022. Exploration spending also grew, notably for lithium, copper and nickel, led by Canada and Australia and with activities growing in Brazil and resource-rich countries in Africa. But moving from exploration to new production can take more than 10 years, and there remain widespread concerns that critical mineral investment will become a constraining factor for clean technology manufacturing and deployment.

Critical minerals and batteries are among the areas where clean technology innovation remains essential. Public spending on research and development has been on a steady upward trend, as has corporate spending. But venture capital funding for clean energy, after reaching a high in 2022, faces headwinds in a more difficult macroeconomic environment.

For a decade, cheap capital has lowered barriers to investment in riskier bets and thereby concealed potential weaknesses in innovation systems. With the cost of money set to rise, the health of these systems and the level of public support will be a critical determinant of how quickly new technology ideas continue to flow.

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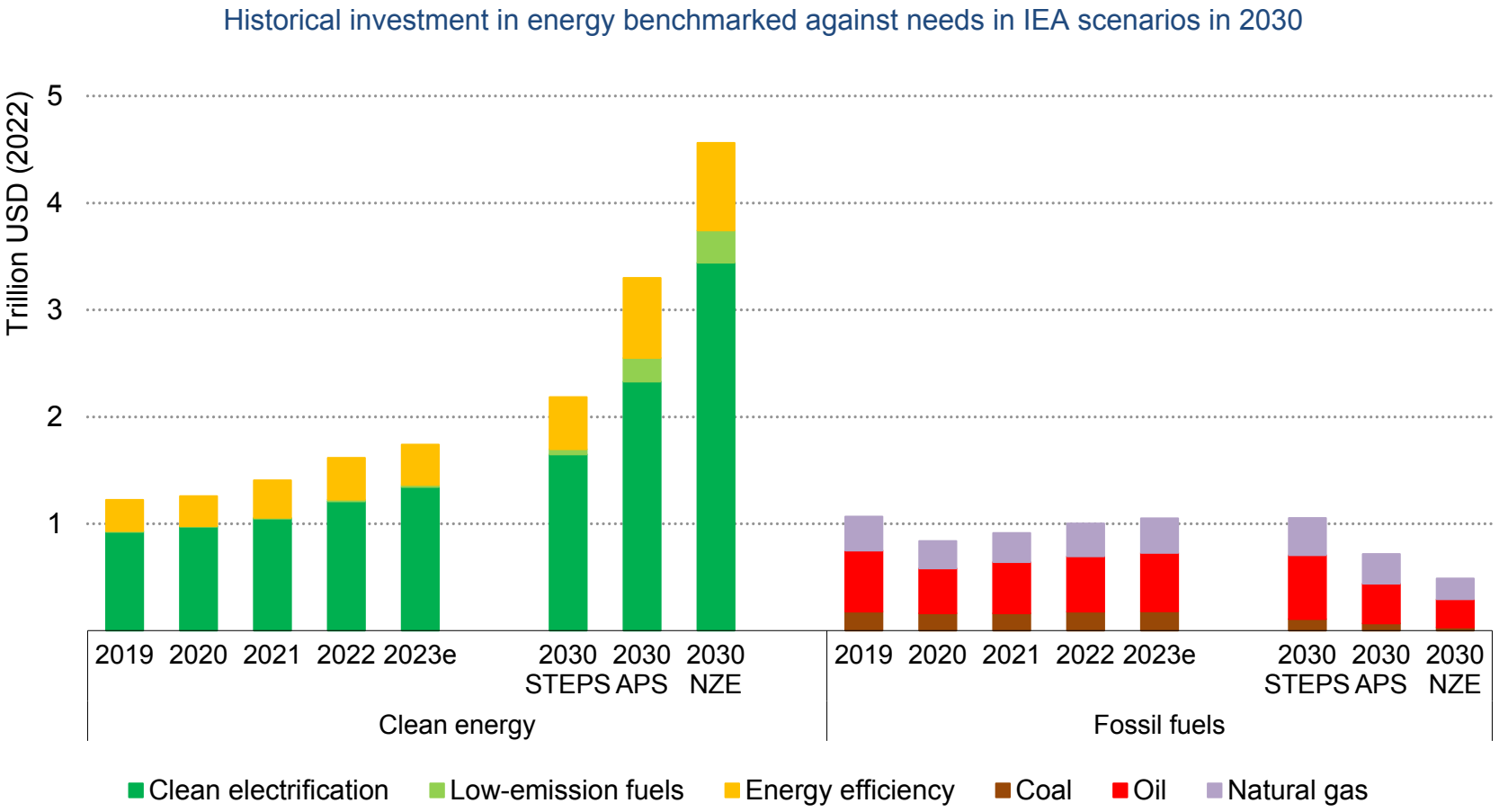
Scaling up clean investment is the key task for the sustainable and secure transformation of the energy sector



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Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. 2023e = estimated values for 2023.

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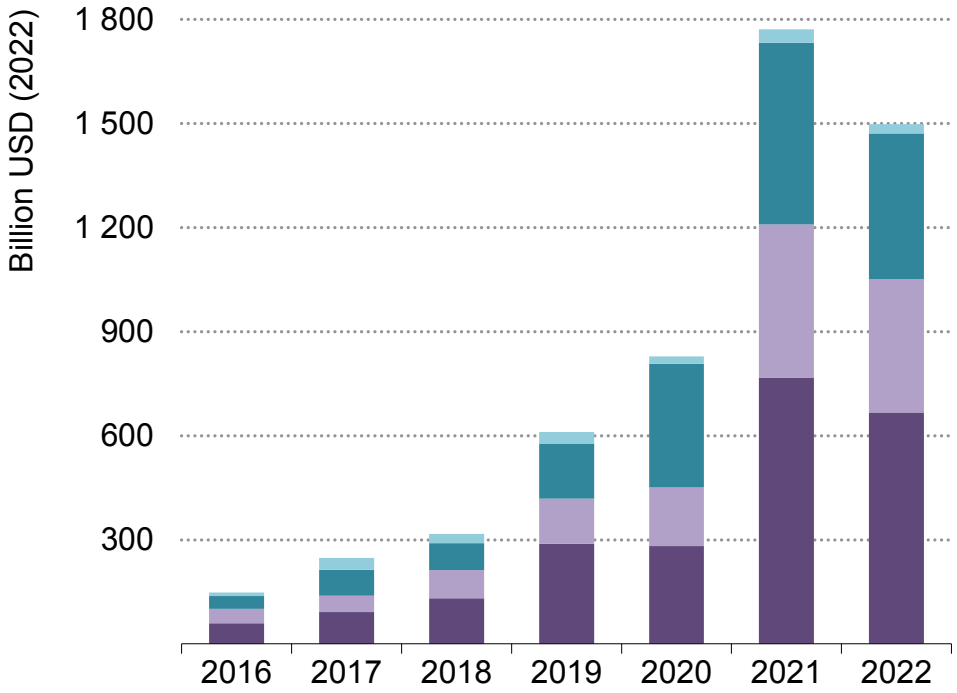
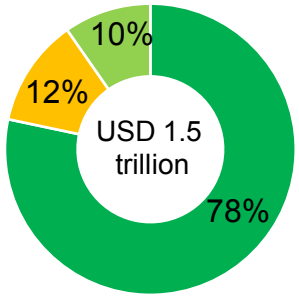
Expanding access to finance will be vital: sustainable finance has weathered the storm of the energy crisis, but remains heavily concentrated in advanced economies

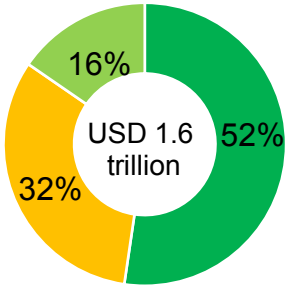
Sustainable debt issuances by issuer type, and region, 2016-2022



Sustainable debt issuances , 2022



Clean energy spending, 2022



Corporates Financials SSA Other Advanced economies China Other EMDEs

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Notes: SSA = sovereigns, supranationals and agencies; this category also includes municipals; Other = asset-based securities and project bonds.
Sources: Bloomberg; Refinitiv.

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Clean energy investment is starting to flow, but imbalances point to continued risks ahead

In the IEA World Energy Outlook 2021, we wrote that "the world is not investing enough to meet its future energy needs … IEA analysis has repeatedly highlighted that a surge in spending to boost deployment of clean energy technologies and infrastructure provides the way out of this impasse, but this needs to happen quickly or global energy markets will face a turbulent and volatile period ahead".

This picture is starting to change: global energy investment is picking up, and the rise in clean energy investment since 2021 is leading the way, outpacing the increase in fossil fuel investment by almost three-to-one. Clean electrification is leading the charge. If it continues to grow at the rate seen since 2021, then aggregate spending in 2030 on low-emission power, grids and storage, and end-use electrification would exceed the levels required to meet the world's announced climate pledges (the APS). For some technologies, notably solar, it would match the investment required to get on track for a 1.5°C stabilisation in global average temperatures (the NZE Scenario).

However, progress has been uneven. Investment in expanding and modernising grids is lagging behind in many countries. A rising share of solar and wind needs to be accompanied by spending on technologies that provide greater flexibility to power systems. Supply chain and skills bottlenecks could constrain growth. And, above all, the geographical imbalances in investment need addressing, with clean energy investment in many emerging and developing economies growing only slowly and the number of people without access to modern energy services remaining stubbornly high.

Other pillars of clean energy transitions do not yet show the same positive dynamics as clean electrification. Investment in energy efficiency has been increasing, but is well off track to meet more ambitious climate scenarios. Investment in low-emission fuels is being spurred by new policy measures, but from a very low base.

Spending on fossil fuels is most closely aligned with the 2030 needs of a scenario reflecting today's policy settings (STEPS), but producers need to watch closely how clean energy spending evolves, particularly the ways in which clean electrification affects demand for fuels in power generation, and for mobility and heat. The risks of locking in fossil fuel use are clear: fossil fuel investment in 2023 is now more than double the levels required to meet much lower demand in the NZE Scenario.

The crucial open question is how quickly clean energy investment scales up in emerging and developing economies, where supportive strategies and policies will need to be accompanied by improved access to finance. For the moment, sustainable finance instruments remain concentrated in advanced economies, accounting for nearly 80% of sustainable debt issuance in 2022. Issuances elsewhere (outside China) are growing from a low base, with India's successful first green bond a landmark in this sector. Scaling up these instruments and mobilising much greater support from development finance institutions will be critical to the continued broadening and acceleration of clean energy transitions.

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Power sector

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Overview of power investment

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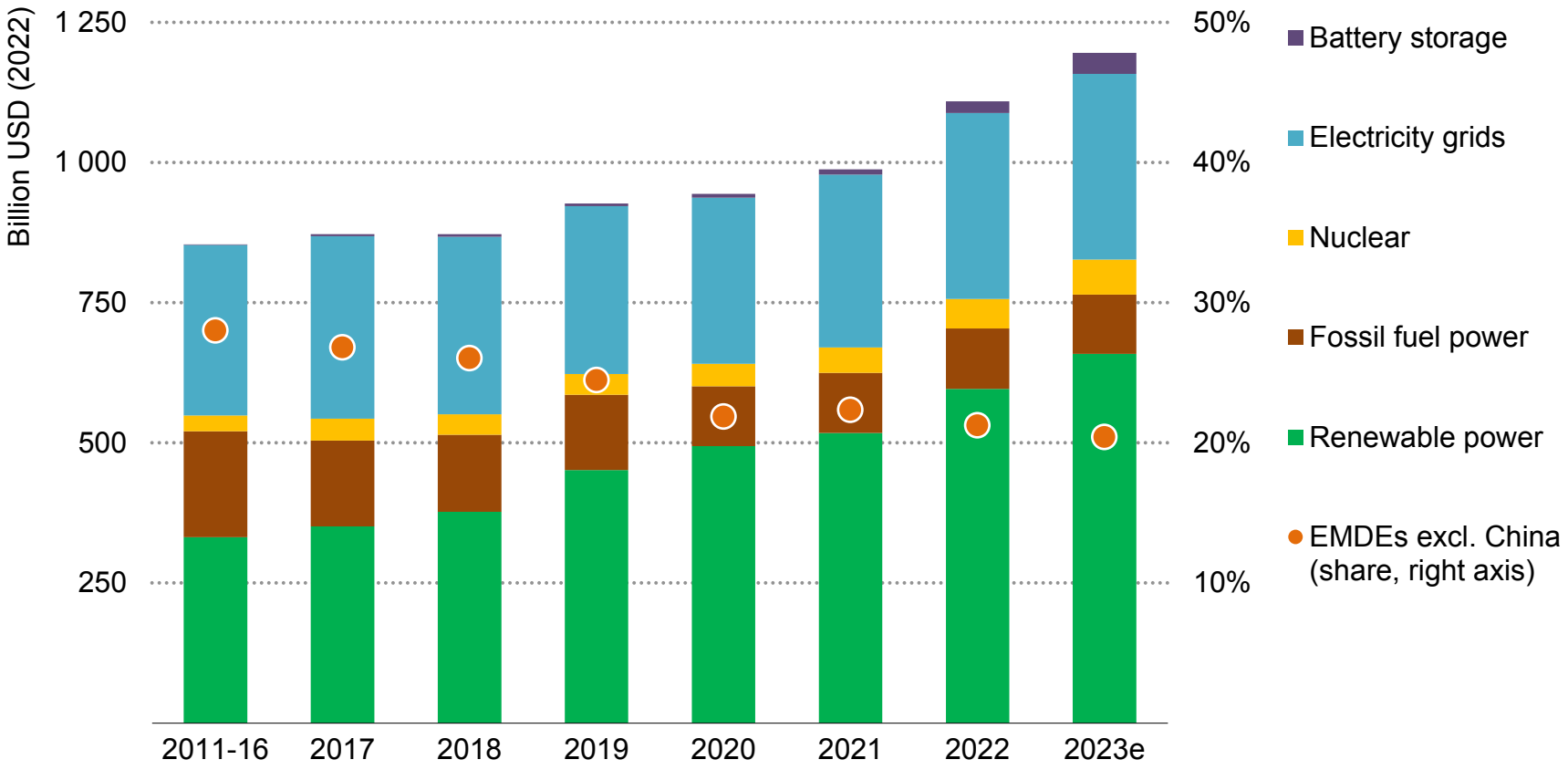
Power sector investment increased by around 12% in 2022 to USD 1.1 trillion with 2023 expected to see further growth to almost USD 1.2 trillion

Global average annual investment in the power sector by category, 2011-2023e



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Notes: Investment is measured as ongoing capital spending on new power capacity; all numbers throughout are in 2022 USD; Fossil fuel power includes unabated and abated power; EMDEs = emerging market and developing economies; 2023e = estimated values for 2023.

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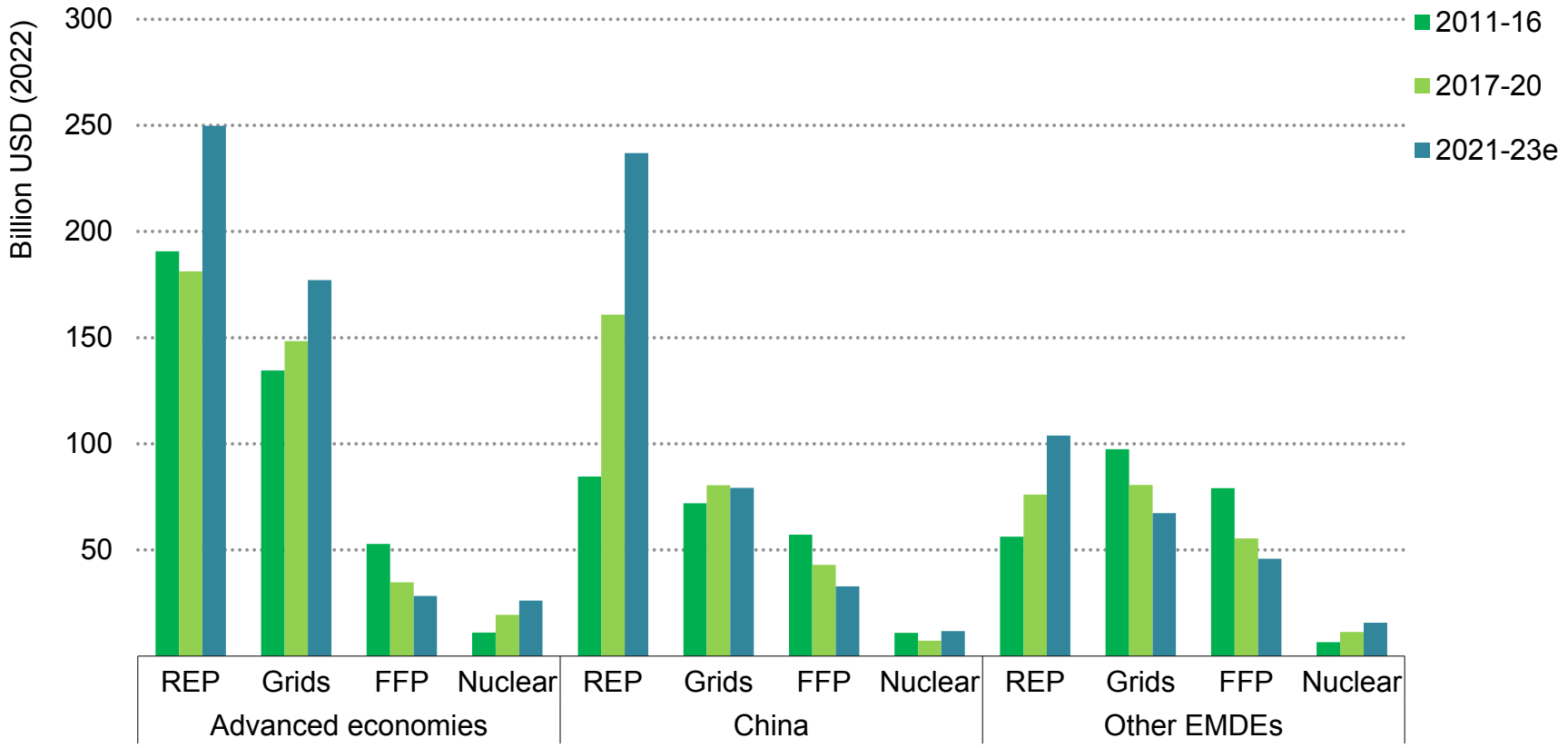
Advanced economies and China lead investment in renewable power generation and grids, while many other EMDEs struggle to mobilise sufficient capital for a clean and secure energy transition

Average annual investment in the power sector by geography and category, 2011-2023e



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Notes: REP = renewable power; FFP = fossil fuel power; batteries are excluded here; 2023e = estimated values for 2023.

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Investment in renewables, grids and batteries has accelerated during the global energy crisis, with capital spending on unabated fossil fuel power generation edging downwards

Power sector investment grew by 12% in 2022, topping USD 1 trillion for the first time, with 2023 expected to see further growth to almost USD 1.2 trillion. Our tracking of capital flows and investments suggests that a major effect of the global energy crisis has been to accelerate the deployment of clean energy technologies. The strong underlying economics of renewables have been reinforced by policy packages such as the US Inflation Reduction Act, the EU REPowerEU plan and Fit-for-55 package, and India's renewables targets. Renewables and grids are the leading components of power investment and are expected to account for more than USD 1 trillion of investment on their own in 2023.

Global spending on renewables hit a new record in 2022 at almost USD 600 billion, driven by solar PV and wind (especially in China) despite cost and supply chain pressures. Given the reinforced push for renewables in a range of large markets (e.g. USA, China, Europe, India) and the gradual unwinding of supply chain problems, we are now expecting higher capacity additions for wind and especially solar PV than last year, with 2023 expected to see another 10% increase in renewables investment to more than USD 650 billion.

Capital expenditure on fossil fuel power increased marginally in 2022 to almost USD 110 billion but this was still significantly lower than the annual average of USD 135 billion in the period 2016-2021. While coal-fired power investment decreased, investment in gas-fired power picked up. Spending on fossil fuel power with CCUS rose but remains marginal at USD 1 billion. Spending on dispatchable clean generation, on the other hand, continues its downward investment trend, with increased spending on nuclear not able to compensate for a drop in hydropower investment.

Spending on electricity grids built on its 2021 rebound with a further 8% increase in 2022, but initial signs suggest a flattening in spending in 2023. Most of the infrastructure investment is in advanced economies and China, underpinned by the need to enable greater electrification and meet grid balancing demands in power systems that are increasingly renewables rich. Spending on grids in most emerging market and developing economies (EMDEs) is falling behind, a worrying signal given the prospect of rapid increases in electricity demand. Battery storage investment in 2022 grew in line with our strong expectations and is set for further growth in 2023, encouraged by the US Inflation Reduction Act and other incentives in Europe, Australia, China, Japan and Korea.

Despite upbeat expectations for clean power, final investment decisions (FIDs) in 2022 had a mixed picture. Solar project approvals remain strong, while offshore wind lags behind. FIDs for coal- and gas-fired plants reached their highest level since 2016, driven almost entirely by China, reflecting security of supply concerns.

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Outside China, power sector spending in many EMDEs remains low; it needs to pick up quickly to meet access, security and sustainability goals

Power sector investment in EMDEs outside China has been averaging around USD 230 billion per year in recent years, only around 20% of the global total. This figure increased by 7% in 2022, but investment spending in advanced economies and in China rose more rapidly by 14%, reaching more than USD 850 billion.

A number of EMDEs are stepping up their efforts to deploy clean power. India remains a dynamic market, in particular for solar PV, with policy makers also focused on building out the grid, promoting new sources of flexibility in power markets, and encouraging the domestic supply chain. India's Production-Linked Incentive (PLI) scheme is providing incentives for domestic manufacturing of high-efficiency solar PV modules as well as for batteries.

Renewable power investment is also starting to pick up in the Middle East, notably for solar in Saudi Arabia, the United Arab Emirates and Oman. Deployment is on a steady upward curve in Brazil. South Africa concluded the sixth round of its Renewable Energy Independent Power Producer Procurement Program. New power projects are urgently needed to relieve chronic power shortages: the South African authorities even declared a "state of disaster" in the energy sector from February-April 2023. Investments in renewables should also benefit from the Just Energy Transition Partnerships (JETPs) that South Africa, Indonesia and Viet Nam have signed with international partners and financial institutions. JETPs aim to boost clean power and reduce reliance on coal assets, while addressing the social implications of change. Kenya also lifted a ban on new power purchase agreements (mainly affecting renewable projects).

However, the landscape for renewable power investment in many EMDEs remains difficult, and much more needs to be done to improve perceived and real investment risks and to reduce costs. Greater investment in clean power in EMDEs is hindered by a range of barriers such as higher financing costs, high debt burdens of electric utilities and the absence of clear clean energy strategies, as well as challenges related to land acquisition, enabling infrastructure and skilled labour. Low levels of spending on grids (even compared with past spending averages in EMDEs) exacerbate challenges with security of supply and electricity access, as well as leaving EMDEs ill-prepared for increased investment in variable renewables.

A step up in concessional funding and other dedicated multilateral support is critically important to increase clean power investment. The upcoming Summit for a New Global Financial Pact, which aims to define a new financial pact with EMDEs, will be an important stepping stone towards realising this goal. A forthcoming joint IEA-IFC report will provide analysis and recommendations.

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Generation

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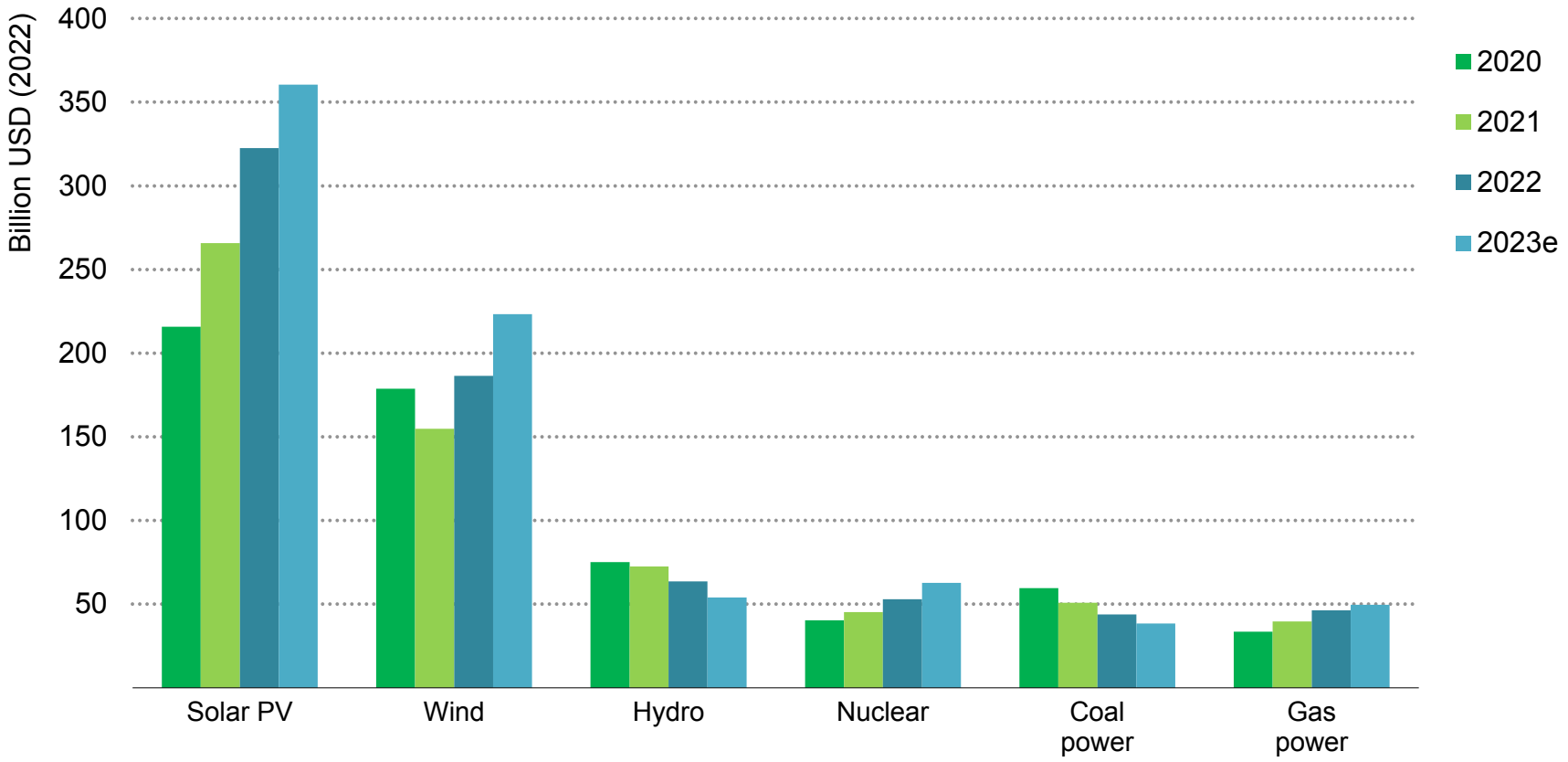
Variable renewables are by far the most dynamic sectors for investment in power generation…

Global annual investment in the power generation by selected technology, 2020-2023e



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Notes: Gas-fired generation investment includes both large-scale plants and small-scale generating sets and engines; hydropower includes pumped-hydro storage; 2023e = estimated values for 2023.

Sources: IEA analysis based on calculations from IRENA (2023) and S&P Global (2023).

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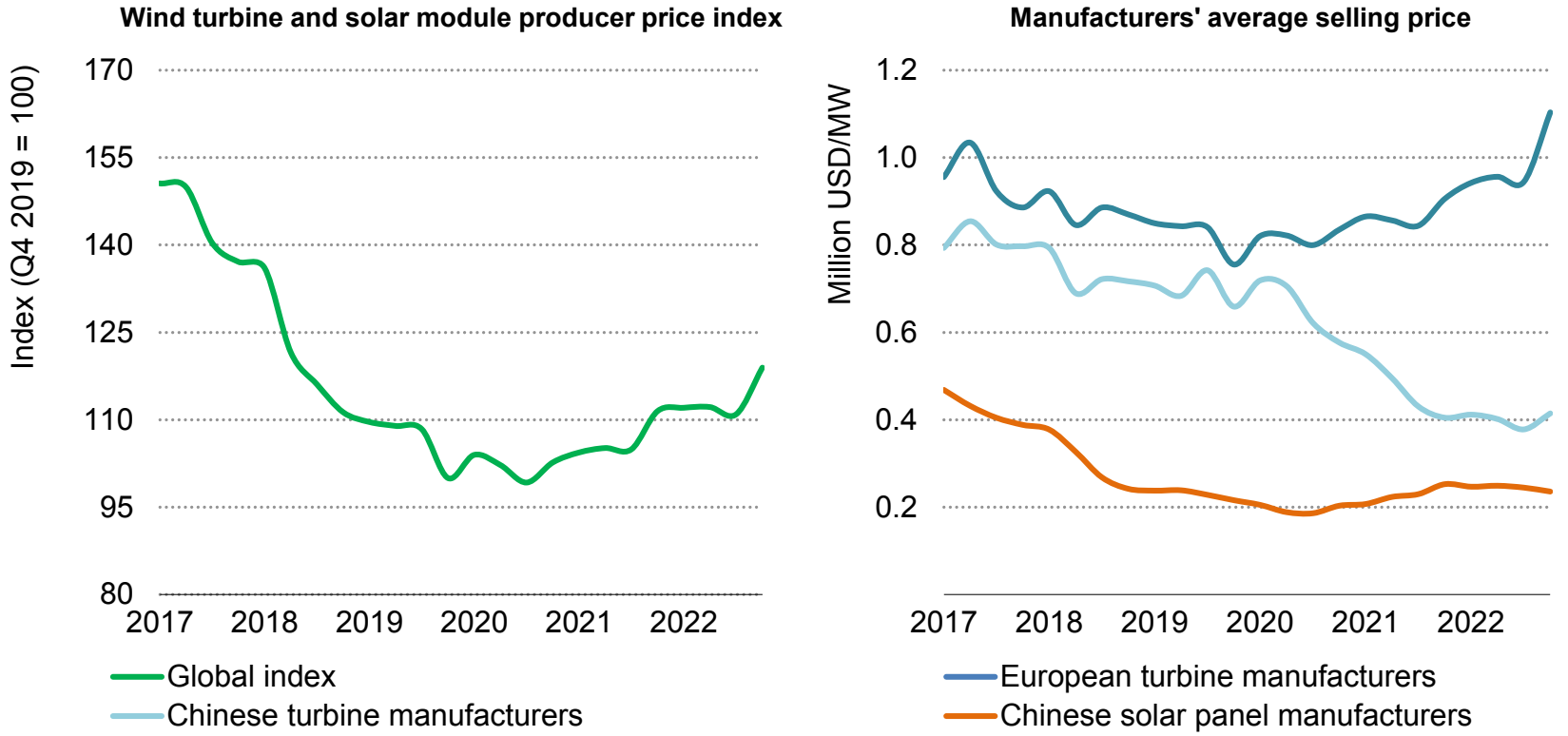
…despite tight supply chains and higher input costs pushing up renewable project costs in many markets

IEA global wind turbine and solar PV module producer price index and average manufacturing prices among key regions



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Notes: The index, developed by the IEA, tracks price movements of a fixed basket of solar PV panels and wind turbines against a base period (Q4 2019); prices are weighted according to the shares of global average annual investment in 2020-2022: solar modules (58%) and wind turbines (42%); wind turbine prices reflect a weighted average of both onshore and offshore turbine manufacturers' prices, noting that this is more sensitive to changes in onshore turbine prices given that they account for a larger share of production; given that the supply of solar PV modules is highly geographically concentrated (with the majority of production based in China), and data availability constraints, where only the price trends of Chinese manufacturers are included.

Sources: IEA calculations based on companies' financial reports, Bloomberg data and BNEF.

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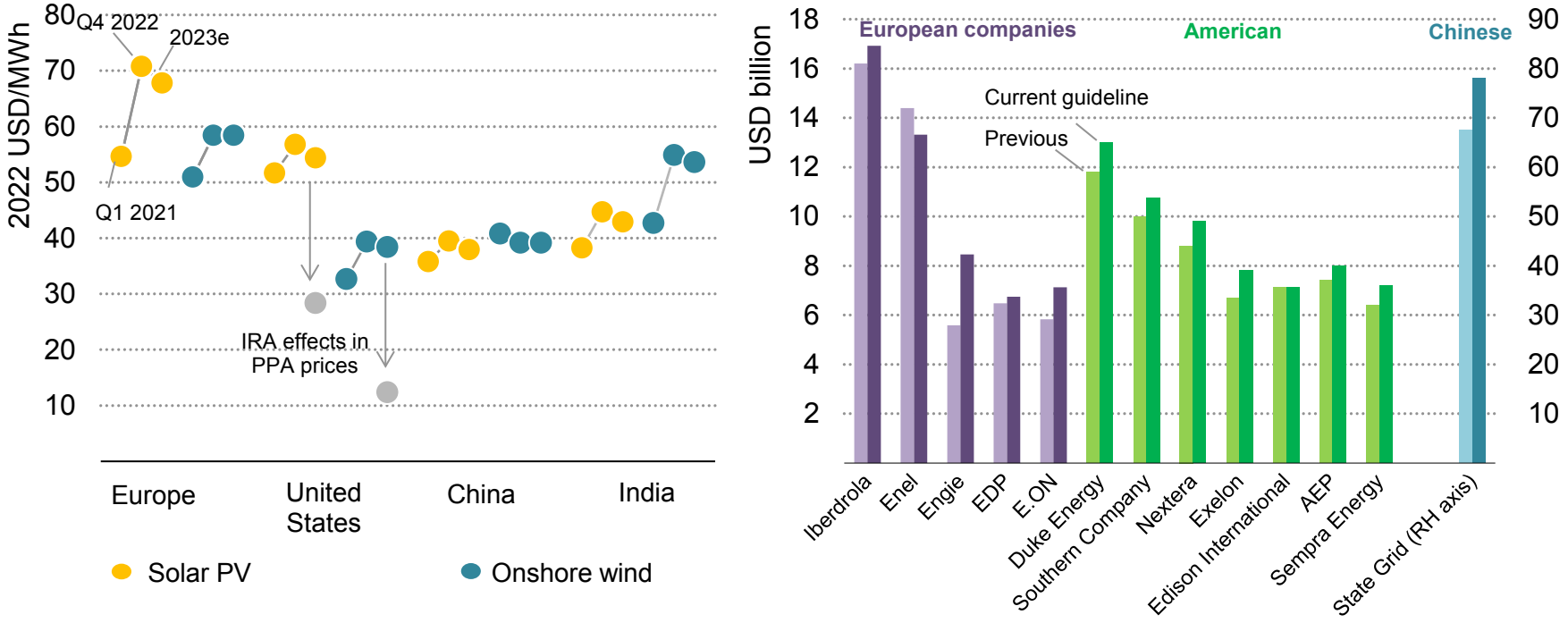
Power company investment plans remain robust, even as levelised costs for renewables moved higher

LCOE estimates of utility-scale solar PV and wind; and average annual short-term investment guidelines of selected power companies



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Notes: LCOEs calculations assume increases in the cost of capital in Europe, United States and India between Q1 2021 and Q4 2022 for both solar PV and wind, while remaining constant in 2023e. Capital costs are assumed to increase in Q4 2022 across the four regions (except wind in China) and reduce or remain flat in 2023, though not totally compensating for the 2022 increase. Capacity factors are consistent with WEO 2022. IRA effects assume a 26 USD/MWh of production tax credit. Annual company investment reflects nominal capital spending guidelines (for all group-level related activities) published in annual reports or strategic plans; for example, if a company announced an investment of USD 15 billion over 2020-2023 and USD 18 billion over 2023-2025 (most recent announcement) this is reflected as USD 5 billion (previous) and USD 6 billion (current); figures for Indian companies were not included as data were unavailable; the drop in Enel's figures is due to Enel streamlining its business (e.g. exiting Argentina, Peru and Romania), but its investment in other geographies remains as planned. 2023e = estimated values for 2023; IRA = US Inflation Reduction Act; LCOE = levelised cost of electricity

Sources: Companies' annual reports.

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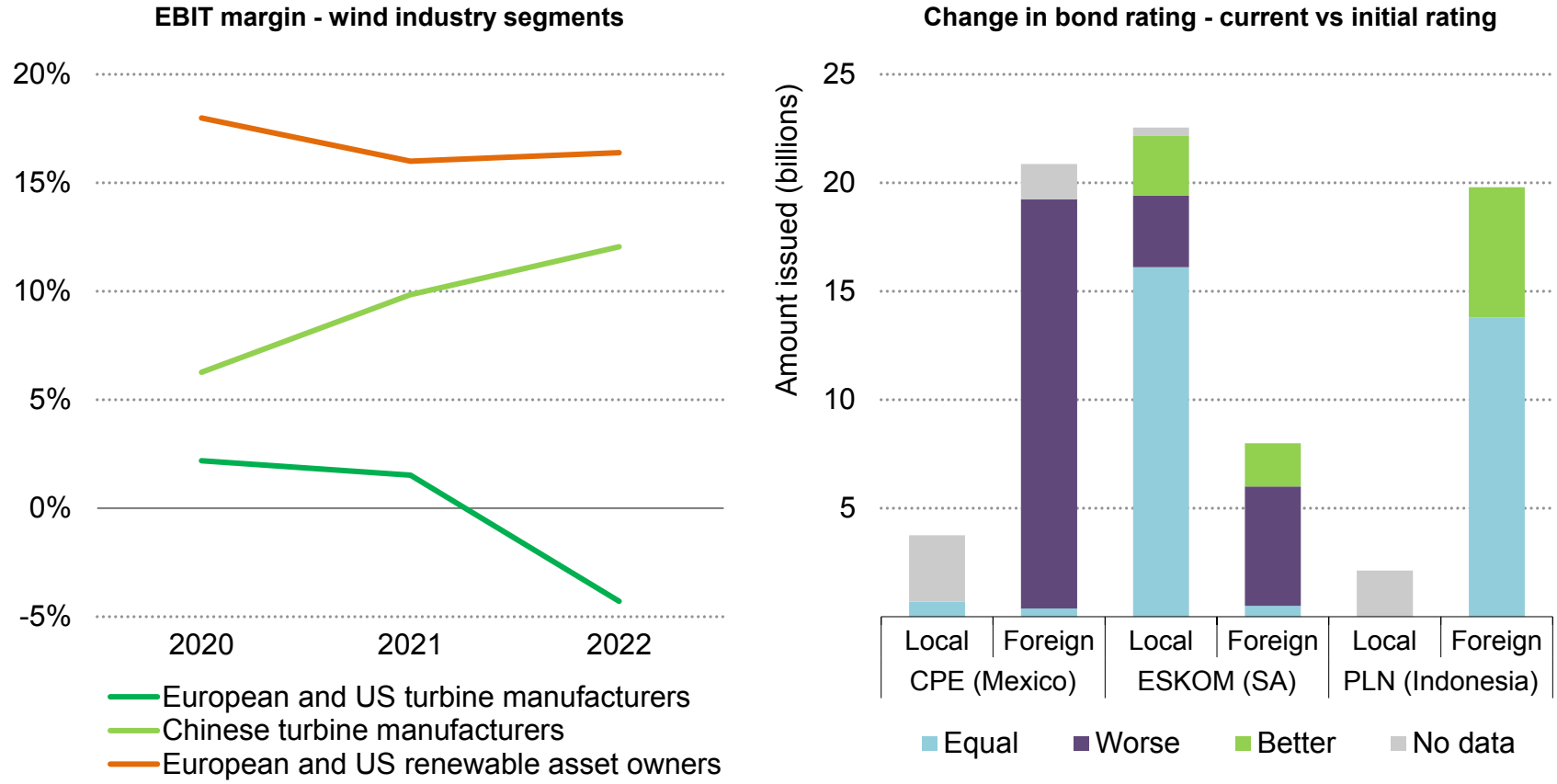
Some key parts of the power investment chain are showing greater signs of stress

Profitability of major wind turbine manufacturers and asset owners; and change in bond rating of SOEs in selected EMDEs



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Notes: EBIT = earnings before interest and taxes, annual basis; European and US manufacturers represent a weighted average (by market share) of Vestas, Siemens Gamesa, Nordex and GE; Chinese manufacturers represent a weighted average (by market share) of Goldwind, Windey and Mingyang; European and US asset managers represent a simple average of Nextera, Ørsted, Iberdrola, RWE and Enel; SOE = state-owned enterprise; “Worse” means that the bond’s rating has been downgraded; “Better” means that the bond’s rating has been upgraded; “No data” means no data on rating available; “Foreign” refers to bonds issued in USD or EUR.

Sources: Companies’ annual reports, Wood MacKenzie and Bloomberg.

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New policies are providing an important boost to the prospects for low-emission power

Key low-emission power policies introduced and proposals announced in 2022-2023 in selected countries and regions

Region	Policies

United States	• Approval of the Inflation Reduction Act
	  ○ Tax credit extensions for solar PV and wind: production credit (per unit of energy) and investment credit (capital costs)
	  ○ Investment tax credit also available for battery storage and zero-emission nuclear
	  ○ Financial support for grids and manufacturing clean power equipment

China	• 14th Five-Year Plan raises renewable target to 33% of power consumption by 2025 (and 18% for non-hydro renewables)

Europe	• Announcements by the European Commission: REPowerEU Plan, Net-Zero Industry Act proposal and other potential reforms
	  ○ Increase EU 2030 renewables target to 45% by 2030 (whole energy matrix not just power)
	  ○ Fast-tracking permitting process plus ~EUR 225 billion in loans for grids
	  ○ Proposed reform of market design and technology-specific targets for EU manufacturing capacity
	• Nine European countries committed to boost offshore wind capacity to over 120 GW by 2030 and over 300 GW by 2050

Indonesia and Southeast Asia	• Indonesia introduced its JETP
	  ○ Renewable energy target up to at least 34% of power generation by 2030, accelerate coal power plant retirement and achieve net zero emissions in the power sector by 2050
	  ○ USD 20 billion of initial funding
	• Thailand introduced new regulation for renewable power procurement, establishing the feed-in tariffs payable by distribution companies and capacity targets (additional 5 GW of biogas, solar, solar with storage, and wind)
	• Philippines set out a 35% renewable electricity generation target by 2030 (from about 20% in 2021) and 50% by 2040

India	• Continues to expand the Production-Linked Incentive (PLI) scheme
	  ○ 50 GWh of battery manufacturing capacity
	  ○ 40 GW of solar PV manufacturing capacity to be added in next three years

Japan	• Government is studying extension to lifetime of nuclear power plants (beyond 60 years)
Korea	• Plan to increase nuclear power to 35% of total generation and renewables to 31% from 10% in 2021 by 2036 • Coal-fired power to reduce to 15%
South Africa	• Government concluded sixth renewable auction
Brazil	• Planning two major transmission auctions in 2023, including the largest ever held in Brazil (in investment terms)

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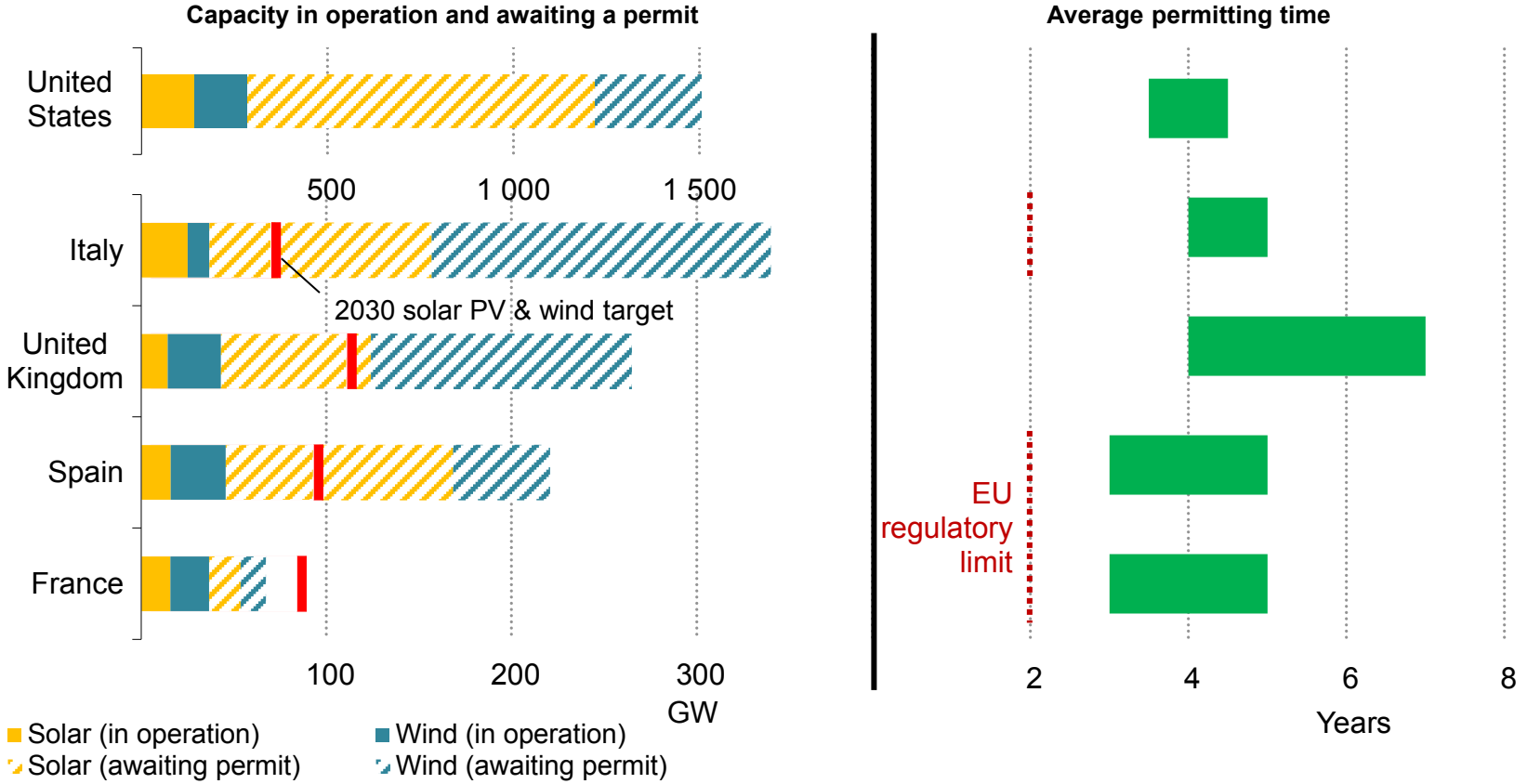
But getting projects up and running has often been slow, putting the focus on permitting and other practical obstacles facing investors

Capacity awaiting permits and under construction and average permitting times in the United States and major European renewable markets



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Notes: United States, United Kingdom and France show capacity in December 2023; Italy shows capacity in January 2023 and Spain in March 2023; wind includes onshore and offshore.

Sources: Red Eléctrica, Terna, Ministère de la Transition Energétique, National Grid and Lawrence Berkeley National Laboratory; BNEF (average waiting times).

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Solar PV made most of the headlines for power generation investment in 2022, although increased financing and capital costs were also part of the story

Capital spending on new generation has been setting new records each year, driven by strong performances from solar, and we expect the same to be true in 2023. China alone added over 100 GW of solar PV capacity in 2022, almost 70% higher than in 2021, and annual installations increased by 40% or more in Europe, India and Brazil, despite inflation and supply chain issues. Investment in wind power increased, albeit less than solar (as mainly large projects continue to face delays) while spending on hydropower continued to fall.

Nuclear power investment also rose, mainly in advanced economies and China. More than a decade after the accident at Fukushima Daiichi, an increasing number of countries are taking a fresh look at how nuclear technologies might provide low-emissions and dispatchable power. Investment in fossil-fuel based electricity was flat, reflecting lower spending on unabated coal power alongside higher investment in gas-fired plants.

Despite the growth in many sectors, power generation investment in 2022 faced some headwinds. On the financing side, the cost of borrowing increased as base rates rose to fight inflation. Equity risk premiums – the premium above risk-free rates that equity investors expect for an average unit – have gone up across the world. This is problematic as highly leveraged companies, like many power utilities, may have to tap into the equity market for financing as higher leverage (more debt) could affect their credit ratings.

A global producer price index of solar PV modules and wind turbines developed by the IEA shows that prices fell to a low point in Q3 2020 but then were pushed up by tight markets for materials and labour, ending 20% higher in Q4 2022. Module prices were around 20% higher in early 2022 y-o-y, but started to come down in early 2023 as input costs declined (solar grade silicon and wafers) and manufacturing capacity expanded (largely in Asia). Wind turbine costs, especially from European manufacturers, remained high in early 2023, at 35% above the low levels of early 2020.

China has followed a different path. Debt financing remained favourable as the People's Bank of China has kept reference lending rates low to boost the economy and renewable projects can access preferential rates. Capital costs for solar PV increased slightly in 2022 before falling back, while wind capital costs were less affected than elsewhere. The price of local wind turbines continued to decrease given Chinese manufacturers' ability to manage supply chain pressures and a growing number of orders.

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Solar and wind retain a strong competitive advantage, although pressures are higher in the wind sector and the conditions for mobilising capital in EMDEs remain challenging

The rise in project costs has translated into a higher levelised cost of electricity (LCOE) across technologies. LCOEs for solar PV and wind, having fallen for years, increased in 2022, but remained a more attractive proposition than fossil fuel power for new generation in most markets around the world.

In Europe the average LCOE for solar PV increased by 30% and by 15% for onshore wind between early 2021 and late 2022, despite continued gains from technology learning. However, absolute values remain low and capital cost pressures are expected to ease in 2023. Investment plans by major European utilities also remain strong. Wholesale power prices have fallen compared to a year ago, but are still high in historical terms, an additional signal for investors, although it remains to be seen how the proposed changes to the EU power market design may affect investors' views.

Recent years have been challenging for the wind equipment manufacturing industry outside China. The average ratio of earnings before interest and taxes (EBIT) to revenues among the largest European and US turbine producers has been meagre if not negative. This measure of a company's profitability saw a big drop in 2022 as revenues were hit hard by supply chain delays, inflationary pressures and in some cases impairments due to Russia's invasion of Ukraine. Higher prices are also contributing to lower order intakes, even as the help near-term results, which are also being assisted by improvements in the service business.

Most EMDEs outside China are experiencing higher costs, especially where investments are denominated in US dollars. State-owned utilities – often the main investor and counterparty with the private sector in EMDEs – remain financially fragile, and rising interest rates and falling domestic currencies make it harder to pay their existing debt, let alone invest. More attractive conditions for renewables investments in advanced economies may also discourage capital from flowing into countries with higher real or perceived risks. India's size and well-developed policy frameworks, especially for solar, underpin continued strong interest from investors and project developers, although offtaker and transmission risks remain.

LCOEs for solar PV and onshore wind rose in the United States in 2022, but PPAs are set for important reductions given the tax extensions in the Inflation Reduction Act. In China LCOEs for solar PV were also up in 2022, while wind LCOEs fell. After subsidies for onshore wind were removed in 2020, investment appetite reduced, forcing domestic turbine makers to slash prices. Increased orders helped offset lower prices for manufacturers, but competition remains strong. Manufacturers have also focused on building bigger turbines, and on innovation and cost control.

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Ambitious new policies to accelerate clean power investments are in place, but there are uncertainties over how quickly these will translate into flows of new projects

The passage of the Inflation Reduction Act in the United States was a major legislative milestone that included significant financial support for low-emission technologies. It includes new or extensions to tax credits for wind, solar PV and storage based on project investment costs (USD) and generation (USD/MWh), tax credits for local manufacturing and grid upgrades, and various other forms of assistance.

The European Union is looking to increase deployment of renewables across power generation and the end-use sectors as part of its goal to reduce greenhouse gas emissions by at least 55% by 2030 and to address the energy market disruption caused by Russia's invasion of Ukraine. A provisional agreement was reached in March 2023 to raise the EU's renewable target for 2030 to a minimum of 42.5% of final energy consumption, up from the current 32% target. The European Commission also proposed a Net Zero Industry Act, which targets domestic manufacture of up to 40% of Europe's clean energy technology deployment needs by 2030. The act would cover eight technologies and simplify regulation, supported by existing funding channels (e.g. InvestEU; the Recovery and Resilience Facility).

In many parts of Asia, policies supporting both renewables and nuclear power are on the rise. Japan is discussing legislation to extend nuclear power plant lifetimes beyond 60 years and South Korea's 10th Electricity Plan incorporates a slightly higher share of nuclear power in the generation mix (35% by 2036) as well as a sharp increase in the share of renewables to 31% by 2036 (up from 7.5% in 2021) Among EMDEs, Indonesia and Viet Nam concluded JETPs to accelerate the energy transition away from fossil fuels and towards renewables. Indonesia's JETP, for instance, expects to receive USD 20 billion of initial funding over the next three to five years, with capital coming from both commercial and concessional sources, and private as well as public money.

Getting projects up and running at the scale and speed needed to reach targets is proving hard, with challenges beyond prices. Permitting has been a key concern for investors and financiers recently, especially for wind and grid infrastructure. Europe has been at the centre of this debate, with substantial renewable capacity in the pipeline waiting for permits, and queues well beyond set limits. Governments are now enacting policies to address this issue. Other risks include transmission bottlenecks (either missing or poor-quality grid infrastructure to connect new renewable projects) and shortages of skilled labour.

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Final investment decisions (FIDs)

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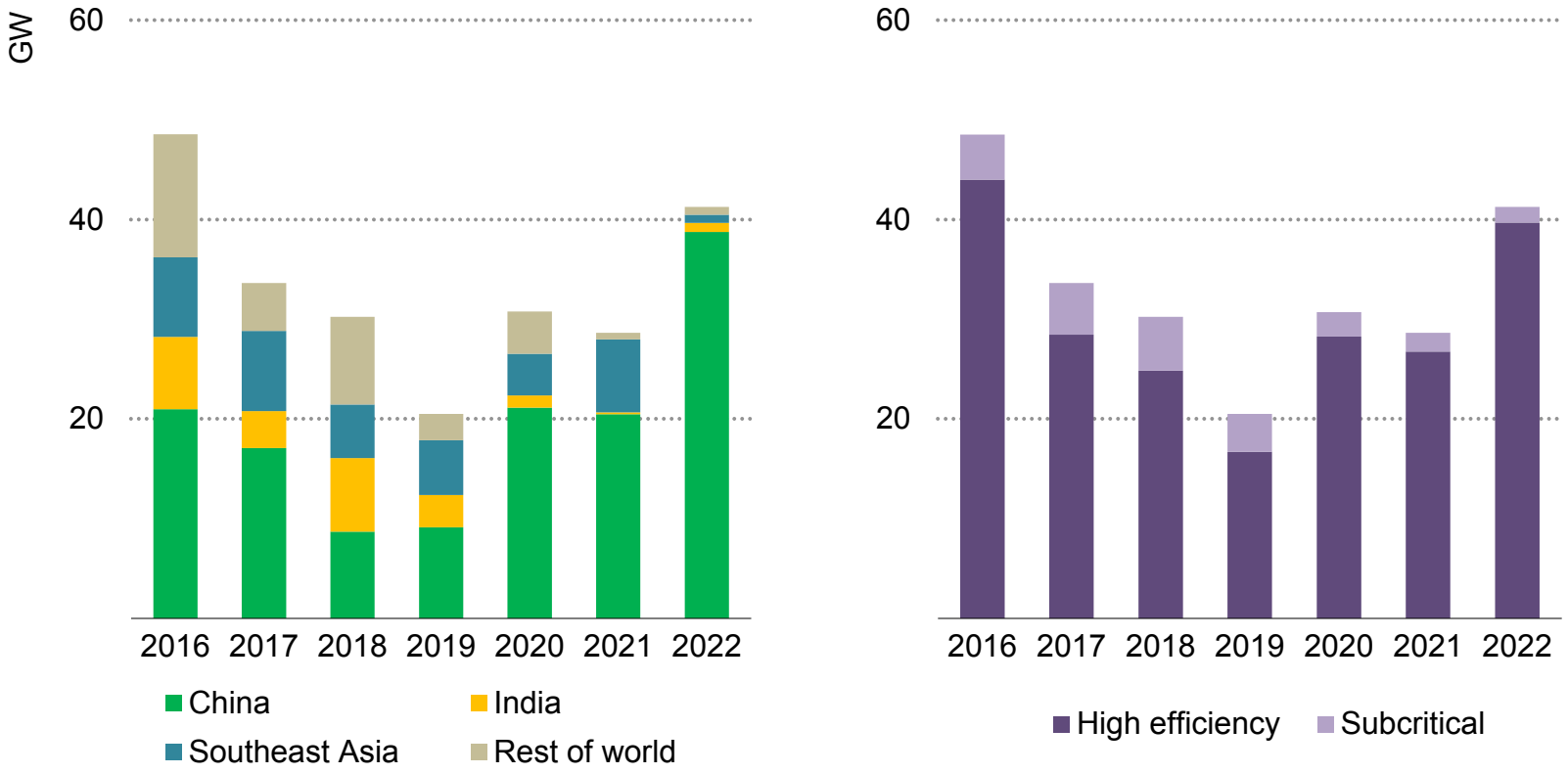
More than 40 GW of coal-fired plants were approved in 2022; almost all of this was in China, reflecting a strong electricity security priority even as low-emissions power scales up fast

Coal-fired power generation capacity subject to a FID by geography (left) and segment (right), 2016-2022



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Notes: FID = final investment decision; FIDs are an indication of the scale of future capacity to come online in the coming few years; the IEA tracks projects that reach financial close or begin construction to provide a forward-looking indicator of future capacity additions and spending activity.

Source: IEA calculations based on McCoy Power Reports (2023).

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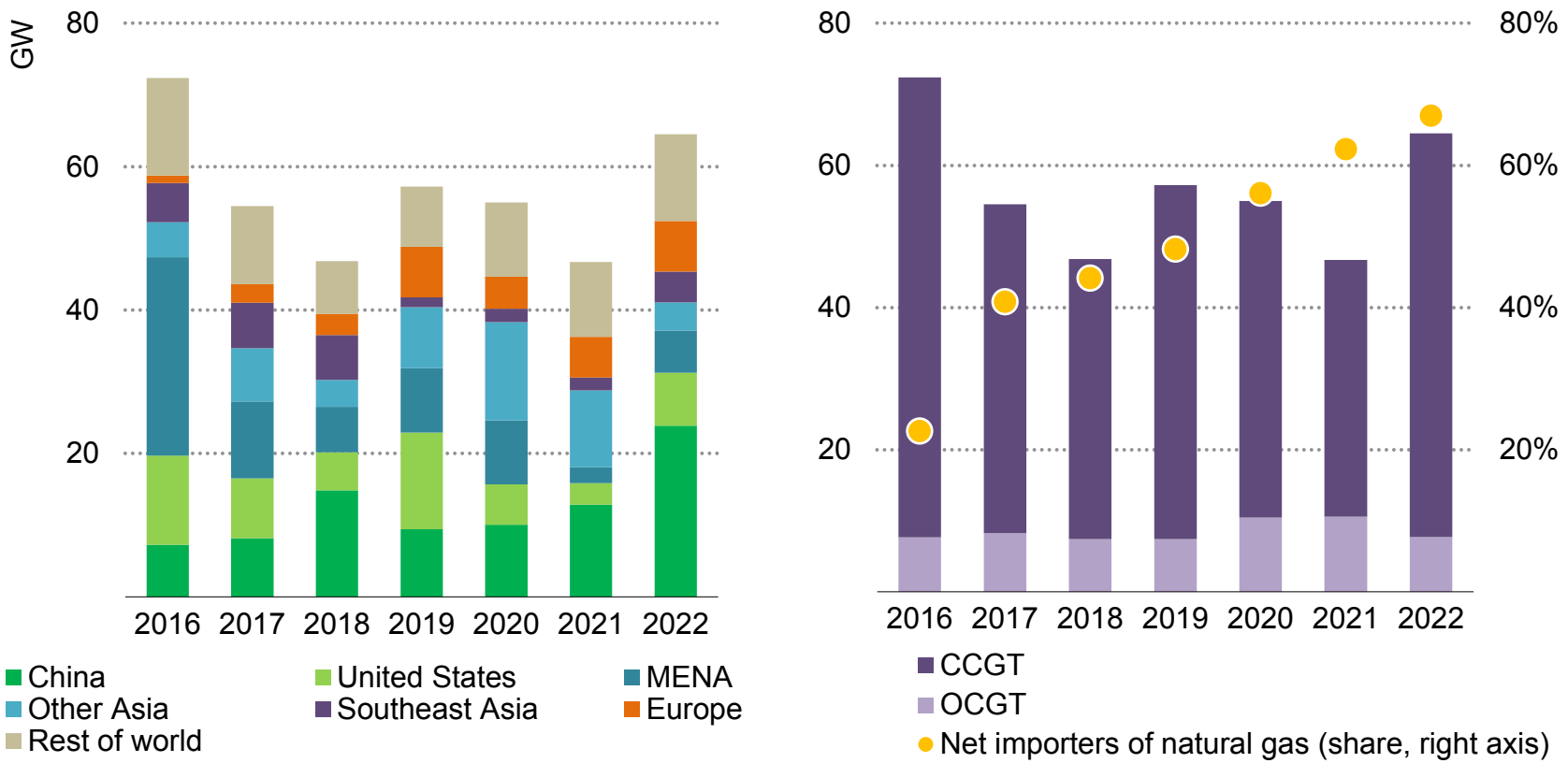
Despite high natural gas prices, FIDs for unabated gas-fired power generation rose in 2022

Gas-fired power generation capacity subject to a FID by geography (left) and segment (right), 2016-2022



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Notes: MENA = Middle East and North Africa; CCGT = combined-cycle gas turbine; OCGT = open-cycle gas turbine; FIDs are an indication of the scale of future capacity to come online in the coming years; the IEA tracks projects that reach financial close or begin construction to provide a forward-looking indicator of future capacity additions and spending activity.

Source: IEA calculations based on McCoy Power Reports (2023).

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In 2022 FIDs for unabated fossil fuel generation reached levels last seen in 2016 on the back of security of supply concerns and diversification

Globally, FIDs for unabated fossil fuel power generation increased by 40% year-on-year to more than 100 GW in 2022, the highest level since 2016, driven by newly approved coal and natural gas capacity. China accounts for the vast majority of these FIDs (95% in coal-fired power) and if China is excluded the global growth rate falls to just 3%.

A severe electricity supply crisis in late 2021 and continued market strains amid a heatwave in 2022 provide the backdrop to China's proposed expansion in capacity. The strains were caused by drought conditions that lowered hydropower output, inflexible interprovincial electricity export contracts, and a combination of rising coal prices and low wholesale tariffs that led some generators to stop operations. This triggered various regulatory changes, as well as central government support for more coal- and gas-fired power investment.

The investment case for this new capacity is hardly clear-cut given the rapid pace of renewable deployment. For the moment, it remains unclear whether this new capacity – if and when it comes online in a few years – will be used primarily for flexibility purposes or for baseload generation; the implications for emissions will depend on the answer to this question.

In Indonesia, in contrast to 2021, there were no new coal FIDs, an encouraging signal given the country's net zero pledge and JETP. In other Southeast Asian countries and the rest of the world (e.g. Lao PDR and Russia), only a very limited number of new coal-fired plants were approved for development, reflecting pledges from a range of countries and financial institutions to stop backing their construction (notably the Chinese commitment to stop building or financing coal plants abroad). Those approved continue to be of relatively high efficiency, with subcritical facilities dropping to below 5% of new FIDs.

Similar to coal, FIDs for gas-fired power generation amounted to 65 GW in 2022 – a jump of almost 40% despite very high prices for natural gas in the wake of Russia's invasion of Ukraine. Some of these new FIDs were from gas-importing countries that were exposed to price pressures from natural gas markets. China is a notable example, approving almost twice as much gas-fired capacity as in 2021. This was largely in the heavily populated southeastern coastal regions, within reach of LNG import facilities; worries about hydro availability also supported decisions to go ahead with gas.

Other regions seeing new gas FIDs were largely those with large resources, such as the United States and the MENA region. While FIDs in Southeast Asia (especially in Thailand and Viet Nam) rose year-on-year, decisions to go ahead with gas-fired power in other parts of Asia, outside China, fell by more than 60%.

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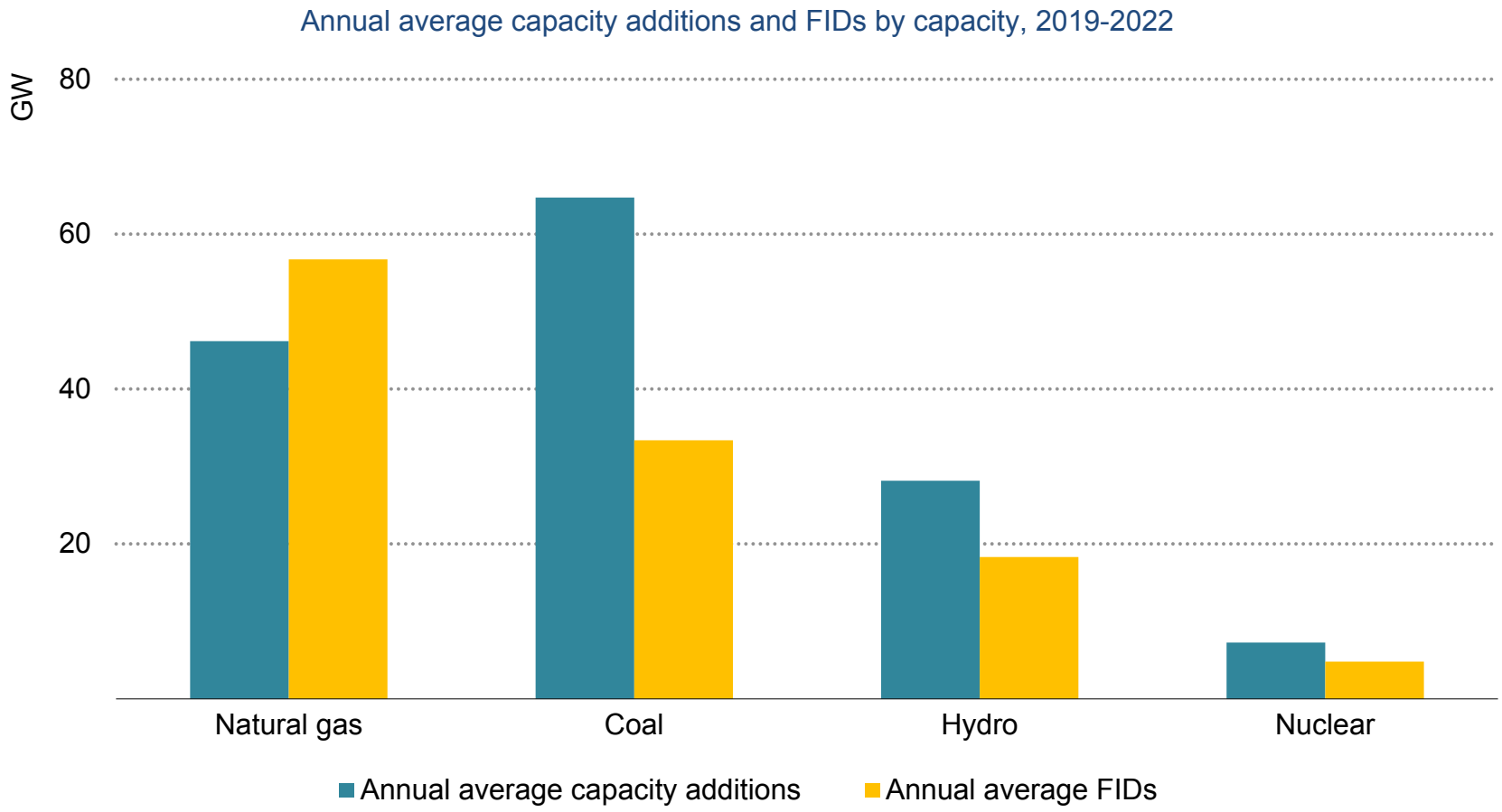
Irrespective of the recent increase in new coal FIDs, the pipeline of new coal, hydropower and nuclear projects is slowing, while gas-fired projects are accelerating



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Notes: Annual average FIDs are an indication of the scale of future capacity to come online in the next few years; the time it takes for a new plant to go online can differ; for example, a new natural gas plant can take three years, while a new nuclear plant can take seven years.

Sources: IEA calculations based on McCoy Power Reports (2023), S&P Global (2023) and IAEA (2023).

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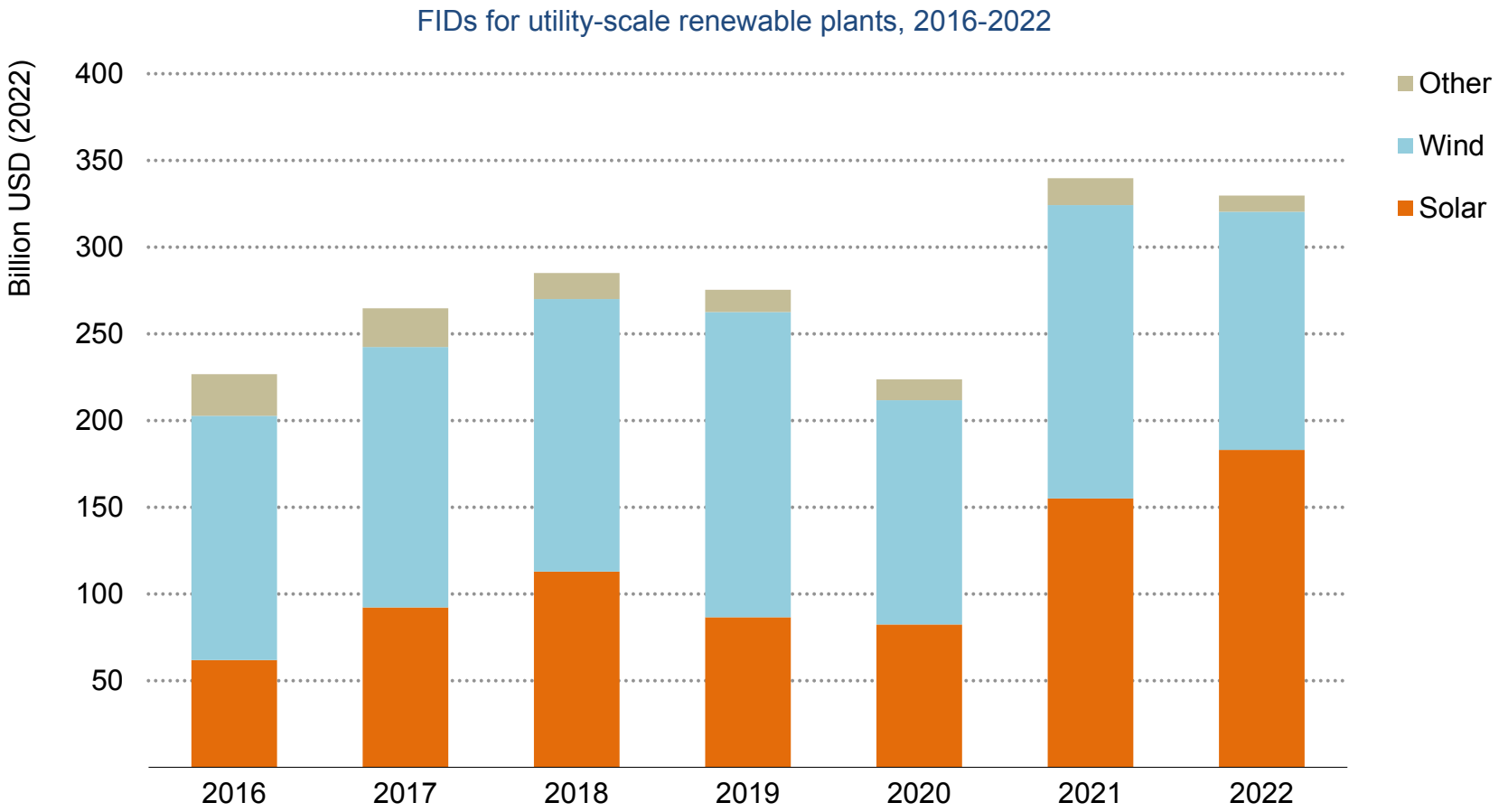
FIDs for utility-scale renewables remained around 2021 levels in 2022, with higher solar but a decline in approvals for wind



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Notes: Excludes large hydropower; Other includes biomass, waste-to-energy, geothermal, small hydro and marine.
Source: IEA calculations based on Clean Energy Pipeline (2023).

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Buoyant FIDs for solar kept utility-scale renewables around record levels in 2022

FIDs for utility-scale renewable plants remained high in 2022, following a record year in 2021. FIDs for solar projects increased significantly, reaching more than USD 180 billion – 20% more than in 2021 – while wind power experienced a drop, in particular for offshore wind projects, which fell more than 50%. The total number of utility-scale FIDs increased, with deals above USD 1 billion playing a larger role.

In monetary terms, utility-scale renewable approvals in China decreased by around 5% overall, though increasing by the last quarter of 2022 (48% higher than in the third quarter). In India, by contrast, decisions for renewables projects tripled, pushed by its 2022 target for 100 GW of installed solar capacity and the continuing push for innovative "round-the-clock tenders" (combining renewables with storage). A similar jump was observed in South Africa, as the country aims to tackle a severe electricity crisis and diversify its electricity mix, supported by the investment plan of its own JETP and a group of leading countries. FIDs in the European Union remained flat, while in the United States they increased by around 5%, with US approvals in particular accelerating in the second half of 2022 after the passage of its Inflation Reduction Act.

FIDs for large hydropower and nuclear power plants decreased significantly to 14 GW and 4 GW respectively (from 20 GW and 6 GW in 2021, respectively). In 2022 China was the only region to start the construction of a new nuclear power plant, while investment in large hydropower was dominated by China and India. Pumped hydro, which can serve as an energy storage facility, constituted 90% of the hydropower FIDs. After an uptick in 2021, the declining pipeline for these projects is a reason for concern given their potential to support power sector decarbonisation and supply security. However, additional capital is being spent on modernising and extending the lifetimes of existing plants, which is not captured by FIDs; and policy is becoming more supportive to new project approvals in future.

Renewable projects have shown uneven growth, with solar gaining relevance in the mix and wind facing major challenges particularly for offshore wind energy, which has experienced setbacks due to construction delays and supply chain constraints. Furthermore, fossil fuel power FIDs have risen as many countries have prioritised energy security projects. However, as Covid-19 regulations are now largely lifted, supply chain pressures easing and prices for key components such as critical minerals are moderating, there is growing support for renewable energy aided by supportive policies in key regions. Recent examples are the US Inflation Reduction Act and Germany's USD 31 billion push to expand wind and solar. This is expected to lead to an increase in FIDs for utility-scale renewables in 2023.

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Electricity grids and battery storage

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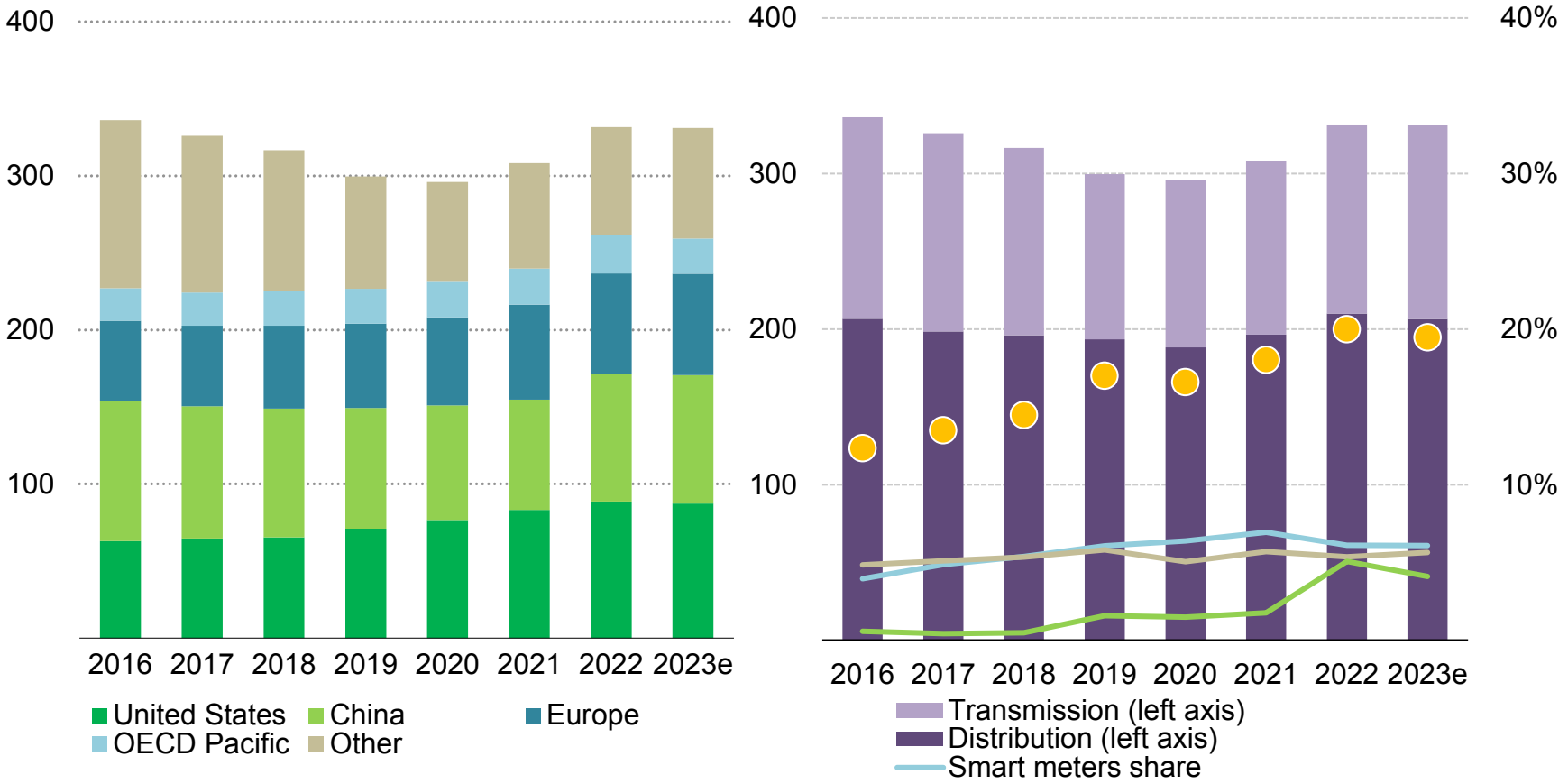
Investment in power grids continues to rise in advanced economies and China, with a rising share of spending on digitalisation…

Investment in power grid infrastructure by geography (left) and segment (right), 2016-2023e



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Notes: Automation and communication include both distribution and transmission; 2023e = estimated values for 2023.
Sources: IEA analysis based on transmission and distribution companies' financial statements, and Guidehouse (2022).

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…but many EMDEs outside China still face challenges in mobilising capital for infrastructure development

Advanced economies and China continue to lead investment in grids, together accounting for 80% of the global spending. Investment in electricity grids is growing at a stable pace in advanced economies, with capital expenditure rising 6% in 2022, and China seeing a steeper 16% rate of growth in investment, despite investment in 2021-2023 overall being lower than in the previous three-year period.

US capital spending on grids remains largely concentrated on enhancing reliability and upgrading outdated infrastructure. The amount invested in this area in 2022 was almost USD 90 billion, around 7% more than in 2021. Europe's spending rose at a similar rate, reaching USD 65 billion.

China's investment continues to grow, especially in ultra-high voltage transmission projects, with over USD 22 billion worth of projects in the second half of 2022 and the start of 2023.

Overall, grid investment in EMDEs (excluding China) has been low in recent years, with 2019-2022 average annual spending around a third lower than in the 2015-2018 period. The Covid-19 pandemic, a focus on affordability for consumers and constrained balance sheets have left grid investment feeble. Privately financed transmission and distribution investment is also low, outside specific regions such as Latin America, where private finance is gaining more relevance. In some regions it is not even allowed. Africa still shows low levels of investment in absolute terms, despite its enormous access needs. In 2022, however, investment in grids increased significantly across the continent. In South Africa, investment rose by a third to USD 290 million, albeit still short of the investment required by its 2023-2027 JETP. The domestic regulator recently approved an 18% tariff increase that should strengthen Eskom's balance sheet and provide financial relief to the power system.

India's investment picked up in 2022, focused on both expanding its network as well as improving efficiency and better supporting the integration of renewables into the grid. The Green Energy Corridor Phase II was approved in 2022, which entails a budget of over USD 1.4 billion being spent over the next four years on capacity additions (lines and substations), interregional transmission and neighbouring links for trade. India's 2022 spending still remains about a third below its 2015-2018 annual investment average.

Digital spending plays a critical role in enhancing the reliability, flexibility and efficiency of power grids. There is an increasing focus on the distribution segment, which now represents over 75% of the total digital spend. Moreover, there has been a substantial upswing in investment in EV charging infrastructure, which has doubled in 2022 compared to the previous year.

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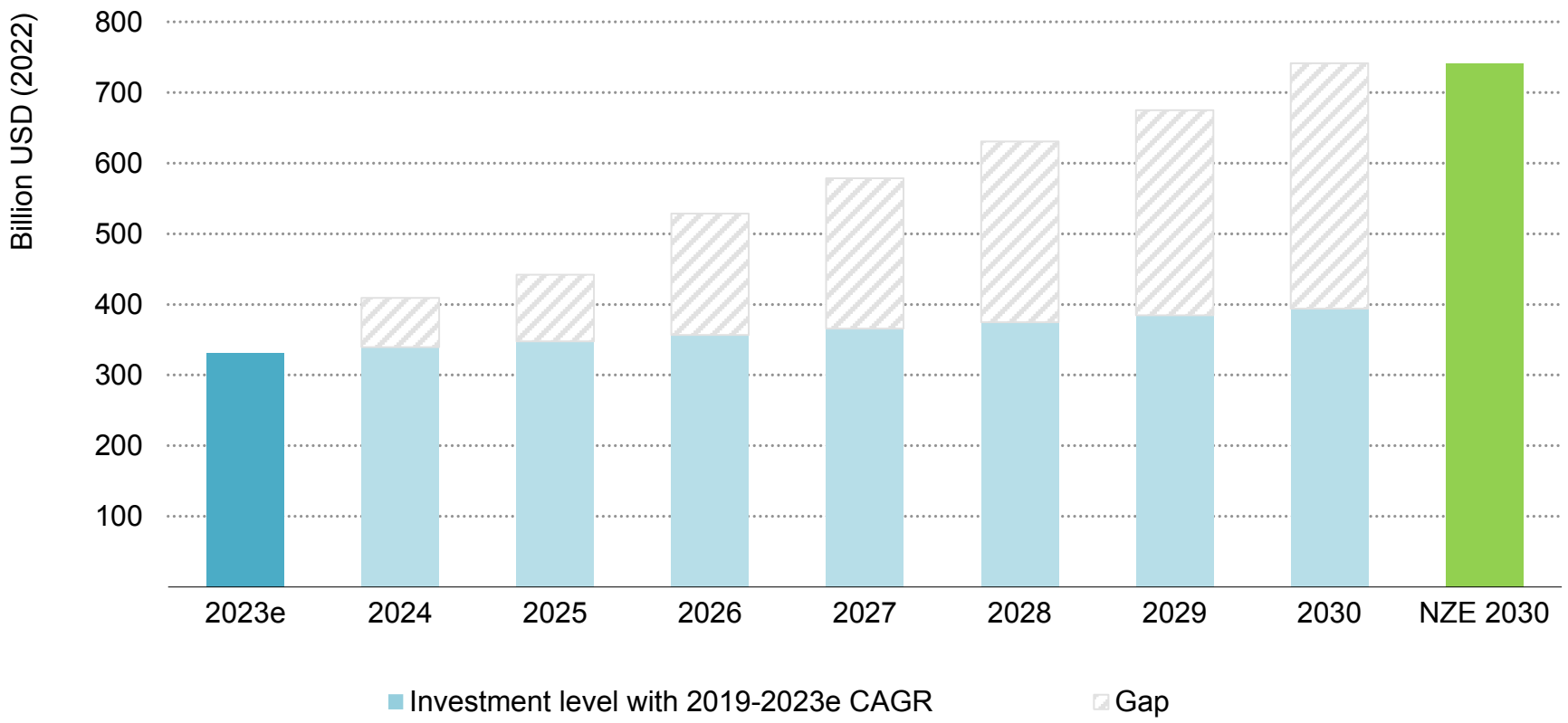
If policymakers and regulators do not provide the necessary incentives for investment in grid spending, it could pose a significant obstacle to the clean energy transitions

Grid investment level with current growth trend and gap to reach NZE Scenario trajectory



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Notes: IEA estimation applying the compound annual growth rate (CAGR) of 2019 to 2023e to grid investment between 2024 and 2030; NZE = IEA Net Zero Emissions by 2050 Scenario; 2023e = estimated values for 2023.

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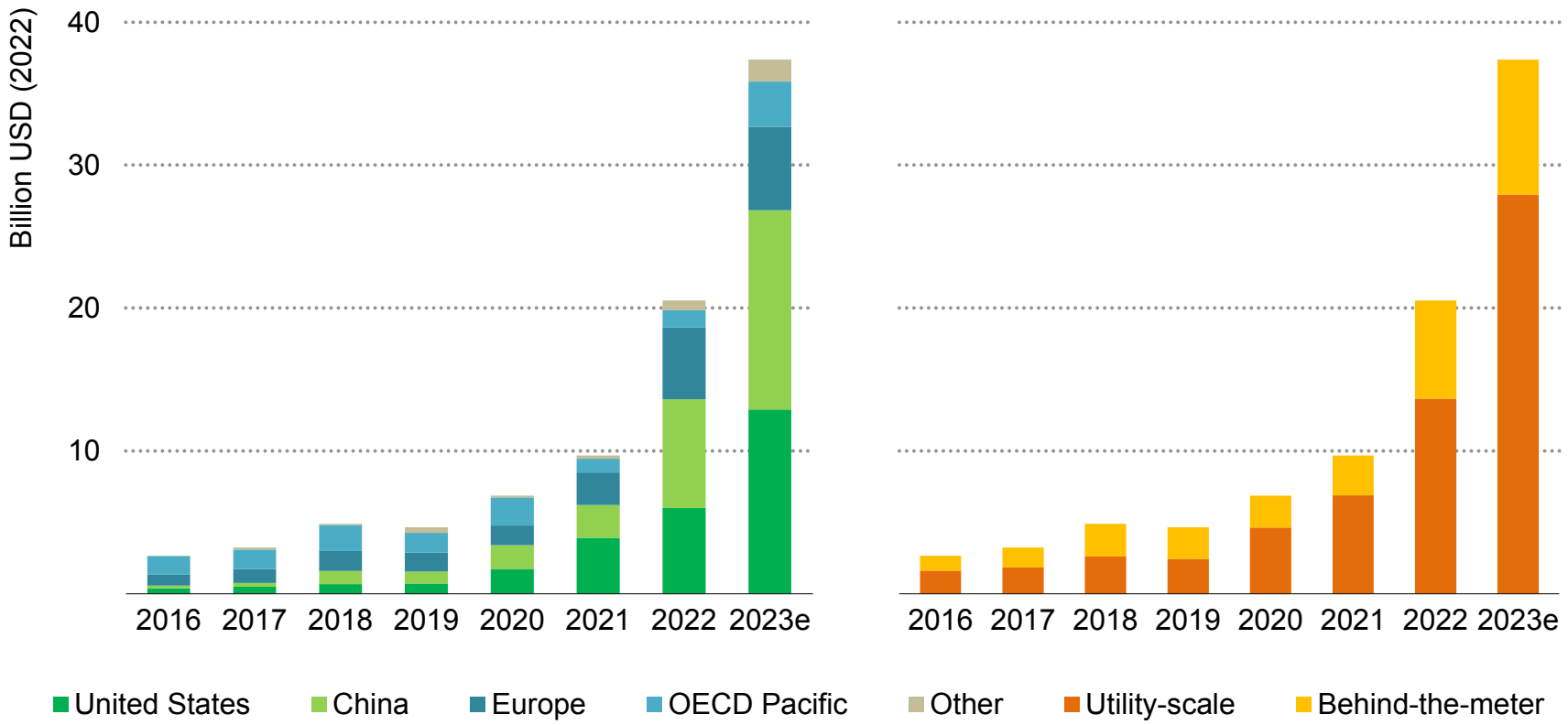
Investment in battery storage is set for continued rapid growth in 2023, notably in utility-scale battery systems

Battery storage investment by geography (left) and segment (right), 2016-2023e



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Note: 2023e = estimated values for 2023.

Sources: IEA calculations based on Clean Horizon (2023), BNEF (2023), China Energy Storage Alliance (2023).

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Investment in battery storage more than doubled in 2022, driven by institutional investment and solar developers

The energy system is undergoing a major transformation towards a more flexible grid that can respond to demand and price volatility. In 2022 expenditure on battery storage exceeded USD 20 billion, with the United States, China, and Europe accounting for 90% of spending. This concentration can be attributed to the technological complexities of the value chain and the need for supportive policies and market designs.

China has demonstrated its commitment to battery storage through significant investments, such as the construction of the world's largest battery storage peak-shaving power station. China has also recently established its first peak-shaving capacity market, which regulates pricing limits for transactions and compensation for demand response. In total, spending on battery storage in China tripled in 2022 to almost USD 8 billion. 2023 is expected to see this increase to USD 14 billion on the back of favourable economics for utility-scale battery storage and strong policy support.

In Europe, although hydro storage remains predominant, investment in battery projects is rapidly gaining ground, reaching USD 5 billion in 2022. A joint venture partnership between Next Energy (70%) and Eelpower (30%), for example, could create up to USD 370 million in investment opportunities.

Spending in the United States totalled USD 6 billion in 2022, 50% more than the previous year. The expectation of increased benefits under the Inflation Reduction Act (see next page) may affect the timing of certain projects, but the environment is increasingly supportive. Consequently, we expect battery storage investments to more than double in the US to USD 13 billion in 2023.

Asia Pacific (excluding China) invested 27% more than last year, reaching more than USD 1 billion in 2022, with 2023 investments expected to triple. India's government, for example, has ambitious targets for battery storage. The government is also supporting the creation of a domestic value chain for the battery industry with financial allocations of over USD 2 billion under the National Programme on Advanced Chemistry Cell (ACC) Battery Storage. Other developing countries have also shown growth, although the absolute level of investment remains relatively low.

Capital costs for batteries increased in 2022 for the first time in a decade due to various factors including tight supply chains for battery metals and a sharp increase in demand. Despite the increase in battery capital costs, a clear regional differentiation still exists: China continues to see the lowest costs for utility-scale batteries, followed by Europe and the United States.

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Impact of the US Inflation Reduction Act on battery storage

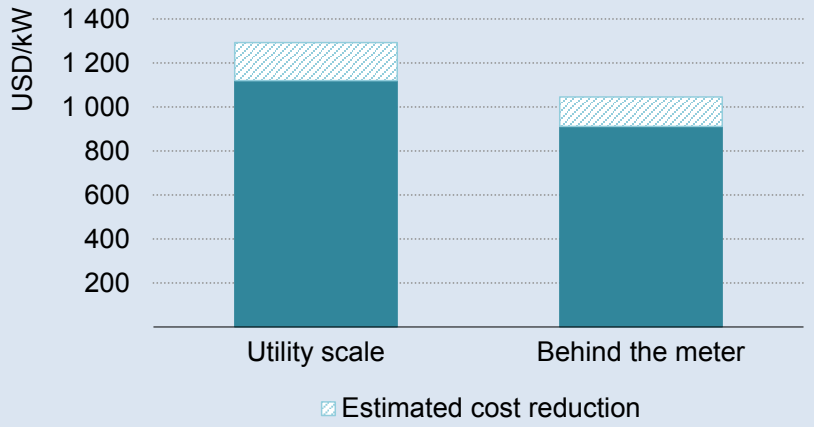
Collectively, the Inflation Reduction Act and the Bipartisan Infrastructure Law offer an estimated USD 24 billion in federal investment in EVs, batteries and infrastructure, on top of tax credits. The long-term regulatory certainty also provides critical stability for private investors in the sector. We estimate that the new federal support could reduce capital costs for battery storage by almost 15%, providing a significant boost to US battery storage investment, which is now expected to double in 2023.

The act also includes provisions that could complicate the timing of investment, such as domestic sourcing requirements for critical materials like lithium that could prevent some battery projects from benefiting. Several Chinese companies are responding to this situation: CATL, for example, recently announced a partnership with Ford to establish a USD 3.5 billion plant in Michigan.

In Europe the act sparked fears that its local content requirements would lead to private investment shifting away from the continent. Major European players such as Volkswagen, BMW and battery maker Northvolt announced new battery manufacturing investments after the US act was adopted. However, most of these announcements concern investment plans predating the act, which have now been accelerated, rather than displacing new European projects.

Moreover, the European Union is now aiming to expand available funding for net zero industries via its Green Deal Industrial Plan. The United States and European Union are also planning to deepen their economic relationship while addressing shared economic and national security challenges in the clean energy transition.

Estimated impact of the US Inflation Reduction Act on average US capital costs for battery storage (in 2022 costs)



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Sources: IEA calculations based on BNEF (2023), Wood Mackenzie (2023) and Lazard (2023).

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Implications

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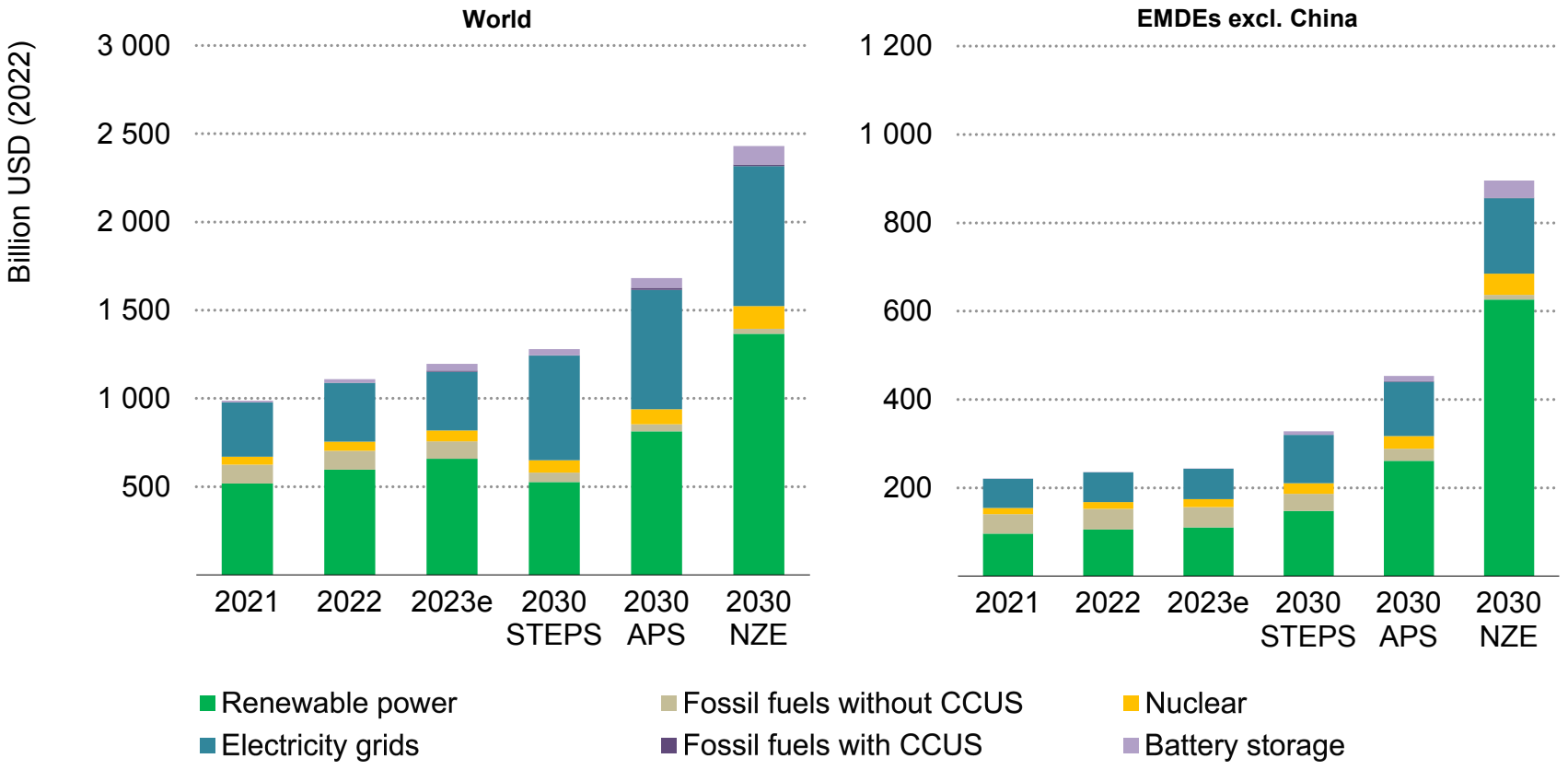
Global power sector investment is growing quickly but unevenly; secure and sustainable development of the power sector will require much higher investment in EMDEs outside China

Investment in the power sector in 2021-2023e compared with investment for IEA scenarios in 2030



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Notes: STEPS = IEA Stated Policies Scenario; APS = IEA Announced Pledges Scenario; NZE = IEA Net Zero Emissions by 2050 Scenario; CCUS = carbon capture and storage; 2023e = estimated values for 2023.

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Despite positive signs, there's much more to be done to get the power sector on track for a 1.5-degree scenario

Recent years have seen considerable growth in clean power investment, and overall spending in generation, grids and storage would need to rise by another 30% by 2030 to be consistent with announced climate pledges (IEA Announced Pledges Scenario [APS]). Aggregate investment trends offer reasons for optimism. The rate of growth seen in power sector capital expenditure over the last five years, if maintained, would be enough to surpass the 2030 figure for the APS.

However, the aggregate numbers mask imbalances across technologies and regions that would need to be addressed to ensure secure and sustainable development of the power sector. And today's global investment would need to more than double by 2030 to get on track for a 1.5-degree stabilisation in global average temperatures, as in the NZE Scenario.

In particular, despite some bright spots such as renewables in India, power sector investment trends in most EMDEs (excluding China) are well off track for scenarios that meet national or global sustainable development goals. Our new analysis suggests that power sector investment in EMDEs outside China could rise by 4% in 2023. It would need to increase by around 20% each year to reach the level projected in the NZE Scenario in 2030, with capital spending on renewables growing at an exceptionally steep rate of 30% every year (compared to 10% in advanced economies). The deficit in spending on grids in many EMDEs is also striking, and difficult to resolve given the financial condition of many utilities.

Elsewhere, the growth trends for power sector investment are more encouraging. If China were to maintain its overall growth trend since 2019, this would be consistent with the investment level required in 2030 for the NZE Scenario, with advanced economies coming close. Total power sector investment in China and advanced economies would need to grow by 5% and 10% every year between 2024 and 2030, respectively. Maintaining such high growth rates throughout the decade cannot of course be taken for granted, not least because supply chains need to be expanded, permits secured, flexibility requirements need to be managed and financing needs to be mobilised.

Among the different technologies, the growth in global capital expenditure in the last five years, if maintained, is on track for an NZE Scenario only for a handful of technologies, led by solar PV and battery storage. Investment growth in wind and hydropower would need to increase considerably, and similarly in electricity grids (especially given their enabling role for renewables penetration).

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Fuel supply

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Overview

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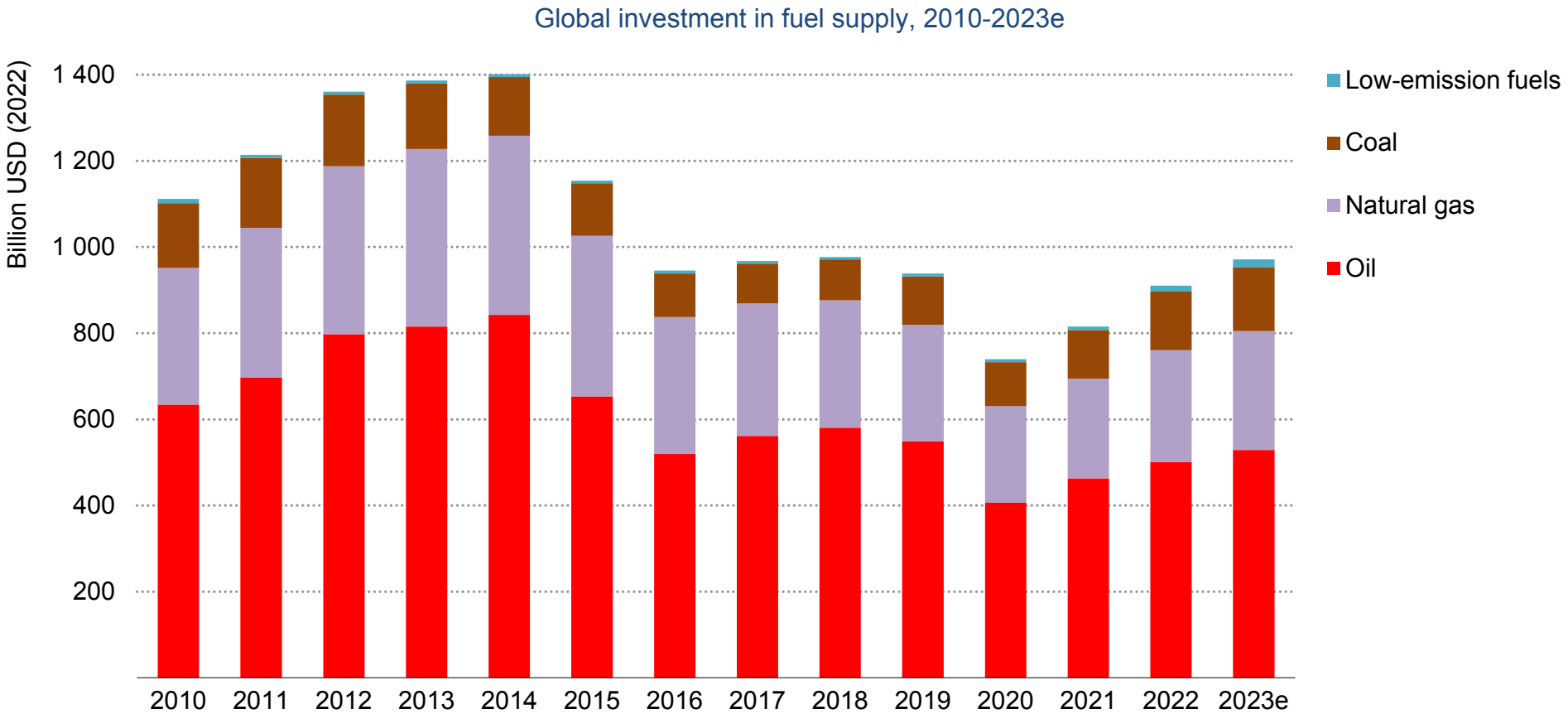
Global investment in fuels rose in 2022 and is expected to return to pre-pandemic levels in 2023



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Notes: Oil, natural gas and coal include upstream and midstream investments. Low-emission fuels = modern bioenergy, low-emission hydrogen and hydrogen-based fuels. 2023e = estimated values for 2023.

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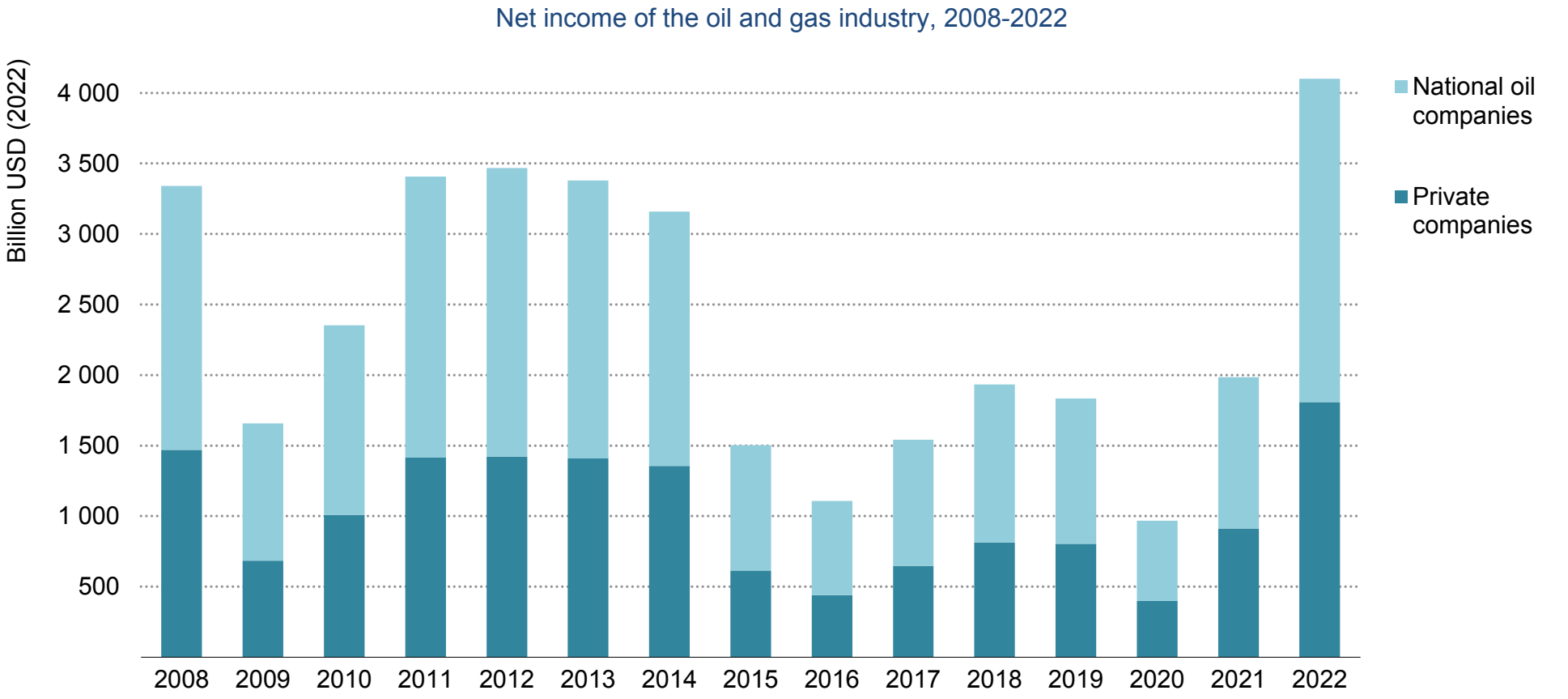
Net income of the global oil and gas industry reached a record high of USD 4 trillion in 2022



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Notes: Net income is calculated from oil and gas production at prevailing oil and gas prices (including subsidies) after operating costs but before taxes; “private companies” here includes listed and non-listed companies.

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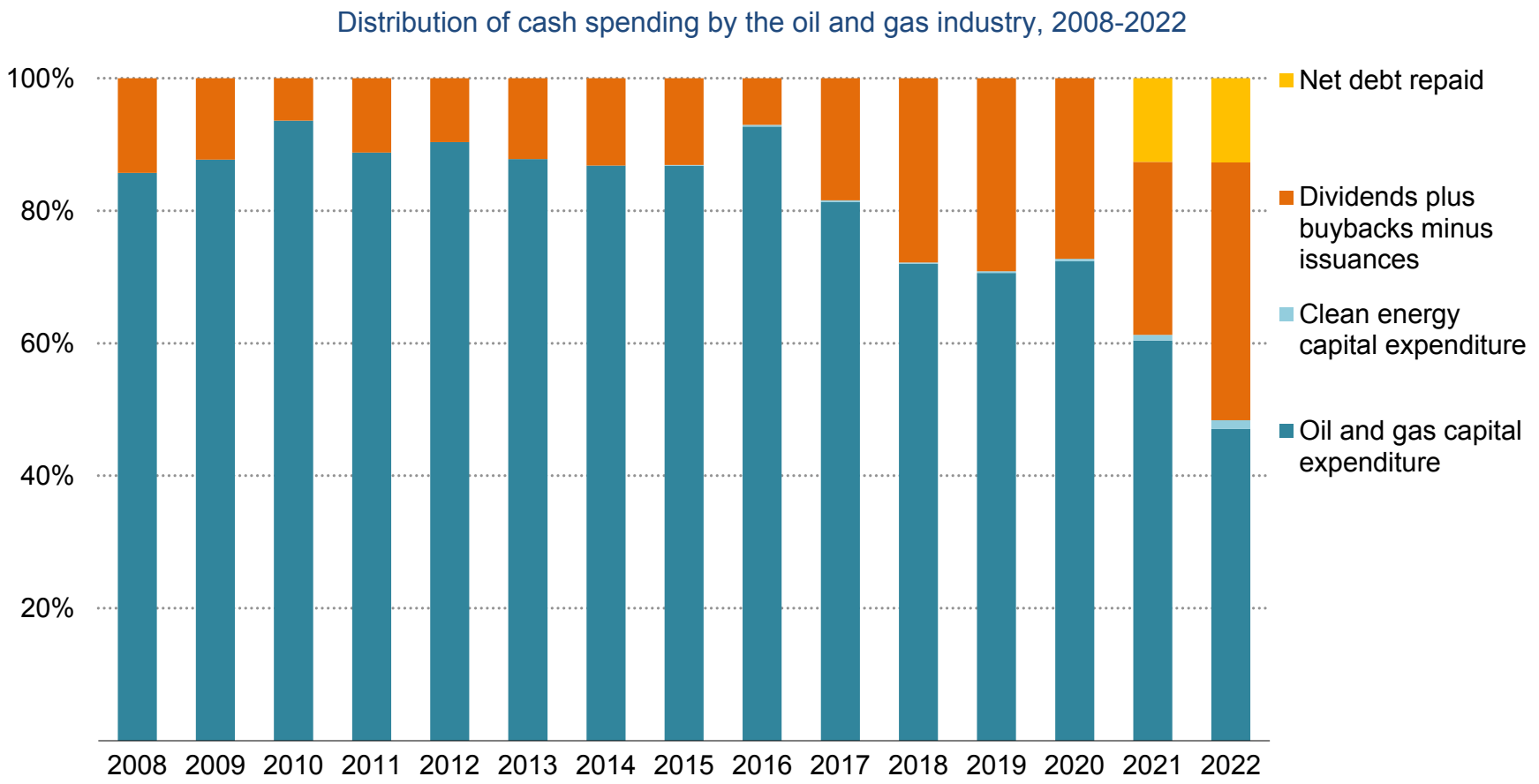
Record income in the oil and gas sector was used to increase shareholder returns and pay down debt, with only a fraction of free cash flow directed towards clean energy investments



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Source: IEA analysis based on S&P Capital IQ.

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Ample revenues and high prices are pushing fossil fuel investment higher, but spending is constrained by worries about costs and long-term demand

The year 2022 was an extraordinary year for fuel suppliers and traders. Russia's invasion of Ukraine drove natural gas prices to record levels in many parts of the world and oil prices back up to levels not seen since the mid-2010s. Net income from fossil fuel sales also rose to levels never seen before, with the global oil and gas industry earning around USD 4 trillion.

High prices have spurred an increase in fossil fuel investment: our expectation, based on analysis of the announced spending plans of all the large and medium-sized oil, gas and coal companies, is that investment in new fossil fuel supply will rise by 6% in 2023 to USD 950 billion.

Some of the windfall gains in 2022 are going back into traditional areas of supply, with companies seeking out "advantaged" resources that can be brought to market relatively quickly, at low cost and with low emission intensities.

But many upstream projects are also facing cost pressures, as tight markets for services and labour and increased raw material costs erode the impact of increases in investment on real activity. Around half of the increase in upstream oil and gas investment in 2023 is likely to be a consequence of cost inflation.

There are significant variations by region and type of company. Only Middle Eastern national oil companies (NOCs) are set to spend meaningfully more in 2023 than they did in 2022, and they are the only subset of the industry spending more than pre-pandemic levels. Real spending on oil and gas supply by most European and North American companies remains below where it was in 2019.

The headline increase in oil and gas spending represents less than half of the cash flow that was available to the oil and gas industry. Between 2010 and 2019, three-quarters of cash outflows (account for capex, dividend and buybacks as well as net debt repaid) were invested into supply. In 2022, this dropped to less than half, with the other half used primarily for dividends, share buybacks and debt repayment.

Hesitation about traditional oil and gas supply investments comes from a variety of factors, including worries about costs, uncertainties over longer-term demand, calls for the industry to step up its role in tackling climate change, and pressures from many investors and owners to focus on returns rather than production growth.

The latter consideration is particularly visible for tight oil and shale gas operators. After a decade in which the shale industry failed to

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generate any positive free cash flows, companies are now being rewarded for increasing value rather than volumes.

Conventional oil and gas resources approved for development in 2023 are likely to be around 25% more than in 2022 but still well below the average level seen over the past decade. The increase in 2023 comes mainly from natural gas, reflecting market pressures as well as the push to substitute the shortfall in Russian deliveries.

In the midstream sector, Russia's cuts in pipeline gas deliveries to Europe have prompted higher spending on LNG infrastructure. New regasification capacity is coming into operation in the near term, but new export facilities take longer to develop. Export projects already under development have been supplemented by a steady stream of new approvals during the energy crisis, promising a major 170 bcm wave of new LNG liquefaction capacity in 2025-2027. A key dilemma for investors in large, capital-intensive gas supply projects is how to reconcile strong near-term demand growth with uncertain but possibly declining longer-term demand.

Robust coal demand and high prices during the global energy crisis are also feeding through into higher global investment. Coal investment increased to USD 135 billion globally in 2022 and is expected to rise to nearly USD 150 billion in 2023. Nearly 90% of this investment takes place in the Asia Pacific region, notably in China and India where both countries have looked to expand production and develop new coal mines.

Elsewhere, nearly all coal investment is focused on maintaining or boosting production from existing mines as concerns over climate change, increased emphasis on environmental, social and corporate governance, slow permitting and public opposition limit the availability of finance for new coal mine development.

In aggregate, fossil fuel investments are now broadly aligned with the Stated Policies Scenario (STEPS) in 2030, a scenario based on today's policy settings. However, if the current momentum behind clean energy investment is maintained and clean energy deployment scales up quickly, demand for oil, natural gas and coal would come under much greater pressure. Benchmarking today's investment levels against scenarios that hit global climate goals illustrates a large potential mismatch. Today's fossil fuel investment spending is now more than double the levels needed in the Net Zero Emissions by 2050 Scenario (NZE Scenario). The misalignment for coal is particularly striking: today's investments are nearly six times the 2030 requirements of the NZE Scenario.

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The surge in revenue in 2022 offers a major opportunity to scale up investment in low-emission fuels; momentum is increasing, but remains well short of where it needs to be

The surge in oil and gas company revenue in 2022 opens up the possibility for accelerated spending by fuel suppliers on energy transitions. This relates not only to increasing investment in low-emission fuels and technologies but also accelerating investment that reduces the emissions intensity of existing fuel production.

Oil and gas industry spending in these areas is rising, and significant new commitments are being made across the whole spectrum of clean fuels. Oil and gas companies boosted their spending on bioenergy to a record USD 11 billion in 2022 with a series of large acquisitions of transport biofuel and biogas producers.

The sector's commitments to carbon capture, utilisation and storage (CCUS) and hydrogen are also growing; many of the largest projects announced in 2022 were underpinned by the participation of oil and gas majors and NOCs, several of which have ambitious capacity targets for 2030. To date, only a handful of these projects have been subject to a FID, meaning that annualised spending on hydrogen and CCUS projects was around USD 1 billion in 2022.

Some NOCs have announced commitments to reduce supply chain emissions, such as Sonatrach's efforts to bring down flaring at Hassi Messaoud and at its LNG export infrastructure.

Policies are increasingly supportive of these kinds of investment, notably via the Inflation Reduction Act in the United States, and the number of announced projects is rising, especially for clean hydrogen and CCUS. But as total investment in low-emission sources of energy (including clean electricity, clean fuels and CCUS) was less than 5% of upstream investment by the oil and gas industry in 2022, much larger shifts in capital allocation are needed to clean up existing production and to position the oil and gas industry as part of the solution to climate change. For example, to maintain its 30% share of total capital spending on CCUS as seen in 2022, the oil and gas industry under the NZE Scenario would have to spend around USD 25 billion annually by 2030. Similarly, its spending levels on hydrogen supply would need to reach USD 19 billion by 2030, based on the current 12% share of investment in electrolyser projects.

This is a crucial topic for COP28 in Dubai. COP President Sultan Al-Jaber has called on the oil and gas industry to "up its game, do more and do it faster". With this in mind, the IEA will be producing new analysis on the role of the oil and gas industry in net zero transitions in advance of COP28.

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Upstream oil and gas

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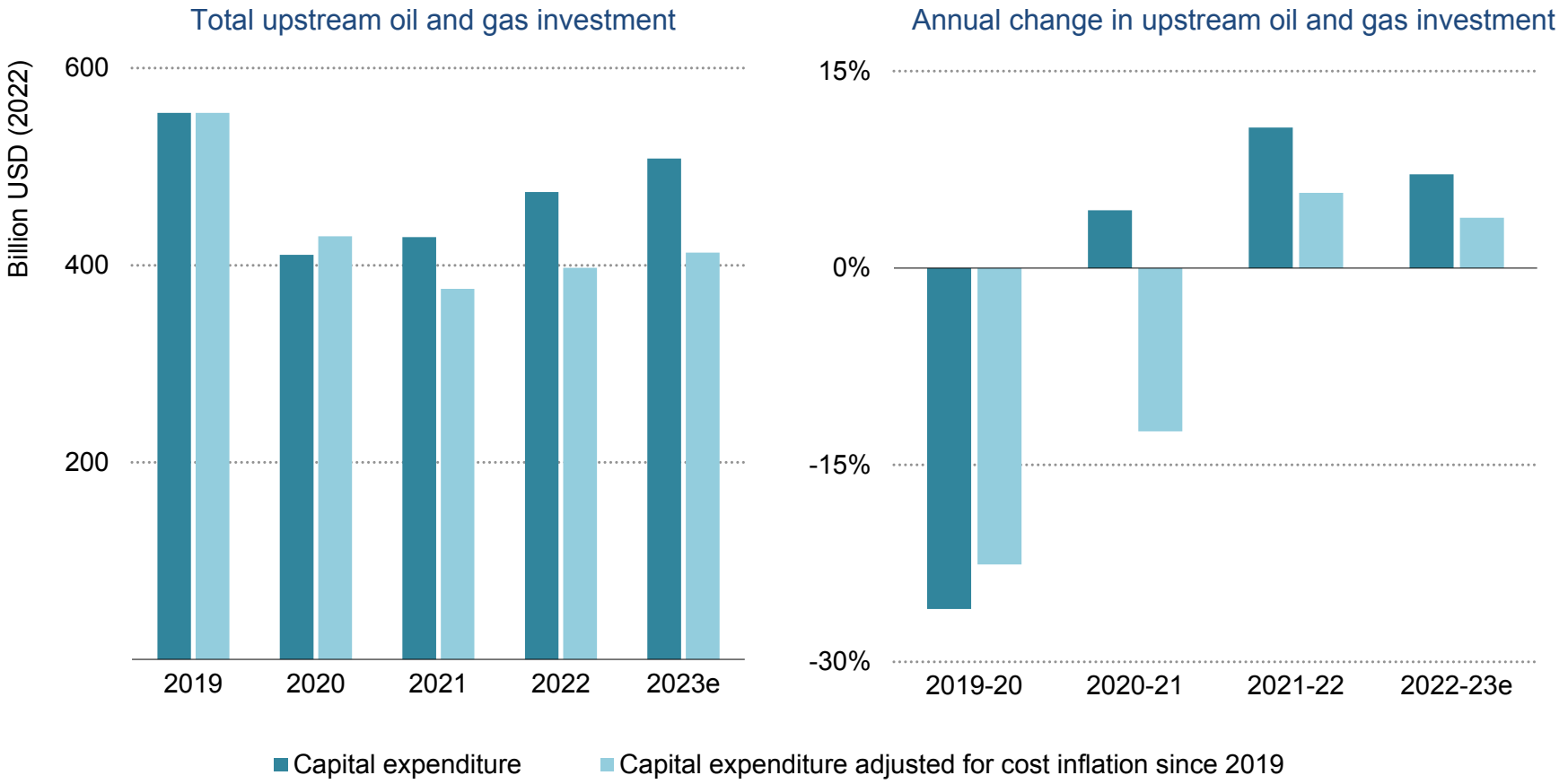
Upstream oil and gas investment rose by 11% in 2022 and is expected to rise by 7% to USD 500 billion in 2023, but half of these increases are absorbed by rising costs



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Notes: "Capital expenditure adjusted for cost inflation since 2019" adjusts capital expenditure for changes in finding and development costs using the IEA's upstream investment cost index that reflects the price of a basket of goods and services required to develop oil and gas fields. 2023e = estimated values for 2023.

Sources: financial report disclosure of a sample of 90 companies; cost index based on data from Bloomberg, FRED and IMF data.

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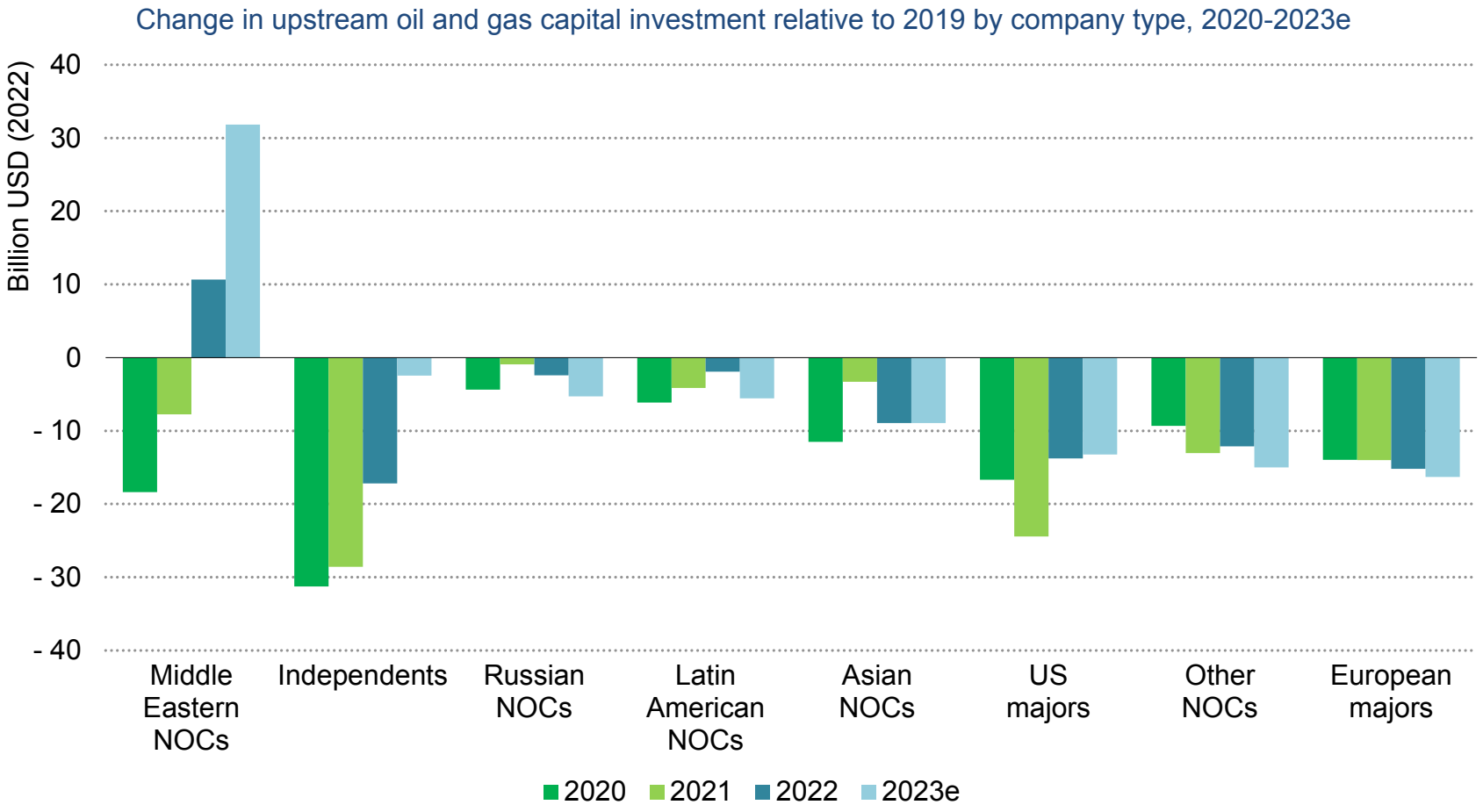
Middle Eastern NOCs are the only segment of the industry spending more than before Covid-19



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Note: 2023e = estimated values for 2023.

Sources: IEA analysis from annual reports and Rystad based on a sample of companies accounting for more than 70% of global production.

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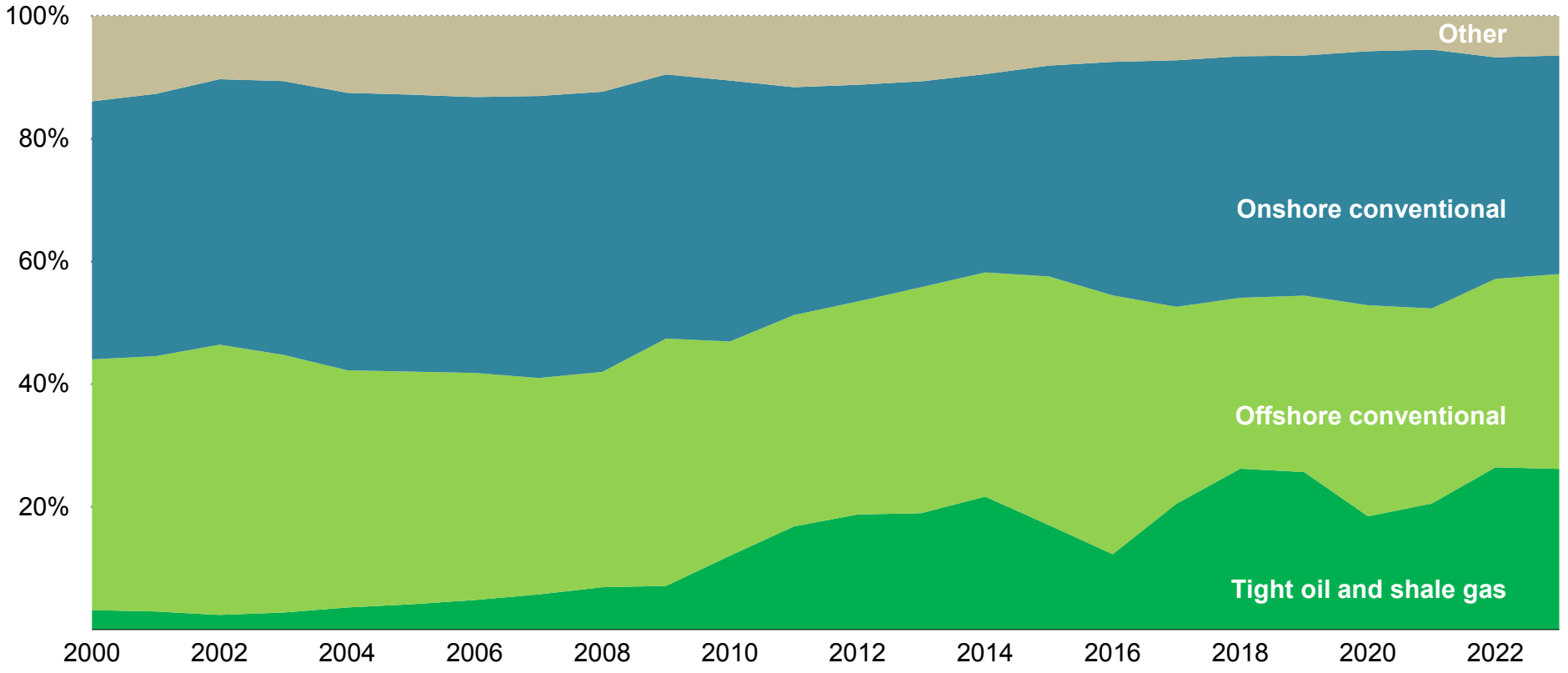
The shale sector represents around a quarter of total upstream oil and gas investment even as operators prioritise returns over production growth

Share of oil and gas investment by asset type, 2000-2023e



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Note: “Other” includes coalbed methane, tight gas, coal-to-gas, extra-heavy oil and bitumen, gas-to-liquids, coal-to-liquids and kerogen oil. 2023 values are estimates.
Sources: IEA analysis from annual reports and Rystad.

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Upstream companies are searching for “advantaged resources” amid rising pressures on costs and renewed energy security considerations

Upstream oil and gas capital expenditure rose by 11% in 2022 and our initial estimate is for a 7% increase in upstream spending in 2023, to reach just over USD 500 billion.

Companies are filtering investment opportunities through an increasingly demanding set of criteria. Advantaged investments need to be competitive on cost, but also have low emission intensities. Deepwater projects tend to score highly on these metrics and areas like Guyana, the US Gulf Coast, Brazil and emerging producers like Namibia (which has seen major discoveries in recent years) are attracting a lot of investor interest.

Another priority is short development cycles. It takes around three to five years on average globally from when a conventional project receives its FID to production starting. The use of standardised designs and existing infrastructure could shorten this time as well as reduce development costs, but despite increasing efforts by the industry to do so, there is little evidence to date of a structural reduction in these development timelines.

Another increasingly important consideration, in the light of the energy crisis, is geopolitical risk. Among other characteristics, companies and potential importers are also looking for “trustworthy barrels”, especially where they can be delivered relatively quickly. Even countries that are actively pursuing rapid energy transitions have proved ready to view some upstream investments through this energy security lens.

Part of the recent increase in spending reflects higher upstream costs: adjusting for rising costs, the increase in activity is only around half the headline increase in upstream investment. This increase in upstream costs in 2022 is due to service companies’ higher margins, the higher cost of drill pipes, casings, tubing and proppants, and, to a lesser extent, higher labour, cement and electricity costs. The US shale industry is experiencing a persistent labour shortage in the Permian Basin, the main producing area, where it is has been challenging to fill mechanical and electrical positions with local residents.

Tight or underdeveloped markets for services and equipment can deter companies from reinvesting their windfall revenues back into the upstream. This is also a feature of deepwater developments where there are constraints on available rigs. Companies such as Petrobras that have actively tendered in recent years for deepwater drilling equipment and rigs have been in a position to move ahead with their upstream ambitions – in Petrobras’ case its large offshore pre-salt fields.

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Windfall gains in 2022 have led to increased investment, but trends differ markedly between regions

Most large oil and gas companies have announced higher planned spending on upstream projects in 2023 from the levels seen in 2022, but only a handful are investing more in this area today than they did prior to the Covid-19 pandemic.

There are major differences between regions. The increase in spending is concentrated mainly among large Middle Eastern NOCs. Notably, Saudi Aramco and ADNOC, invested considerably more in 2022 than in 2019 (prior to the Covid-19 pandemic) and plan to boost investment further in 2023. Both companies are spending to meet announced capacity expansion targets for 2027 – Saudi Aramco to reach 13 million barrels per day (mb/d) and ADNOC 5 mb/d – and are also looking to boost local supply chains and manufacturing capacity. Since 2015 Saudi Aramco has been looking to source an increasing share of its procurement domestically as part of the In-Kingdom Total Value Add programme. As of 2022, 63% of Saudi Aramco's spending was directed to domestic suppliers, up from 35% in 2015 (the target is to reach 75% by 2025). Saudi Aramco has announced a 30-60% increase in capital expenditure for 2023, to reach a total of USD 45-55 billion.

A number of NOCs in Asia announced increases in spending for 2023 on the back of robust revenues in 2022. In Southeast Asia, Malaysia's Petronas now plans to spend about USD 14 billion each year during 2023-2027, a rise of more than 40% compared with the average for the last five years. Indonesia's Pertamina and Thailand's PTTEP have also increased their planned expenditure for the coming years. Natural gas is the prime target for the region's NOCs given the squeeze on supply and high prices during the energy crisis in 2022, with Malaysia's floating ZLNG project and Indonesia's Tangguh UCC project among those likely to move forward.

Upstream investment by Chinese NOCs is expected to be broadly similar to levels seen in 2022 at around USD 60 billion per year. China's leading oil and gas companies are expanding their transition investments but their core mandate remains to ensure oil and gas security on their home market. Higher revenues may allow China's NOCs to target higher-cost domestic resources such as shale or coalbed methane.

There is also a push by some Latin American companies to increase upstream oil and gas spending in 2023. These could come under pressure as some of the largest producers – including Petrobras and Ecopetrol – could be tasked by new government administrations to balance upstream investment with an increase in renewables and downstream investment. Currently, exploration and production account for three quarter of Petrobras' total capital investment.

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US and European majors announced record profits in 2022, but have not substantially modified the investment plans they made prior to the energy crisis. One notable exception is BP, which recalibrated its plans to cut upstream production by 40% and will now target a 25% reduction in output by 2030. By and large the European majors have been trading a lower multiple of share price to earnings compared with their US counterparts, with European companies not getting much credit thus far from investors for their higher transition-related commitments.

For US tight oil and shale gas, the number of rigs in operation rose steadily throughout the first half of 2022, but has since remained around this level. Companies continue to emphasise capital discipline and the importance of returning revenue to shareholders. Cost inflation has also dampened the appetite to increase investment. Investment in the shale sector in 2023 is expected to be similar to 2019 levels, although the number of wells drilled and completed is likely to be substantially lower.

The oil and gas investment picture in Russia is subject to a high degree of uncertainty, and as with many aspects of Russia's energy sector, has been noticeably less transparent over the last year, as companies stopped providing much detail on their financial performance or plans. The information that is available highlights some of the strains, including regular complaints from companies about higher taxes.

Investments in Russia's upstream sector rebounded from Covid-19-induced lows in 2020 but as Russia becomes increasingly shut off from the global energy market, investments have sunk well below levels seen in the pandemic-affected years of 2020 and 2021.

Rosneft managed to keep spending around 2021 levels, but the company has not provided any information on its 2023 investments. On noticeable exception is Gazprom which announced a 16% increase in investment in 2023 from 2022 levels, focusing mainly on the development of new production and gas processing centres as well as the Power of Siberia pipeline. Other large Russian companies, including Lukoil, Gazpromneft, Tatneft and Sibur, announced at different points that their investment programmes are under review, but have not disclosed any further information.

In the meantime, many of the upstream investments by western companies in Russia are in legal limbo, with the investors having announced their exits and written down the value of these investments. They are also facing official restrictions on their ability to divest from Russian assets. For the moment, there are few signs of other non-western players stepping in to take their places.

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Midstream and downstream oil and gas

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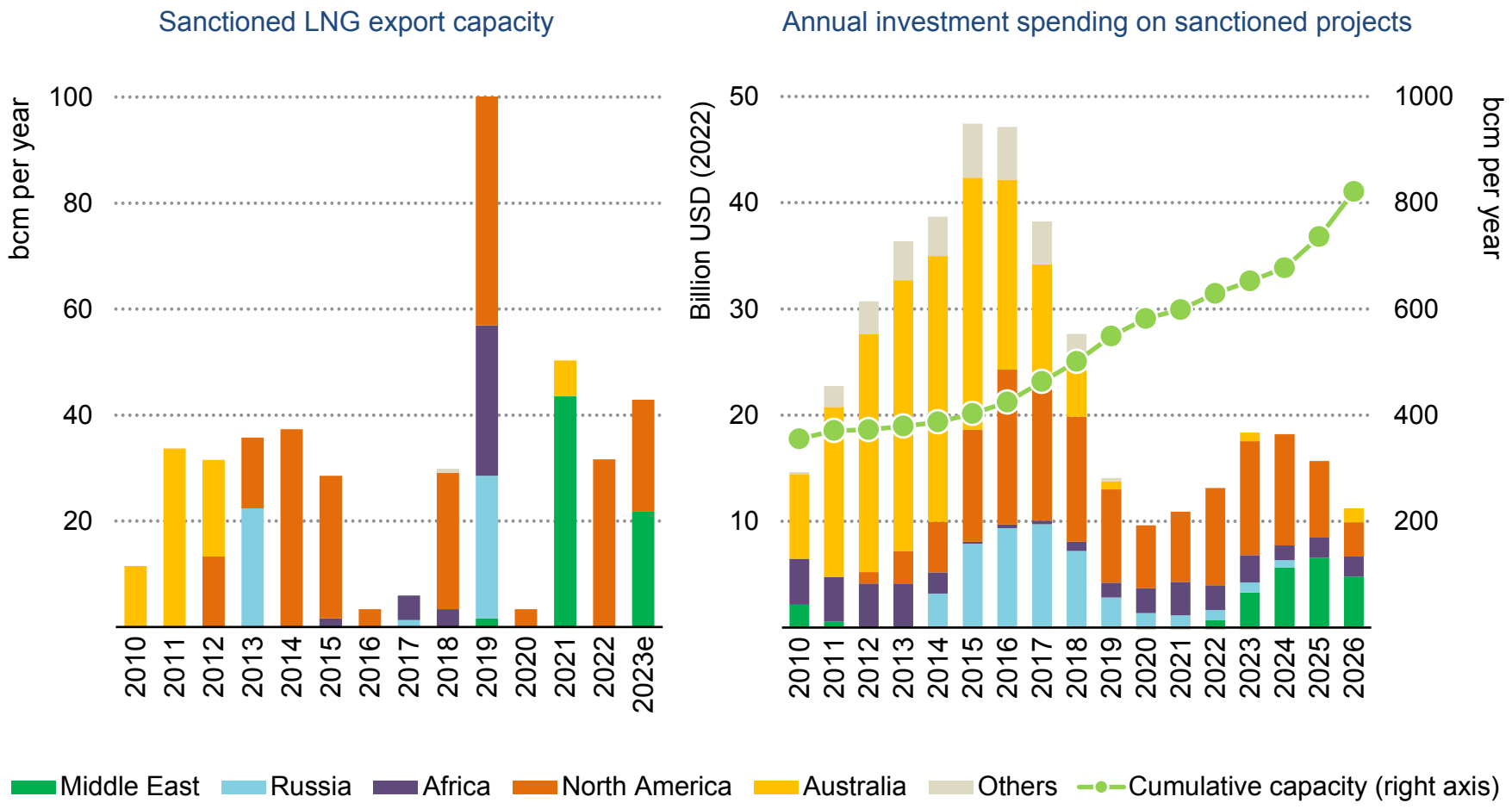
Investment in new LNG projects is picking up, with a long line of projects looking to move ahead, but spending remains well below the levels seen in the 2010s



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Note: Investment spending is profiled assuming a three-to-six-year construction period. 2023e = estimated values for 2023.

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Interest in contracting for new LNG supply has risen following Russia's invasion of Ukraine, but European buyers are wary of long-term commitments

Despite key gas price benchmarks reaching record highs, 2022 was far from a bumper year for investment in LNG. FIDs were made for two projects in the United States (Plaquemines and Corpus Christi Stage 3) and a small floating LNG project in Malaysia (ZLNG Sabah). The total committed capital investment was USD 24 billion, similar to levels in 2021. Investment in regasification facilities, however, saw a large uptick in 2022 as EU-based companies announced, revived or accelerated plans for around 130 bcm of new LNG import capacity, including more than 20 projects based on floating storage regasification units (FSRUs). Around 45 bcm of new regasification capacity is expected to come online by the end of 2023, with Germany the focal point.

The long-lived nature of gas infrastructure, alongside Europe's 2050 climate target, has prompted a debate about the risk of lock-in or stranded assets for new LNG import infrastructure. Regasification terminals typically cost around USD 250/tonne of capacity, around a fifth of the cost of liquefaction terminals. Long-term capacity rights are usually held by private companies, who take the marketing risk and can see utilisation rates vary substantially over the long term.

The recent flurry of investment in LNG import capacity in Europe has not been matched by a parallel wave of long-term supply contracting. Of the 100 bcm of new LNG term contracts signed in 2022, almost half were by portfolio players, while buyers in Asia picked up a third, leaving around 20% earmarked for Europe. This share is well above historical levels, but total firm contracted volumes (around 70 bcm) remain well below annual requirements: buyers in Europe have mainly been relying on spot and flexible LNG to cover the shortfall left by reduced Russian gas deliveries.

Two LNG export projects have so far seen a FID in 2023, both in the United States: the USD 8 billion expansion of Plaquemines LNG (contracted mainly to US portfolio players and independents), and the USD 13 billion Port Arthur terminal (a large proportion of which is contracted to Europe-focused players). There are additional projects in North America – as well as Qatar's North Field South expansion – that have made progress towards an eventual FID; in the US alone more than 20 pre-FID sale and purchase agreements (totalling around 40 bcm) have been signed since Russia's invasion of Ukraine. Portfolio players have contracted around 40% of this total, with Chinese and European buyers each signing up for around 20%.

The proliferation of LNG projects due to come online in the 2025-2027 period raises the possibility of cost inflation, as multiple projects compete for a limited pool of specialised contractors. There will be

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trade-offs between value and speed, and the deadlines for some of the approved projects may well slip further into the latter part of the 2020s.

Investing in LNG remains a complex value proposition, as there is a near-term need for additional capacity but far less certainty about future requirements, especially as an unprecedented wave of around 170 bcm of new capacity is due online between 2025 and 2027 (even though some large projects such as Mozambique LNG and Arctic LNG may be at risk of delay). Accelerated climate ambitions and sensitivity to high gas prices also loom large in the backdrop: we assess the net present value (NPV) of LNG plants currently under construction at over USD 300 billion, assuming prices remain in the range of around USD 9-11/MBtu over a 30-year economic lifetime (consistent with STEPS prices). However, lowering the assumed gas price by 20% would bring the NPV down to zero.

Investment in long-distance gas pipelines remained muted in 2022. Russian state-controlled transport companies such as Gazprom and Transneft have announced plans for double-digit growth in investment for 2023; this reflects a sense of urgency to redirect export flows from Europe to Asia, rather than to bring online new upstream developments. However, there was no firm announcement from Russia and China about new gas pipeline infrastructure, notably the Power of Siberia 2 project, which would connect Russia's major existing fields in Western Siberia and the Yamal peninsula with China. India remains the key market for new gas distribution network investment, but high import prices and growing domestic competition from electricity in the transport and industrial sectors have dampened annual investment levels in the sector.

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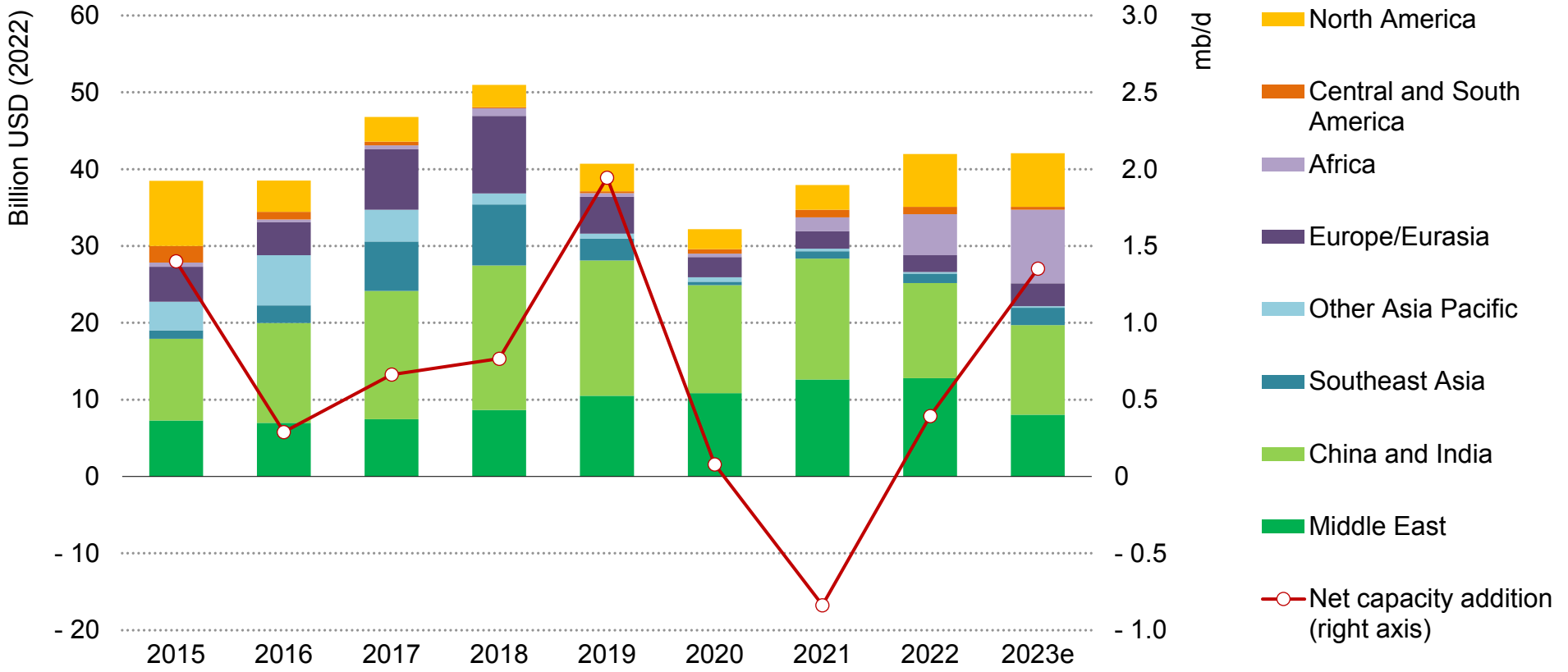
Investment in oil refining continued to rise in 2022, but is expected to slow from 2023 onwards

Investment in oil refineries (greenfield and upgrades) by region and net refining capacity additions, 2015-2023e



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Notes: Investment figures do not include maintenance capital expenditure. 2023e = estimated values for 2023.

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The current healthy margins may not necessarily translate into higher investment levels in the coming years, highlighting the importance of demand-side measures to curb demand growth

The very tight oil product market in 2022 stemmed from a strong rebound in oil product demand, a net reduction in refining capacity, high natural gas prices and lower inventory levels. These factors combined to push refining margins to record highs, especially for middle distillates such as diesel and kerosene. Margins have moderated since late 2022 due to weakened demand. Middle distillate cracks in particular have eased further in early 2023 due to the limited cuts in Russian diesel exports, and have been overtaken by gasoline cracks in the Atlantic Basin. However, despite the recent fall, refining margins remain healthy compared with past averages.

The effects of sanctions and embargoes on Russian oil trade flows were a key variable in global oil markets. Shipments of Russian crude oil to Europe declined visibly following the import ban in December 2022, but these were offset by the surge in imports into India and China, keeping overall Russian export volumes stable. A similar pattern is being observed in product trade flows following the enforcement of the European products embargo in February 2023. While Russian product exports to Europe are falling, some of the volumes are being rerouted to Asia, Africa and the Republic of Türkiye. Despite sustained volumes, Russia's export revenues are nonetheless dwindling. Export revenue in April 2023 is estimated at USD 15 billion compared with nearly USD 20 billion a year ago.

Thanks to healthy margins and tight market conditions, investment in oil refineries (excluding maintenance spending) continued its growth in 2022, reaching USD 40 billion. The increase was primarily driven by the Middle East, China, India and North America, where several large-capacity plants (e.g. the Al-Zour refinery in Kuwait, and the Jieyang and Shenghong refineries in China) started operations or are expected to come online in 2023. After the net reduction in capacity in 2021, the refining industry increased its net capacity by around 0.4 mb/d in 2022 and is set to add a larger amount in 2023.

As the current wave of new capacity additions reaches completion, investment is expected to wane in the coming years. Despite the current healthy margins, it is likely to become increasingly challenging to commit multi-billion dollar investment in new capacity given lingering uncertainty around the long-term outlook for oil demand. Rather, investment in new growth areas, such as low-emission hydrogen, biofuels and petrochemicals, and plastic recycling, is set to account for a larger share of overall investment by refiners. Refining companies already represent around 80% of today's renewable diesel production capacity and over half of the planned projects. This highlights the risk of a potential tightening of refined product supplies in the medium term and the importance of demand-side and efficiency measures to ease such tensions.

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Oil and gas industry transitions

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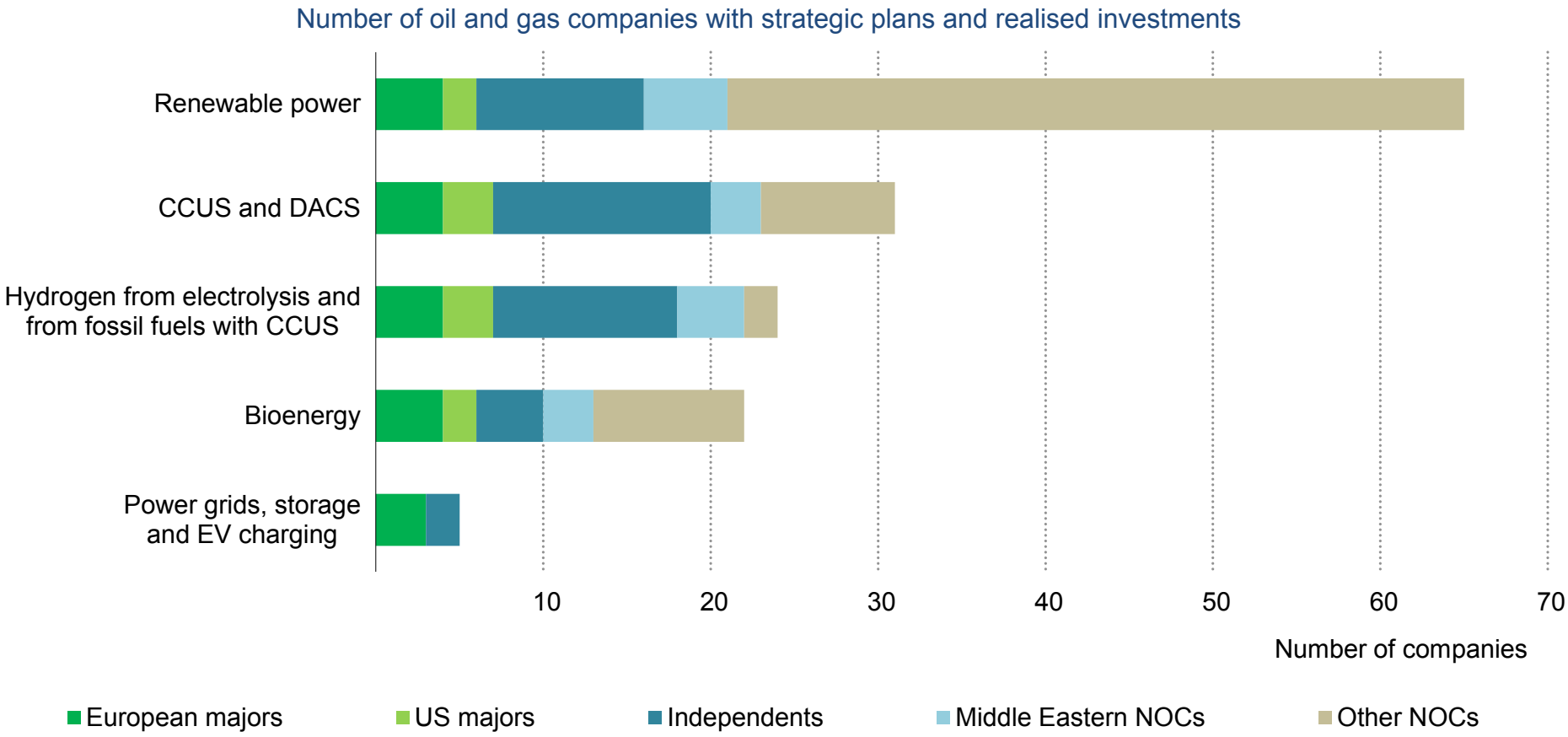
Renewable power is the diversification option being pursued by the largest number of oil and gas companies



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Notes: Takes into account companies having made investments and/or strategic pledges. Low-emission hydrogen includes hydrogen from electrolysis and from fossil fuels with CCUS
Sources: IEA analysis using annual reports, BNEF and Clean Energy Pipeline.

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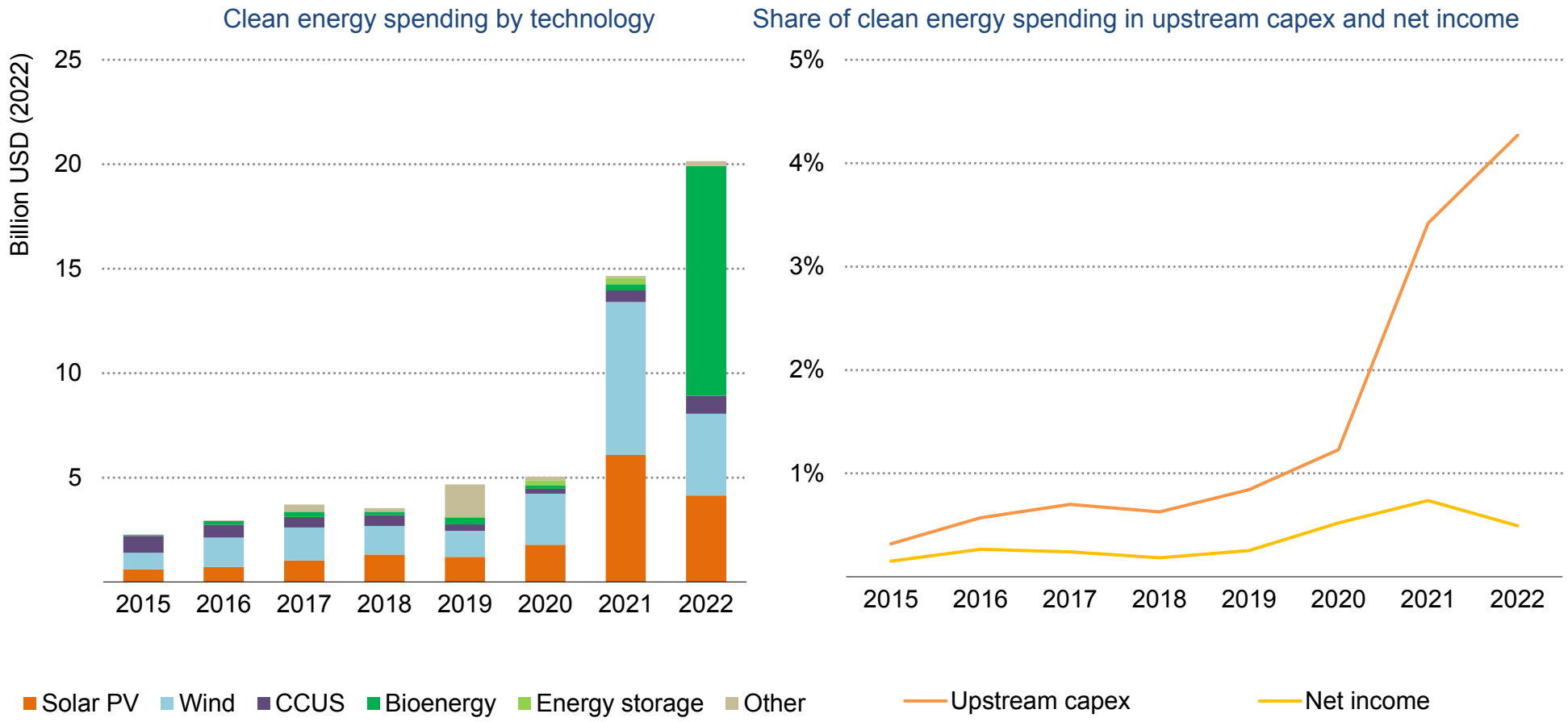
Clean energy investment by oil and gas companies doubled in 2022 to around USD 20 billion, around 4% of their upstream capital investment and 0.5% of net income



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Notes: Spending in this figure includes mergers and acquisitions (investment figures in the rest of this chapter do not); Other = hydrogen, geothermal, small hydro and hybrid projects.
Sources: IEA analysis using annual reports, Clean Energy Pipeline, BNEF, Rystad and IJ Global.

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Oil and gas companies' investment in clean energy is increasing but remains small relative to overall capital investment; bioenergy investment rose significantly in 2022

Our tracking of oil and gas company expenditure shows that around 4% of their upstream capital expenditure in 2022 went to areas outside traditional supply, such as clean fuels, CCUS and clean power. This was 3 percentage points higher than the respective share in 2020. Bioenergy accounted for more than half of clean energy spending by the industry in 2022 as oil and gas companies took major stakes in several bioenergy producers. Our preliminary estimate is that investment levels will remain broadly constant in 2023 although much depends on the number and size of mergers and acquisitions.

There are wide company-by-company variations in this area, but an increasing number of oil and gas companies have now made some sort of commitment to reducing emissions or to diversify their investment spend (typically European majors and independents). The most common type of pledge relates to the emissions associated with the companies' own operations, whether directly (Scope 1) or indirectly (Scope 2). Our assessment is that oil and gas industry operations are responsible for just under 15% of energy-related GHG emissions today. Companies accounting for just under half of global oil and gas production today have announced plans or targets to reduce their Scope 1 and 2 emissions.

For many companies, the pick-up in non-core spending is aimed at reducing the company's own emissions. ExxonMobil, for example, announced plans to spend USD 17 billion on emission reduction initiatives until 2027; of this, 40% will be directed to initiatives with third parties (with a primary emphasis on CCUS, biofuels and hydrogen), but the majority will be towards reducing the company's Scope 1 and 2 targets.

Reducing flaring and methane leaks has to be a core priority. The methane emissions intensity of oil and gas production is edging downwards, but the IEA's Global Methane Tracker underlines that these leaks remain unacceptably high. Likewise, global gas flaring decreased slightly in 2022, largely thanks to reductions in Nigeria, Mexico and the United States, as well as consistent efforts from Kazakhstan and Colombia, but almost 140 bcm of gas was nonetheless wasted in a year when gas supplies were very tight and prices exceptionally high.

There is a growing realisation that leading oil and gas companies' active participation in emission reduction efforts is preferable to them simply selling off their most carbon-intensive assets to meet emission reduction goals. Analysis by the Environmental Defense Fund highlights the general movement of upstream assets in recent years towards companies with weaker climate commitments. From 2018 to 2021, more than twice as many deals moved assets away from operators with net zero commitments than the reverse.

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Renewable power remains the main outlet for non-core oil and gas company spending, but investment in clean fuels, such as bioenergy, hydrogen and CCUS, is picking up

The pipeline of clean energy investment projects that have oil and gas industry participation is picking up. The past several years have seen oil and gas companies – particularly European majors – build up a portfolio of renewable assets through acquisitions, joint ventures and direct investment. The early focus was on wind and solar developments, and there have been large moves into offshore wind: TotalEnergies announced in 2022 a project pipeline of 6 GW of offshore wind, taking the total to 11 GW, Shell also has around 9 GW in the pipeline and Equinor has ambitions to install 12-16 GW by 2030. If realised, these capacity additions would rival those of pure-play offshore wind developers such as Ørsted over the same period. More recently, oil and gas companies have increased their focus on bioenergy, spending around USD 11 billion in 2022, mainly on the acquisition of biomethane and biodiesel producers.

There is increasing policy support for CCUS, biogases and low-emission hydrogen, all of which are a good match for the engineering and project management strengths of oil and gas companies, as well as their experience in handling liquids and gases.

Several oil and gas companies have announced large-scale capital-intensive flagship projects in these sectors in recent years. For example, in 2022 BP took a 40% stake in the hydrogen-focused Western Green Energy Hub in Australia, set to be one of the largest renewable projects in the world. This was followed by BP's USD 2 billion commitment to develop hydrogen, biofuels and renewable energy around its refining operations in Valencia, Spain. Shell in 2022 took a FID for an integrated hydrogen project in the Netherlands – Holland Hydrogen I, one of the largest hydrogen projects in Europe.

NOC activity in this area is also picking up. ADNOC is developing two CO_2 recovery projects at existing gas plants and, along with BP and Masdar (the state-owned renewable energy company in the United Arab Emirates), is participating in the United Kingdom's H2Teesside project for hydrogen from natural gas with CCUS. In 2022 Saudi Aramco announced plans for a CCUS hub with a target to reach 9 Mt CO_2 capacity by 2027. The company's first sustainability report, released in mid-2022, also contains a target to reach 11 Mt of hydrogen production capacity by 2030. Petronas reached a FID on the 3.3 Mt CO_2 Kasawari offshore CCUS project.

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Low-emission fuels

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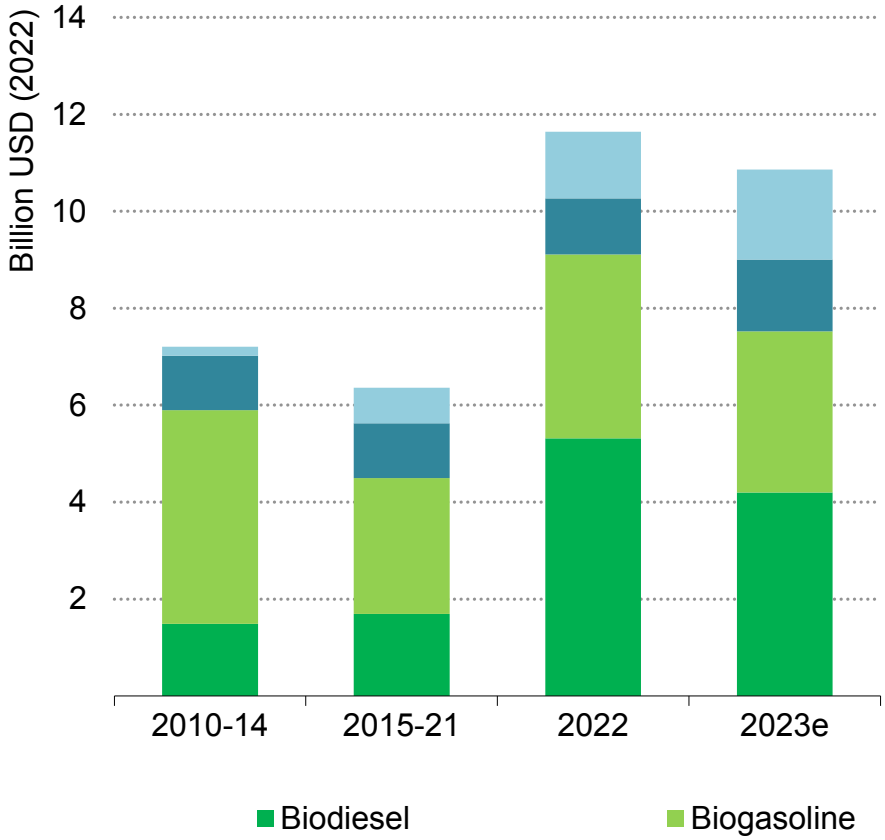
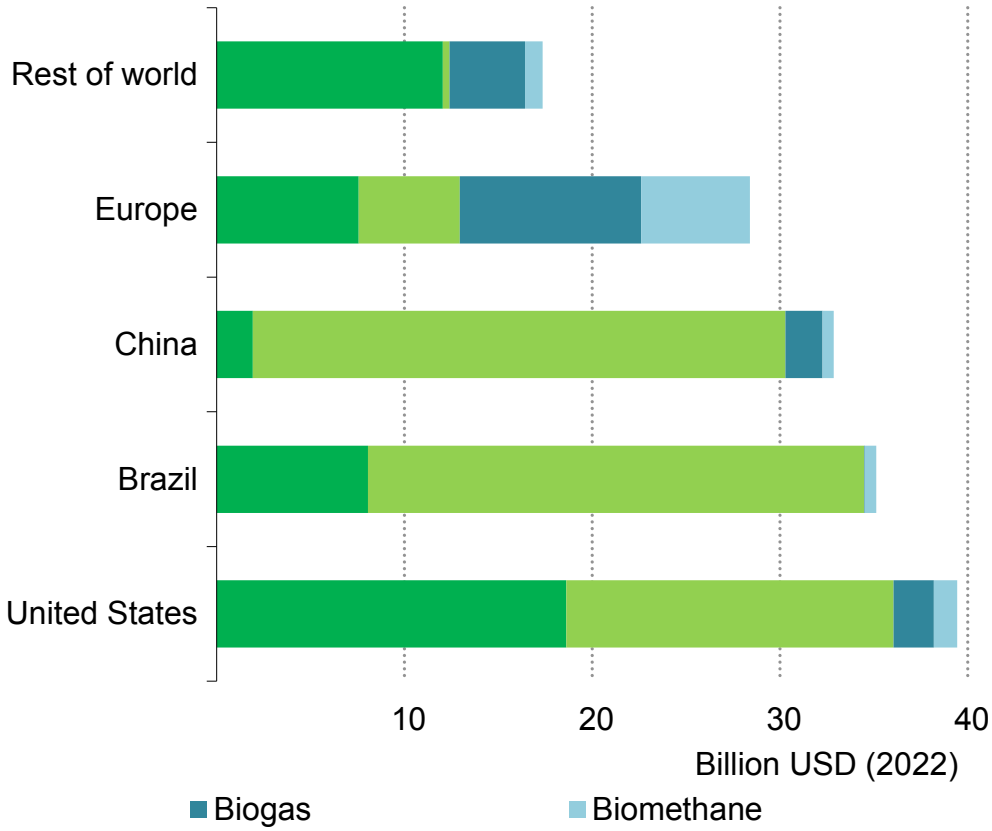
Modern gaseous and liquid bioenergy saw a sharp uptick in investment spending in 2022, led by advances in renewable diesel and biomethane

Average annual investment in biogases and transport biofuels



Cumulative investment by region, 2010-2022



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Note: Biomethane investment includes the cost of producing biogas as an interim step before upgrading to biomethane. 2023e = estimated values for 2023.

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A flurry of acquisitions in recent years has seen the oil and gas industry take major stakes in bioenergy producers

Global transport biofuel capacity expanded by 7% in 2022, its largest annual increase in over a decade. Biorefineries focused on renewable diesel made up the bulk of the growth, thanks to attractive policies in the United States and Europe, while bioethanol capacity saw notable increases in Brazil, Indonesia, India and China.

Biofuels investment saw a large uptick in 2022 as capacity additions reached a decade high of around 260 kb/d. Large investments were announced in renewable diesel refining, notably the Marathon-Neste USD 1.2 billion joint venture in California and Imperial's USD 720 million investment in Canada. Several large companies are also making forays into sustainable aviation fuels; this underpinned Neste's USD 2.2 billion expansion of its renewable fuels plant in Rotterdam. In the European Union alone there are over 30 advanced biorefinery projects in operation, and a further 10 are slated for operation before 2025; several are developing sustainable aviation fuels and renewable diesel production capabilities. The United States is likely to lead growth in this sector in the near term, thanks to generous fiscal incentives; the Inflation Reduction Act includes an estimated USD 9.4 billion in tax credits and financial support for new production capacity and biofuel infrastructure generally.

Through a series of acquisitions and new partnerships, oil and gas majors are increasingly gaining a foothold in the biomethane industry. BP bought Archaea Energy in late 2022 for USD 4 billion, Shell acquired Denmark-based Nature Energy for USD 2 billion, and Chevron bought biofuel-focused Renewable Energy Group in a USD 3 billion acquisition (alongside the acquisition of Beyond6, a compressed natural gas refuelling network). TotalEnergies has made a series of smaller acquisitions, such as the purchase of Poland-based biogas producer PGB, and entered into an agreement with Veolia to produce biomethane from waste treatment plants.

Vigorous debate continues about the sustainability of different feedstocks for bioenergy; currently around 90% of liquid biofuels and the majority of biogases are derived from conventional food crop feedstocks. The EU Renewable Energy Directive II foresees a 7% cap on these feedstocks, favouring those derived from waste streams instead. The cost of bioenergy feedstocks has also been rising in recent years due to volatile crop prices and high demand for biofuels as countries enact more ambitious blending mandates. There is a possibility of a feedstock supply crunch over the coming years, as demand for vegetable oil and waste and residue oils and fats for transport biofuels is expected to grow by nearly 60% to 80 Mt by 2027.

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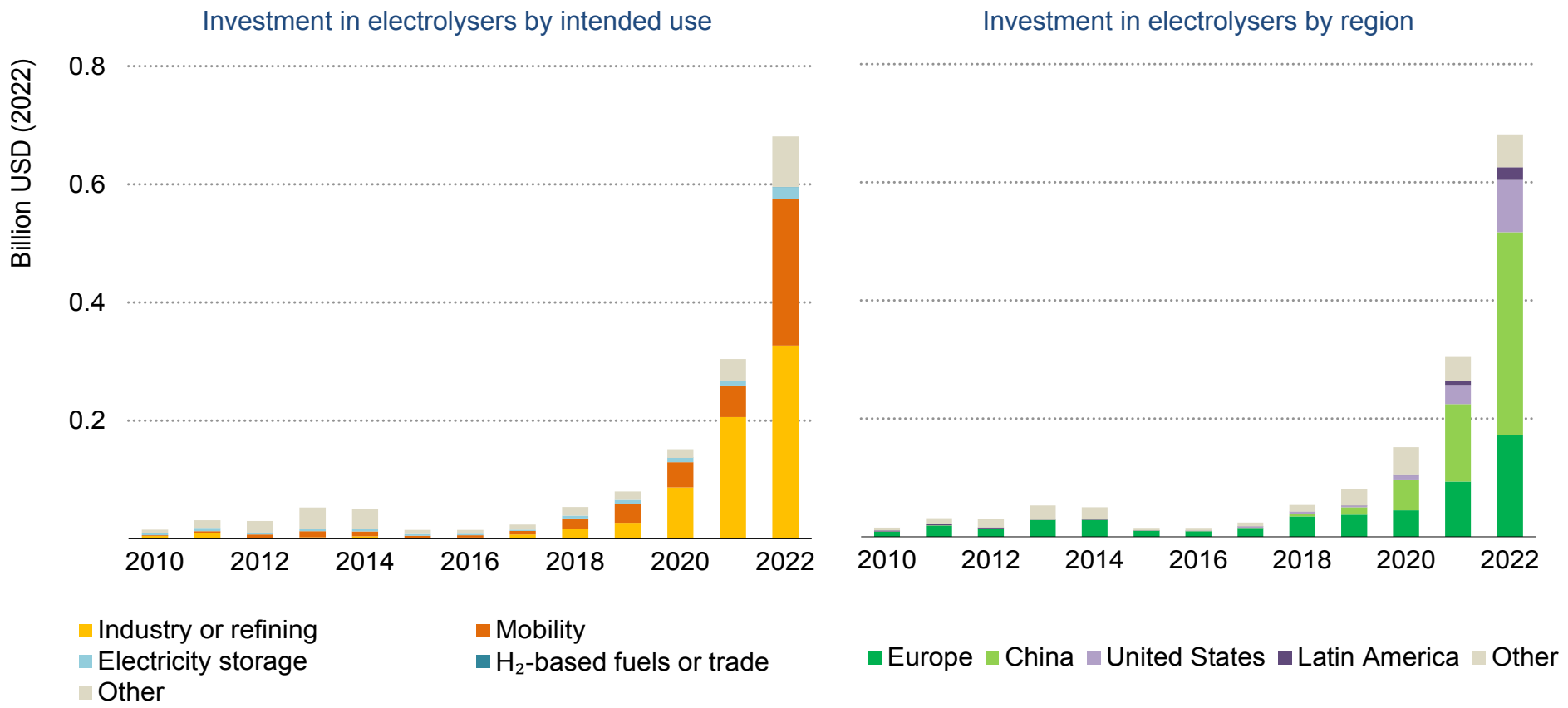
Spending on electrolysis projects for hydrogen is growing fast, led by end uses in mobility, oil refining and industry, especially for iron and steel



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Notes: 2022 values are estimated annualised spending on projects that are under construction and due to enter operation in 2023. Estimates are based on capital cost assumptions and announced capacities of electricity input or hydrogen output volumes per project and include electrolysers for hydrogen supply used for energy purposes or as an alternative to fossil fuel use in industry (such as chemical production and oil refining). "Mobility" includes projects for which the hydrogen output is intended for use in vehicles; hydrogen intended for conversion to hydrogen-based fuels is included in "H_2-based fuels".

Sources: IEA analysis based on IEA hydrogen project database and recent announcements.

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Hydrogen spending is driven by major projects in China and Europe that are due to start up in 2023-2025; US policy incentives are yet to translate into FIDs

Global electrolyser capacity additions fell by one-third in 2022, yet this trend does not reflect the amount of capital committed, nor does it imply a slowdown stemming from weaker macroeconomic conditions. A single 150 MW expansion in China in 2021 almost equalled total new capacity in 2022, and no new additions of that size began operation in 2022. Another major Chinese project – a 260 MW facility at a refinery in Xinjiang – is scheduled to start in mid-2023. Our estimate of spending on projects nonetheless shows significant growth due to the ongoing construction of projects not yet in operation.

Overall, there remains a positive expectation among hydrogen developers that investment will grow exponentially in the near future, driven by government incentives. However, it is too early to see any boost to spending from recent flagship hydrogen policies in Europe and the United States, for which rules are still being finalised.

A sign of the rising investment appetite for hydrogen projects in the energy sector are the FIDs taken in 2022 for more industrial-scale projects. All are linked to dedicated renewable electricity capacity. The largest among these, in Saudi Arabia, will have electrolyser capacity of 2 GW in 2026 if completed to plan, eight times larger than the next biggest in the world. As most of its output is intended for export to users outside the Middle East, it is an example of the entry of serious new players in low-emission hydrogen that are not driven by local decarbonisation policies. Egypt, Oman and the United Arab Emirates are also proposing to become exporters.

The next largest group of projects are all integrated into the use of the hydrogen. Shell's Holland Hydrogen I in the Netherlands and Air Liquide's Normand'Hy in France, at 200 MW each, will have capacities ten times that of Europe's biggest existing plant and are aiming to supply existing refineries by 2025. The Shell FID was taken without government support. In China, Sinopec started constructing a roughly 200 MW electrolyser in Inner Mongolia with associated hydrogen storage to supply a coal-to-chemicals facility. State-owned Dalian Capital Investment began building 60 MW of electrolysis capacity that will run on seawater. In Sweden, an FID could be taken in 2023 for the first new steel mill in Europe since the 1970s, equipped with 720 MW of electrolysis, backed by a public loan guarantee.

Two projects for producing hydrogen from natural gas equipped with CCUS also took FIDs in 2022. A Hydrogen Energy Complex is under construction by Air Products in Canada, to produce around 0.5 Mt of hydrogen for power generation and other uses, with 95% of the CO_2 captured and stored from 2024. The capacity is equivalent to 3 GW of electrolysis running 100% of the time. It has grant funding from the federal and Alberta governments. In the United States, financial close

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was reached in February 2023 on a facility in Texas to produce 0.2 Mt of hydrogen for fertiliser production from 2025 with over 90% CO_2 capture. The capacity is equivalent to around 1.7 GW of electrolysis. The destination of the captured CO_2 has not been yet disclosed. While several similar projects are well advanced in Europe and the Middle East, the more favourable investment environment in North America has made it the leader in hydrogen production with CCUS.

Additional major FIDs in Europe and the United States are widely expected to flow from major policy initiatives stemming from post-pandemic stimulus funding, the ongoing energy crisis and regional ambitions to secure value chains. Under the Important Projects of Common European Interest (IPCEI) scheme, the Commission approved EUR 10.6 billion in country-level support to projects focused on technology and infrastructure in 2022. For example, the delayed 100 MW REFHYNE 2 project at a refinery in Germany is on the IPCEI list and could take FID once funding is clarified, as long as electrolyser manufacturing also scales up. The United Kingdom's March 2023 budget promised GBP 20 billion over 20 years for electrolysis and CCUS-equipped hydrogen production; 408 MW of electrolysis projects were shortlisted in March 2023 for a first GBP 340 million funding round.

The biggest boost to investment is likely to stem from the 2022 US Inflation Reduction Act, coupled with the Hydrogen Hubs initiative launched the year before. Among other provisions, the act provides tax credits of up to USD 3/kg of hydrogen produced in line with certain emission and other criteria, and up to USD 85/tonne of CO_2 stored (noting, however, that this CCUS provision is worth the equivalent of just under USD 1/kg of hydrogen and cannot be claimed in addition to the hydrogen tax credit). The act also provides credits for investment in the manufacturing of related equipment, plus grants and loan guarantees for demonstration projects.

The pay-for-performance approach and magnitude of the tax credit system compared to project-based funding competitions has led to speculation that the act might lead to the relocation of projects to the United States, especially electrolyser and component factories. Uncertainty about the environmental requirements for hydrogen to qualify for EU incentives has also fuelled this opinion. While many new US projects have recently been announced, there is only anecdotal evidence to date that these developers' other projects outside the United States no longer have their full commitment. In early 2023 Johnson Matthey and Plug Power announced an electrolyser manufacturing partnership for a 5 GW factory by 2025 that would more than double existing US capacity and be five times the size of the largest operational factory in the world today. However, Plug Power has also announced an expansion in Korea and, of the 38 electrolyser factory plans announced with a capacity of over 1 GW, only six are in the United States, of which three were announced after the passing of the Inflation Reduction Act. On balance, the act is likely to raise international hydrogen investment and pull its centre of gravity of towards North America in the near

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term, but this will depend on how EU countries respond and whether developers, suppliers and service providers can service multiple large projects in parallel.

Other notable announcements of public support include AUD 2 billion in payments for hydrogen production from renewable-based electrolysis to 2030 and USD 1.6 billion granted by Japan to the Hydrogen Energy Supply Chain in Australia. That project would combine lignite, CCUS and seaborne shipping of hydrogen to Japan from around 2029 if approved by Australian stakeholders. India announced USD 11 million in funding available for consortiums developing hydrogen projects. The European Commission published a concept for a European Hydrogen Bank that could contract with hydrogen producers and consumers to fill the gap between production costs and tolerable purchase prices, whether the producer is in the European Union or outside. EUR 800 million is suggested for an initial auction, echoing a similar model used by the German initiative H2Global, which has a EUR 900 million initial budget and launched an ammonia auction in 2022.

Several investments were also made into hydrogen-related infrastructure. These include an FID by fertiliser company OCI to expand by 200% its 0.4 Mt ammonia import terminal in the Netherlands by the end of 2023. In mid-2022 the US Department of Energy Loan Program Office finalised a USD 504 million loan guarantee for an electrolysis and large-scale underground hydrogen storage project.

In 2022 multilateral development banks indicated their willingness to finance hydrogen projects. Announcements included: a World Bank and IFC facility for concessional finance for projects (Barbados, Mexico and South Africa) and governments (Chile, India and Namibia); an agreement for a potential loan of EUR 500 million from the European Investment Bank (EIB) to Namibia; and two loans from the Inter-American Development Bank (USD 400 million) and World Bank (up to USD 350 million) to Chile. Since these loans to Chile were announced in November 2022, some consolidation of projects in the country appears to have begun, as fewer of the consortiums shortlisted for public funding have progressed through to the environmental assessment phase than expected. This outcome is likely to be repeated in other countries as the long lists of announced projects are winnowed by commercial, regulatory and public budget hurdles.

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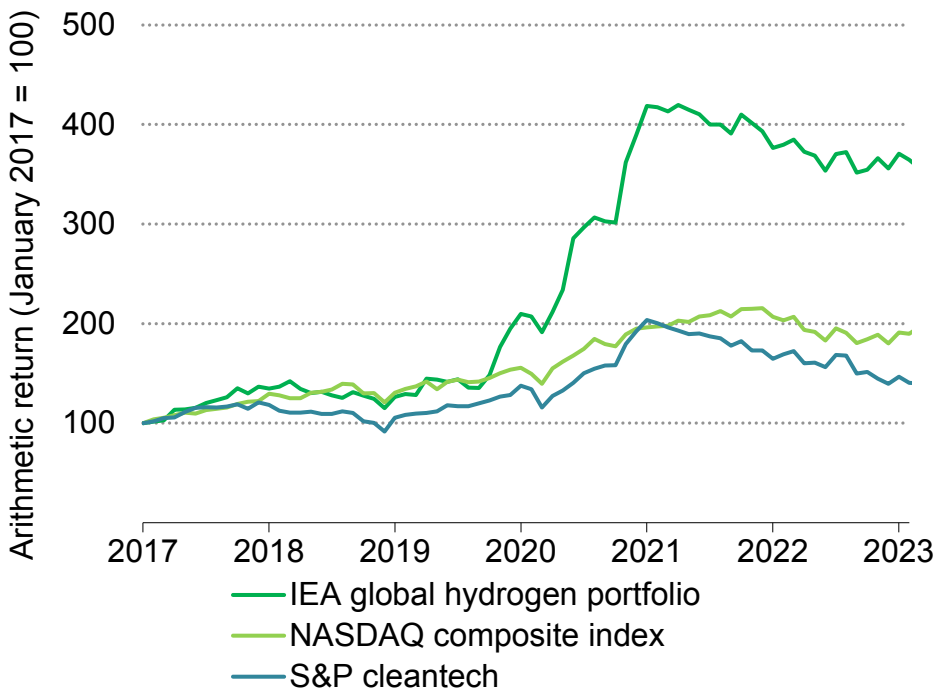
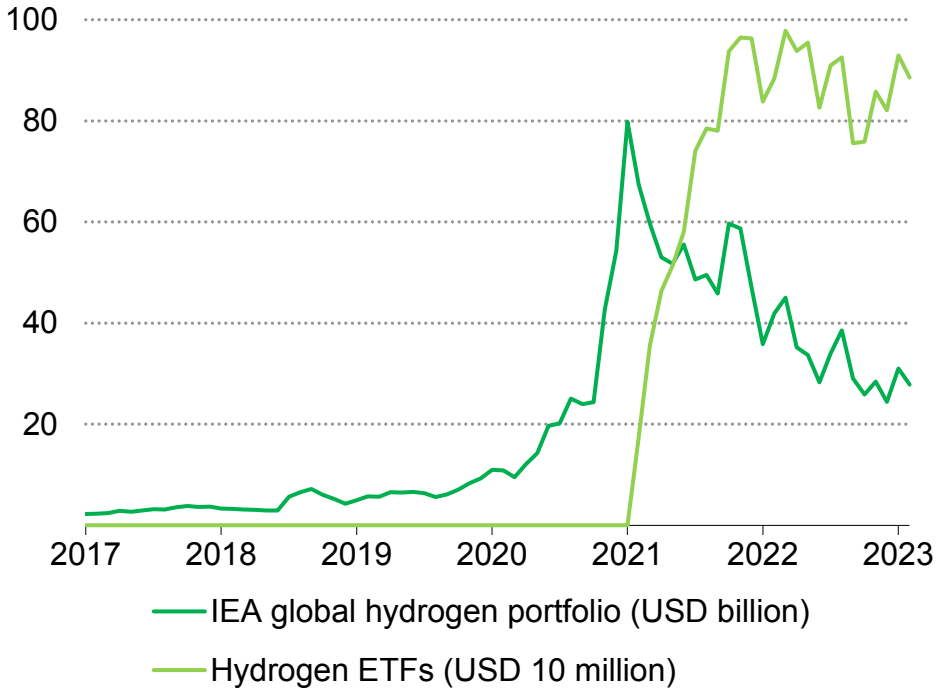
Since mid-2022, returns from a portfolio of 41 low-emission hydrogen firms have stabilised, but their market capitalisation has suffered in line with lower valuations for technology firms

Monthly returns of hydrogen companies and funds



Market capitalisation of hydrogen companies and funds



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Notes: ETFs = exchange-traded funds; portfolio member tickers: 0051720D US, 288620 KS, 332142Z LN, 336260 KS, 702 HK, ACH NO, ADN US, AFC LN, ALHRS FP, AMMPF US, BE US, BLDP CN, CASAL SW, CI SS, CWR LN, F3C GY, FCEL US, FHYD CN, GNCL IT, GREENH DC, H2O GY, HDF FP, HTOO US, HYON NO, HYPRO NO, HYSR US, HYZN US, HZR AU, IMPC SS, ITM LN, LHYFE FP, MCPHY FP, NEL NO, NHHH CV, NXH CN, PCELL SS, PHE LN, PLUG US, PPS LN, PV1 AU, SPN AU, TECO NO, VIHD US, VYDR US.

Source: IEA calculations based on Bloomberg (2023).

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Despite uncertainties facing some early-stage "pure play" hydrogen companies, funds that raise money to invest in hydrogen projects have held their value over the past year

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 publicly traded companies whose success depends on demand for low-emission hydrogen growing. To try to be as representative as possible since WEI 2022, we have expanded the portfolio from 33 to 41 members. These companies span a range of sectors, including electrolyser and fuel cell manufacturing, low-emission hydrogen and ammonia project development, hydrogen distribution infrastructure and hydrogen-fuelled vehicles.

The total market capitalisation of the portfolio tracks some of the major clean energy trends since 2019: initial hopes for high growth were buoyed through the Covid-19 pandemic by expectations that governments would ensure a quick recovery, but rising interest rates in 2022 were compounded by the energy crisis and this led investors to withdraw equity from sectors struggling to meet shareholder requirements. By the end of February 2023, the market capitalisation of the portfolio had dropped back to its level in November 2020. Meanwhile, the monthly investor returns and revenues of this portfolio are almost three times higher than five years ago, and they continue to outperform more general cleantech indices. This suggests that investors treat hydrogen stocks as high-tech innovative businesses (as represented by the NASDAQ composite index), which gives them preferential access to government programmes focused on future competitiveness.

Even as the value of listed hydrogen companies has been adjusted downwards, publicly traded dedicated hydrogen funds have maintained their value. These funds are established to invest equity in a blend of private companies and projects that are scaling up low-emission hydrogen supply and use. Since 2022 these funds have shifted their attention more towards projects, which they now expect to yield higher returns relative to technology companies in the medium term. For example, HydrogenOne Capital Growth has invested EUR 17 million in the project developers Strohm and HH2E since mid-2022. The unlisted Clean Hydrogen Infrastructure Fund, which raised over USD 1 billion in early 2022, has not expanded further but in early 2023 it took a 49% stake in a new EUR 200 million venture to develop hydrogen infrastructure in Nordic countries. Since WEI 2022, United Hydrogen Limited joined these other investors; it has a stronger focus on company ownership and, despite a lower valuation at USD 39 million, a goal of becoming the world's largest diversified hydrogen conglomerate. Funds are also being raised in regions that have been less active to date: in April 2023, Avaada, a

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solar project developer, raised USD 1 billion from a Canadian investment fund for hydrogen-related projects in India.

Start-ups working on hydrogen-related technologies and businesses raised record amounts of early-stage and growth-stage equity in 2022. At USD 660 million, early-stage deals were only marginally higher than in 2021, but this was over ten times higher than the annual average of the previous five years. Notable deals included those for Hysata, an Australian electrolyser developer raising USD 29 million, Hygenco, an Indian project developer raising USD 24 million, and Levidian, a British developer of methane cracking raising USD 13 million. Growth-stage funding rounds, which tend to be much larger than early-stage, rose by 150% in 2022, to USD 2.9 billion. This is an even more impressive achievement in light of only a 1% increase overall in growth-stage equity funding for energy firms. The largest deal, at over USD 300 million, was for Monolith, a US developer of methane pyrolysis.

As the size of hydrogen projects grows, the share of start-ups that are project developers, not technology owners, has risen. However, growth-stage investment and acquisitions still tend to favour technology companies. In an analysis of 391 start-ups founded since 1990 with activities related to hydrogen, 70% were found to hold at least one patent application. More than 80% of the growth-stage investment in hydrogen start-ups since 2000 was in companies that had already filed a patent application. Overall, 55% of all venture capital funding for hydrogen start-ups went to the 117 companies that had filed patent applications in the period 2011-2020.

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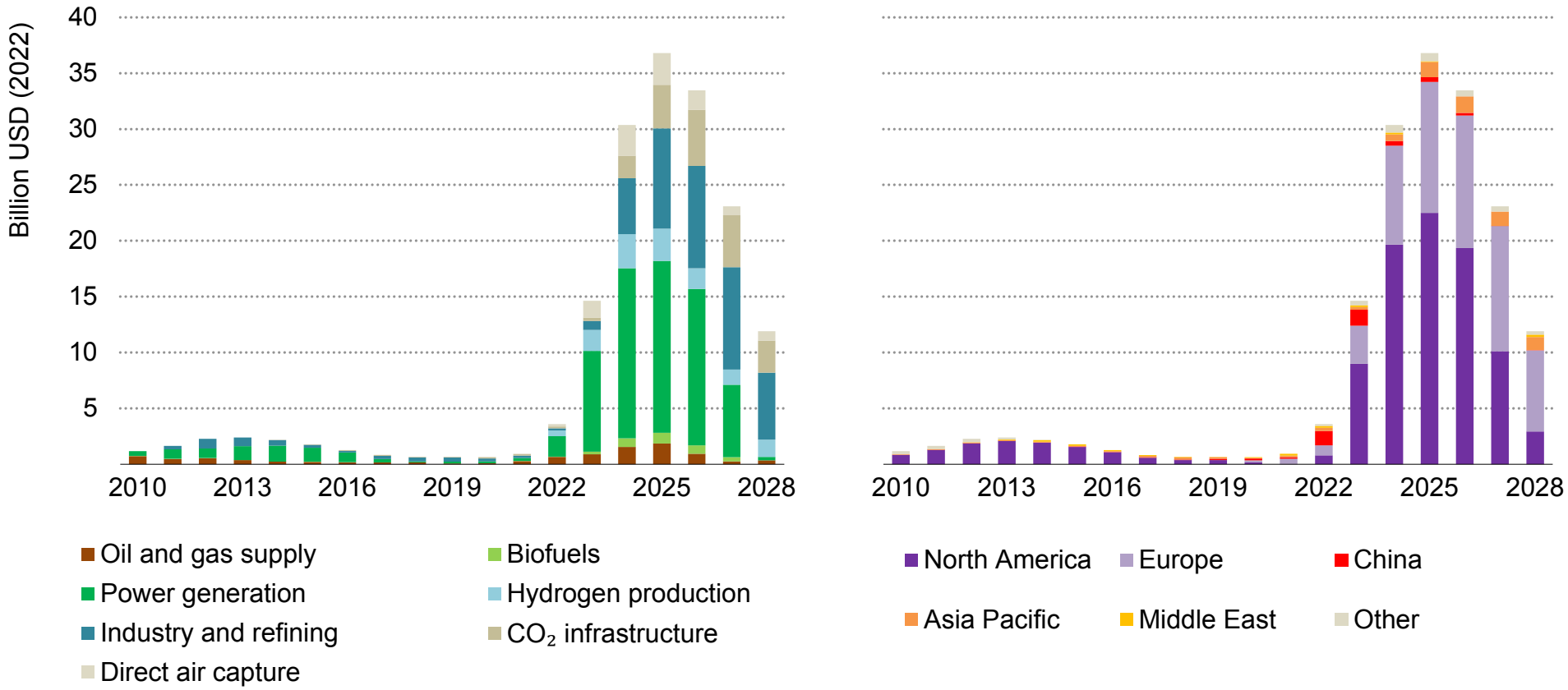
Recent FIDs for CCUS projects are set to push 2023 spending to a new record

Annualised historical and potential spending on advanced CCUS projects based on announced project timelines



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Notes: Includes commercial capture and full-chain CCUS projects with a capacity of over 0.1 Mt CO_2 per year; 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 are unavailable; Other includes Africa, South and Central America and the Middle East.

Source: IEA analysis based on IEA CCUS projects database.

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CCUS project announcements have been galvanised by public support packages in the United States, which support the trend towards risk management by breaking up the value chain

When the Taizhou power station CCUS project enters operation – it is scheduled to do so this year – it will become the third facility in China since 2018 to capture more than 0.5 Mt CO_2 per year. One of the other two plants, at the Qilu refinery, started operating just last year, establishing China as the centre of CCUS investment recently.

However, the coming years will be dominated by significant growth in investment in the United States, spurred by government support policies that close the cost gap. Since November 2021, five US projects that will each handle over 0.5 Mt CO_2 per year took FID. The entry of these projects into the construction phase likely helped push CCUS investment to a record USD 3.1 billion in 2022. They also provide confidence that CCUS spending will continue to grow.

If all advanced projects take FID in line with their schedules, global CCUS spending could reach USD 34 billion in 2025. This dramatic potential ramp-up reflects the extent to which the CCUS project pipeline has expanded recently. Over 180 projects have been announced since January 2022 along the CCUS value chain. CO_2 capture projects are shared between different sectors, with many relating to hydrogen or bioethanol production. The higher unit cost of projects in the power sector led to its roughly 50% share of total possible investment in 2023-2028. The full project pipeline could raise global CO_2 capture capacity from around 45 Mt CO_2 per year today to over 300 Mt CO_2 per year by 2030. But this would still fall short of the 1 200 Mt/yr envisaged by the NZE Scenario in that year. While 30% of the announcements since the start of 2022 were in the United States, the project pipeline is becoming more global. New projects are planned in Bulgaria, Croatia, Libya, Portugal, Singapore and Thailand, among others.

Most developers expect to rely on direct public support to make projects profitable, in some cases via the backing of state-owned enterprises. To date, FIDs have typically been enabled by grant funding, and many recent announcements follow this pattern. Newly available US grant support for developers of so-called H2Hubs has prompted CO_2 transport and storage projects that could link to multiple CO_2 sources, not just hydrogen production. Among the recent US FIDs is the Central Louisiana Regional Carbon Storage project, which reached financial close in early 2023 on up to 10 Mt CO_2 of storage capacity.

This is reflective of a wider trend towards splitting the different parts of the CCUS value chain into separate projects. While "full-chain" projects (where CO_2 is transported from one capture facility to one injection site, sometimes involving a single operator) were a natural response to calls for demonstration projects, they suffer from high investment needs, cross-chain risks and liabilities that are borne by

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a single developer. Breaking up the CCUS value chain can help mitigate these hurdles. In 2022, projects to develop over 210 Mt of new dedicated CO_2 storage capacity were announced, more than double the amounts in 2020 and 2021. One of most advanced projects under construction is Northern Lights, in Norway, which is developing large-scale CO_2 storage that can accept CO_2 from multiple sources that have incentives to reduce emissions. In May 2023, Denmark awarded around USD 1.2 billion to meet the costs of capturing 0.4 Mt CO_2 per year from biomass combustion for storage at the Northern Lights site from 2026. Separately, pilot CO_2 injection began offshore in Denmark in 2023.

Recent policy developments support this trend by offering financial rewards for storage of CO_2 or production of clean products. Mechanisms such as tax credits, contracts for difference and public procurement create bankable demand for CO_2 transport and storage services, which reduces the risks associated with infrastructure development. Among these, the tax credits offered by the US Inflation Reduction Act – up to USD 85/t CO_2 stored or USD 3/kg of hydrogen – are set to stimulate the most investment, supported by proposed emissions rules for power plants. A different model is found in the European Commission's proposed Net Zero Industry Act, which links the production of fossil fuel to a requirement to develop CO_2 storage capacity. The act's suggested target of 50 Mt CO_2 of available storage capacity by 2030 is ambitious but falls well short of that required in the NZE Scenario. Together, these initiatives begin to address a long-standing issue over where the responsibilities and rents will lie in a commercial CCUS value chain.

Policies are also taking shape in some EMDEs. For example, in March 2023 Indonesia issued its first regulation governing the procedures and responsibilities for proposed projects that integrate CCUS with natural gas extraction and processing. Fifteen projects have been identified that could advance under this regulation. Malaysia, where raw natural gas also has a high CO_2 content, has signalled that it will also proceed along similar lines. CCUS is also expected to play a key role in delivering the net zero emissions pledges of many EMDEs, including in coal-related sectors, where policy development has been slower.

Start-ups working with CCUS technologies raised more early-stage and growth-stage funding in 2022 than in any previous year. Most of the USD 440 million of early-stage equity went to the area of CO_2 capture, followed by hydrogen-based fuels that utilise CO_2. Notable growth-stage deals included a USD 318 million investment in Svante by Chevron and co-investors including the Oil & Gas Climate Initiative, and a USD 300 million investment in Entropy; both are Canadian firms with new CO_2 capture methods. Direct air capture (DAC) developers continued to attract investment bets in 2022, bolstered by US policy incentives. These included Climeworks (USD 650 million), Carbon Direct (USD 60 million), Mission Zero (USD 5 million) and RepAir (USD 1.5 million). Paebbl, a Dutch start-up making construction material from CO_2, raised USD 8 million.

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Coal

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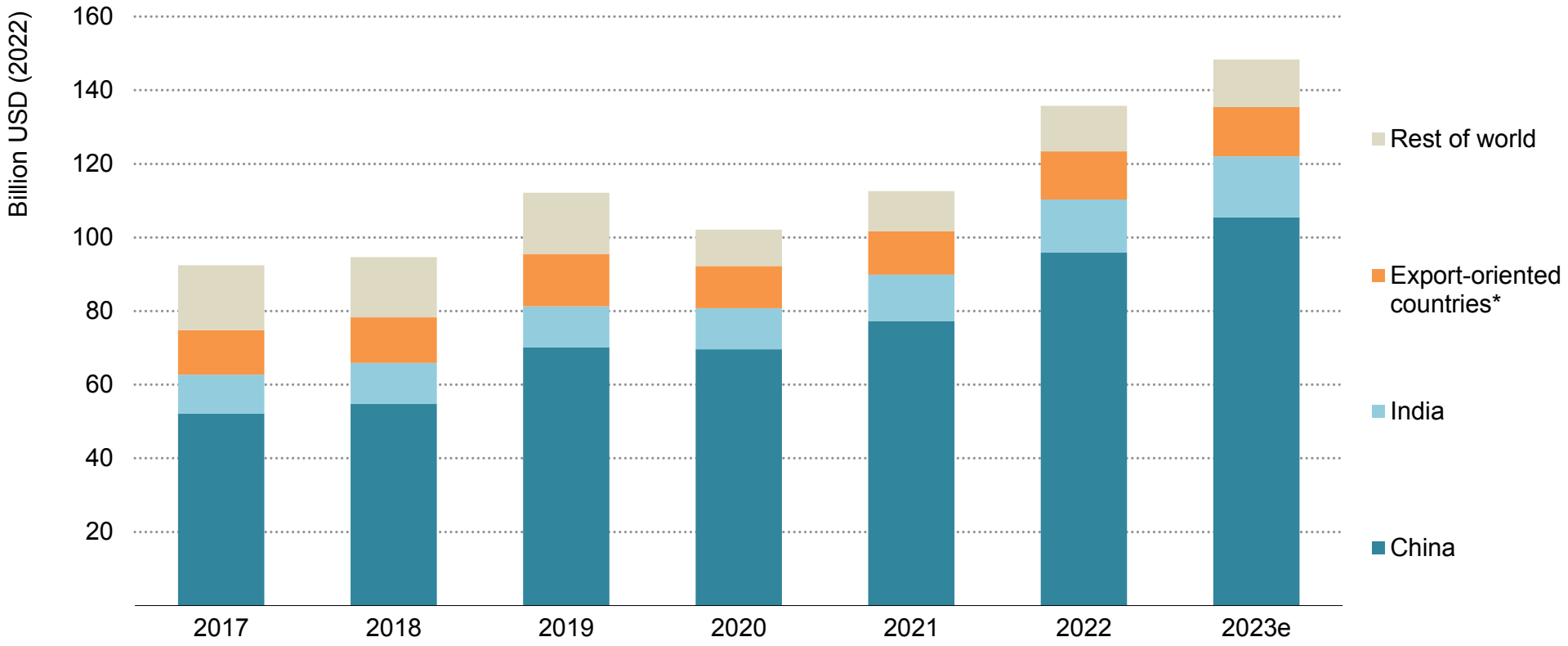
Global coal investment rose in 2022 – surpassing 2019 levels – and is set to rise again in 2023

Global investment in coal production by region, 2017-2023e



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* Export-oriented countries = Australia, Indonesia, Russia, Colombia and South Africa.
Note: 2023e = estimated values for 2023.

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Strong demand and high prices sent a powerful signal for new investment – especially in China and India – although cost inflation has muted some of the impact on production capacity

Global coal demand reached an all-time high in 2022, with prices rising to unprecedented levels in October 2021 and reaching record highs on several occasions in 2022. Globally, coal investment increased to USD 135 billion in 2022, a 20% increase on 2021 levels. Almost 90% of investment occurred in the Asia Pacific region, predominantly in China and India.

The majority of coal investment in 2022 was used to maintain production at existing mines, with smaller amounts used to expand production at brownfield developments. New greenfield projects are limited in most parts of the world amid investor and company concerns over the impacts of coal on climate change, environmental social and corporate governance issues, slow permitting and public opposition limiting the availability of finance. The exception to this is China and India, where energy security concerns and power shortages have led to the development of new mines as well as the expansion of existing mines.

China saw power shortages in December 2020, mainly caused by a lack of power capacity adequacy, and there were shortages and rolling blackouts in 10 provinces over the summer of 2021, mainly because of shortages in coal supply. The government has pledged to avoid a repeat of these events and coal capacity has increased substantially since October 2021. Annual mining capacity increased by around 300 Mt per year in 2022, half from new mines and half from expanding production at existing mines – more than the rest of the world combined. The four major producing regions of Shanxi, Inner Mongolia, Shaanxi and Xinjiang are the focus of investment and capacity additions.

India's government has been looking to reduce coal imports by boosting domestic production and improving logistics. A key pillar of the strategy is to task government-owned Coal India to increase production both by its own means and by outsourcing it to "Mining Developers cum Operators". The strategy also aims to increase commercial mining and a number of auctions for blocks have taken place: since 2020, 87 mines have been awarded licences to commence production, and a further 106 mines were offered in the seventh round of auctions in March 2023.

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Coal industry profits in 2022 were mainly returned to shareholders or used to diversify into other commodities, meaning increases in investment in 2023 are likely to be more muted

Coal producers announced large profits in 2022 despite higher energy prices and other price pressures driving up production costs. The largest share of these profits was returned to shareholders through dividends and share buybacks. Profits were also used to help producers diversify into other commodities and pay off debt. Some companies also used profits to buy coal assets from other companies looking to reduce their exposure to coal. For example, Glencore purchased shares in the El Cerrejón coal mine from Anglo American and BHP, and Thungela bought Idemitsu's stake in Ensham mine in Australia. Companies are also investing to reduce their Scope 1 and 2 emissions.

Global coal investment is expected to increase by around 10% in 2023 to just under USD 150 billion. In China, increases are likely to be more muted following the large ramp-up seen since October 2021, given the government's goal of reaching peak coal demand before 2030. Investment to modernise mines will continue and overall coal production is likely to stabilise before starting to decline. In India, the government expects that total production in the country will surpass 1 billion tonnes by 2023-2024; Coal India alone targets to produce 1 billion tonnes by 2025-2026. Mining Developers cum Operators and commercial operators will be important if India is to achieve its target.

Indonesia's flexible export-oriented supply chain allowed it to ramp up production quickly in response to recent price spikes, but this has not required new large-scale investment. In Australia, investment increased by around 10%, driven by high prices, but it is still at half its 2012 level, in part given mounting development difficulties, especially for greenfield projects.

In the United States, coal demand has been falling for more than a decade. Some producers are looking to expand exports, particularly for metallurgical coal, but a lack of finance and labour force, as well as bottlenecks in the supply chain, have slowed investment and this trend is likely to continue.

In Russia, producers are increasing their focus on eastern markets following the country's invasion of Ukraine. This will require investment in new infrastructure, but the prospects for this are very uncertain.

Logistical challenges and electricity loadshedding in South Africa have been impeding new large-scale investment. The public electricity utility Eskom is unable to finance coal mining itself given its financial difficulties, while the private sector, Development Finance Institutions and local banks are reluctant to finance coal in South Africa.

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Critical minerals

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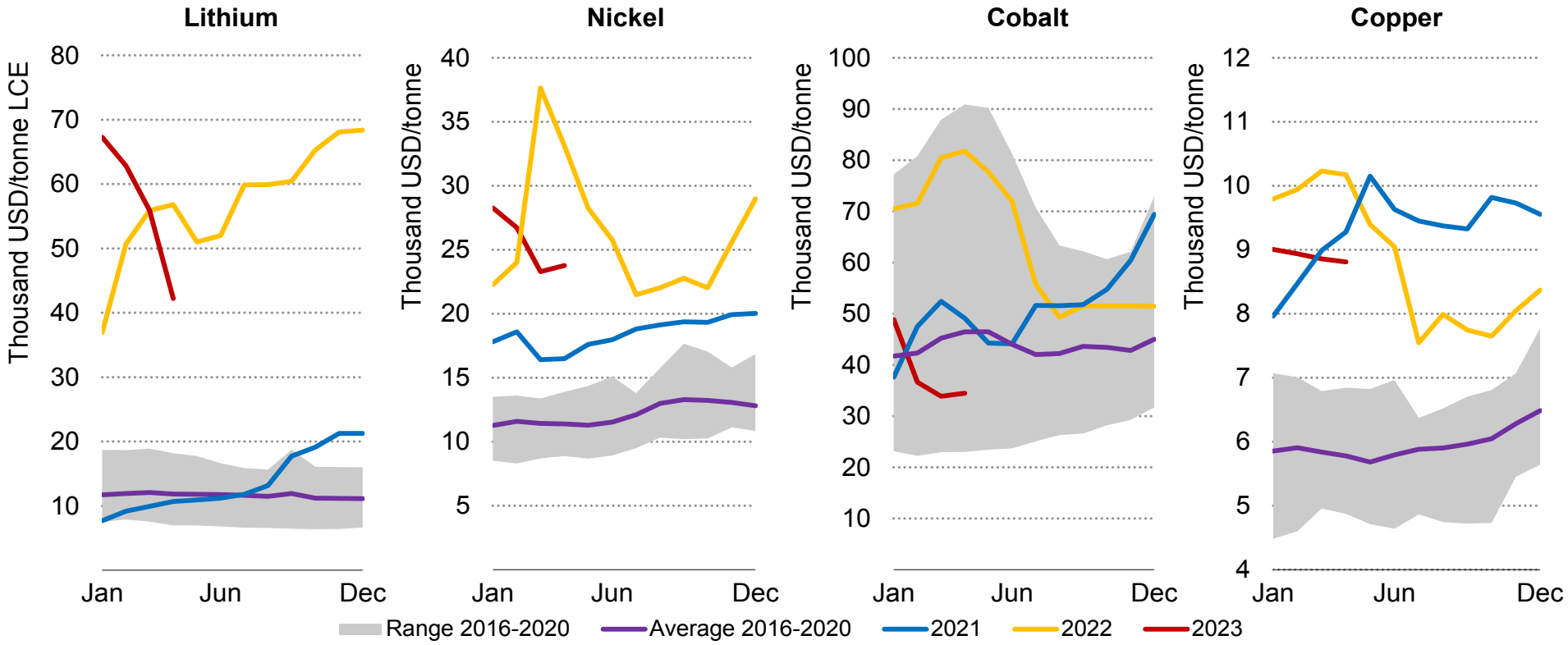
After the surge in 2021 and 2022, many critical mineral prices started to moderate in 2023 but remain well above the historical averages

Price development for selected energy transition minerals and metals, 2016-2023



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Notes: Assessment based on LME Lithium Carbonate Global Average, LME Nickel Cash, LME Cobalt Cash and LME Copper Grade A Cash prices; LCE = lithium carbonate equivalent.

Source: S&P Global (2023).

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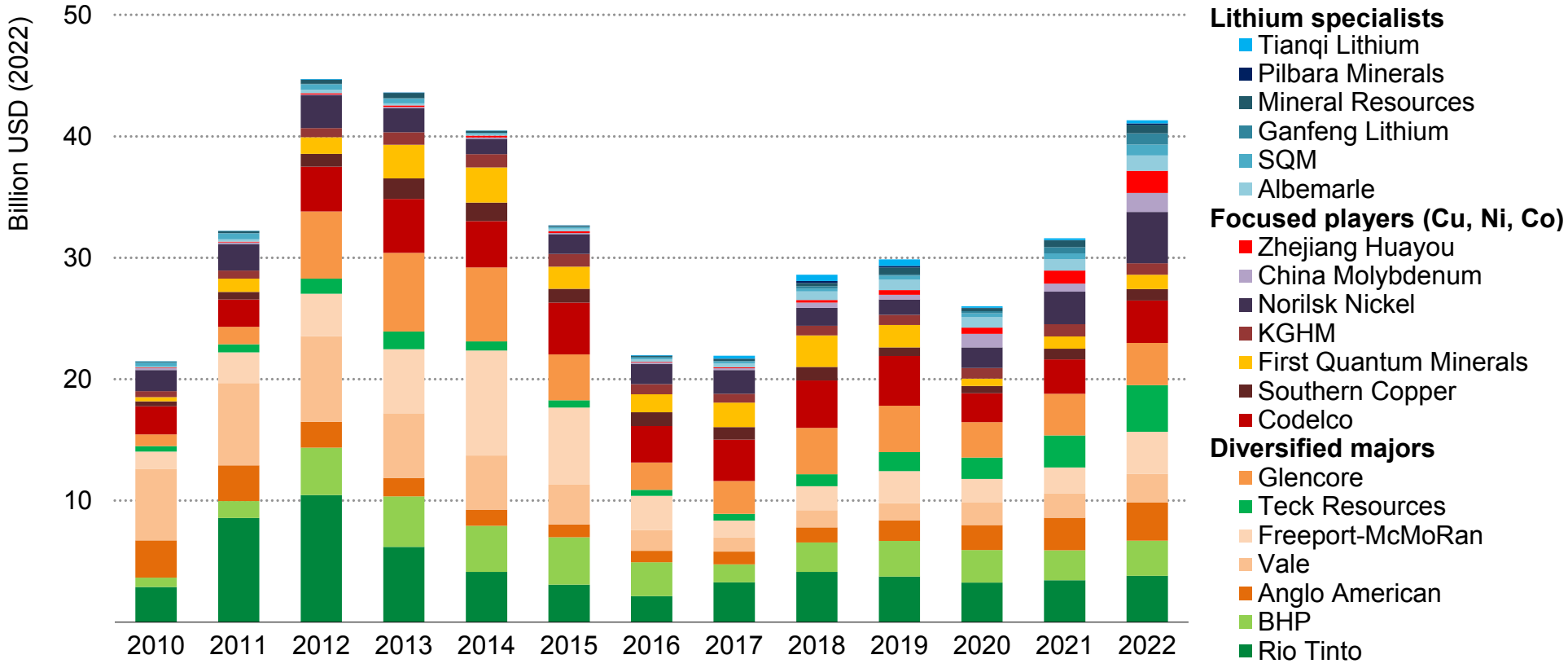
Investment in critical mineral mining rose by 30% in 2022 as strengthening momentum for energy transitions offers prospects for robust demand growth

Capital expenditure on non-ferrous metal production by major mining companies, 2010-2022



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Notes: Co = cobalt; Cu = copper; Ni = nickel; for diversified majors, capex on the production of iron ore, coal and other energy products is excluded.
Sources: IEA analysis based on company annual reports and S&P Global (2023).

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The need for continued investment in critical minerals development to support rapid energy transitions remains firm, despite the recent fall in prices

Many of the critical minerals that are vital for clean energy technologies registered broad-based price increases in 2021 and early 2022, which had the effect of reversing a decade-long trend of cost declines for solar panels, wind turbines and batteries. Except for lithium, most prices started to moderate in the second half of 2022. Expectations of China's reopening underpinned a brief rally at the end of 2022, but prices resumed their fall in 2023, including lithium, on the back of weak consumption, new supply plans and concerns over possible recession. The impact of EV subsidy reductions and price cuts on conventional cars in China added to pressure on prices.

Nonetheless, prices remain well above their historical averages and medium-term pressures persist as schedule delays or cost overruns remain a possibility for many announced projects. Cobalt is a notable exception, as the rapid adoption of lithium-ion phosphate in battery chemistries is weighing on the demand outlook for cobalt.

Thanks to high prices and growing policy support (e.g. the US Inflation Reduction Act and the EU Critical Raw Materials Act), many mining companies are increasing investment in critical mineral development. We have assessed the aggregate investment levels of 20 major mining companies that have a strong presence in developing energy transition minerals. Following the 20% increase in 2021, investment spending recorded another sharp uptick of 30% in 2022. Companies specialising in lithium development increased their spending by 50%, followed by those focusing on copper and nickel development. Companies in China almost doubled their investment spending in 2022. Exploration spending also continued its upward march in 2022, largely driven by the record pace of growth in lithium exploration, followed by copper and nickel. Canada and Australia led this growth, especially in hard-rock lithium plays, but activities are also growing in Africa and Brazil.

While the increase in investment and exploration spending will translate into production growth in the coming years, the expected rate of growth still does not match the pace of manufacturing capacity additions for batteries, solar modules, electrolysers and so on. This triggered concerns among automakers, battery cell makers and equipment manufacturers about securing raw material supplies. Long-term offtake agreements became a norm in the industry's procurement strategies and many companies started to be involved directly in the raw material value chain in order to safeguard their production pipelines. For example, in February 2023 General Motors announced investment of USD 650 million in Lithium Americas to develop Nevada's Thacker Pass lithium mining project. In the same month, LG Energy Solutions took a financial stake in Piedmont Lithium to secure lithium from Canada.

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Implications

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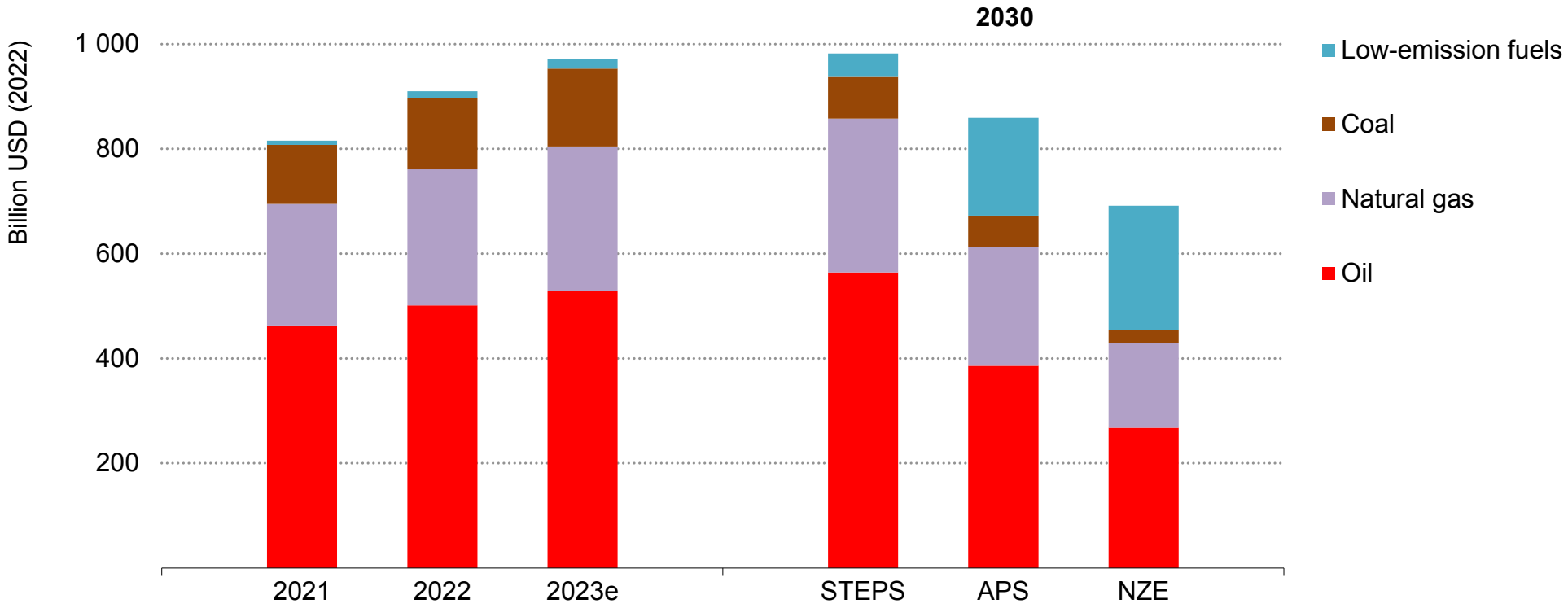
Fossil fuel investment in 2023 is close to 2030 levels in the STEPS and more than double the amount needed in 2030 in the NZE Scenario

Global investment in fuel supply, 2021-2023e, and in IEA scenarios in 2030



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Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Low-emission fuels = modern bioenergy, low-emission hydrogen and hydrogen-based fuels. 2023e = estimated values for 2023.

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There are upside and downside risks to fossil fuel demand but if clean energy momentum is maintained, far less fossil fuel investment will be needed

Oil and gas investment in 2023 is now about the level needed in 2030 in the STEPS, a scenario that reflects today's policy settings. Oil and gas demand in the STEPS rises by around 0.5% each year on average from 2024 to 2030, much lower than the 1.3% annual average increase in the 2010s. This depends on continued robust global growth in clean energy investment – most notably solar PV and electric cars – to arrest fossil fuel demand growth. If today's policy settings change or if some clean energy deployment does not materialise globally at the anticipated pace and scale, future fossil fuel demand growth would be greater than in STEPS and additional oil and gas investment would be needed to balance markets.

Conversely, enhanced efforts to tackle climate change would represent a major downside risk to fossil fuel demand and a commercial risk for producers. Fossil fuel investment is now more than double the amount needed in 2030 if the world is to limit the long-term temperature rise to 1.5°C (the NZE Scenario). Today's coal investment is far above the levels required in the STEPS and six times higher than the 2030 requirements in the NZE Scenario. This creates the clear risk of locking in fossil fuel use and pushing the 1.5°C temperature limit out of reach.

Our scenarios illustrate the dynamic relationship between spending on clean energy and fossil fuels. In the STEPS, investment in clean energy grows to more than USD 2 trillion in 2030, meaning that for every USD 1 spent on fossil fuels in 2030, USD 2 is spent on clean energy. In the NZE Scenario, the ratio of clean-to-fossil investment is more than nine-to-one in 2030.

The declines in fossil fuel demand in the NZE Scenario are sufficiently steep that they can be met in aggregate without supply from any new oil and gas fields. Still, investment in oil and gas is still required in 2030, both to minimise the emissions intensity of production and for some low-cost extensions to existing fields. A strong policy push to reduce oil and gas demand whilst scaling up investment in clean energy is crucial to orderly, secure and rapid energy transitions.

Oil and gas companies can help drive the necessary reallocation of capital by devoting more of their resources to clean energy including to low-emission fuels. Investment in these fuels – such as bioenergy, hydrogen and CCUS – is picking up but needs to increase nearly twentyfold in the NZE Scenario. This may appear a daunting challenge, but it is by no means out of reach of the financial and technological resources of the oil and gas industry. The USD 1.5 trillion returned to shareholders in the form of dividends and buybacks from 2020 to 2022 could have fully covered the investment requirements in all clean fuels in the NZE Scenario between 2023 and 2030.

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Energy end use and efficiency

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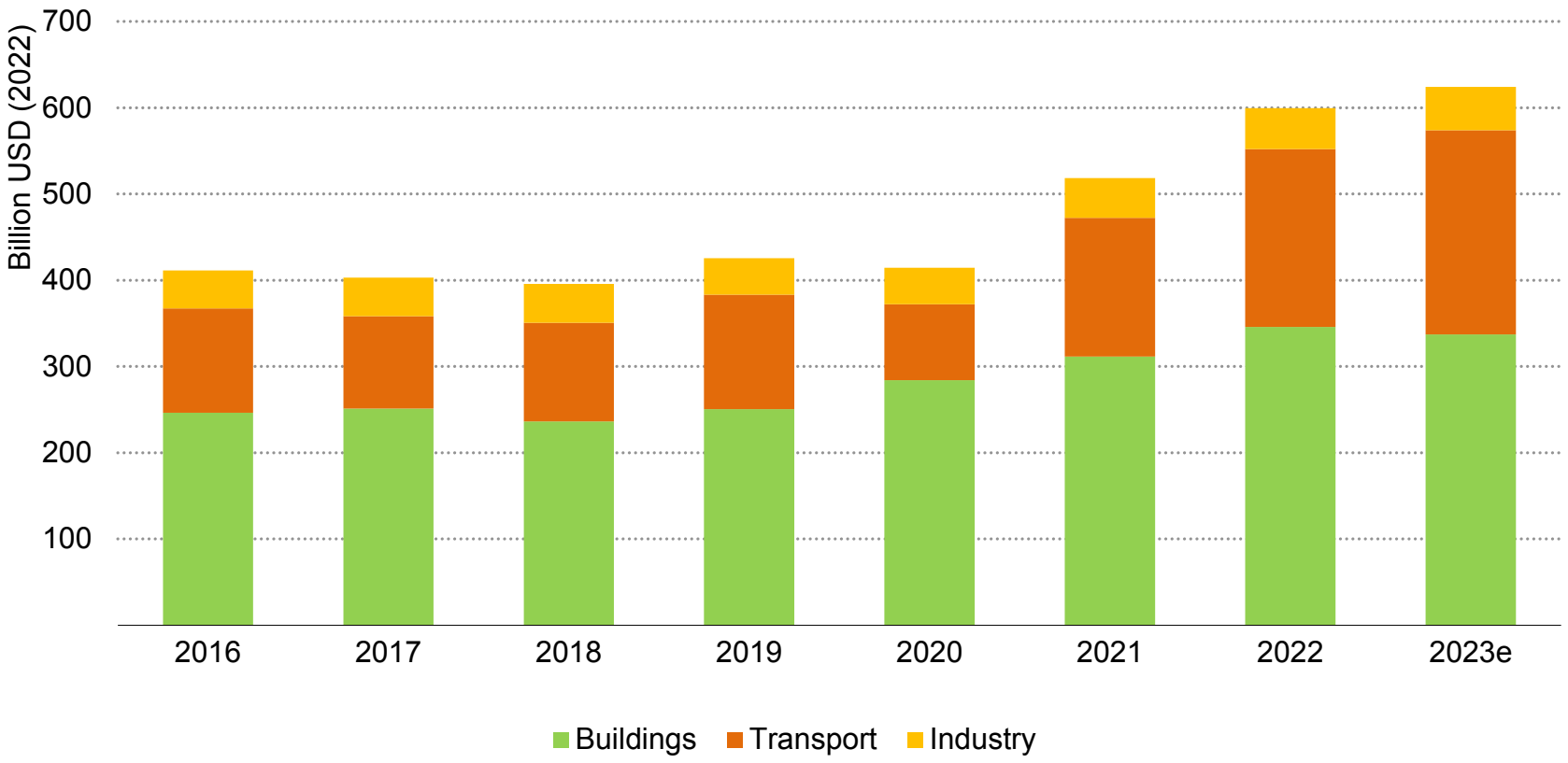
Global efficiency, electrification and end-use investment reached record levels in 2022, driven by the buildings sector and strong EV sales, but the rise in spending could slow in 2023

Global investment in energy efficiency, electrification, and renewables for end uses by sector, 2016-2023e



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Notes: Investments which are aimed at reducing energy consumption in buildings, industry, and transportation sectors are grouped under the end use category. They include energy efficiency, electrification, and direct use of renewables for heating, cooling, or industrial processes. Energy efficiency investments refer to spending on new energy-efficient equipment or refurbishments that decrease energy usage. Electrification encompasses electric vehicles in transportation and heat pumps in buildings and industrial sectors; 2023e = estimated values for 2023.

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The global energy crisis boosted spending on efficiency, electrification and end uses in 2022, but efficiency investment faces headwinds in 2023

The global energy crisis boosted investment in energy efficiency, electrification and end-use renewables by 16% in 2022, reaching new highs across all three end-use sectors that are tracked in the *World Energy Investment* report (buildings, transport, and industry).

The buildings sector experienced 11% growth in investment due to government initiatives in Europe and the United States responding to gas shortages, rising electricity prices and higher inflation. Emerging market and developing economies (EMDEs) saw a 19% increase in investment, with China being the only country experiencing a decrease in energy efficiency investment due to continuing Covid-19 lockdowns and the real estate crisis. 2022 also saw double-digit growth for heat pump installations.

Investment in electrification of the transport sector grew by 60% in 2022, with EV sales hitting record levels, passing 10 million units globally. Growth came from all parts of the world including EMDEs, which have seen exponential growth from a low base. Maintaining this trend in 2023 will depend on increased model availability, investment in charging infrastructure, and a well-managed phase-down of government incentives for EVs as upfront costs become closer to internal combustion engine (ICE) models.

The industrial sector experienced high input prices, including gas and electricity, leading some factories to curtail production and investment in Europe and China. However, renewed activity in EMDEs and the United States led to an 3% growth in energy efficiency investment in the sector in 2022. While some of the technologies needed for complete decarbonisation of industrial processes are still being developed, high energy prices could lead to new investment in industrial efficiency and electrification in 2023.

Investment in energy efficiency could face headwinds in 2023 across all sectors. The global indicators that typically offer insights into investment trends were sending mixed signals in the early stages of the year. The European Union's housing lending market has almost ground to a halt in recent months. Inflation also remains high in many regions. Much will depend on the extent to which robust government interventions and regulatory policies in the United States and Europe offer support for continued efficiency and end-use investment, notably for the electrification of heat and transport. At this stage, we anticipate that overall spending on energy efficiency, electrification and end-use renewables will grow modestly by 4% in 2023, with electrification remaining the most dynamic sector and efficiency spending lagging behind.

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Buildings

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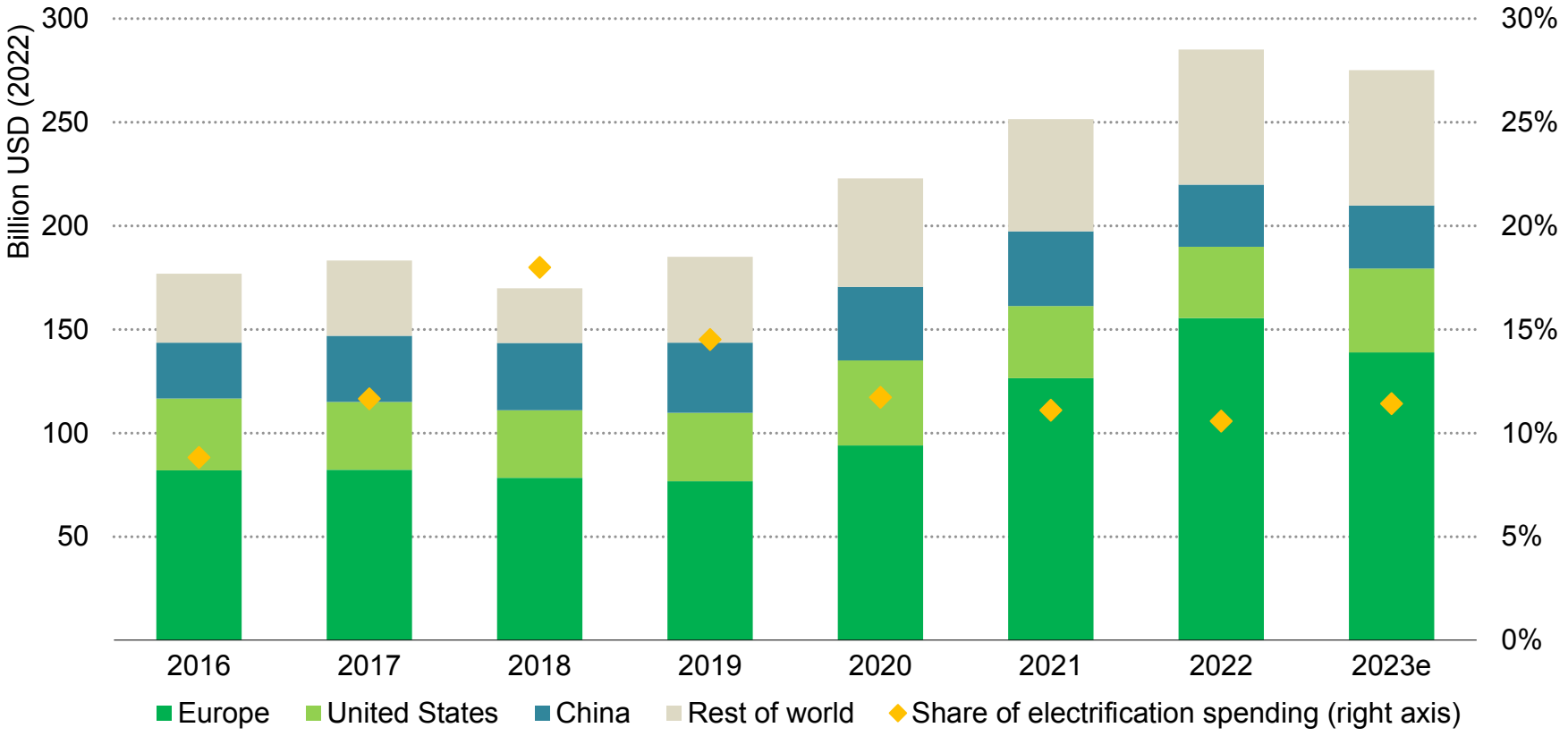
Energy efficiency spending on buildings rose in 2022, but the ongoing cost-of-living crisis and economic uncertainty could reduce investment in 2023

Investment spending on energy efficiency and electrification by region in the buildings sector, 2016-2023e



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Notes: Spending on electrification (e.g., Heat pumps) is included in the total spending, and represented as a share of total spending on the right axis; 2023e = estimated values for 2023

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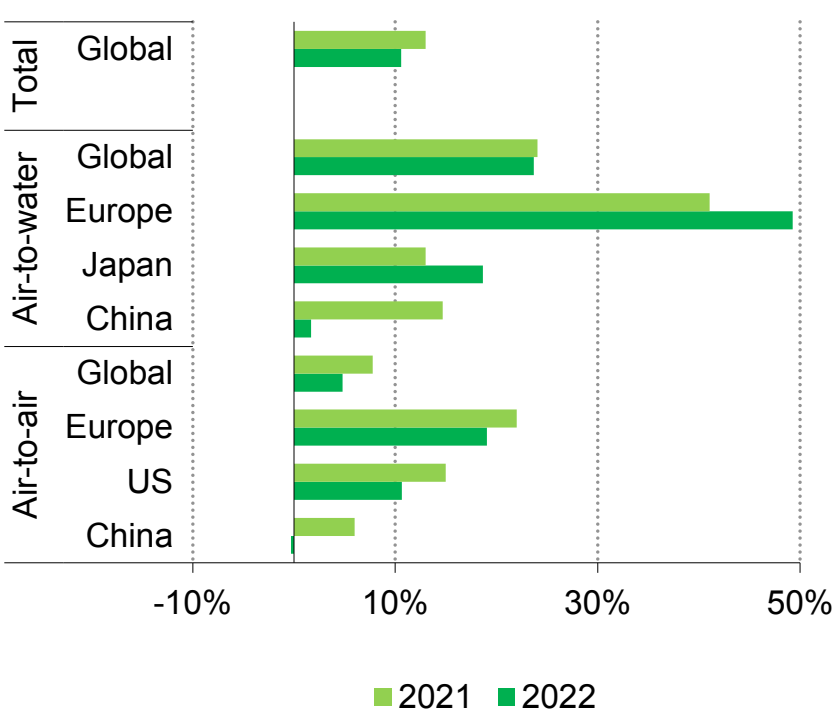
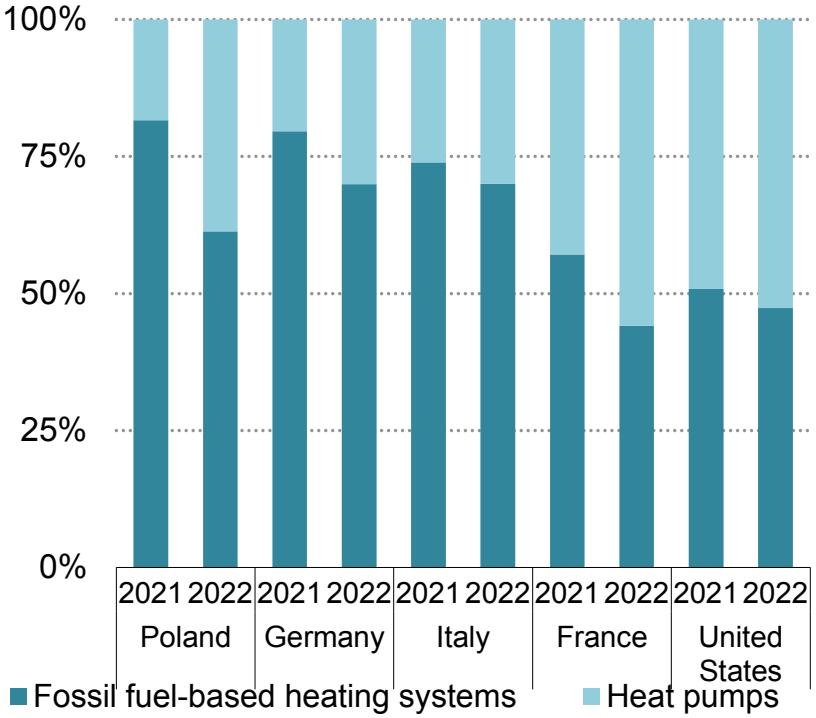
Heat pump sales experienced double-digit growth for a second year in a row in many areas as they start to replace fossil fuel-based heating systems

Rate of growth of heat pump sales in 2021 and 2022 (left) and market share of heat pumps in global heating system sales (right)





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Notes: Air-to-water units include heat pump water heaters; total also includes ground- and water-source heat pumps.

Sources: IEA (2023), Global heat pump sales continue double-digit growth, based on data from AHRI, Assoclima, Assotermica, BDH, CHPA, ChinaIOL, EHPA, JRAIA, SPIUG and Uniclima.

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Investment in buildings energy efficiency in 2022 was underpinned by direct public investment to tackle energy insecurity, alongside a cautious reopening of the global construction sector

In 2022 energy efficiency investment in the global buildings sector increased by around 14% on 2021 levels, continuing the strong growth trend of the past few years. Spending on efficiency is projected to fall back in 2023 as the effects of increased borrowing costs and economic uncertainty reduce market activity.

The total investment of around USD 285 billion in 2022 marks a strong increase in efficiency spending and electrification from the previous year and is the result of a continued effort, led by Europe, in response to the energy crisis triggered by the Russian invasion of Ukraine, along with policy- and price-driven increases in spending in other countries, for example in the in the United States within the Inflation Reduction Act.

The increase in 2022 was in line with recent trends, but early signals suggest a slowdown in spending in 2023 as the global economy experiences increased uncertainty due to the continuing conflict in Ukraine, the growing impacts of the cost of borrowing on construction demand in economies across the world, uncertainty of credit availability and lending, and several large government programmes seeing curtailment.

The increased efficiency investment in 2022 was the result of sustained spending in major markets such as the United States, Germany and Italy. Over USD 33 billion was spent in the United States through the continued funding of the Department. of Energy efficiency programmes (e.g., weatherisation) or utility demand-side management. Government led efficiency spending in the United States is expected to further expand by USD 970 million in 2023 through the newly created State and Community Energy Office under the Inflation Reduction Act. Budget allocation dedicated to efficiency by the German government moderated in 2022 to around USD 51 billion, which was accompanied by changes to the design of some support programmes. The conditions for the federal funding for efficient buildings programme (BEG) were adjusted in several stages, starting from end of July 2022, to facilitate better access to funding and streamline application processes. The KfW loan programmes continued but the grants were discontinued, and single measures are now only subsidised directly by BAFA, with reduced rates (on average by 5% of the given measure) to allow more applicants to benefit from available funds. A new subsidy scheme for “climate friendly new construction” entered into force at the beginning of 2023, introducing a expanded coverage of eligible expenses under the BEG, including material costs for own work and a broader definition of eligible investors.

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The Italian Superbonus programme resulted in a near doubling of investment in energy efficiency between 2021 and 2022 in Italy, from USD 23 billion to around USD 57 billion. However, the recent announcement of major changes to the programme means spending beyond 2023 is unclear and expected to fall. The maximum tax credit rate has been lowered from 110% to 90% and, as of 17 February 2023 homeowners applying for the bonus will no longer be able to directly transfer eligible tax credits to a bank or directly to their construction company to receive a discount on the final invoice.

Another major change affecting spending in 2022 resulted from a 10% reduction in real estate development investment in China compared with 2021, resulting in a slowdown in the delivery of green buildings. This slowdown is also expected to further affect the delivery of buildings reaching China's green standard, which were initially set to be around 50% of all new dwellings by 2020 in the country's 13th Five-Year Plan. Likewise, France's investment in efficiency fell somewhat due to a slowdown in construction sector output. The United Kingdom also saw a modest fall in efficiency spending due to a slowing construction sector and changes to the Affordable Warmth Scheme, although the government has added USD 186 million under the Green Homes Grant scheme. Japan's focus on delivering new buildings that achieve the zero energy housing (ZEH) standard and that approach ZEH has seen the proportion of new green buildings increase from 19% of construction in 2018 to over 34% in 2021. Japan has a target of 63% of new buildings achieving the ZEH standard by 2025.

Some emerging markets saw an overall increase in construction activity and investment in buildings energy efficiency. India, for example, doubled spending to USD 3.25 billion. Most countries, however, only saw a modest increase in 2022, which was primarily related to construction activity picking up from pandemic-level lows. Overall, Europe experienced a very modest uptick of around 3%, while Central and South America saw an increase of around 5% in construction sector spending, which might hinder further investment in energy efficiency for 2023.

International concessional finance continues to support investment in the global building stock. For example, the European Bank for Reconstruction and Development committed over EUR 67.5 million to Lithuania to finance energy efficiency renovations in residential buildings, and EUR 40 million to support improving school buildings efficiency in Albania. Financing through the International Finance Corporation's EDGE programme also continues to benefit energy efficiency, including a USD 65 million green bond in South Africa and a USD 60 million loan to support green mortgages in Peru.

Green products offered by commercial banks are also slowly gaining traction, with 19 of the top 100 largest banks globally offering green mortgages to their clients, although their level of utilisation and overall impact remains unclear. Of these, five are located in the United Kingdom where the market for green financial products has been quite dynamic in recent years. In Hungary, the Magyar Nemzeti Bank's Green Home Programme and Green Mortgage Bond

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Purchase Programme were launched to provide refinancing against green home loans at 0% interest and encourage the issuance of higher-quality green mortgage bonds.

Addressing building fabric efficiency performance remains a major part of spending, but recent efforts are directing investment towards technologies that can more easily enable zero-carbon ready buildings, such as heat pumps. Data for Europe in 2022 suggest that around 3 million heat pumps were installed in buildings, an increase of almost 40% compared with the previous year. The European heat pump market is estimated to be worth around USD 14 billion. According to the latest IEA analysis, global heat pump sales grew by 11% in 2022 in unit terms, marking a second year of double-digit growth for the central technology in the transition to secure and sustainable heating.

In order for the growth of heat pump deployment to continue, it is important to have secure and resilient supply chains. The global market for heat pumps is dominated by companies with headquarters in Japan and China, accounting for nearly 70% of the market. While the five largest global manufacturers are based in the Asia Pacific region, only about half of their production capacity is located there. Supply chains are currently strained, particularly for crucial components like chips. Manufacturers have already committed to expanding heat pump production capacity, with investment totalling more than EUR 4 billion as of November 2022. However, an additional USD 15 billion in global investment would be needed to close the 60% gap that exist between the expected output from announced projects and the 2030 Net Zero Emissions by 2050 Scenario needs for the technology. There are also new incentives that are likely to drive further manufacturing announcements, such as the Defense Production Act and Inflation Reduction Act in the United States and the upcoming Net Zero Industry Act and European Sovereignty Fund in the European Union.

As a result, investment in electrification is the most resilient area of overall spending on buildings, increasing by about 4% in 2023, and increases its share in the total. Efficiencies in technology costs mean that every dollar spent goes further and we estimate a faster growth of heat pumps in unit terms.

Fiscal stimulus measures from the pandemic period have also begun to be wound down, and further reductions in government and private-sector spending due to increased borrowing costs mean that 2023 is likely to see a reduction in efficiency spending. Investment in global energy efficiency in the building sector is projected to drop by up to 5% due to both construction market uncertainty in Asia, South America and Europe, and changes to several large European programmes. This potential change in direction for investment in the buildings sector is problematic given that energy efficiency measures not only reduce demand but also shield households and businesses from the impacts of future fuel price volatility.

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Transport

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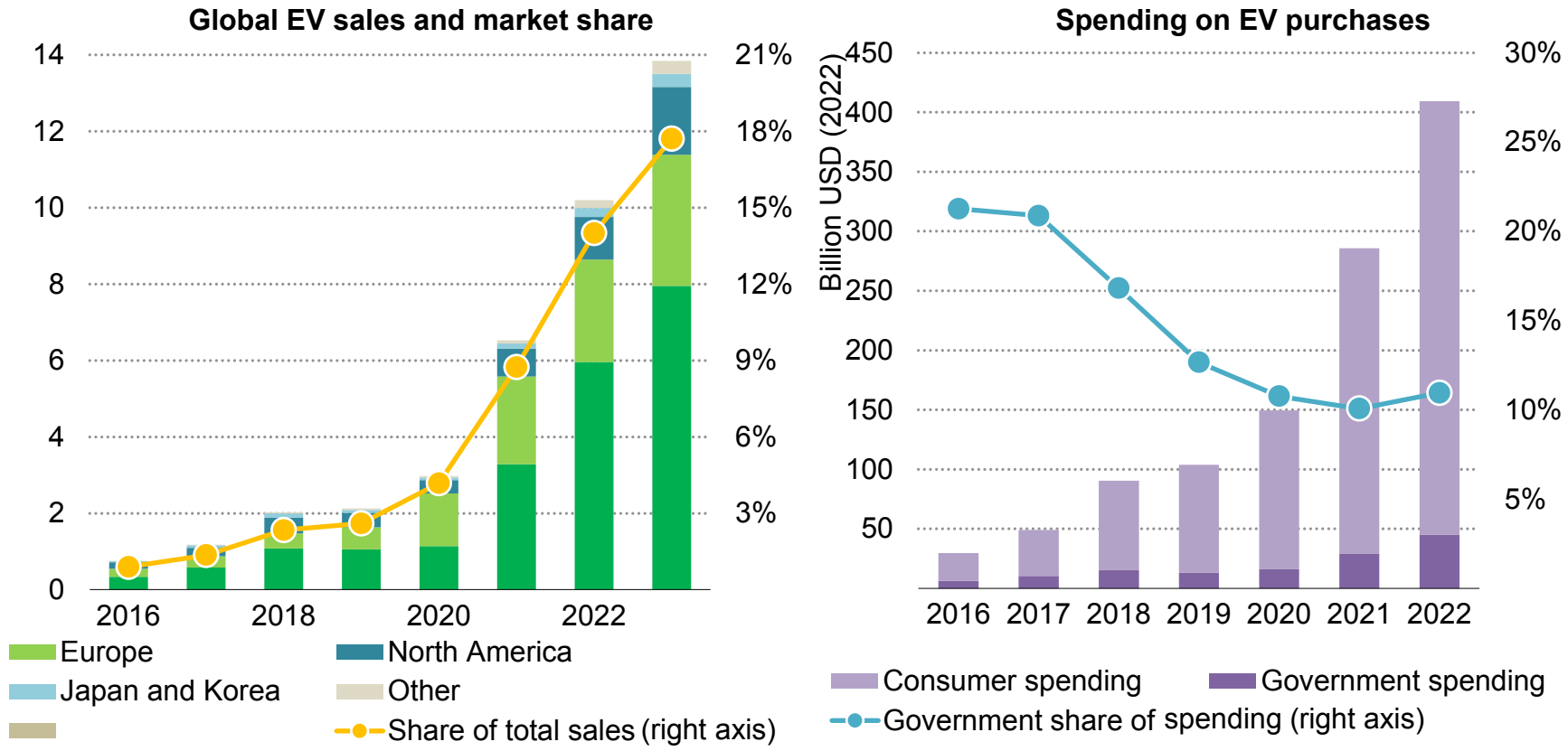
Sales of passenger EVs passed the 10 million mark for the first time in 2022…

Global trends in electric passenger light-duty vehicle markets, 2015-2023e



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Note: EV includes battery electric and plug-in hybrid passenger vehicles; 2023e = estimated values for 2023.
Sources: IEA (2023), Global EV Outlook; Marklines.

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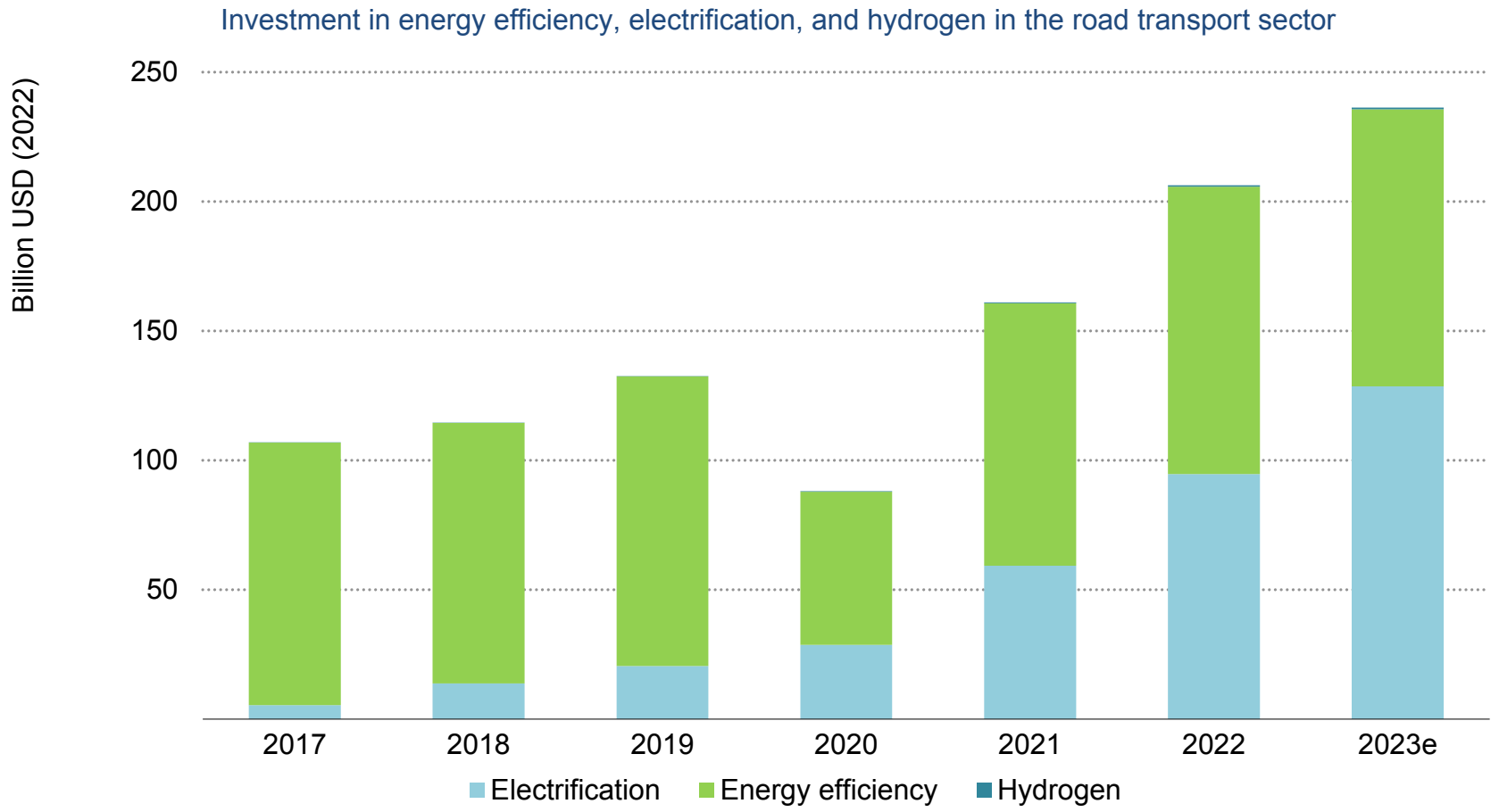
…driving investment in road transport efficiency and electrification to record highs



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Note: 2023e = estimated values for 2023.

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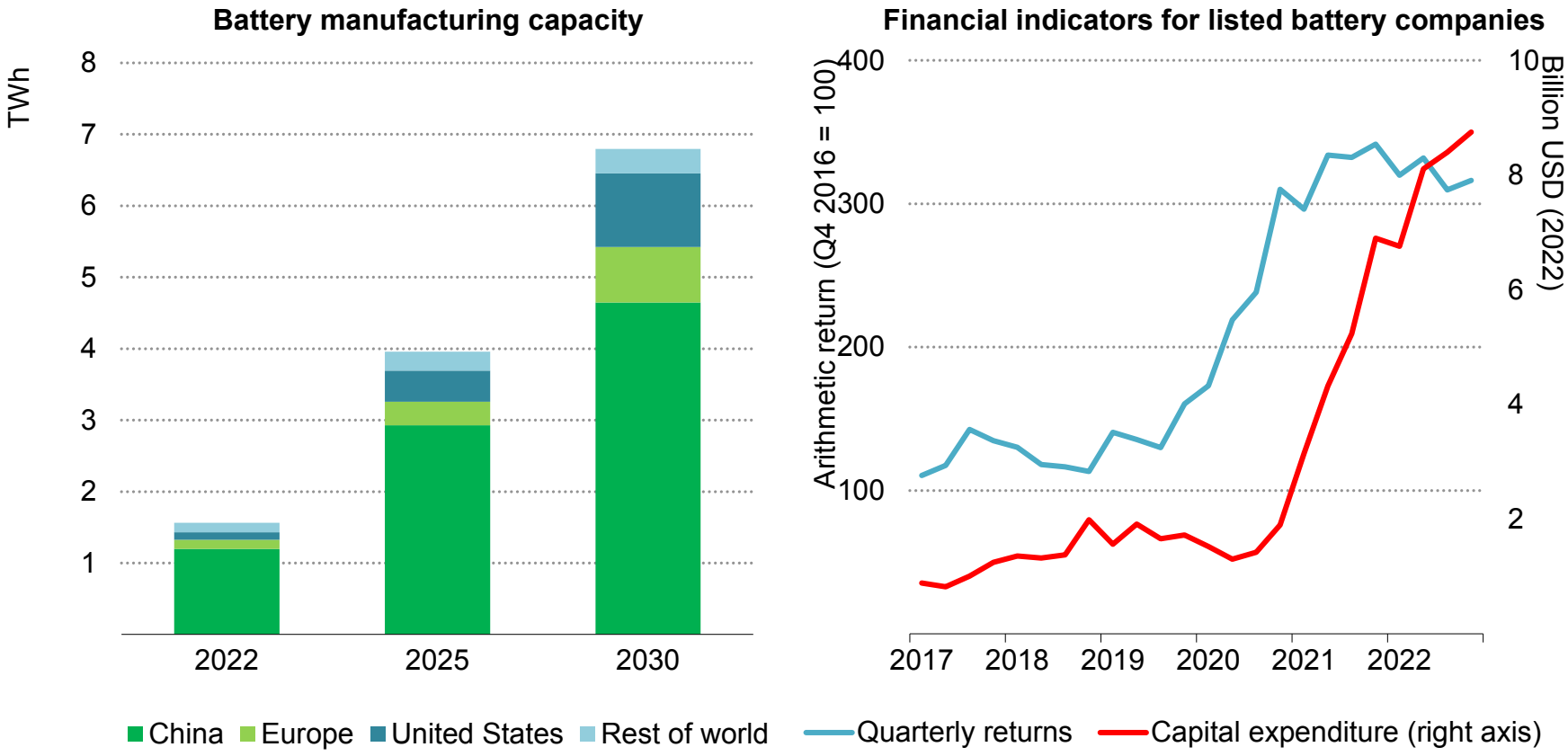
Capital expenditure by listed battery manufacturing companies surged to USD 9 billion in Q4 2022, sharply lifting production capacity

Global trends in the battery manufacturing industry, 2017-2025



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Notes: Listed battery companies include LG Energy Solution, BYD, Contemporary Amperex Technology, Samsung SDI, Gotion High-tech, Eve Energy and Farasis Energy Gan Zhou; 2022 values are based on fully commissioned capacity; 2025 values are based on announced, under construction and fully commissioned capacity.

Sources: IEA calculations based on Benchmark Mineral Intelligence and Bloomberg Terminal (2023).

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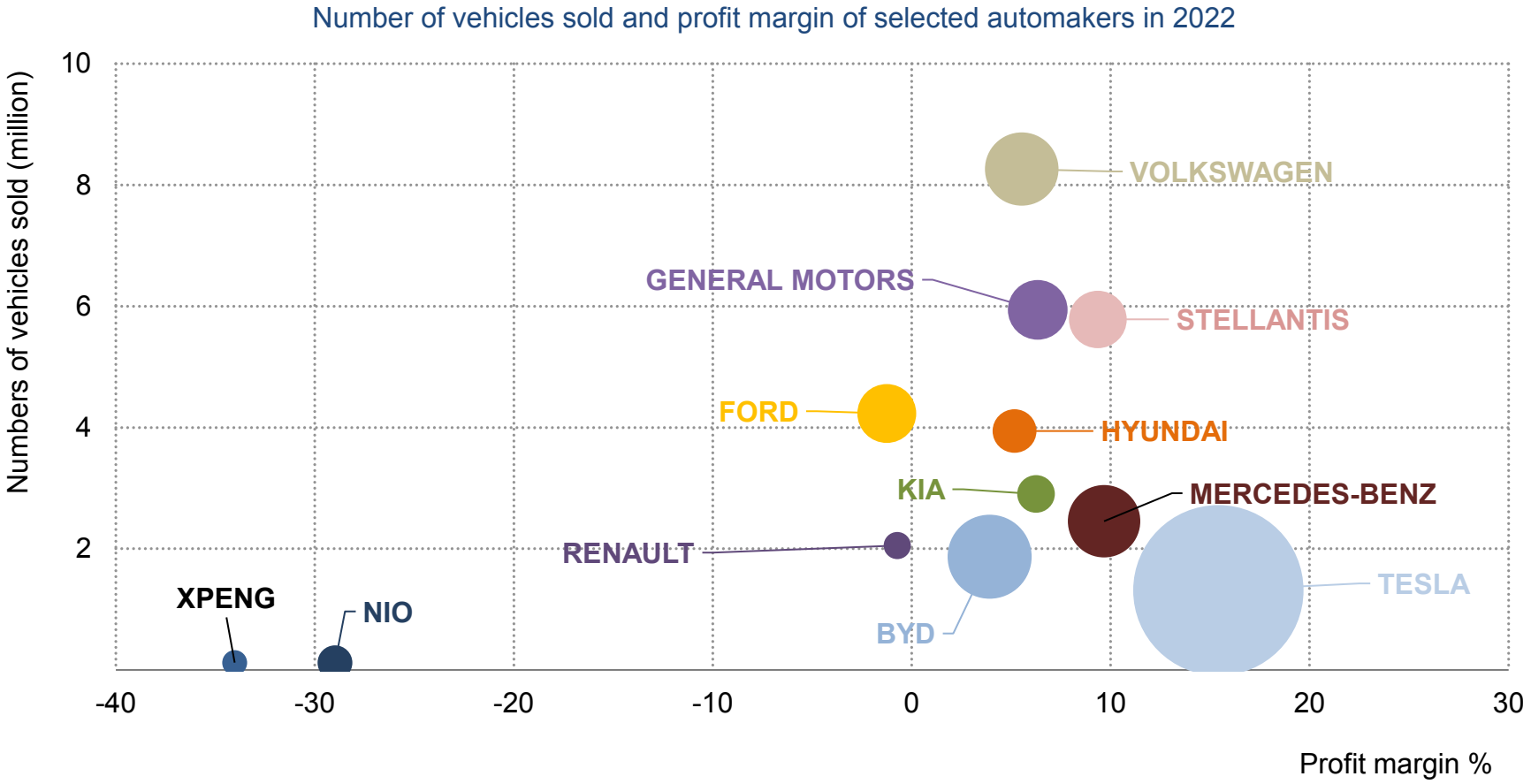
With growth in sales and market share, profitability is consolidating for the largest EV manufacturers but remains elusive for new entrants and smaller companies



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Notes: Margin reflects sales of both EVs and ICE vehicles; bubble size corresponds to market capitalisation.
Source: IEA analysis based on data from Bloomberg Terminal.

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The future is electric: spending on EVs and battery manufacturing remains strong amid uncertainties with volatile raw material costs and diminishing subsidies

Sales of electric cars saw yet another record year in 2022, even in the context of supply chain disruptions, macroeconomic and geopolitical shocks, high commodity and energy prices, and a global contraction in the car market. Registrations of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) surpassed 10 million, representing a 55% increase from 2021. This 10-million figure is greater than the total number of cars sold in the entire European Union (9.4 million vehicles) and half the number sold in China in 2022. The percentage of electric cars in total car sales increased from 9% in 2021 to 14% in 2022, which is more than five times their share before the Covid-19 pandemic.

Europe provides an illustration of this trend: 2.7 million EVs were sold in 2022, the 15% increase on 2021 representing slower year-on-year growth compared with that seen in recent years. The tail end of supply chain disruptions caused by the pandemic, high inflation and weakening consumer confidence, and the instability caused by the war in Ukraine compounded the challenge of maintaining high growth rates as the European market matures. Fossil fuel subsidies aimed at shielding consumers from peak oil prices, delays in implementing low-emission zones and uncertainty over the European 2035 ICE ban may also have played a role.

In 2022 China saw an 80% increase in EV sales compared with 2021, reaching 6.2 million vehicles. The country accounted for almost 60% of all new electric car registrations worldwide, and for the first time in 2022 it had over 50% of all the electric cars on the world's roads, totalling 13.8 million. This impressive growth can be attributed to consistent policy support for early adopters, and the extension of incentives until the end of 2022, which were originally planned to be phased out in 2020. However, sales fell in January 2023 as the central government decided to end a 10-year-old national subsidy for EV purchases, before rebounding somewhat in February. How this will affect the market for the rest of 2023 remains unclear.

Sales in the United States surged by 50% in 2022 as compared with 2021, registering robust growth for the second consecutive year after a slump in 2019-2020. Overall, the country accounted for 10% of the global growth in electric car sales, as model availability grew and incentives remained strong. The trend is expected to be sustained and even to accelerate in 2023, largely supported by a regulatory boost. For instance, several EV manufacturers announced plans to invest USD 28 billion in North American EV supply chains, as the Inflation Reduction Act ties purchase subsidies to vehicles manufactured domestically.

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The three regions described above represent more than 95% of new EV sales globally. From a low base, 2022 also saw increased sales in some other parts of the world, especially in Asia, where countries such as India saw sales tripling, and Viet Nam where sales went from close to zero in 2021 to 7 000 units in 2022 and where a quadrupling is expected for 2023. The penetration of EVs in EMDE markets faces challenges stemming from the lower ability to pay and the limited availability of affordable EV models, as many are geared towards higher-end consumers, such as SUVs. Smaller electromobility models, such as two- and three-wheelers are relatively more successful in these countries.

On the financing side, as government blanket subsidies are tending to wind down, new types of financial products are being designed to encourage EV adoption. For instance, interest-free loans with a repayment term of up to 10 years are available in Australia. Lower-income households in France will have access to interest-free loans for a two-year trial period starting in 2023 if they wish to switch to EVs. The Canada Infrastructure Bank has been offering low or zero-interest loans for the purchase of zero-emission buses since 2022, with repayments sourced from the savings generated by lower operating costs. Additionally, Slovenia offers subsidised loans for people interested in purchasing an EV through its Eco Fund programme.

For the first time in recent years the average price of a battery pack has seen an increase, at about 2% in 2022, reflecting a broader trend of chip and material shortages, as well as increasing commodity prices. However, the trend seemed to be reversing in early 2023 with lithium prices easing and capex investment by battery manufacturers remaining at high levels to reach close to USD 9 billion in the last quarter of 2022. In response to continuing demand growth and incentives offered by governments, which are gradually switching from consumers to charging infrastructure and battery manufacturing, record investment in new battery manufacturing capacity were made in 2022, increasing available capacity by 60% compared with 2021, and reaching close to 1.6 TWh. If all announcements were to materialise, 2.5 TWh of new capacity could be available by 2025 and 6.8 TWh of total capacity would be commissioned by 2030, three-quarters in China, but partly as a result of the Inflation Reduction Act, a growing share is in the United States.

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Industry

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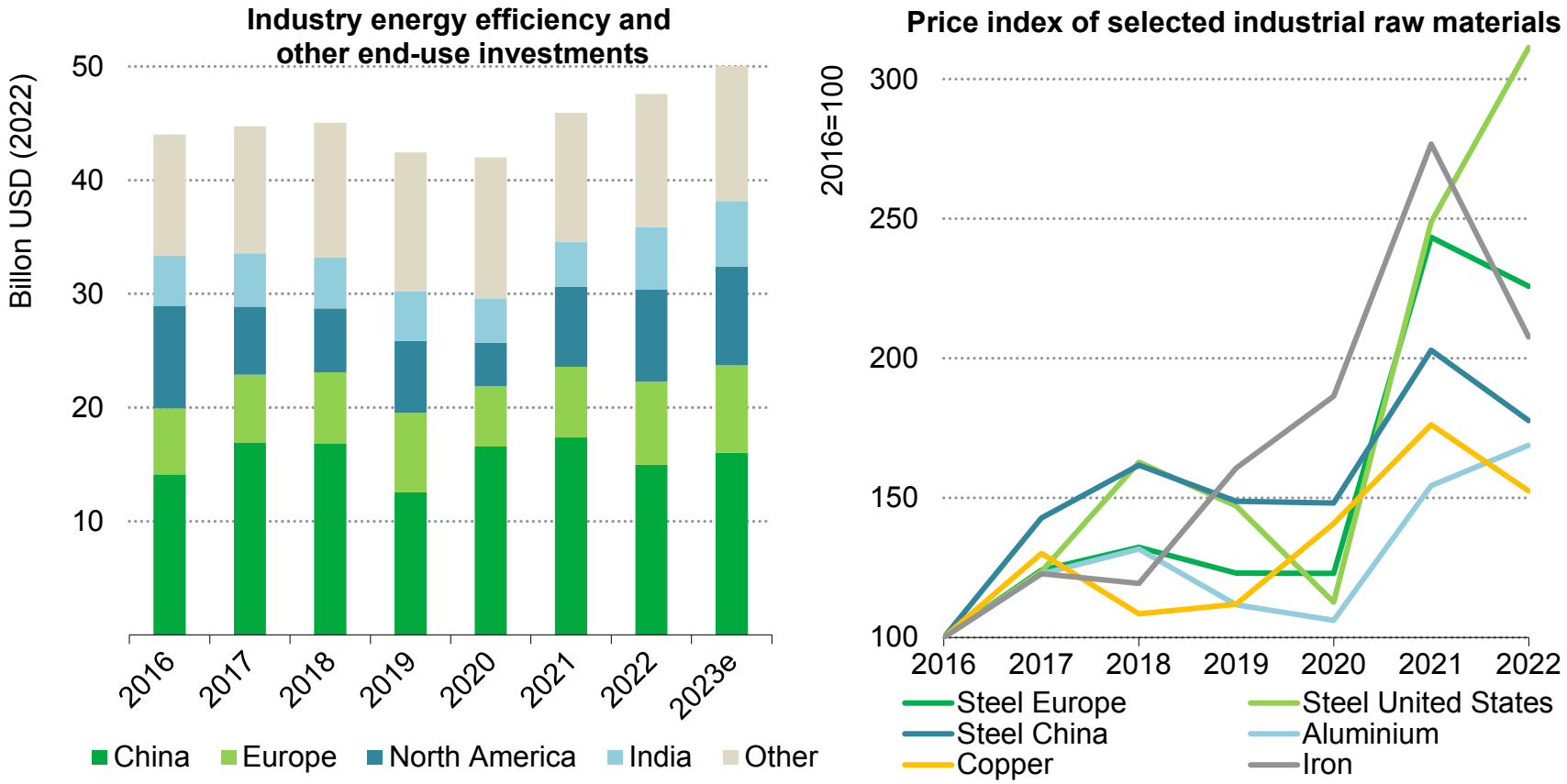
Investment in the industrial sector remained stable in 2022 as China continued to experience supply chain constraints, while the United States and India picked up

Energy efficiency investment in the industrial sector, 2016-2023e, and cost index for selected raw materials, 2016-2022



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Note: EV includes battery electric and plug-in hybrid passenger vehicles; 2023e = estimated values for 2023.
Source: IEA calculations based on data from Oxford Institute of Economics and Statistics Global Economics database.

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High energy prices and policy support in key markets are putting a floor under industrial efficiency investments

Investment in energy efficiency and electrification in the industrial sector grew modestly in 2022, consolidating the record gains experienced in 2021, despite an adverse macroeconomic environment.

Industrial output came under pressure in China as strict Covid-19-related restrictions remained in force for a large part of 2022. Steel production fell by 16% from 2020, while cement fell even more sharply. A recovery in construction activity is held back by an overhang in the stock of buildings as a result of the housing bubble. We estimate that industrial energy efficiency investment in China was down by 14% year-on-year. The lifting of Covid restrictions and the slow revival of economic demand in the last quarter of 2022 should be conducive to a strong rebound in the early months of 2023.

In Europe the war in Ukraine and sky-high gas prices forced industry to adapt and to cut its natural gas demand by over 25 bcm compared with 2021 levels. Half of this reduction came from production curtailment, for instance in the steel sector where factories produced 25% less than before the Russian invasion. As gas is a key component in the production of ammonia, the fertiliser industry was probably the most affected by the price rise, resulting in approximately 70% of capacity being taken offline at some point during the past year. Another 7 bcm of savings came from gas to oil switching, and only 3 bcm from energy efficiency measures. Industrial processes that require high temperatures are more challenging to replace with cleaner energy sources. However, some large European industrial businesses have already announced plans to accelerate investment in energy efficiency and green electrification as a result of volatility in energy prices. For now, however, capex by major industrial companies has remained stable in Europe.

The story is different in the United States, where the enactment of the Inflation Reduction Act is set to generate renewed tailwinds for industrial efficiency and abatement. The legislation contains a wide variety of incentives for industrial decarbonisation, making clean technology investments financially accessible for carbon-intensive sectors, such as steel, cement and chemicals manufacturing. The act includes a 10-year clean hydrogen production tax credit for facilities constructed before 1 January 2033, charting the path for competitive zero-emission steel production. The act also provides essential incentives to decarbonise cement manufacturing and provides for government priority purchasing of green products, sending a strong long-term message to the industry. A strong rebound in production in China, India and Southeast Asia is anticipated for 2023 compared with other parts of the world.

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The EU Green Deal Industrial Plan and the Net Zero Industry Act

In February 2023 the European Commission presented a Green Deal Industrial Plan in a multipronged effort to meet its clean energy transition commitments, respond to the US Inflation Reduction Act and address the continent's high reliance on China for clean energy technologies. The strategy has four main pillars: 1) a predictable and simplified regulatory environment, 2) quicker access to finance, 3) enhanced skills, and 4) open trade for resilient supply chains.

As part of the first pillar, the Net Zero Industry Act, proposed in March 2023, aims to provide a regulatory environment suited to the scale-up of the net zero industry, with the overall target of domestically manufacturing at least 40% of Europe's clean energy technology by annual deployment by 2030. Additionally, the act sets out ambitious 2030 manufacturing targets for eight strategic net zero technologies: solar PV and thermal, batteries, heat pumps and geothermal technologies, electrolysers and fuel cells, sustainable biogas/biomethane technologies, CCUS, and grid technologies. In addition, other technologies such as advanced nuclear and small modular reactors, stand to benefit from the act's measures, but are not assigned 2030 targets. To achieve the targets, the act introduces specific policy measures, including fast-tracking permitting for net zero technologies by establishing "one-stop shops", including supply chain criteria in public tenders to favour diversification, and investment in the upskilling of the European labour force.

Contrary to the Inflation Reduction Act, however, the Net Zero Industry Act does not provide direct funding or subsidy schemes to spur domestic manufacturing (Article 15 highlights that further support can be made available via resources from the European Investment Bank Group or other international financial institutions including the European Bank for Reconstruction and Development). According to the second pillar of the Green Deal Industrial Plan, most of the cost is expected to be shouldered by member states, at least partially through a redirection of ETS revenues. The plan grants more flexibility for member states to support clean manufacturing, including through higher notification thresholds for state aid and the possibility to allocate targeted aid for major new production projects in strategic net zero value chains. The realisation of the EU act's targets would, however, come at a cost. For most of the technologies listed, importing from third countries is much cheaper than EU production. For example, estimates point to an extra cost of USD 11.9 billion to meet the act's target of 550 GWh of domestically produced batteries by 2030, compared to a scenario where demand is entirely met by batteries made in China.

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Implications

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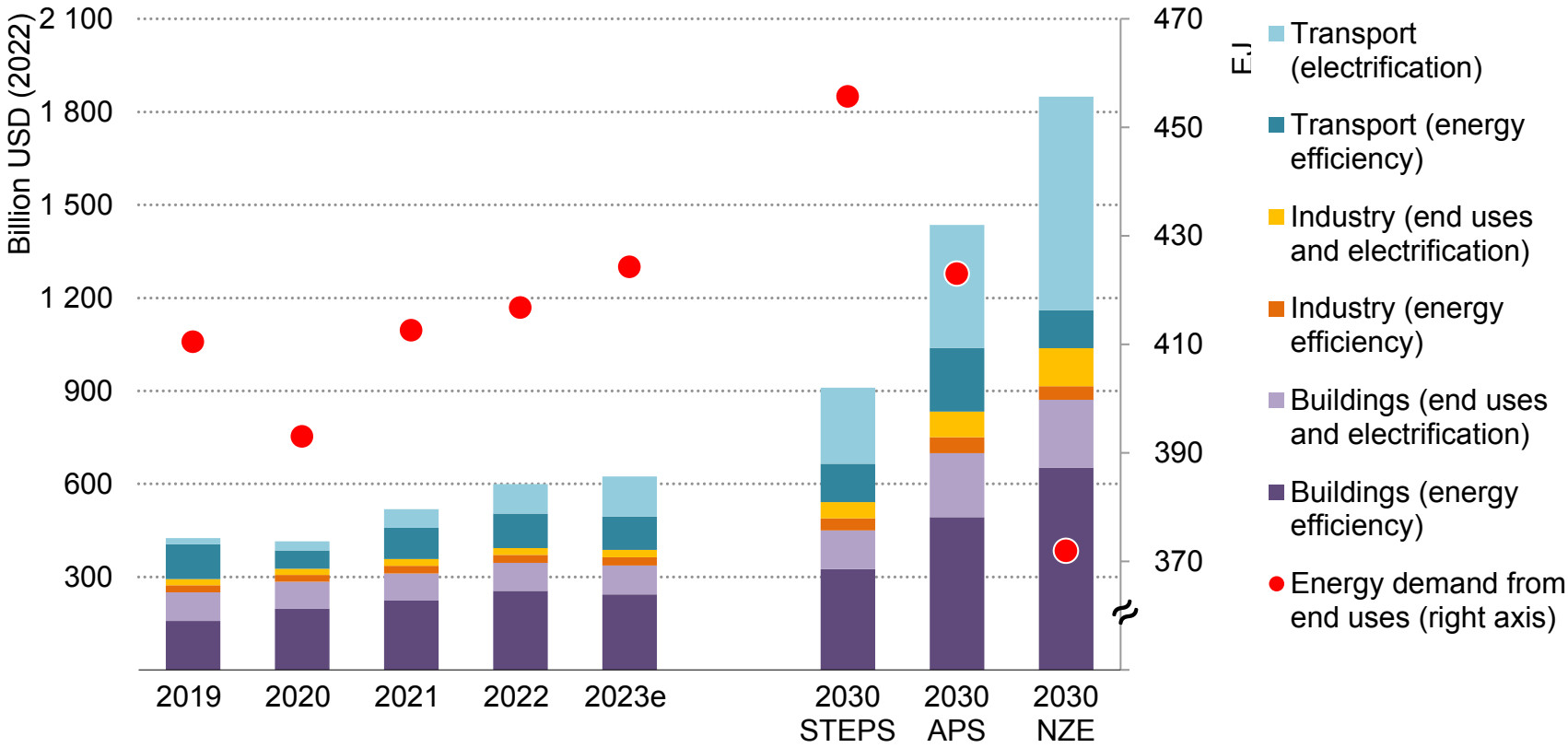
Spending on energy efficiency and electrification is reaching new highs thanks to dynamic growth in electrification of the transport sector

Global investment in energy efficiency, electrification and renewables for end uses and energy demand for end uses compared with annual average investment needs in 2030, by scenario



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Notes:.APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario; includes end-use renewables in the buildings and industrial sectors; 2023e = estimated values for 2023.

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But there are some clouds on the horizon, notably for efficiency spending: overall investment would need to triple by the end of the decade to keep the 1.5-degree target in sight.

The rapid progress made on EVs sales, heat pumps and energy efficiency investments in 2022 and the transformative legislation passed in the United States and Europe as a response to the global energy crisis means than the world has taken steps in the right direction towards achieving the investment levels for efficiency, electrification and end-use spending required to hit climate goals. Last year we reported that investment in these sectors needed to quadruple from 2021 levels by 2030, but we are now able to show that “only” a tripling of annual investment by 2030 would put the world on track with the NZE Scenario, while the gap with announced pledges (the APS) has come down to a 2.5-time increase.

The size of the gap is largest in emerging and developing economies (outside China), where annual investment in end uses is 10 times higher than today in the NZE Scenario in 2030. This reflects the need for a sharp rise in EV sales in such a scenario, alongside wide-ranging investment in more efficient industrial processes, transport and buildings, for example a huge increase in zero carbon ready buildings in response to rapid urbanisation. This tenfold increase compares with less than a twofold increase in China and a two and a half-time rise in advanced economies.

In terms of sectors, annual investment in the transport sector is five times higher than today by 2030 in the NZE Scenario. This level is achievable if the growth of electric vehicles sales observed in the last two years persists, and if investment in charging infrastructure follows, but ensuring such consistent and broad-based growth remains an enormous task.

The incentives for continued investment in energy efficiency in the building and industry sectors will continue to depend on long-term, predictable, and ambitious signals from policy makers as well as a favourable macroeconomic outlook. The current headwinds in the construction sector, high energy prices in the industrial sector, high inflation and tightened access to finance all complicate the prospects for achieving a consistent ramp-up in spending in these areas. By 2030, investment in energy efficiency in the building sector in the NZE Scenario is seven times what it is today as mandatory building codes and retrofit mandates become the norm globally and investment in energy efficiency and electrification of the industrial sector doubles.

Ensuring the long-term viability of incentive mechanisms will be crucial, especially as many countries face fiscal constraints in a higher interest rates environment. Although the use of capital markets and commercial finance is quite at an early stage in this space, it will have to play an increasing role in providing access to larger pools of finance for energy efficiency investments.

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R&D and technology innovation

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Did the world spend enough on clean energy innovation when money was cheap?

The market and policy context for energy innovation is changing. On the one hand, macro conditions are getting tougher, with rising interest rates and other headwinds typified by the collapse in 2023 of Silicon Valley Bank (SVB), a US-based provider of finance to innovative start-ups. On the other hand, policy support in many countries is stepping up as governments respond to the energy crisis and seek more resilient and diversified clean energy supply chains. The US Inflation Reduction Act, for example, provides a huge boost to clean energy innovation funding.

This government stimulus for clean energy innovation comes at a time when financing for innovative small companies is under severe pressure and co-operation on technology between some major economies is increasingly shaped by geopolitical considerations. Concerns that investors will retreat from riskier bets on new technologies are legitimate. Overall, the world may regret not spending more on clean energy R&D and early-stage innovators when capital was cheap over the past 15 years.

The fallout from the failure of SVB shows how inflation can rapidly hit start-up funding, which is the mechanism by which many ideas are tested and, if successful, launched on the market. It highlights how fragile the balance between the financial needs of innovative start-ups and the financial entities that provide their capital can become at times of stress. In 2022 the value of non-venture capital (VC) assets in the portfolios of many large financers fell as interest rates rose and revenue forecasts were revised down. This increased the share of VC assets in portfolios above the institutional targets of these financers (so-called limited partners), who began to withdraw from VC funds and indicate that they would invest less in the near future. A nervous atmosphere has permeated a previously buoyant part of the innovation system.

However, there are bright spots relating to clean energy innovation. Government policies provide investors with confidence that effective new technologies can find receptive buyers for clean energy products. Early-stage VC investment into clean energy start-ups reached a new high of USD 6.7 billion in 2022.

In real terms, public spending on energy R&D grew by 10% in 2022, an outcome largely driven by growth in China, while increases in other regions were offset by inflation. Expectations for public funding for pre-commercial technologies soared with the passing of the US Inflation Reduction Act, especially in areas such as hydrogen, CCUS and critical minerals. The advent of new industrial strategies and the priority attached to reshoring clean energy supply chains will have multiple implications for innovation, reinforcing policy support in key countries while also having the potential to fragment aspects of international technology learning.

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Spending on energy R&D

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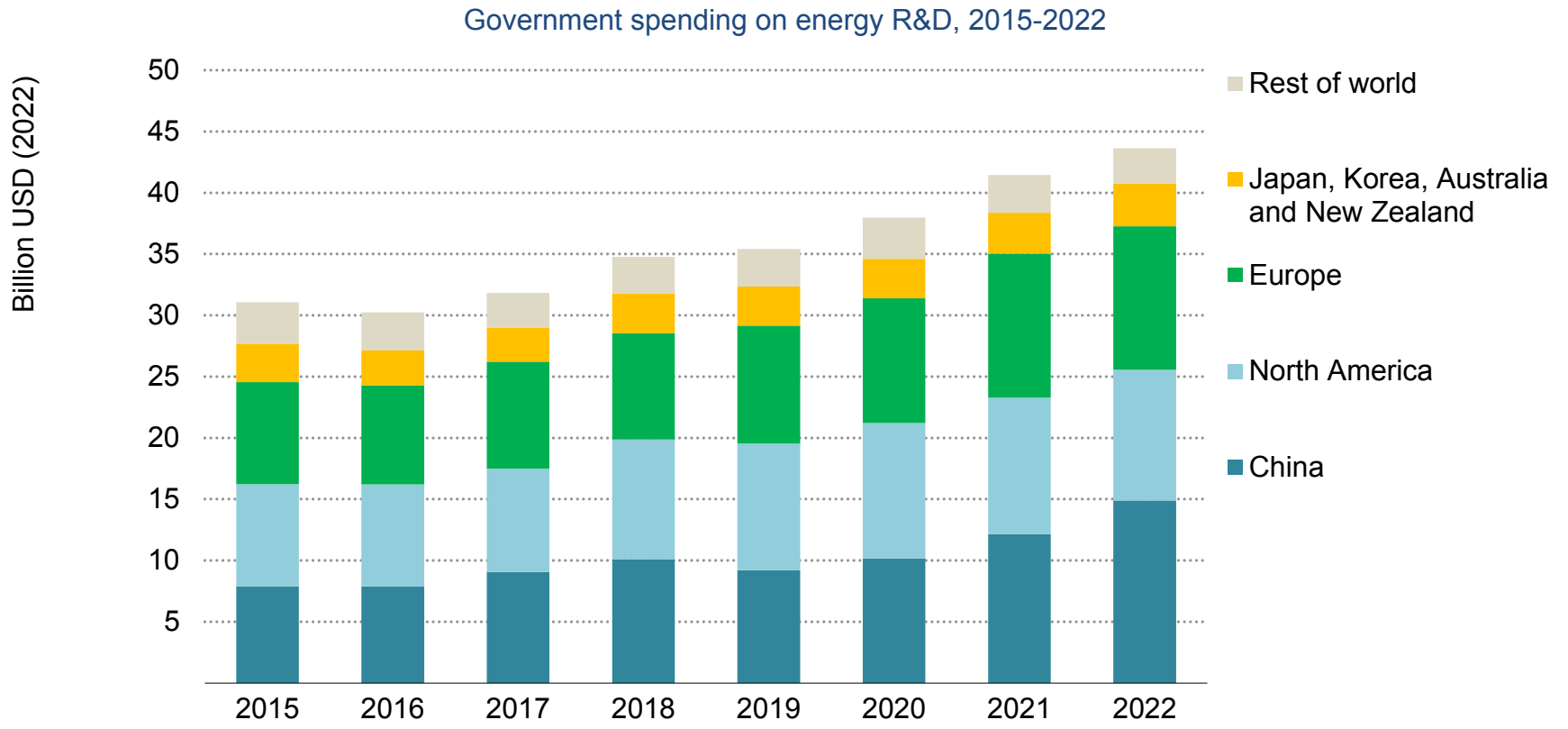
Government spending on energy R&D continued to rise in 2022, as marked growth in China outpaced modest progress in other regions



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Notes: Includes spending on demonstration projects (i.e. RD&D) wherever reported by governments as defined in IEA documentation; 2022 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 2022 estimate is based on reported company spending where available; IEA estimates for countries including India and Russia include state-owned enterprise R&D, which was not included in WEI 2022; the IEA Secretariat has estimated US data from public sources.

Source: IEA Energy Technology RD&D Budgets: Overview.

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Growth in direct public R&D spending is being supplemented by a jump in support for projects that will indirectly catalyse innovation

Globally, public spending on energy R&D rose by 10% in in 2022, to nearly USD 44 billion according to our estimates, with 80% devoted to clean energy topics. This continues a trend that has buoyed innovation in recent years despite macroeconomic uncertainty. However, growth in China masks sluggishness elsewhere. China's 14th Five-Year Plan (2021-2025) includes a planned increase in energy R&D spending of 7% per year, which we estimate it to have exceeded, based on policy statements and recent filings by Chinese state-owned enterprises. This maintains China's status as the largest public spender on energy R&D. Australia, Belgium and Norway have also reported notable increases, but they do not offset an overall dip of 1.5% in real terms among those IEA countries for which 2022 data are available. Such a stagnation does not bode well for countries that are seeking to invigorate their competitiveness in clean energy supply chains and manage inflationary pressures.

However, while some governments are struggling to increase direct R&D funding – we estimate that it fell 3% in the United States in 2022, for example – most attention in the past year has focused on some major policy packages for countercyclical investment. These could significantly accelerate the competitiveness of pre-commercial clean energy technologies but also, in some cases, could erect barriers to knowledge sharing between regions.

The US Inflation Reduction Act, adopted in August 2022, is perhaps the largest single boost to clean energy innovation funding in recent history. Its mix of direct R&D funding and support for the scale-up of near-commercial technologies and induced innovation (i.e. creation of a more lucrative and less risky market, thereby incentivising companies to develop better products) is expected to raise the pace of technology development. Direct R&D funding in the act includes USD 2 billion for improvements to federal laboratories up to 2027, which is likely to be additional to normal annual expropriations. An easier path to scaling up will be supported by USD 3.6 billion to guarantee up to USD 40 billion of loans to innovative technology projects, 50% grants to demonstration projects for industrial decarbonisation by 2026, and tax credits up to 2045 that offer up to USD 180/t CO_2 that is captured from the atmosphere and geologically stored. Induced innovation is likely to be spurred dramatically by a wide range of tax credits and rebates for the domestic manufacturing of clean energy equipment, low-emission fuel production, home retrofits and vehicle purchases. These incentives are additional to the Infrastructure Investment and Jobs Act measures described in WEI 2022, for which the rules and numerous calls for projects have since been published. There are indications from companies that the levels of support will be sufficient to make otherwise uncompetitive technologies attractive.

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In the European Union, a similar package of measures will take shape as countries implement the Net Zero Industry Act and Green Deal Industrial Plan. These include targets for EU-based manufacturing of clean energy technologies, public procurement guidelines and endorsement of certain regulatory exemptions granted to clean energy technology projects. However, while the financing for these strategies is not yet clear, a more long-standing EU programme, the Innovation Fund, awarded EUR 1.8 billion of direct funding to 17 large projects in mid-2022. These cover batteries, hydrogen, solar and wind. As a response to the ongoing energy crisis, the budget for the fund's next round has been doubled to EUR 3 billion.

Individual countries are also expanding *indirect* innovation support by directing attention to supply chains. Canada's 2023 budget proposes a 30% tax credit and a halving of corporate income tax for makers of clean energy equipment and higher credits for hydrogen and CCUS projects. Germany has taken a lead in establishing funds for large, early commercial hydrogen projects as a means of stimulating the market. Italy's Recovery and Resilience Plan allocates EUR 2 billion for investments to 2026 to pursue Italian leadership in selected energy technology areas, including financial support for clean energy start-ups. France published calls for projects under its EUR 1 billion fund for building solar PV and floating wind sectors. In 2022 Australia unveiled a Critical Minerals Accelerator Initiative for projects that build new supply chains.

New programmes for research and demonstration were also announced over the past year. Funding for new nuclear reactor designs was boosted by higher budgets in France, where EUR 1 billion was made available to 2030, and the United Kingdom, which plans to spend GBP 0.4 billion. Canada's 2023 budget proposes an additional CAD 0.5 billion for its main clean energy research programme. In December 2022 Germany announced over EUR 150 million for battery research projects, including for digitalisation and recycling techniques. In China, a national innovation platform is proposed to unite university and industry R&D efforts to implement the development plan for large-scale commercialisation of new energy storage technologies by 2030, complemented by new policies in Guangdong and Inner Mongolia.

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change concluded that clean energy innovation systems in EMDEs need strengthening. In late 2022 India advanced its plan for hydrogen, one of its strategic innovation priorities, with a USD 11 million call for proposals from regional consortiums, while its Green Hydrogen Mission earmarked USD 200 million for R&D and pilot projects. Indonesia signed an agreement with Japan to accelerate technological innovations relating to hydrogen, ammonia and CCUS. Also in 2022, the United Kingdom expanded its six-year GBP 1 billion fund for energy R&D projects in EMDEs to include hydrogen and critical mineral topics. Brazil launched processes in 2023 for new strategies for innovation in general and electricity sector innovation specifically.

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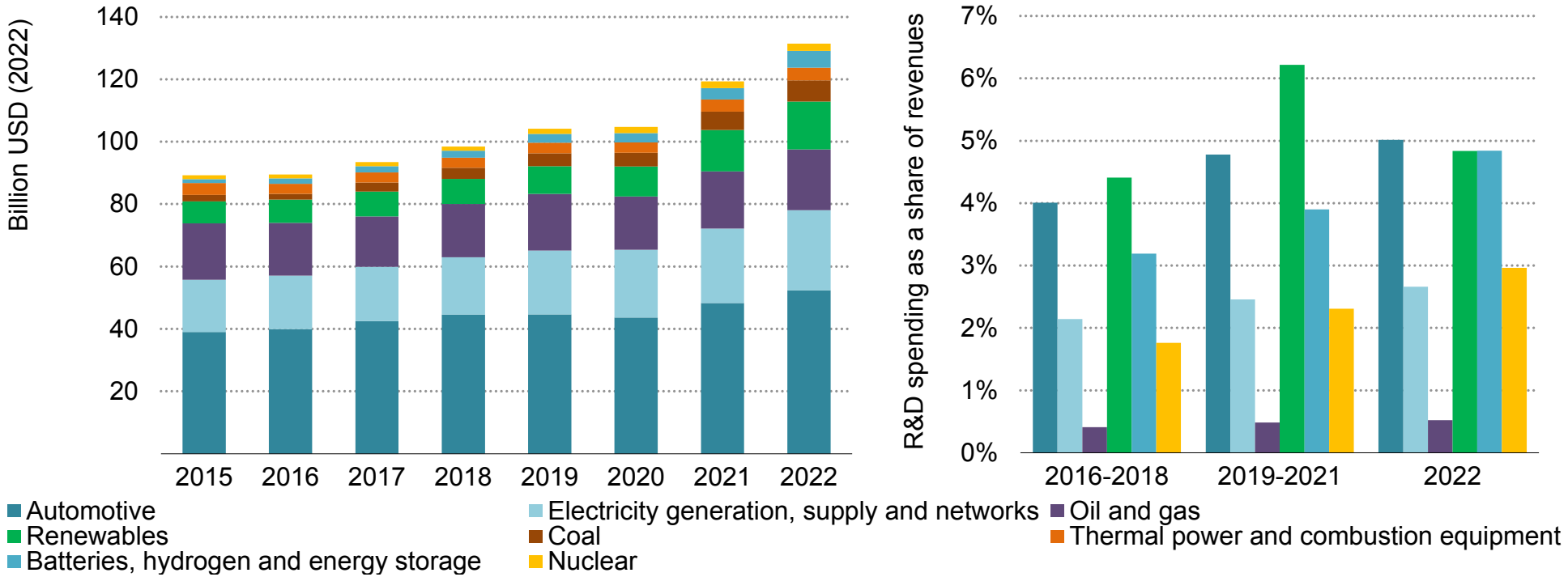
Corporate energy R&D spending rose by 10% in 2022, returning to its pre-Covid trajectory, but it did not keep pace with higher revenues

Spending on energy R&D by listed companies (left) and R&D budgets as a share of revenues (right), by sector of activity, 2015-2022



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Notes: Values for 2022 are estimates based on reported data at the time of drafting; includes only publicly reported R&D expenditure by companies active in sectors that are dependent on energy technologies, including energy efficiency technologies where possible, based on the Bloomberg Industry Classification System; 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; values may include both capitalised and non-capitalised costs, including for product development; 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 analysis based on data from Bloomberg (2023).

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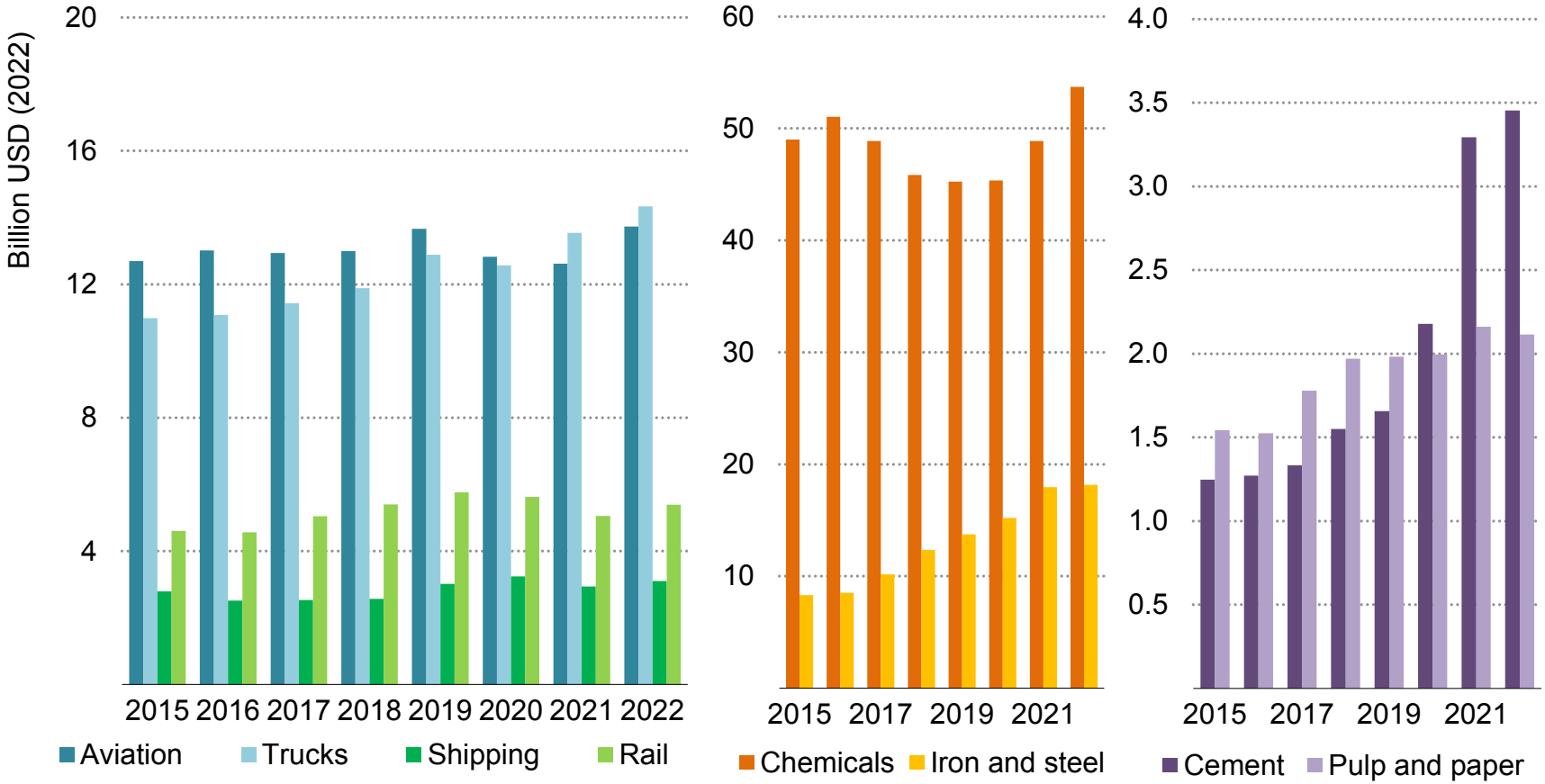
Corporate spending on R&D keeps rising in most “hard-to-decarbonise” sectors

R&D spending by globally listed companies in heavy and long-distance transport (left) and industry (middle, right) by activity, 2015-2022



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Notes: Values for 2022 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. Year-on-year changes can result from new companies entering the dataset or companies ceasing operations, as well as changes in R&D spending. Some changes compared to WEI 2022 relate to avoiding double-counting of parent and subsidiary companies.

Source: IEA analysis based on data from Bloomberg (2023).

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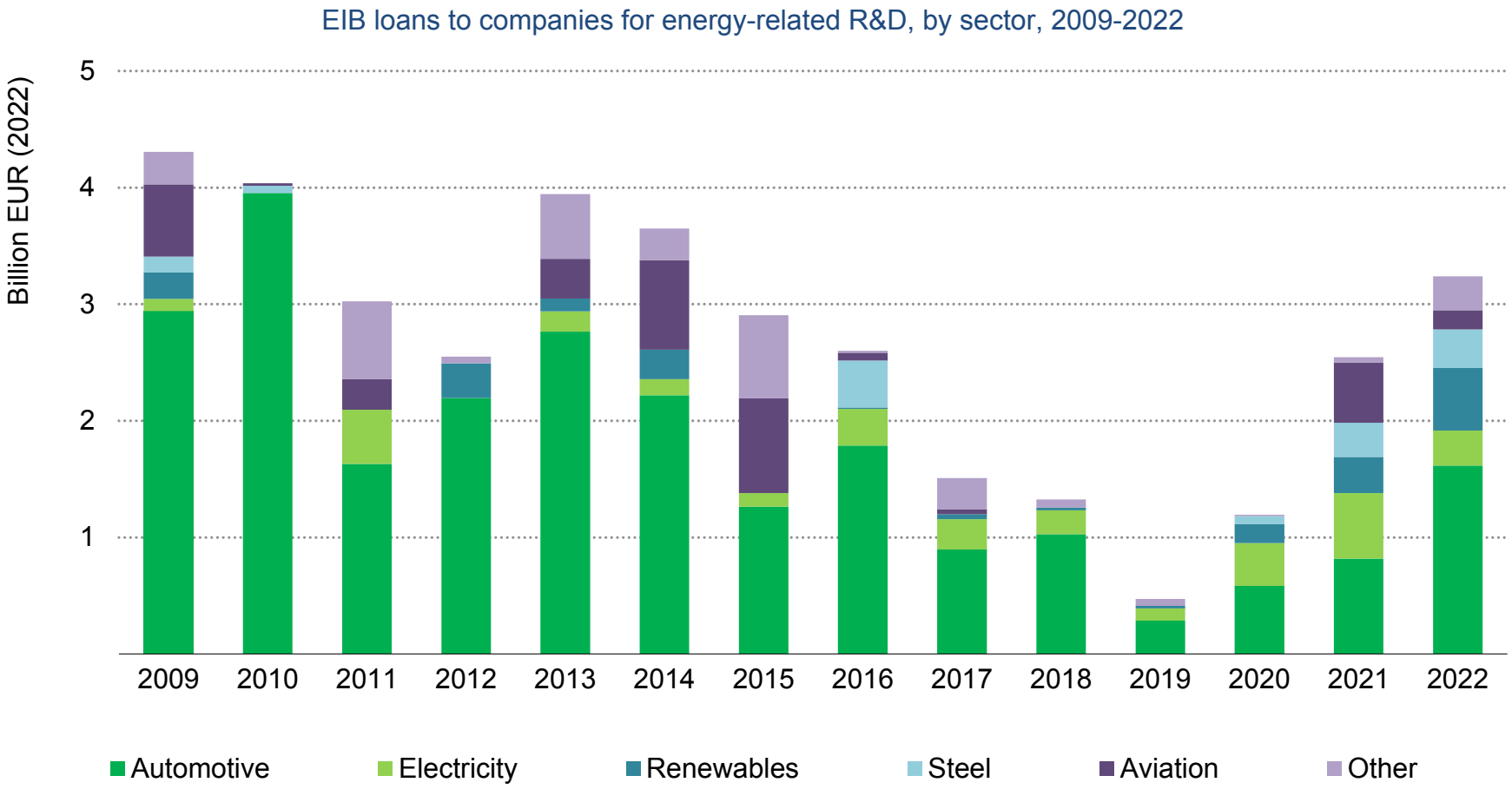
Public-sector credit for corporate R&D can sustain innovation during times of macroeconomic uncertainty, steering it towards clean energy, as illustrated by European Investment Bank loans



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Notes: “Other” includes cement, energy efficiency, energy storage, hydrogen, marine transport, fossil fuels and rail.
Source: IEA analysis based on data provided to the IEA by the European Investment Bank.

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Companies are reacting to the competitive pressures of energy transitions by funding more R&D and higher revenues in 2022 offer a further opportunity to support clean innovation

Preliminary data show positive news for the R&D outlays of listed companies in energy-related sectors. The 10% year-on-year growth in 2022 was high relative to recent years despite economic uncertainty and higher costs of capital. While the trends and competitive pressures vary across sectors, in the aggregate this can be interpreted as a response of companies to the threats and opportunities of the energy transition. As the technological basis of these sectors shifts, R&D is a central strategy for growing, or simply maintaining, market share. The shift in the automotive market is already very pronounced and increasingly globalised, and it is the growth in this segment of energy R&D that steers the overall trend.

A bumper year for energy sector corporate revenues in 2022 offers a further chance to increase spending. This was not yet reflected in research budgets, reflecting the fact that these are typically set in advance and that high energy prices were unanticipated. Therefore, a major opportunity arises for energy companies to increase clean energy R&D budgets in 2023 and beyond, even if just to keep the average ratio of R&D to revenue stable. There is also a good strategic case for a spending increase in areas like clean energy manufacturing: the ability to pair internal R&D with new public funding sources for energy innovation can make this capital more productive in an environment of greater capital discipline.

Outside the typical scope of the energy sector, corporate R&D is rising in so-called hard-to-decarbonise sectors. This is a positive signal that companies in the industrial sectors are embracing the challenge of rapidly changing their long-standing technological practices. Most spending in these sectors is by Chinese firms. With no uptick in R&D spending yet, the long-distance transport sectors (aviation, rail, shipping and trucks) remain outliers, however.

In times of economic uncertainty, governments can adopt measures to protect corporate R&D budgets from the threat of cuts arising from lower revenues or more expensive capital. This can bolster competitiveness through a downturn and can also be a chance to direct companies towards specific policy priorities. Since 2020 the EIB has extended EUR 7 billion in loans to support the energy-related R&D programmes of 45 firms. In 2022 new energy R&D credit from the EIB reached its highest value since 2013, when such loans were a response to the global financial crisis. The recent focus is less on the automotive electrification than in 2012-2017 and more on renewable energy and industrial decarbonisation. Germany's federal R&D tax credit, launched in 2020, has so far attracted applications from over 2 000 mechanical engineering projects, among 14 000 overall. The US Infrastructure Investment and Jobs Act delays the need to amortise corporate R&D until 2025.

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VC funding of early-stage energy technology companies

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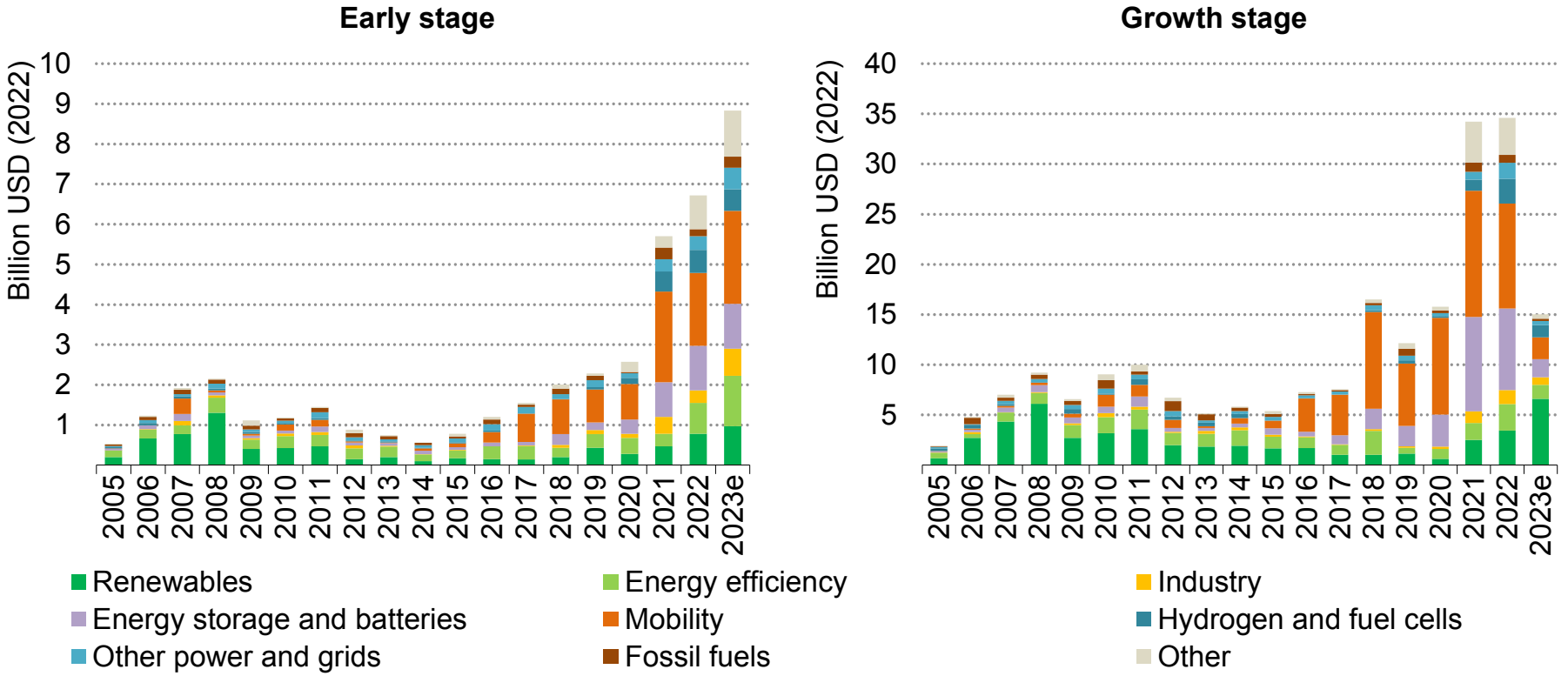
Early-stage equity funding for energy start-ups is booming, led by clean mobility and renewables, but 2023 could be leaner for later-stage deals

VC investment in energy start-ups, by technology area, for early-stage and growth-stage deals, 2004-2023e



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Notes: 2023e is an estimate based on Q1 data; 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 growth-stage investments; industry includes start-ups developing alternative routes to materials such as building materials, steel and chemicals; mobility includes technologies specific to alternative powertrains, their infrastructure and vehicles, but not generic shared mobility, logistics or autonomous vehicle technology; "Other" includes CCUS, nuclear, critical minerals and heat generation; fossil fuels cover start-ups whose businesses aim to make fossil fuel use cheaper or otherwise more attractive, including fossil fuel extraction and fuel economy of hydrocarbon combustion vehicles; a review of the data classifications for *WEI 2023* has modified trends published by the IEA in prior years

Source: IEA analysis based on Cleantech Group (2023) and Crunchbase (2023).

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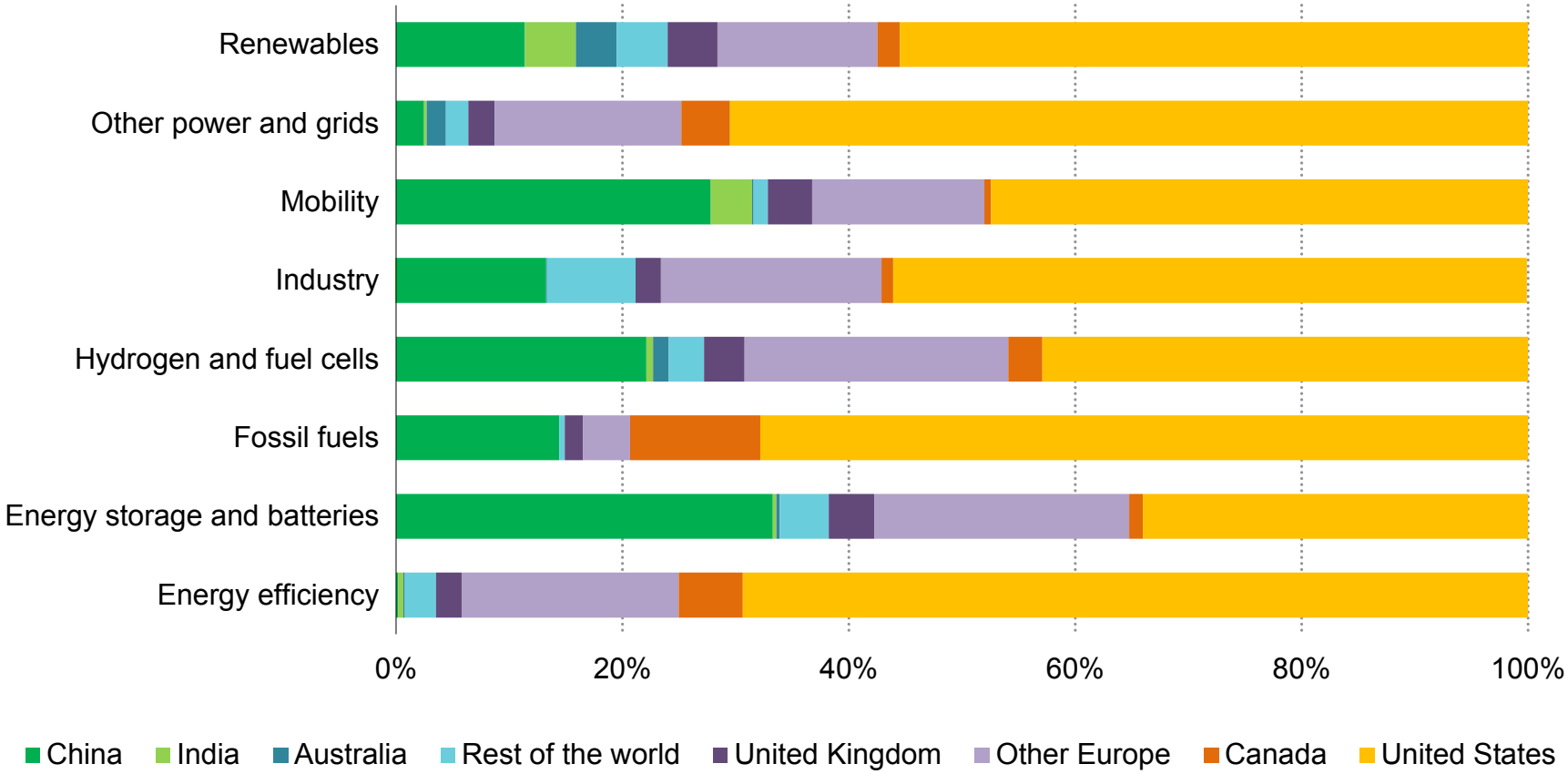
Most VC funding for energy technologies has flowed to US-based start-ups, with Europe having a strong presence in hydrogen and China active in mobility and batteries

Early- and growth-stage equity investment in energy start-ups by region and technology area, 2020-2022



IEA. CC BY 4.0.

Note: Regions are presented according to the headquarters of the start-up receiving investment.
Source: IEA analysis based on Cleantech Group (2023) and Crunchbase (2023).

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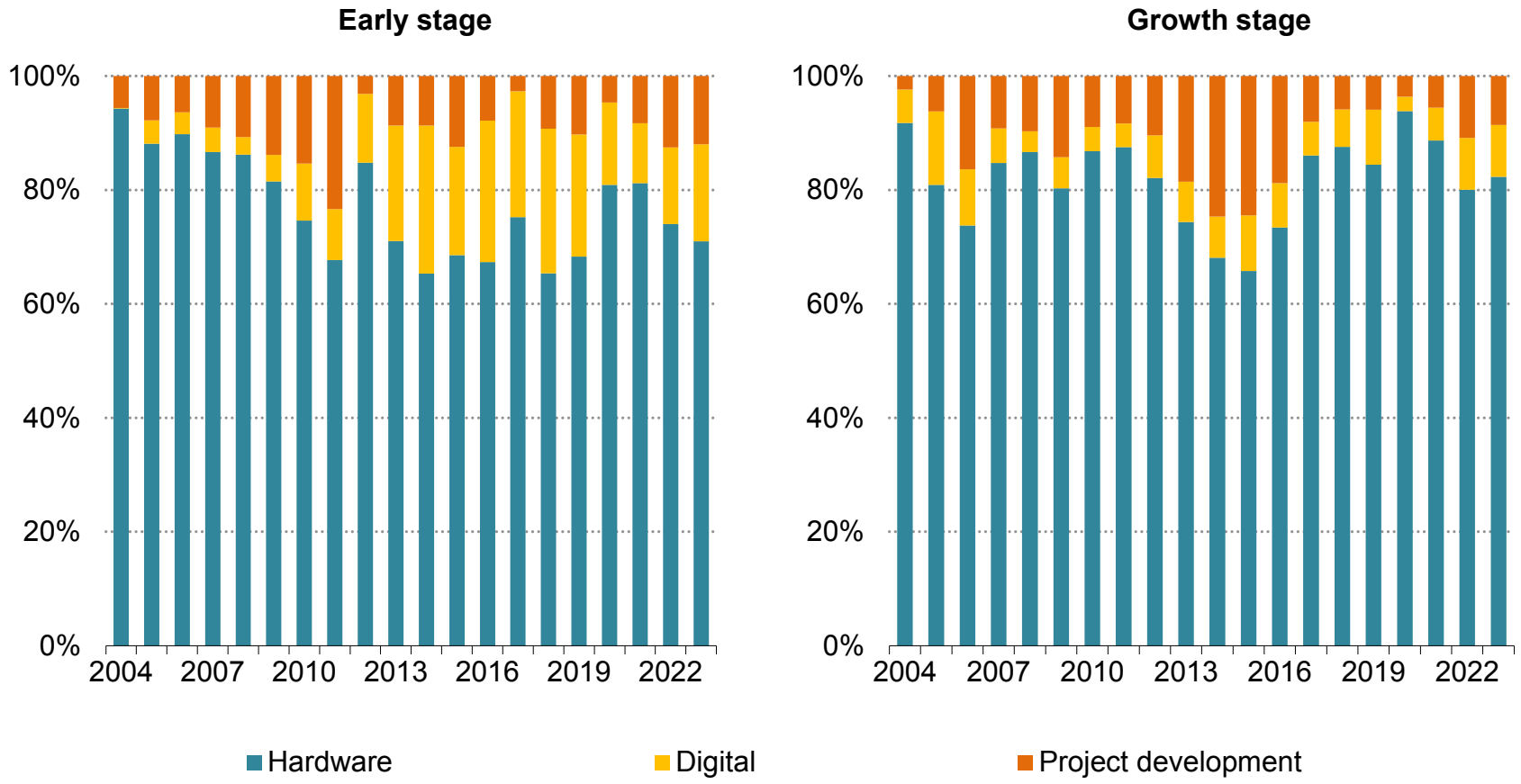
Most of the recent VC investment boom in energy is for companies working on hardware improvements, but more than 25% went to less risky digital technology and project developers

Share of early and growth-stage VC investment in energy start-ups, by type of start-up, 2004-2023



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Note: 2023 data are for Q1 only.

Source: IEA analysis based on Cleantech Group (2023) and Crunchbase (2023).

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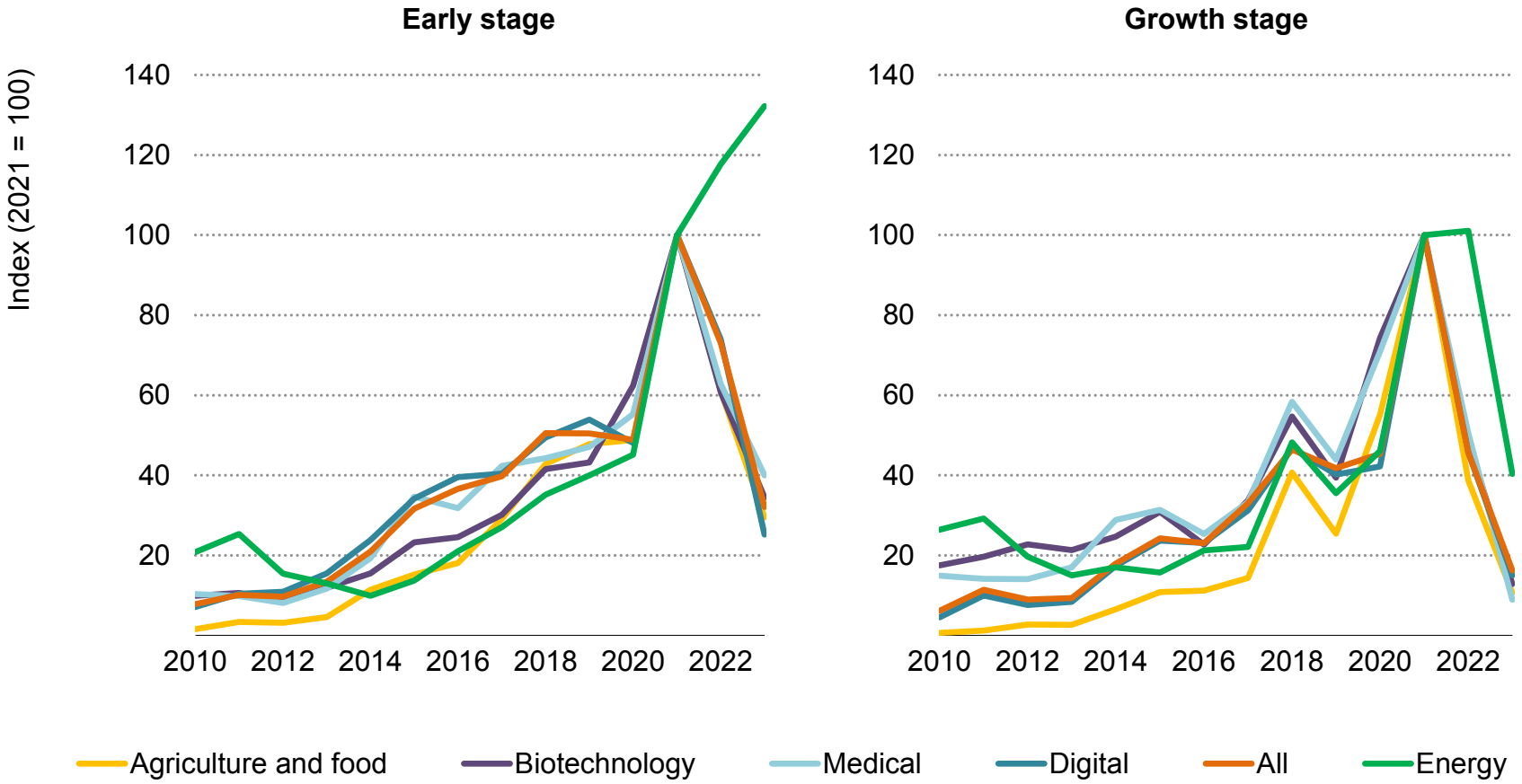
Energy has outperformed other VC segments since 2021, particularly for early-stage equity funding for start-ups, which has experienced growth while VC investment has fallen in general

Growth in global VC investment by sector of start-ups, 2010-2023



IEA. CC BY 4.0.

Note: 2023 trend is based on the rate of change between Q1 2022 and Q1 2023.
Source: IEA analysis based on Cleantech Group (2023) and Crunchbase (2023).

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Clean energy continues to outperform other VC segments, demonstrating investor confidence in energy transitions, but it is not escaping the slowdown in the wider technology sector

For energy start-ups, 2022 was the biggest year to date for early-stage equity funding, with increases in most clean energy technology areas. Most notably, start-ups in CO_2 capture, energy efficiency, nuclear and renewables nearly doubled or more than doubled their 2021 level of funding, which was already much higher than the average for the preceding decade. This type of funding supports entrepreneurs with technology testing and design, and plays a critical role in honing good ideas and adapting them to market opportunities. Growth-stage funding, which requires more capital but funds less risky innovation, rose by only 1% in 2022 and was very weak in Q1 2023. If Q1 is a good guide to the annual trend, the value of growth-stage deals for energy start-ups could fall by nearly 60% in 2023.

Prevailing macroeconomic conditions have dented the amount of capital available and raised the cost of scaling up nascent businesses. This is despite higher fossil fuel prices in 2022 that could have pushed many clean energy start-ups closer to market. With ongoing restraint in the banking sector, investment is not expected to bounce back quickly. Limited partners, the primary backers of VC funds, will continue to rebalance their portfolios to manage risk exposure, leaving more intense competition between start-ups for early-stage funding. In addition, banking services and loans are likely to become more costly for small, innovative firms. While the downward cycle for technology companies in North America was underway before the collapse of Silicon Valley Bank, the trends have now become more pronounced. It is expected that start-ups will have to survive longer between funding rounds or before an “exit” (becoming a public listed company or being acquired by a larger firm), with less access to bridging capital. For hardware start-ups, there will be difficult decisions relating to retention of research staff and investment in prototyping and testing.

However, the prospect of lower growth-stage investment is not reflected in the early-stage trend. Deals in Q1 2023, if maintained, indicate that early-stage VC funding in 2023 could continue to grow strongly. In addition, clean energy is set to continue to outperform other segments for which VC investment has fallen dramatically since 2021, a sign of how much clean energy VC investing has matured.

Much of the need for clean energy technology innovation relates to the development of hardware solutions, yet growth in early-stage funding for energy start-ups developing hardware is flat. For growth-stage investment, VC funding for hardware companies fell in 2022.

While funding for hardware developers remained dominant, at almost 75%, their share of early- and growth-stage deals tends to shift with

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changing risk perceptions. In the aftermath of the “cleantech bust” in 2010-2011, the share of funding for hardware dropped dramatically, to around 65% of early- and growth-stage equity investment in energy start-ups at its lowest point. Hardware products can take many years of VC funding to be developed to meet customers’ needs, but these start-ups can achieve high valuations and pay-offs for investors. By contrast, energy software and project development companies can have a quicker path to market but offer lower returns. The share of hardware climbed up again in 2020-2021, but has declined in 2022-2023, likely reflecting lower willingness among VC funds to make large, long-term bets. As an indicator, the proportion of energy VC going to digital, hardware and project development can help track investor preferences and the investment climate for solving hardware challenges. In a given technology area, the share represented by project developers can indicate technology and policy maturity.

Regionally, start-ups based in the United States raised more than those in other regions in every technology area between 2020 and 2022. The investors in the vast majority of these deals were US-based. While China, Europe and India have consistently represented growing shares of the total as investment has increased in recent years, this is not evenly spread between funding stages or technologies. When looking at early-stage investment only, European start-ups attracted 29% of the global total, but this falls to 22% for growth-stage funding. China has become a major location for the scale-up of energy storage and electric vehicle companies, but barely registers in the data for energy efficiency and power grid technologies. Indian start-ups are most present in renewable energy and mobility technologies, especially electric two/three-wheelers and charging.

Among hardware technologies, early-stage funding was mostly directed to electric vehicle start-ups, but these represented a much lower share of the total in 2022 than in the past five years. This is potentially due to the greater challenges facing start-ups looking to break into a more mature electric vehicle market. Gains were made in areas including nuclear (exemplified by Newcleo raising USD 294 million), batteries (exemplified by Greater Bay Technology, USD 150 million, Verkor USD 118 million, and Lithion Recycling USD 116 million), geothermal (exemplified by Quaise raising USD 52 million), and heating and cooling (exemplified by Exergyn and Submer raising USD 33 million apiece).

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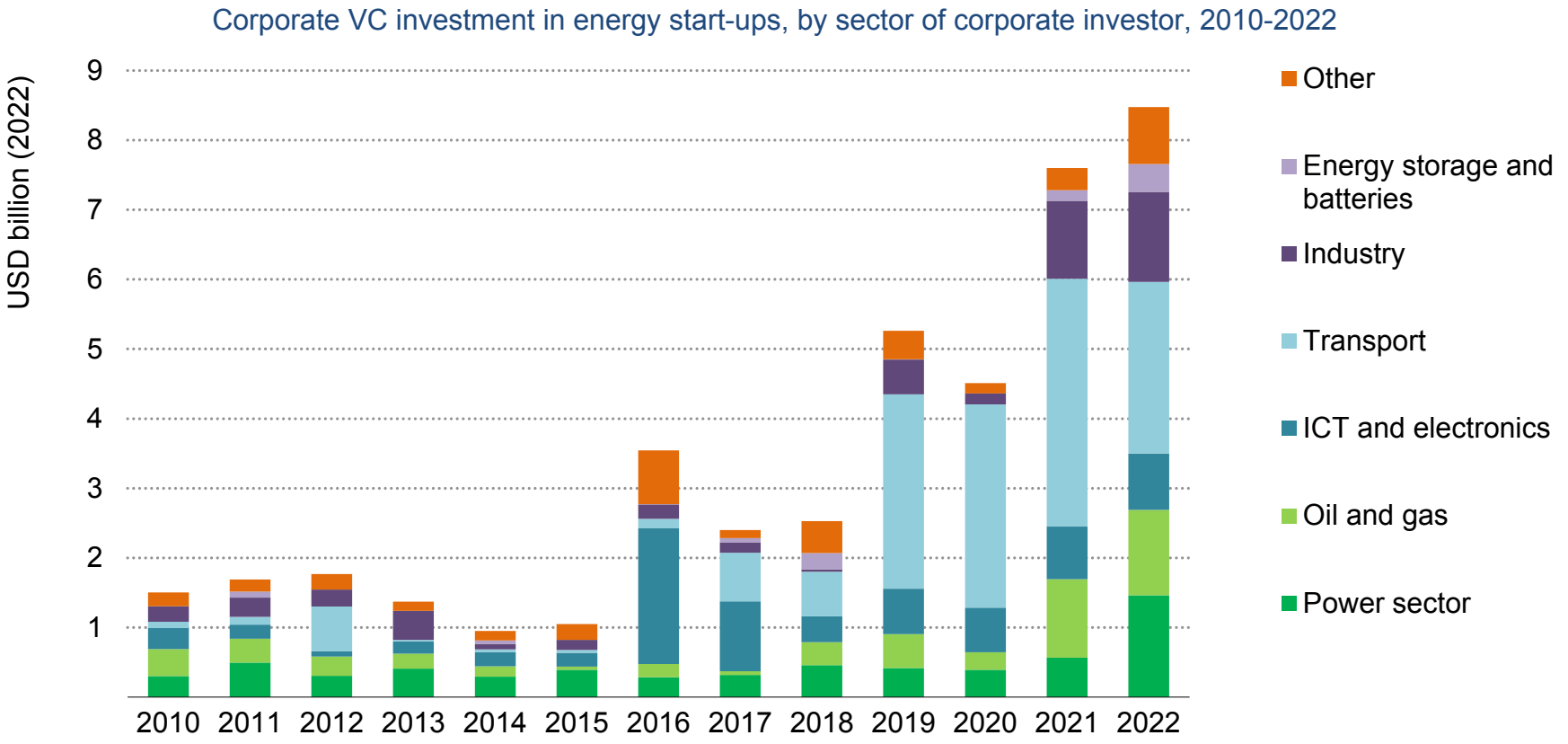
Corporate VC investment in clean energy start-ups remains high, with a higher contribution in 2022 from electricity, oil and gas, and heavy industry companies



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Notes: Includes early- and growth-stage deals; includes only investment by private-sector investors; where there are several investors, deal value is evenly split across them; ICT = information and communications technology; Industry includes chemicals, cement, commodities, construction (excluding real estate), iron and steel, and other equipment suppliers; Power sector includes independent power producers, and electricity and renewables equipment and services; "Other" includes food, health, research and mining; values are slightly lower than in WEI 2022 due to some reclassifications by the IEA of start-ups and investors.

Source: IEA analysis based on Cleantech Group (2023) and Crunchbase (2023).

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Higher strategic corporate investment in energy start-ups indicates how firms are seeking to stay competitive or break into a fast-moving landscape

Corporate venture capital (CVC) investment in clean energy start-ups stayed at historic highs in 2022, exceeding USD 8 billion. With the technological landscape changing rapidly, companies increasingly use CVC investments in start-ups to enter new technology areas. The increase in 2022 was led by investors from the industrial, electricity and energy storage sectors.

Mirroring our findings about the high share of energy VC funding for firms developing digital products between 2013 and 2020, CVC investment in energy start-ups by ICT firms grew markedly from 2016 (as these start-ups became closer to the market). However, the ICT sector's share of energy-related CVC was not maintained and in 2022 there was a more even spread of CVC among corporate sectors than previously. Industry sectors like chemicals, construction materials, and iron and steel are playing a larger role in CVC investment in clean energy start-ups with hardware products.

While CVC remains lower than corporate R&D budgets, it has been growing quickly since 2015. In an energy sector that anticipates disruption from mass-produced, modular and quick-to-scale technologies, CVC can be particularly 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 conditions of 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. This is most evident in the case of fossil fuel companies, which increased their energy-related CVC activity in 2022. Oil and gas companies invested USD 2 billion between 2020 and 2022, mostly in CCUS, energy efficiency and renewable energy developers. Start-ups must weigh the benefits of CVC against the possibility that their agility and rapid growth ambitions may not always fit with the strategies of the firms that take stakes in them.

Notable investments in 2022 included equity from Chevron and the Oil & Gas Climate Initiative into Svante, a Canadian CO_2 capture firm that raised USD 318 million of growth equity, and Sinopec's participation in a USD 130 million growth-stage round for Kuntian New Energy, a Chinese battery component maker. Equinor invested in Solid Power, a US solid-state battery firm. Repsol invested in Enerkem, a Canadian waste-to-energy company. Eni invested in C-Zero, a US natural gas-to-hydrogen start-up. Gerdau and Asahi Kasei invested in Plant Prefab, a Dutch maker of efficient buildings. Holcim invested in Blue Planet, a CO_2 mineralisation start-up.

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Implications

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Energy innovation investment has largely remained resilient to shocks in a turbulent 2022, but more tests lie ahead and capital availability varies between regions and types of innovation

The latest investment data for energy R&D and innovation are broadly positive, and reflect some of the themes running through the chapters of this report. The impacts of the Russian invasion of Ukraine are yet to become fully apparent, with government support for clean energy helping it to buck macroeconomic trends so far. In innovation, this is most evident in the resilience of VC funding for clean energy, despite a downturn in VC funding for technology start-ups more generally. Similarly, corporate R&D spending data echo the findings for capital expenditure in the energy sector: there is little evidence from 2022 that spending will rise in line with higher revenues, but there is a strong case for an increase in, for example, oil and gas company R&D in coming years.

Any outlook for clean energy innovation globally must accommodate several competing drivers that have become more pronounced in the past year. Firstly, any reduction in bilateral co-operation and trade between major regions restricts flows of knowledge, thereby slowing the advance of the technology frontier. Secondly, regulatory preferences for more local supply chains could lead equipment suppliers, such as vehicle manufacturers, to relax their efforts to keep up with technological developments abroad. Thirdly, and in contrast with the previous two points, hindrances may be counteracted by industrial policies inspired by competition in international clean energy value chains. By projecting stronger market signals over the medium term, industrial policies can steer significant new capital to selected technology challenges, which spurs eligible innovators to compete with each other to secure contracts and win market share.

Regional differences are set to widen, not converge

Unlike in some other areas of energy investment, China's share of innovation spending does not tower over global spending. Public R&D spending is quite even across China, Europe and North America, while VC investment is more concentrated in the United States, followed by Europe. These three regions, plus Japan and Korea for R&D spending, play an outsized role in energy innovation compared with their future energy investment needs.

The NZE Scenario requires over half of clean energy investment to be in EMDEs. However, in 2022 EMDEs (excluding China) accounted for just 5% of public energy R&D, 3% of corporate energy R&D (by country of headquarters) and 5% of energy VC (by country of start-up).

Government support is crucially important for stimulating R&D investment, and policy incentives for clean energy innovation are expanding impressively in the regions that are already leaders. Costs

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of capital are diverging between advanced economies and EMDEs in a way that could entrench this difference at a time when innovation co-operation between regions appears more challenging.

Innovation in EMDEs is typically more targeted to their specific social, economic and climatic contexts. In addition, it can help to position them in clean energy technology value chains, thereby boosting economic growth and accelerating global efforts towards climate goals. Advanced economies and multilateral development banks have a role to play in ensuring that investment opportunities for energy innovators are as global as possible, even as competition intensifies in areas from batteries to energy management software, hydrogen, heavy industry, heat pumps and air conditioning.

The scope of energy innovation investment is expanding, signalling more VC appetite for hardware developers

The recent surge in VC investment in clean energy has been accompanied by a high share of bets on hardware-focused start-ups. However, the innovation efforts devoted to digital solutions seen during 2013-2019, which drew the world's biggest IT companies into energy-related research, remain important. Rather, the share of hardware has risen along with a broadening range of hardware areas attracting funding from public and private sources. Investors in clean energy technologies now cover aerospace, critical minerals, direct air capture, industrial feedstocks and manufacturing techniques.

Demonstration project funding grabs headlines, but underlying innovation systems also need attention

In the coming years, editions of *World Energy Investment* will track how the major government funding announcements translate into public budgets, project awards, project expenditure and then technology improvements. For first-of-a-kind demonstration projects, the extent to which tax credits and performance incentives attract private capital will be watched closely. The magnitude of this spending, especially with many incentives in the US Inflation Reduction Act being uncapped, will ensure publicity for these projects.

However, energy transitions depend just as heavily on functioning innovation systems that channel appropriate types of capital to researchers and entrepreneurs as they develop new ideas. Effective innovation systems balance public spending, intellectual property rights, knowledge networks, market opportunities and incentives for the private sector to put capital at risk. For a decade, cheap capital has lowered barriers to investment in long-term, risky bets and thereby concealed weaknesses in innovation systems. With the cost of money set to rise, the health of these systems will be a more critical determinant of whether new technology ideas continue to flow in line with the "learning curve" assumptions of decarbonisation scenarios. There is plenty that governments can do to nurture good ideas and give them the highest chance of being available to apply for the next

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waves of VC or demonstration funding in 5 or 10 years' time. This includes guiding the brightest minds towards key policy challenges for clean energy technologies.

More than in other parts of the energy sector, innovation investment reflects the balance between long-term thinking (to mitigate the risks of long-term unsustainability and uncompetitiveness) and near-term shocks. Despite positive outlooks in some areas (such as public R&D and demonstration funding, and fundraising by project developers), others face headwinds (including the cost of capital for early-stage hardware start-ups, and international knowledge flows). All stakeholders in successful energy transitions are therefore bound by a need to address weaknesses and keep the investment balance in favour of seeking long-term opportunities.

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Sustainable finance

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Overview

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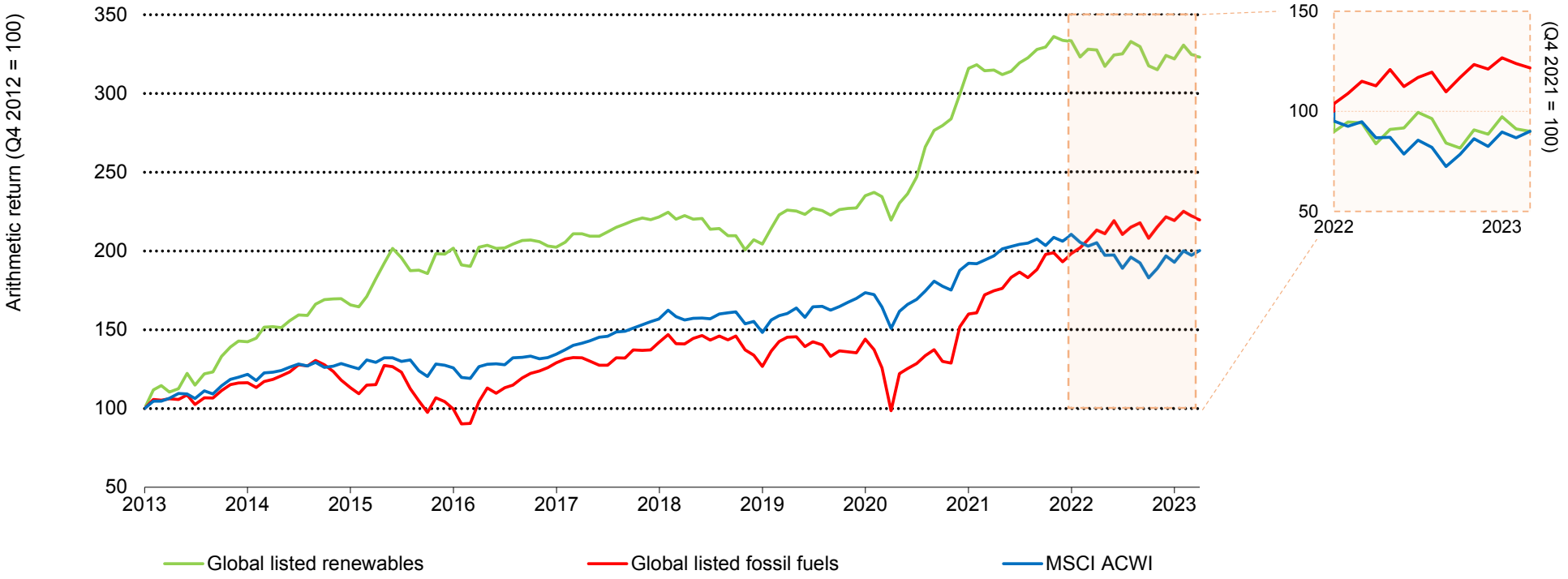
The energy crisis led fossil fuel companies to significantly outperform the benchmark last year, although renewables proved resilient following years of strong returns

Monthly returns of energy-related sample portfolios, 2013-2023 (left) and Q4 2021-Q1 2023 (right)



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Note: MSCI ACWI = MSCI All Country World Index.
Source: IEA analysis based on data from Bloomberg (2023).

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Investing in clean energy has faced challenges due to the strong performance of fossil fuels in 2022, but the continuing development of sustainable finance regulation can act as a tailwind

The financial community has a critical role to play in the massive ramp-up of clean energy spending needed to meet climate goals and the orderly reallocation of capital away from fossil fuels. The proliferation of sustainable finance practices is a strong indicator of this direction of travel, with a growing number of financial institutions pledging to align their financing with net zero scenarios.

Last year represented a major challenge to these practices, with the Russian invasion of Ukraine causing fossil fuel companies to significantly outperform the market. This put short-term pressure on investment strategies that underweighted or excluded these entities. Despite this, signs from European and North American shareholder voting season (March-June) show that actors within the financial community remain concerned about climate risks and the implications of rapid transitions for fossil fuel assets. Climate-related proposals, particularly on emissions targets, are up compared to last year – although the test will be how many win a majority vote. There are also more proposals to cut off or phase out fossil fuel financing at banks and insurers, although last year all nine such proposals that went to vote in the United States failed to receive support above 20%, and the current energy security climate is likely to soften support.

The continuing appetite for sustainable finance practices in such a challenging market demonstrates the important foundation laid by regulators globally. Regulators are strengthening sustainable finance architecture by issuing clear definitions of green or sustainable activities and guidelines to prevent "greenwashing", while mandating granular sustainability disclosures and reflective risk and opportunity assessments. Some of the major trends and developments are:

Green taxonomies: In 2022 green taxonomies were introduced in South Korea, Indonesia, South Africa, Colombia, Sri Lanka and Georgia. Mexico also announced a new taxonomy in March 2023, with several other countries announcing that taxonomies are under development, as in Australia. Meanwhile China, one of the largest green finance markets, published the Green Bond Principles in July 2022 and later the Common Ground Taxonomy, which outlines commonalities with the EU taxonomy.

Transparency and labelling: There has been growing concern around the use of "ESG" (environmental, social and governance), "sustainable" and "green" terminology on financial products and the data that go into it. Regulators from at least 13 jurisdictions have proposed or introduced disclosure requirements on ESG or sustainable funds to improve labelling. Regulators have also looked at individual companies, with cases brought against DWS (Germany) and Goldman Sachs (United States) over the alleged misleading of investors in green or ESG investments. Regulators are also

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increasingly looking at ESG data and ratings providers; Japan, the United Kingdom and the European Union are publishing either codes of conduct or proposing future regulation for ratings providers.

Disclosures: The proliferation of non-financial reporting standards and regulation generally emphasises emission and climate risk disclosures. The International Sustainability Standards Board issued two voluntary standards on climate-related reporting – IFSR 1 and 2 – in June 2022, becoming effective in January 2024. EU sustainable finance regulations also advanced with the Corporate Sustainability Reporting Directive, which will require large and listed companies to report on, among other things, their environmental risks, opportunities and impacts. The Sustainable Finance Disclosures Regulation (SFDR) also entered its second phase in early 2023 whereby sustainability disclosures and reporting on climate and environmental impacts became mandatory for financial market participants. A report by ISS also found that countries in Asia – notably Malaysia, Singapore, India and Japan – had been particularly active in introducing sustainable finance-related regulation, including around disclosures, sustainable lending and stewardship practices.

Climate stress testing: A growing number of central banks are conducting climate stress tests and in at least 18 jurisdictions banks either are or will soon be subject to requirements to implement such testing. A climate risk stress test by the European Central Bank conducted in 2022 found that around 60% of the 104 participant banks did not have a climate stress testing framework in place, and that about two-thirds of banks' income from non-financial corporate customers stemmed from greenhouse gas-intensive industries. The Network for Greening the Financial System, which provides central banks and supervisors with climate scenarios and guidance for such tests, found that there are multiple different approaches to stress testing across jurisdictions and encouraged greater co-ordination. Equally, they highlighted that the lack of availability and comparability was reducing the quality of stress testing. As a result, stress tests currently serve primarily as learning exercises, with no immediate requirement for follow ups, but they show that banks stand to experience notably higher credit losses under a disorderly transition.

Achieving the NZE Scenario requires clean energy spending to rise nearly threefold by 2030, with an estimated 65% of this needing to come from the private sector. Sustainability-related regulation and guidance act as a tailwind for these investments. This chapter explores the alignment between growth in sustainable finance and clean energy investment, particularly in relation to EMDEs, which account for 55% of clean energy investment by 2030 under the NZE Scenario. While the emphasis here is on private investment, numerous other public finance initiatives are also underway that are likely to support an increase in clean energy spending. Notably, these include the Bridgetown Initiative announced by Barbados Prime Minister Mia Mottley at COP27, which proposes several steps to reform development and climate finance.

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Sustainable investing

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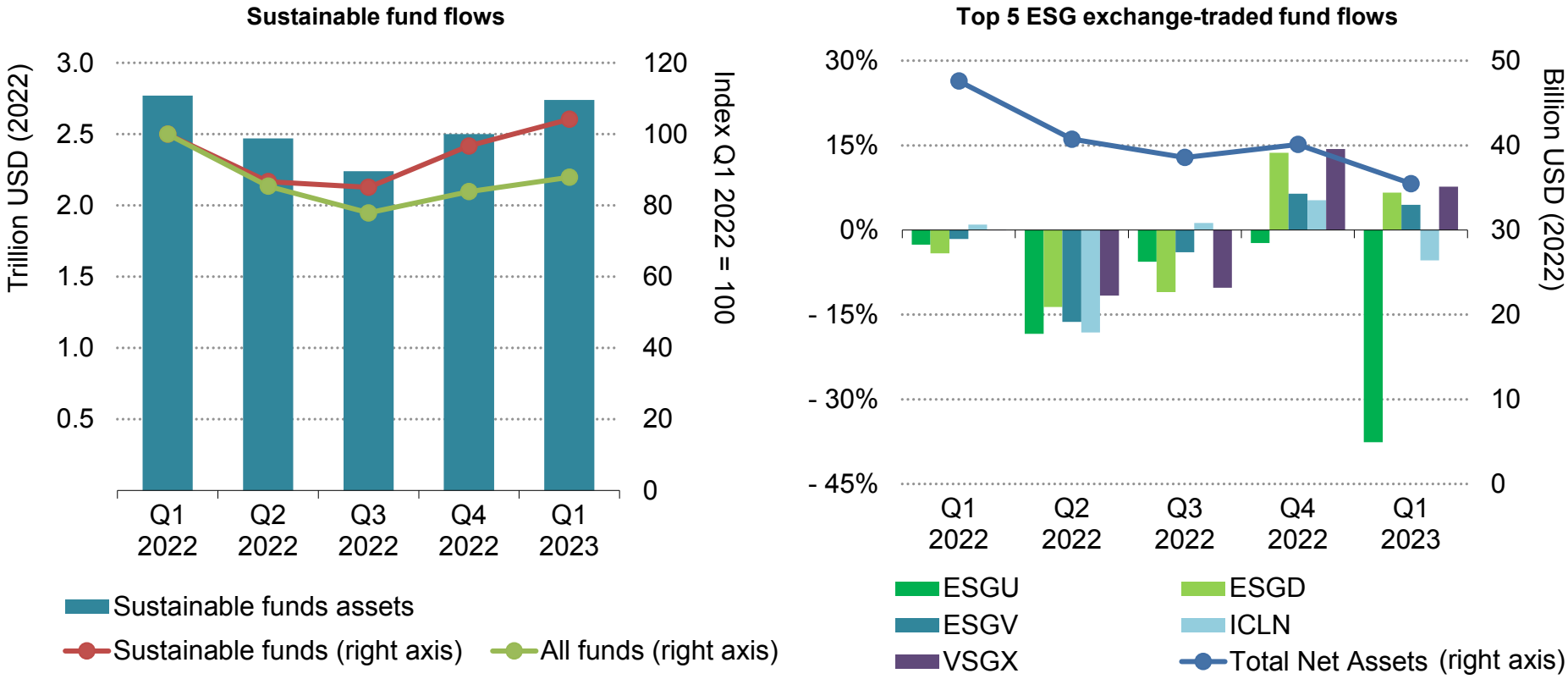
The value of assets in funds globally fell during 2022, although sustainable funds showed more resilience and have rebounded in early 2023 despite major outflows from some large ESG funds

Trends in sustainable fund and ESG exchange-traded funds (ETF) flows, Q1 2022-Q1 2023



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Notes: ESGU = iShares ESG Aware MSCI USA ETF; ESGD = iShares ESG Aware MSCI EAFE ETF; ESGV = Vanguard ESG US Stock ETF; ICLN = iShares Global Clean Energy ETF; VSGX = Vanguard ESG International Stock ETF; ETF = exchange-traded fund.

Sources: IEA analysis based on data from Refinitiv (2023), Morningstar (2022, 2023).

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Sustainable funds weathered a challenging year despite the pressure on investment strategies that limited exposure to high-performing fossil fuels

After years of inflows, in 2022 ESG funds recorded their first net outflows since 2011. Outflows were particularly heavy in the first half of the year, as fossil fuel prices spiked and concerns around inflation, interest rates and recession hit the market as a whole. How these pressures impacted ESG funds varied significantly according to their chosen approach. Funds that focused on screening – which often involves underweighting or excluding fossil fuel companies and overweighting high-performing sectors with lower ESG risks like technology – faced particularly tough questions around their performance compared to the market.

Large one-off outflows from ESG ETFs in early 2023 have also highlighted the impact of concentration risk within certain areas of sustainable investing. In March, nearly USD 4 billion was withdrawn from iShares ESG Aware MSCI USA ETF (ESGU), the largest ESG ETF, contributing to a 38% fall in the ETF's asset value in Q1. This quarter also saw withdrawals from other major funds, including iShares Global Clean Energy ETF, which saw a USD 260 million outflow triggering a 5% loss in asset value. Several analysts have attributed these outflows to risk rebalancing by institutional investors who own large portions of these funds. In 2022 Bloomberg estimated that roughly 22% of new investment in ESG ETFs went to just 10 funds, and most of these investments were made as one-off allocations. This indicates that choices among certain large investors or by key funds or indexes that ETFs track can skew trends within the market.

Despite these challenges, sustainable funds generally proved resilient against market conditions, based on quarterly reviews by Morningstar. Throughout the year and into the first quarter of 2023, the valuation of sustainable funds saw less volatility than all funds globally, and thanks to a rebound in equity valuations in early 2023, sustainable funds have almost returned to levels seen in early 2022.

The impact these trends have on alignment with investment under the NZE Scenario is mixed. The correlation between a push for sustainable investment practices and a reduction in fossil fuel spending is clear, but questions remain over the extent to which sustainable investing is driving the necessary increase in clean energy investment. For example, the EU SFDR groups funds into three broad categories based on their level of sustainability. Article 9 funds are the most ambitious, whereby funds demonstrate they have a "sustainable investment objective". In Q4 2022 there was a series of reclassifications, with 40% of Article 9 funds downgraded to the less ambitious Article 8, where funds must "promote environmental or social characteristics". Notably, these included the iShares Global Clean Energy ETF, suggesting that Article 9 alignment is not a prerequisite to supporting the energy transition.

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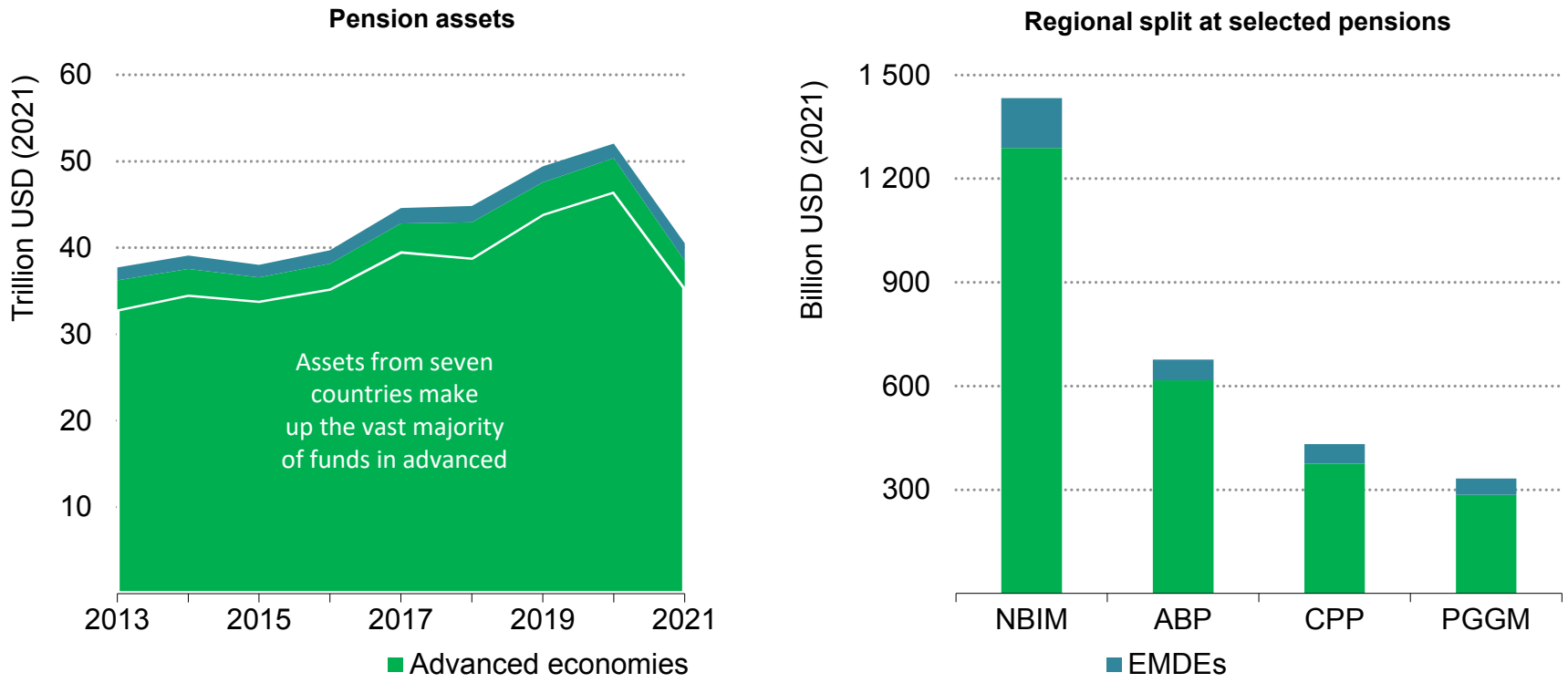
Institutional capital is heavily concentrated in advanced economies with only a small share being allocated to EMDEs…

Pension asset regional spread and allocations to EMDEs at selected pensions



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Notes: The seven countries that make up the majority of pension assets are Australia, Canada, Japan, the Netherlands, Switzerland, the United Kingdom and the United States; NBIM = Norges Bank Investment Management; ABP = Stichting Pensioenfonds; CPP = Canada Pension Plan; these four funds were selected based on their inclusion in an OECD survey on pension fund assets in developing countries.

Sources: OECD, Pension Markets in Focus; World Bank, World Development Indicators; Annual report from NBIM, ABP, CPP and PGGM.

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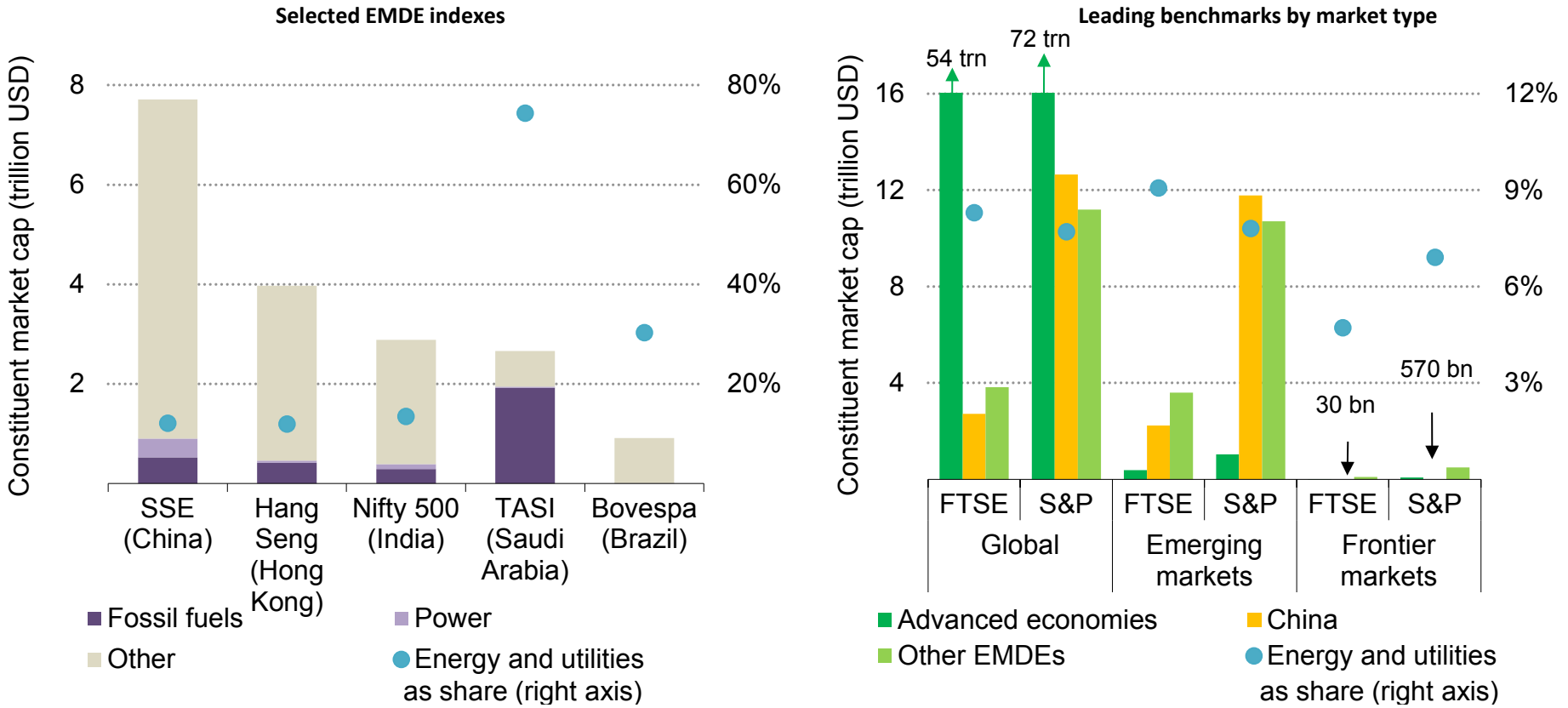
… and increasing these allocations is complicated by the lack of accessible investable assets

Characteristics of indexes in selected EMDEs and leading benchmark providers



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Notes: EMDE indexes were selected based on the size of the local stock markets and availability of data; benchmark indexes do not include MSCI, the third major provider, because constituent country data were not publicly available.

Sources: IEA analysis based on data from Refinitiv; World Bank, World Development Indicators; Index factsheets from S&P and FTSE Russell.

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Structural issues and the limited pool of investable assets are preventing capital from flowing to key areas needed to meet the Net Zero Emissions by 2050 Scenario

In the NZE Scenario, clean energy investment in EMDEs triples by 2030, by which time it accounts for over half of the global total. This represents a sharp break from current trends; clean energy investment in EMDEs has risen by only around 30% in the past five years (most of which has been in China).

The imbalances are unsurprising when you consider that around 80% of financial assets are held in advanced economies, according to estimates by the Financial Stability Board. Looking at pension funds, which can provide a valuable source of patient capital, seven advanced economies accounted for nearly 90% of global pension assets in 2021 (latest data available). An OECD survey found that only around 8% of surveyed pension assets were allocated to developing countries and 85% of these assets came from just four funds.[1] According to these funds' latest reporting, allocations to EMDEs totalled roughly USD 300 billion in 2021, or 11% of their combined portfolios. These allocations may have fallen over 2022 due to changing risk perceptions in the wake of Russia's invasion of Ukraine and the subsequent energy crisis, and the worsening macroeconomic environment in many EMDEs.

One of the major constraints on further investment in EMDEs from such institutions is the lack of projects that meet their size and liquidity requirements. Entities from EMDEs (excluding China) account for less than 15% of the global market capitalisation of listed companies. Indexes tracking the 10 largest EMDE stock exchanges, excluding Saudi Arabia whose exchange is dominated by Aramco, show that energy and utility companies on average account for 15% of the indexes by market capitalisation, and within this fossil fuel companies are on average two and a half times larger than power companies. Combined with their different risk–return profiles, this puts power companies at a disadvantage when seeking to attract investment.

The difficulty of accessing investable projects is also visible when reviewing major equity indexes. Indexes play a key role as benchmarks and as the basis for passive investment, which has risen in popularity in recent years. Indexes are generally split into developed, emerging and frontier market categories, and although performance of the latter two has been relatively similar, many mainstream investors will limit their exposure to frontier markets. There are currently 40 EMDEs[2] included in emerging or frontier indexes from the top three index providers, but frontier market

[1] The survey did not include US, UK or Japanese pensions, which are some of the largest globally.

[2] Based on the IEA categorisation. Please see glossary in methodology for further details.

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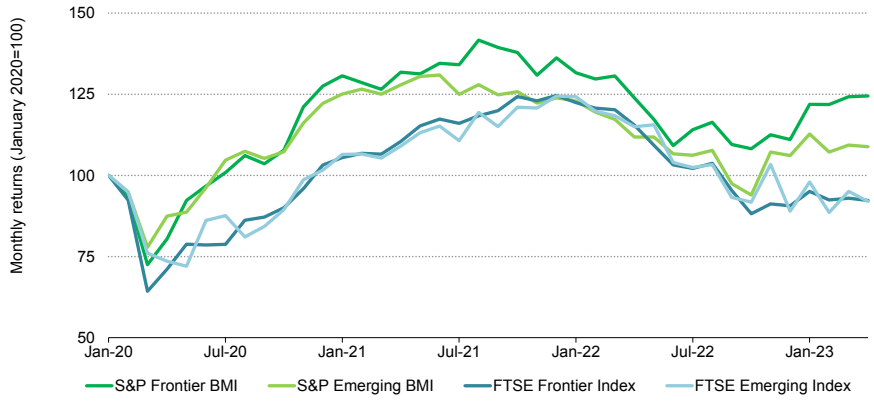
indexes are on average less than 5% the size of their emerging market peers, based on net market capitalisation. Frontier market indexes also tend to be a lot more concentrated. For example, the top 10 constituents account for 37% of the S&P Frontier BMI Index, compared to 14% in the Global BMI Index. This therefore limits the number of companies that investors can access within these riskier markets.

Performance of key emerging and frontier benchmarks



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Source: IEA analysis based on data from Bloomberg (2023).

When looking at climate-aligned benchmarks, the investable universe in EMDEs shrinks even further. MSCI's Emerging Markets Climate Paris Aligned Index includes only 427 constituents compared with 1 377 in their Emerging Markets Index that it is based on. There is no Paris aligned version of MSCI's Frontier Markets Index, which makes it very challenging for investors to access these markets while also pursuing a strategy based on Paris-alignment. Even without the index challenge, there is a risk that the move to decarbonise financial portfolios will disadvantage EMDEs since ESG and climate-related data are less widely available in these markets. For example, of the nearly 5 000 companies that have committed to set science-based targets, only 16% are in EMDEs (and 29% of those are China). Where ESG scores do exist, the IMF recently found that listed EMDE firms tend to have lower scores on average than their advanced economy peers and that allocations to EMDEs by ESG funds are lower than non-ESG funds.

All of these limitations restrict the amount of equity investment from large institutional capital into clean energy in EMDEs. Such capital can play a key role in supporting on-balance sheet financing, refinancing or the acquisition of existing assets. Institutional investors need to balance regional and sector risk across their portfolios, which is always likely to act as a ceiling on their investment in clean energy in EMDEs. Further efforts to increase the pool of listed clean assets in EMDEs would support diversification, but these must happen in tandem with other strategies to reduce perceived and actual risk in those markets. Public capital, as well as concessional tools such as guarantees or blended finance approaches, will play a key role here. Over the longer term, growing domestic institutional capital will also be vital. This has the advantage of not creating a currency mismatch and is also likely to be better aligned given the smaller size of many domestic finance sources in EMDEs.

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Sustainable debt issuances

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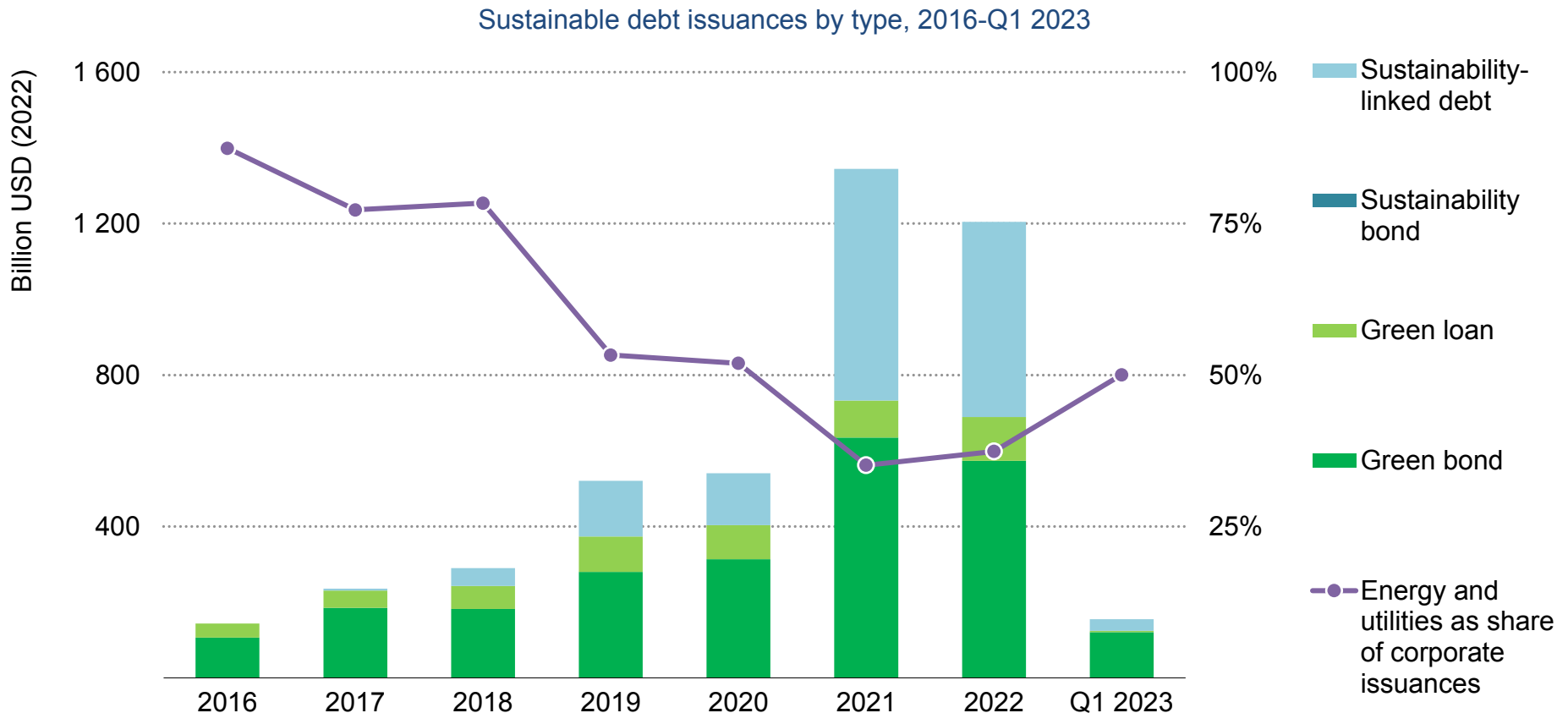
Labelled sustainable debt issuances fell in 2022 for the first time, but were still significantly higher than in 2020, including from issuers of corporate energy and utility debt



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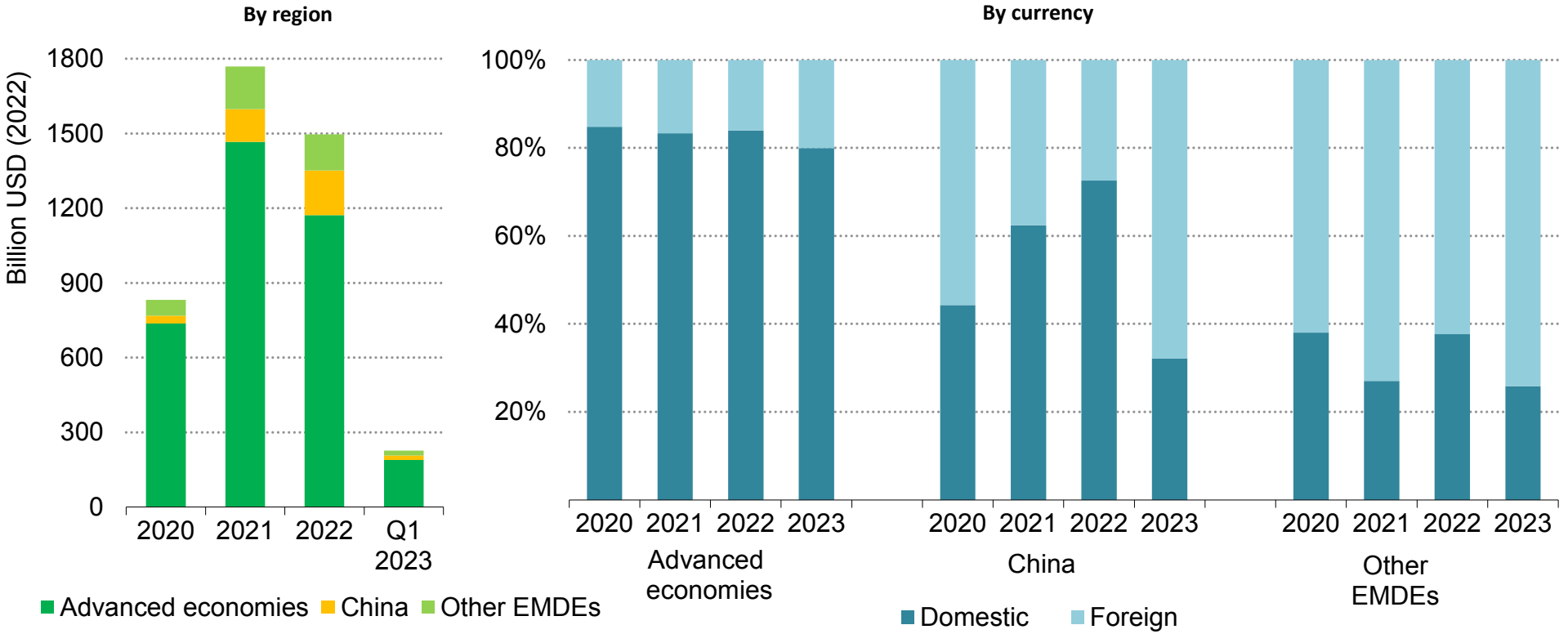
Advanced economies continue to dominate issuances, and in EMDEs (excluding China) most issuances are still in foreign currency, primarily USD and EUR

Sustainable debt issuances by region and currency, 2020-2023



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Despite a difficult year, early indications show a positive outlook for sustainable issuances in 2023, including in the growing green-labelled loan space

Labelled sustainable debt issuances remained significantly higher in 2022 than the 2016-2020 average, but saw a decline in issuances for the first time since their inception. This reflected trends across the fixed income market, with sustainable issuances holding steady at 5% of the global market in both 2021 and 2022. Green bonds still make up the largest share of issuances at 40%, closely followed by sustainability-linked bonds, despite questions around their real-world impact (see Box below). Although corporate issuances in the energy and utility sectors fell slightly from 2021 levels, they were nearly double the level seen in 2020, showing the general upward trend.

Advanced economies still account for over 80% of issuances, although China has been the second largest issuer since 2021. Issuances in other EMDEs marginally increased from 8% in 2020 to 10% in 2022. Where EMDE issuances do occur, they are still dominated by hard currency, making them more appealing to international investors but exposing them to foreign exchange risk.

Trends in Europe, China and the United States indicate that 2023 is likely to see a continuing high level of issuances. In Europe, the European Central Bank – the largest buyer of corporate bonds – has committed to tilt its corporate bond purchases to green, which is likely to result in higher spreads for heavy emitters, and further demonstrate the pricing benefits of green issuances. Meanwhile the release of China's Green Bond Principles in July 2022 and the Common Ground Taxonomy that outlines commonalities with the EU taxonomy is likely to spur further growth in China's green bond market. Green bond issuances in the United States are also likely to be boosted by the Inflation Reduction Act, as incentives drive clean energy project development. Alongside these regulatory tailwinds, higher interest rates are likely to push more towards sustainable debt issuances due to the possibility of a "greenium", i.e. a pricing benefit based on the issuance's green credentials.

An interesting development is that labelled green loans had been relatively static since 2019, totalling between USD 90-100 billion, but rose by nearly 20% in 2022 as more sectors outside energy and utilities began adopting them. Green loans play an important role in part because they are smaller instruments than bonds and hence have a wide array of uses, including in EMDEs. Despite the rise in green loans, banks are still providing more support to fossil fuels. A report from Bloomberg found that in 2021 (latest available data), banks lent 81 cents for financing low-carbon energy supply for every one dollar they provided to fossil fuels. The report found large regional variations based on supply conditions and regulations, ranging from a ratio of 2.6:1 in Europe to 0.1:1 in Africa and the Middle East.

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Sustainability-linked bonds

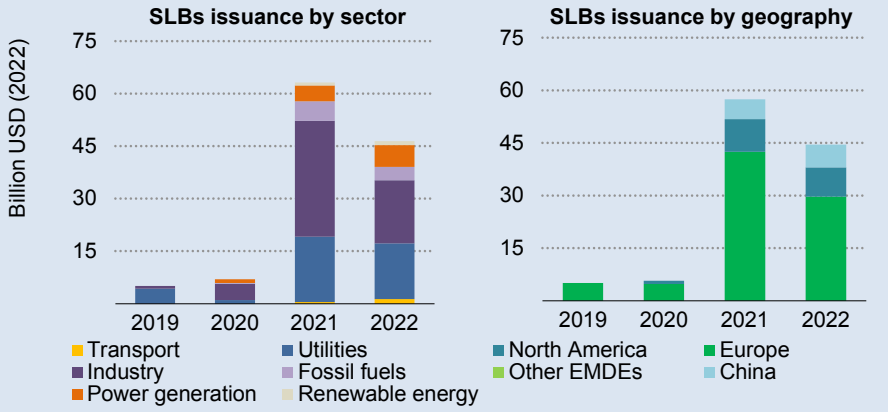
Sustainability-linked bonds (SLBs) provide a flexible way for companies or governments to access the green debt market, especially those in sectors that are difficult to decarbonise or those that need to implement organisation-wide decarbonisation measures. These bonds are like traditional bonds but have a unique structure where the interest paid to bondholders can vary based on the issuer's achievement of certain sustainability targets, such as reducing emissions intensity or absolute emissions reductions.

Unlike green bonds, SLBs do not require strict reporting on the use of proceeds, making them available to a wider range of companies and governments who may otherwise struggle to identify enough projects that would meet the use of proceeds limitations. SLBs have been used by a wide variety of industries including fossil fuel power operators, notably in China, and utilities in Europe. Chile and Uruguay piloted the issuance of sovereign SLBs linked to GHG reduction targets.

SLBs can serve as valuable source of transition finance, although there have been occasional instances where concerns have been raised regarding the perceived justification of the financial benefits enjoyed by issuers, for instance in the case where the specified sustainability targets are already met at the time of issuance. Or when companies with higher emission profiles use these bonds while having less ambitious decarbonisation targets than their peers.

Analysis has also shown that, on average, the savings from reductions in the cost of debt tended to exceed the maximum potential penalty that issuers would need to pay in case of failure of the sustainability performance target. The credibility of SLBs would benefit from standardisation and clearer regulation, through initiatives such as the ICMA Sustainability-Linked Bonds Principles that help hold governments and companies to their climate commitments.

SLB issuance by sector and country, 2019-2022



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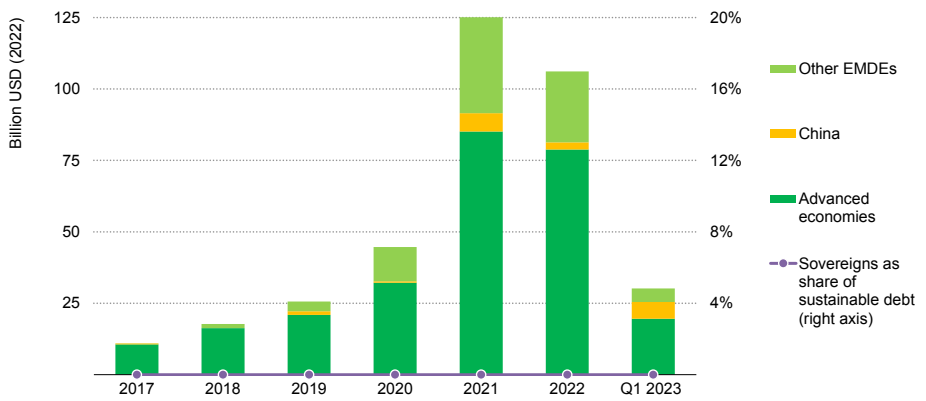
After a slow start, sovereigns issuances have more than doubled since 2020, providing a useful tool to raise lower-cost capital and to drive sustainable practices within local capital markets

The first sovereign green bonds were issued in 2017 by Poland and France, and since then there have been 41 new issuers, many of whose bonds have been oversubscribed. Sovereigns have grown from 4% of total sustainable debt issuances in 2017 to 7% in 2022. Much of the growth has been in hard currency, and European governments make up over half of issuances. There is significant potential for further growth, with sustainable debt issuances between 2017 and 2021 accounting for only 0.5% of total sovereign issuances.

The long tenors and pricing advantages of sustainable debt make them a useful tool for governments. The longest green bond issuance came from Singapore in August 2022 when the government raised SGD 2.4 billion (USD 1.7 billion) with a 50-year tenor. As with corporate issuances, most sovereign green bonds have attracted lower yields than comparable vanilla bonds. This can be particularly valuable in middle-income countries that do not have easy access to concessional debt but where the debt burden remains high.

Despite their benefits, challenges remain. “Use of proceeds” bonds have been slower to take hold with sovereigns because of concerns around fungibility. Public finance management practices, sometimes enshrined in law, may preclude the use of funds for a specific purpose. This is driving the rise of sustainability or sustainability-linked bonds, which provide more flexibility.

Sovereign sustainable debt issuances, 2017-Q1 2023



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Sources: IEA analysis based on data from Bloomberg and Refinitiv (2023).

Beyond providing a useful source of public finance, sovereign issuances play a key development role for local capital markets. Notably, 38 countries that have issued sovereign green or sustainable bonds have also announced green bond frameworks in line with the International Capital Market Association principles. Often facing higher levels of scrutiny, sovereign issuances are able to demonstrate best practices, such as the use of external reviewers, mandatory impact assessments, and rules on the share of capital raised that can be used for refinancing versus new investments.

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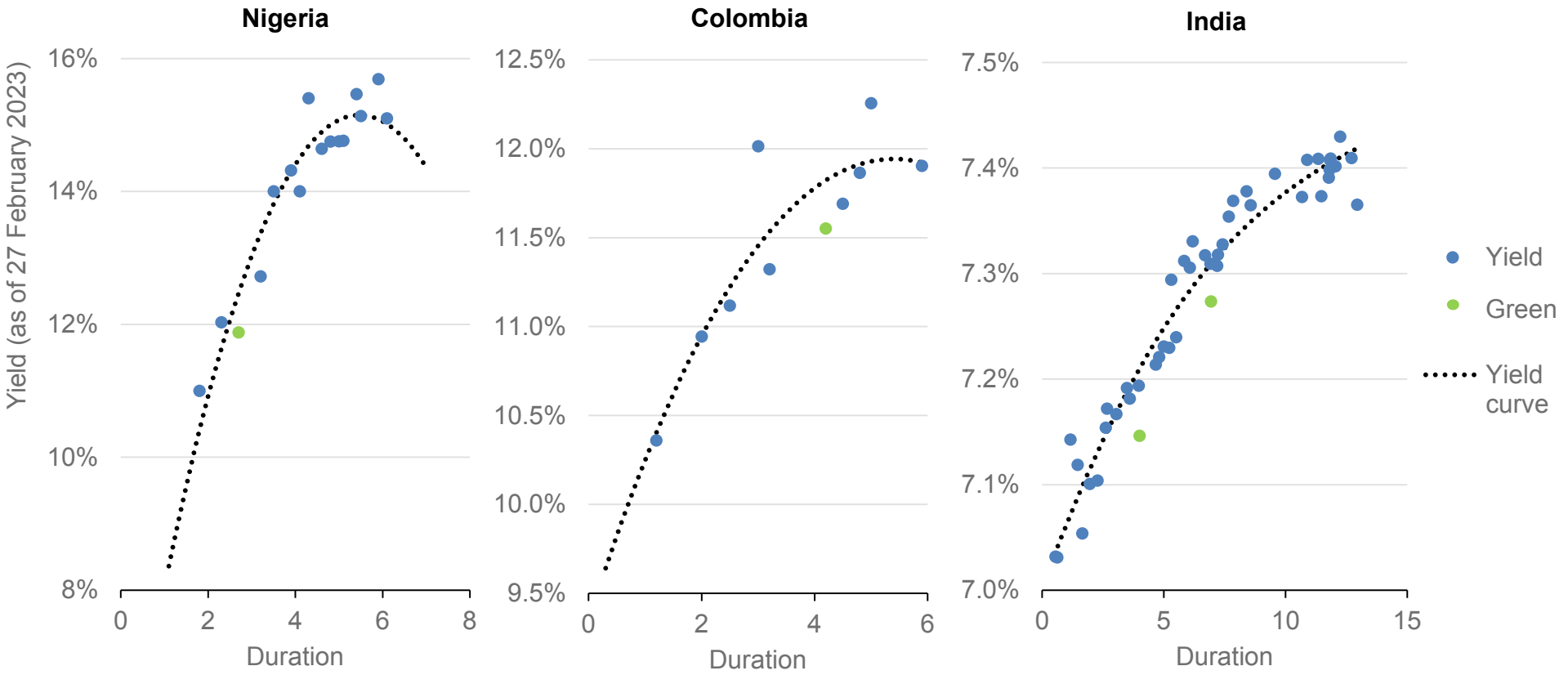
Sovereign green bonds in EMDEs have benefited from a greenium, demonstrating their value as a tool for governments that already have high debt burdens

Yield curve of sovereign bonds from selected emerging and developing countries



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Sovereign bonds can have knock-on effects for green corporate bonds and domestic currency financing from both local and international sources

EMDE governments have used green bonds to raise local currency financing for infrastructure projects, and even without an investment-grade rating, they have benefited from the greenium. Green bonds are likely to be most applicable to countries that have reasonable debt sustainability and have a growing domestic capital market.

Nigeria: The Nigerian government launched the Green Bond Market Development Programme in 2017. So far, under the programme there have been two sovereign issuances with a combined value of NGN 25.7 billion (USD ~70 million) and four corporate issuances totalling NGN 32.7 billion (USD ~72 million). The 2017 sovereign green bond was the first of its kind in Africa and was followed by a second in 2019. Both bonds achieved a greenium and were used to support projects in renewable energy, primarily rooftop solar and rural electrification, and afforestation. However, questions have been raised about the implementation of projects and reporting has not been made available on the environmental impact of the bond proceeds. Ensuring best practices on reporting is likely to increase confidence in the market, particularly among international investors.

Colombia: In September 2021 the Colombian government released a national green taxonomy, followed by a COP 750 billion (USD 200 million) green bond. Originally planned at COP 500 billion, the bond was upsized after being 4.6 times oversubscribed by investors. At the time of issuance, it was estimated that the bond secured a greenium of 7 basis points (bps). A second sovereign green bond was issued a month later, with the government estimating a 15 bps greenium. Roughly 40% of the bond investors were domestic, demonstrating their comfort with this type of instrument and having knock-on positive effects for corporate green issuances. Proceeds from the bonds will support the development of sustainable transport systems and renewables, among other environmental goals.

India: In late 2022 the Indian government launched the country's first green bond – an INR 80 billion (USD 1 billion) deal divided equally into a 5-year and a 10-year tranche. The deal was 4 times oversubscribed, and a month after the initial offering, both tranches were reopened for a further INR 40 billion (USD 500 million). The proceeds will be spent on a variety of renewable power projects, low-emissions hydrogen, public transport and afforestation. Both the initial offerings and the reopening attracted a greenium of 5-6 bps, although these have reduced over time due to illiquidity in the market. Alongside pricing, one of the primary benefits of these instruments is tapping into new financing sources. Many of the corporate green bond issuances in India have previously been in US dollars, and it is likely that the government is hoping the sovereign issuances will help develop a local market. The majority of investors were domestic, with foreign investors seemingly deterred by the currency risk.

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Annex

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Abbreviations and acronyms

ADNOC	Abu Dhabi National Oil Company
APS	Announced Pledges Scenario
BEV	Battery-Electric Vehicles
CAGR	Compound Annual Growth Rate
CCGT	Combined-Cycle Gas Turbine
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon Dioxide
CVC	Corporate Venture Capital
DAC	Direct Air Capture
EMDE	Emerging Markets and Developing Economies
ESG	Environmental, Social, and Governance
ETF	Exchange-Traded Fund
ETS	Emissions Trading Scheme
EUR	Euro
EV	Electric Vehicle
FID	Final Investment Decision
FSRU	Floating Storage Regasification Unit
GBP	British Pound Sterling
GHG	Greenhouse Gas
ICE	International Combustion Engine
ICT	Information and Communications Technology
IPCEI	Important Projects of Common European Interest
IT	Information Technology
LCE	Lithium Carbonate Equivalent
LCOE	Levelized Cost of Electricity
LNG	Liquified Natural Gas
MENA	Middle East and North Africa
NOC	National Oil Companies
NZE	Net Zero By 2050 Scenario
OCGT	Open-Cycle Gas Turbine
OECD	Organisation For Economic Co-Operation and Development
OPEC	Organization of The Petroleum Exporting Countries
PACE	Property-Assessed Clean Energy
PHEV	Plug-In Hybrid Electric Vehicle
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development and Demonstration
SES	Solid Energy Systems
SOE	State-Owned Entity
STEPS	Stated Policies Scenario
USD	United States Dollar
VC	Venture Capital
WEI	World Energy Investment

Units of measure

g	Gram
GW	Gigawatt
GWh	Gigawatt Hour
kg	Kilogram
mb/d	Million Barrels of Oil per Day
MBtu	Million British Thermal Units
Mt	Million Tonnes

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MW	Megawatt
MWh	Megawatt Hour
TWh	Terawatt Hour

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