Renewable Energy Market Update

Outlook for 2023 and 2024

International Energy Agency

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Abstract

The key areas examined by the report include the latest data and analysis on renewable power capacity additions in 2022 – globally and for major markets – as well as forecasts for 2023 and 2024.

The update will look at key topics for renewables this year and next, including how the energy crisis will affect their deployment in the EU, their impact on energy affordability, and the latest trends in the United States, China and India. It will also explore the implications of developments affecting major technologies like solar, wind and biofuels – including market dynamics, financing, energy security priorities, manufacturing and power system integration.

The report provides the IEA's latest assessment of the state of play in renewables markets since the publication of our Renewables 2022 report in December.

In exploring the most recent market and policy developments as of April 2022, our Renewable Energy Market Update forecasts new global renewable power capacity additions and biofuel demand for 2023 and 2024. It also discusses key uncertainties and policy-related implications that may affect projections for 2024 and beyond.

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Executive summary

Led by solar PV, renewable power growth is surging – driven by the global energy crisis and policy momentum

Global renewable capacity additions are set to soar by 107 gigawatts (GW), the largest absolute increase ever, to more than 440 GW in 2023. This is equivalent of more than the entire installed power capacity of Germany and Spain combined. This unprecedented growth is being driven by expanding policy support, growing energy security concerns and improving competitiveness against fossil fuel alternatives. These factors are outweighing rising interest rates, higher investment costs and persistent supply chain challenges.

Solar PV capacity, including both large utility-scale and small distributed systems, accounts for two-thirds of this year's projected increase in global renewable capacity. In response to higher electricity prices caused by the global energy crisis, policy makers in many countries, particularly in Europe, have actively sought alternatives to imported fossil fuels that can improve energy security. This shifting focus created a favourable environment for solar PV, especially for residential and commercial systems that can be rapidly installed to meet growing demand for renewable energy. These smaller distributed PV applications are on track to account for half of this year's overall deployment of solar PV – larger than the total deployment of onshore wind over the same period.

Following two consecutive years of decline, onshore wind capacity additions are on course to rebound by 70% in 2023 to 107 GW, an all-time record amount. This is mainly due to the commissioning of delayed projects in China following last year's Covid-19 restrictions. Faster expansion is also expected in Europe and the United States as a result of supply chain challenges pushing project commissioning from 2022 into 2023. On the other hand, offshore wind growth is not expected to match the record expansion it achieved two years ago due to the low volume of projects under construction outside of China.

Solar PV additions will continue to increase in 2024 while challenges remain for wind expansion. Declining module prices, greater uptake of distributed solar PV systems and a policy push for large-scale deployment are driving higher annual solar additions in all major markets – including China, the European Union, the United States and India. In contrast, without rapid policy implementation, global onshore wind additions in 2024 are expected to fall by around 5% from 2023 levels. While China's wind energy additions will continue to increase in 2024, they are set to be more than offset by undersubscription of auctions and pending permitting delays in Europe. The situation in Europe is expected to improve once

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new legislation is implemented. Overall, cumulative world renewable capacity is forecast to reach over 4 500 GW at the end of 2024, equal to the total power capacity of China and the United States combined.

Global renewable capacity additions could reach 550 GW in 2024 in our accelerated case, almost 20% higher than in the main forecast. This is mainly due to a more rapid deployment of residential and commercial PV installations, assuming a faster implementation of recent policies and incentives. The upside for utility- scale onshore wind and solar PV projects mostly depends on the pace of permitting, construction and timely grid connection of projects under development.

Renewables are at the forefront of Europe's response to the energy crisis

The crisis triggered by Russia's invasion of Ukraine has accelerated renewable energy deployment in the European Union, driving the bloc to urgently reduce its dependence on Russian natural gas imports. Policy actions in many European countries has led us to revise our forecast for renewable capacity additions in the EU in 2023 and 2024 upwards by 40% compared with before the war. Rapid growth in distributed solar PV is the main reason for the more positive outlook, accounting for almost three-quarters of the EU forecast revisions. This is driven by high electricity prices that make solar PV more financially attractive and by increasing policy support in key EU markets, especially in Germany, Italy and the Netherlands.

European countries introduced more policy and regulatory changes to ease permitting in the last 18 months than over the entire previous decade. While permitting has become a key policy focus in Europe to accelerate the deployment of large-scale wind and solar PV and early benefits are starting to be visible, the proposed policy changes are expected to have limited impact on the deployment of renewables in 2023 and 2024 compared with other drivers, such as installations of small-scale residential and commercial solar PV.

EU electricity consumers are set to save an estimated EUR 100 billion during the 2021-2023 period thanks to newly installed solar PV and wind capacity. Accelerating renewable energy deployment in Europe since 2021 has mitigated the economic impact of the energy crisis. Low-cost wind and solar PV are on course to displace an estimated 230 terawatt-hours (TWh) of expensive fossil fuel generation over the 2021-2023 period, helping to reduce wholesale electricity prices in all European markets. Without these capacity additions, the average wholesale price of electricity in the EU in 2022 would have been 8% higher, hurting consumers, businesses and government budgets.

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Renewables could help Europe displace more natural gas for heating buildings next winter. Last year was the second warmest winter on record in Europe, which helped the EU use less gas for heating buildings. Projected growth of renewable energy such as clean electricity, bioenergy boilers, heat pumps, and solar thermal and geothermal technologies could displace almost 8 bcm of EU buildings-related gas consumption annually in 2023 and more than 17 bcm in 2024. This would represent a significant contribution to cover increasing gas demand, should harsher winters and hotter summers occur over the course of 2023-2024.

China is poised to outpace the rest of the world in renewable capacity installations in 2023 and 2024

China's contribution to global renewable capacity additions is expected to increase in 2023 and 2024, consolidating its position as the undisputed leader in global deployment. In 2022, China accounted for almost half of all new renewable power capacity worldwide. By 2024, the country's share is set to have expanded to a record 55% of global annual renewable capacity deployment. By 2024, China will deliver almost 70% of all new offshore wind projects globally, as well as over 60% of onshore wind and 50% of solar PV projects.

In the United States, capacity additions will rebound this year after a difficult 2022. The US markets for wind and solar PV contracted last year due to restrictive trade measures and supply chain constraints, but annual additions for both technologies are set to increase by around 40% in 2023, with solar PV setting a new record. The current forecast is underpinned by existing tax incentives, while the Inflation Reduction Act will show its full effect after 2024, providing unprecedented certainty for renewable energy projects until 2032.

India's renewable capacity additions are expected to increase again in 2023 and 2024, owing to faster onshore wind, hydropower and distributed solar PV deployment. However, utility-scale solar PV projects, India's largest renewable electricity growth segment, are expected to slow briefly this year due to supply chain challenges, lower auction volumes and trade policies. While large-scale PV manufacturing is emerging in India, import tariffs are causing short-term demand and supply mismatches.

Competitiveness of wind and solar PV has improved, but policies need to adapt to changing market conditions

Electricity generation costs from new onshore wind and solar PV plants are projected to decline by 2024 but will likely remain 10-15% above their pre-Covid levels in most markets outside China. Regardless, solar PV and onshore wind remain the lowest cost options for new electricity generation in most

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countries. Future power contracts for the end of 2023 and into 2024 in the European Union, the United States, Japan, Australia and India indicate wholesale power prices two to three times above 2020 averages. Today, wind and solar PV plants can provide electricity at prices 30-50% lower than those of future power contracts in most key markets, increasing renewables' attractiveness for investors.

Policy uncertainties and volatile prices left one-sixth of renewable energy auction volumes unallocated in 2022. Competitive renewable energy auctions resulted in the awarding of a record-breaking 100 GW of capacity. However, 20 GW remained unallocated, the highest ever level with Europe accounting for two-thirds of it. Government auction designs need to take into account recent inflation, interest rate rises and turbulence in commodity prices – and to envisage dynamic indexation methods to attract investments.

Market-driven procurement is expected to contribute to approximately one-fifth of solar PV and wind capacity expansion in 2023 and 2024, driven by corporate power purchase agreements. The United States leads expansion in corporate power purchasing agreements, followed by Brazil, Australia, Spain and Sweden. These agreements are motivated by the economic attractiveness of renewables, by the opportunity to hedge against rising and volatile power prices, and by sustainability goals.

The financial health of renewable energy value chains is critical for the industry's sustainable growth. Despite challenges from volatile commodity prices, higher interest rates, supply chain constraints and trade measures, the renewable energy industry has shown financial resilience overall. However, there is significant variation across sectors and countries. The solar PV manufacturing sector has a positive outlook with increasing capacity additions, but potential supply gluts and declining prices may reduce company profit margins. Western wind manufacturers face challenges from high commodity prices, as well as permitting and auction designs that do not reflect changing financing environments. While the energy crisis has also hurt the profitability of some specific electricity utilities, these companies overall are maintaining their role as large investors in renewables.

Global manufacturing capacity of solar PV is projected to reach nearly 1 000 GW in 2024, sufficient to meet annual demand in the IEA's Net Zero Emissions by 2050 Scenario. In contrast, wind equipment manufacturing is expanding more slowly and may struggle to keep up with demand growth through 2030. While China will continue to dominate global manufacturing capacity for solar PV, announcements of solar PV manufacturing projects in the United States and India have doubled since December, indicating that supply chains are diversifying in the medium term.

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The rapid expansion of wind and solar PV needs to be accompanied by policies and market rules supporting grid infrastructure and flexibility investments. An increasing amount of electricity generation from wind and solar PV is being curtailed in many markets, particularly where grid infrastructure and system planning lag behind deployment of these variable renewables. However, curtailed generation remains relatively low, ranging from 1.5% to 4% in most large renewable energy markets. Multiple countries in Europe – including Spain, Germany and Ireland – will see their annual share of wind and solar PV reach over 40% by 2024, which will require effective grid management to hold back rising curtailment rates.

Biofuels have supported energy security during the recent crisis but are facing challenges of their own

Biofuels avoided the consumption of 2 million barrels of oil equivalent per day (mboe/d) in 2022, equivalent to 4% of global transport sector oil demand. Argentina, India and Indonesia all accelerated biofuel use in 2022. However, while biofuels offered energy security benefits, their prices climbed more quickly than those of gasoline and diesel in many countries. To mitigate increases in transport fuel costs, Brazil, Sweden and Finland delayed planned increases to biofuel blending obligations in 2022.

Biofuel prices are set to decline in 2023 and 2024 while remaining well above pre-Ukraine war levels. Biofuel prices have declined in all major markets from their peaks in 2022. In the first four months of 2023, ethanol prices declined 7%-16% from their 2022 average and biodiesel prices dropped 15%-28% across different markets. While below 2022 peaks, prices for major biofuel feedstocks such as corn, sugar and vegetable oils are expected to remain above pre-war price levels, keeping biofuel prices at historically high levels through 2024.

Biofuel demand is to expand by 11% by 2024, supported by existing policies targeting energy security objectives. Only Indonesia and Brazil are accelerating deployment by 2024. In advanced economies, new policies are not likely to influence production until after 2024 as high prices, feedstock concerns and technical constraints limit additional growth potential.

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Introduction

The IEA created the *Renewable Energy Market Update* in March 2020 to evaluate the short-term impact of the unprecedented Covid-19 crisis on renewable energy. As part of the IEA's Renewables Market Report Series, this update concentrates on short-term deployment trends rather than offering a comprehensive five-year forecast for electricity, transport and heat developments. The 2020 and 2021 assessments focused on renewable energy market implications of the Covid-19 pandemic in an increasingly challenging economic environment.

In 2022, the Russian Federation's (hereafter "Russia") invasion of Ukraine sent shockwaves through energy and agriculture markets, resulting in the world's most serious energy crisis to date. Last year's edition of this report therefore provided an early assessment of possible short-term impacts of the war on renewable energy capacity additions and biofuel demand.

This year, with geopolitical tensions, a fragile global economy and high energy prices persisting, policy makers and investors as well as industry and civil society members involved in renewable energy have more questions than answers concerning recent developments. This year's *Renewable Energy Market Update* has thus been redesigned to address 21 key questions that focus on the renewable energy outlook for 2023 and 2024.

Despite the global energy crisis, renewable electricity capacity additions broke another record in 2022, prompting us to ask:

1. ***Did all renewable electricity technologies break deployment records in 2022?***

The answer is no, but this leads naturally to a more pertinent question concerning the short-term outlook:

2. ***Will renewable electricity capacity additions continue to break new records in 2023 and 2024?***

The global energy crisis that followed Russia's invasion of Ukraine hit Europe's energy systems hard due to their dependence on Russian natural gas imports. This report attempts to answer four questions concerning Europe's changing policies and market developments, and their implications for renewable energy in 2023 and 2024:

3. ***How will the energy crisis affect EU renewable energy deployment in 2023 and 2024?***
4. ***How much less money is the European Union spending on expensive electricity thanks to additional renewable energy capacity?***
5. ***Will hydropower in Europe recover in 2023?***

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6. ***How are European countries addressing permitting challenges to accelerate renewable energy development?***
7. ***To what extent can renewable energy use displace gas consumption in EU buildings in 2023 and 2024?***

While the European Union is accelerating deployment to address energy security concerns, the People's Republic of China (hereafter "China") remains the world's largest renewable energy market for all renewable energy technologies. The country's share in global capacity additions depends on policy changes and market conditions, impacting the global outlook. This report's seventh question is therefore:

8. ***Will China's share in global renewable energy deployment decline in 2023 and 2024?***

In the United States, the Inflation Reduction Act (IRA) has introduced unprecedented policy uncertainty for wind and solar PV developers, begging the question:

9. ***How will the US Inflation Reduction Act impact wind and PV deployment in the short term?***

Meanwhile, in India, considerable supply chain challenges stemming from the Covid-19 crisis have affected renewable energy development, causing us to wonder:

10. ***Will India's renewable energy deployment boom in 2023 and 2024?***

The global energy crisis has placed energy and supply chain security at the heart of global policy discussions. Although enlarging renewable energy use could tackle multiple policy challenges at the same time – including those related to energy security, climate change and affordability – deployment could be deterred by supply chain challenges, high prices and elevated interest rates. The next four questions therefore address emerging policy and regulatory hurdles and ongoing macroeconomic challenges:

11. ***Are competitive renewable energy auctions increasingly undersubscribed?***
12. ***Will market forces now drive the expansion of wind and solar PV plants, or is policy still key?***
13. ***Is the renewable energy industry's financial health improving?***
14. ***Will solar PV and wind costs finally begin to fall again in 2023 and 2024?***

While more favourable policies and market conditions can accelerate renewable capacity deployment, system integration and grid expansion implications are bound to arise. Our next two questions therefore address the threats of rising curtailment rates and slow grid expansion, which could impede project application:

15. ***Do higher shares of wind and solar PV generation always imply more curtailment?***

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16. How are higher shares of wind and solar PV challenging power systems?

Demand for solar PV panels and wind turbines will grow drastically over the next decade to meet the IEA Net Zero Emissions by 2050 Scenario targets. The race to acquire the capacity to meet this demand is therefore ongoing and clean energy technology manufacturing is expanding rapidly, but we have to wonder:

17. Will global solar PV and wind technology manufacturing capacity be adequate to meet Net Zero demand in 2030?

Even though electricity remains at the core of global energy discussions, the transport sector registers greater final energy consumption than the electricity sector. Because the energy crisis has also affected biofuel supply, demand and prices worldwide, our final section of questions relates to the impact of biofuels on energy security:

18. Where were governments able to rely on biofuels to secure energy supplies during the 2022 energy crisis?

19. Will energy security concerns drive biofuel growth in 2023-2024?

20. Will we see lower biofuel prices in 2023-2024?

21. What are governments and companies doing to avoid a supply crunch, and is it enough?

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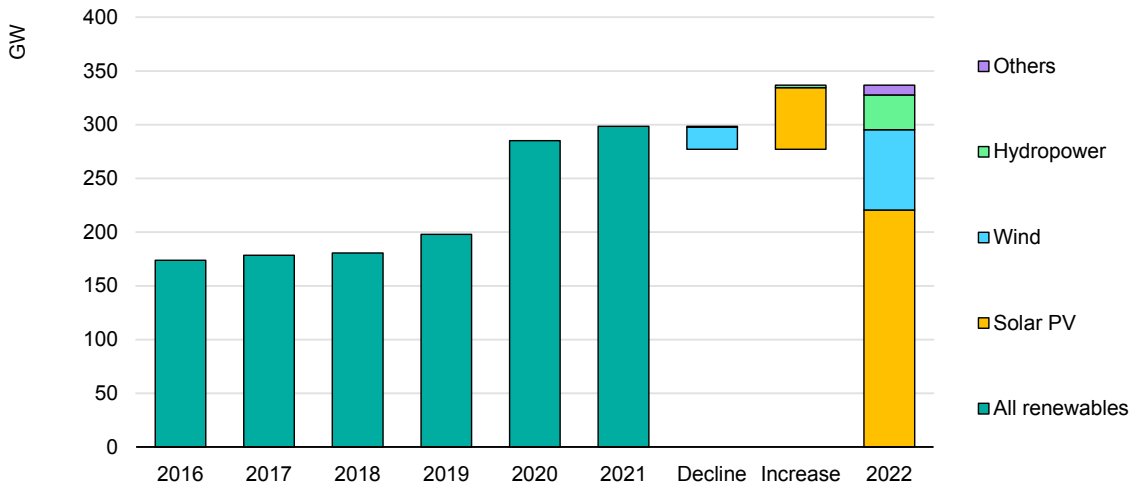
Did all renewable electricity technologies break deployment records in 2022?

Solar PV was the only technology to break a record for annual capacity additions

Overall renewable energy capacity additions rose by almost 13% to nearly 340 GW in 2022. However, solar PV was the only technology that broke a deployment record last year, with net additions of nearly 220 GW – a 35% increase from 2021. Expansions in China and the European Union alone accounted for over 85% of the growth in annual PV capacity additions.

Annual PV growth rose in all major markets last year except the United States, where it shrank almost 15% due to supply chain challenges and rising costs. After solar PV, hydropower was the next-largest contributor to record-level renewable energy expansion globally, owing to the commissioning of multiple large projects, mostly in Asia. While global hydropower capacity additions did not break any records, they were the highest they have been since 2016 thanks to continuous expansion in China.

Renewable electricity net annual capacity additions, 2017-2022



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Wind power capacity additions decreased the past two consecutive years

Annual wind capacity additions fell 21% from 2021 to 2022, declining for the second year in a row following record-level expansion in 2020, when developers in China were rushing to complete projects before subsidies from the central government ended that year. In 2022, Covid-related restrictions delayed the commissioning of multiple wind projects in China, resulting in a drop in annual additions.

Like in China, capacity additions in the US market declined for the second consecutive year because of policy uncertainty ahead of promulgation of the Inflation Reduction Act (IRA) and supply chain constraints leading to project delays. In the European Union, however, wind capacity growth was much stronger thanks to rapid expansion in Germany with the commissioning of previously auctioned capacity, and in Spain owing to its large corporate PPA market.

Global additions of bioenergy production for power generation also declined in 2022 due to the phaseout of subsidies in China, the world's largest market. For geothermal and concentrated solar power (CSP) technologies, global annual market growth remained small but stable because policy support is concentrated in just a few countries.

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Will renewable electricity capacity additions continue to break new records in 2023 and 2024?

The deployment of new renewable electricity installations is expected to break records in both 2023 and 2024 thanks to strong and continuous policy support as well as high electricity prices, which will increase the economic attractiveness of distributed PV systems. Global renewable capacity additions are set to soar by 107 gigawatts (GW), the largest absolute increase ever, to more than 440 GW in 2023. Despite a hike in interest rates, rising system costs and persistent supply chain challenges, faster solar PV and wind expansion underpins this acceleration due to continuous policy support and improving competitiveness. Renewables will break another annual deployment record in 2024, driven by solar PV, which will account for the two-thirds of next year's entire renewable capacity additions.

2023: Solar PV dominates growth, and onshore wind additions rebound to break the 2020 record

Solar PV remains the main source of global renewable capacity expansion in 2023, accounting for 65% of growth with distributed applications, including residential and commercial systems, accounting for almost half of global PV expansion. Since Russia's invasion of Ukraine, the global energy crisis has driven up wholesale and retail electricity prices in many parts of the world, making small solar PV systems more economically attractive for residential and commercial customers. Policy makers in many countries, especially in Europe, have been seeking options for immediate diversification away from imported fossil fuels, improving the policy environment for distributed solar PV systems that can be installed rapidly.

Following two consecutive years of decline, annual global onshore wind capacity additions are expected to jump 70% in 2023 to break the 2020 record. This surge is being fuelled mostly by the commissioning of projects in China that were delayed by Covid-related restrictions last year. Supply chain challenges also slowed the pace of construction in the United States and Europe, pushing project commissioning from 2022 to 2023.

Offshore wind growth is also expected to recover from a major drop in annual additions last year resulting from a policy rush in China in 2021. While annual

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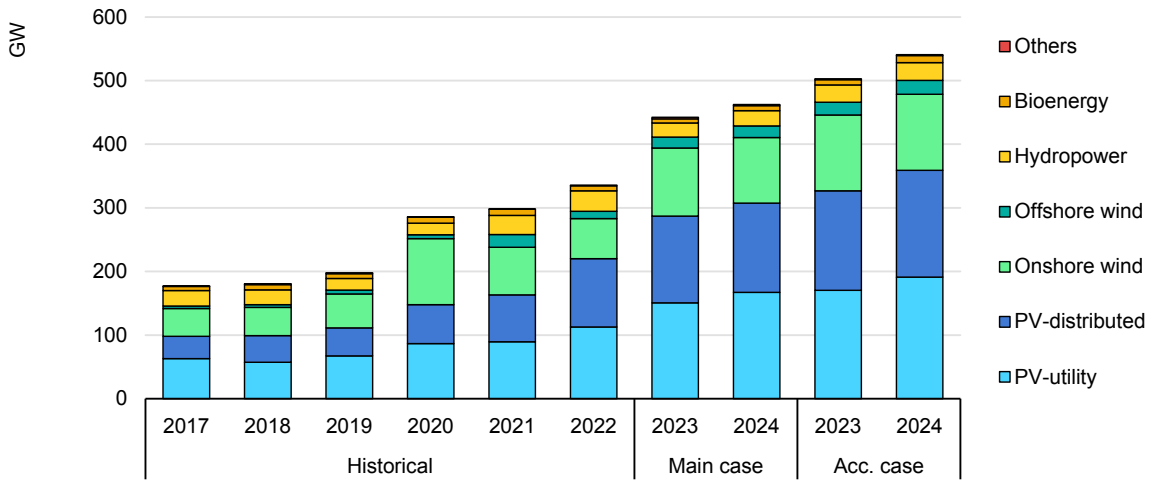
offshore additions are forecast to increase almost 50% in 2023, this growth is not sufficient to match the record-level expansion of two years ago.

In the accelerated case, renewable capacity additions could reach over 500 GW this year, almost 15% higher compared with the main case. Distributed solar PV accounts for the largest upside. While new policies incentivise residential and commercial PV installations and higher electricity prices improve the business case, uncertainty remains over the pace of consumer adaption considering current macroeconomic environment with elevated interest rates. The upside for utility-scale onshore wind and solar PV projects mostly depends on the pace of construction, permitting and timely grid connection of projects under development.

Net renewable electricity capacity additions by technology, historical, main and accelerated cases



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2024: Another record year for global capacity additions, led by solar PV

Annual solar PV market growth is expected to continue, reaching almost 310 GW in 2024, an increase of over 7% from 2023. Lower module prices, greater distributed PV system uptake and a policy push for large-scale deployment trigger higher annual additions in all major markets including China, the European Union, the United States and India. In Brazil, policy changes on net metering rules reduce remuneration rates for surplus generation and cause additions to decline from 2023 to 2024.

For onshore wind, annual additions are expected to fall around 4% from 2023 to 2024. While China's wind energy expansion is forecast to continue with the commissioning of large-scale onshore projects in mega-bases in the northeast as well as provincial incentives that support offshore plants, additions in other major

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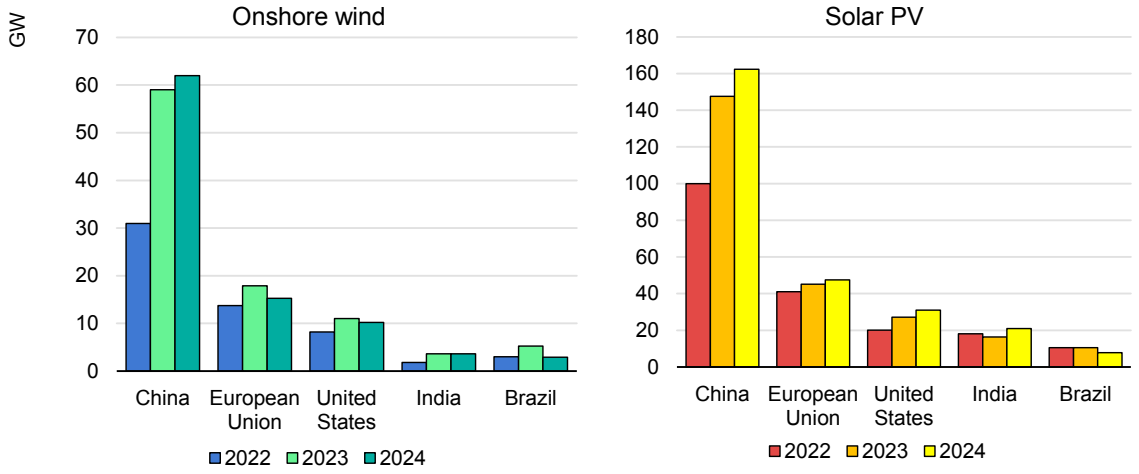
markets are expected to decline. In Europe, undersubscription in multiple auctions in Germany and Spain, permitting delays in France and turbine placement restrictions in Poland prevent faster wind expansion. In the United States, the pace of adding new capacity decelerates in 2024 because production tax credit rates are lower than under the previous federal policy.

Net renewable electricity capacity additions by country/region, main case



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Meanwhile, higher turbine prices in India due to supply chain challenges reduce the bankability of already-auctioned projects, resulting in delays. Limited auction capacity in the Brazilian market also cuts annual wind additions by half between 2023 and 2024.

In the accelerated case, renewable power capacity additions in 2024 could be 17% higher than in the main case forecast, reaching over 540 GW. This will require both faster deployment of distributed PV systems and expedited commissioning of large-scale solar and wind projects in the pipeline, especially in China, Europe, India and the United States.

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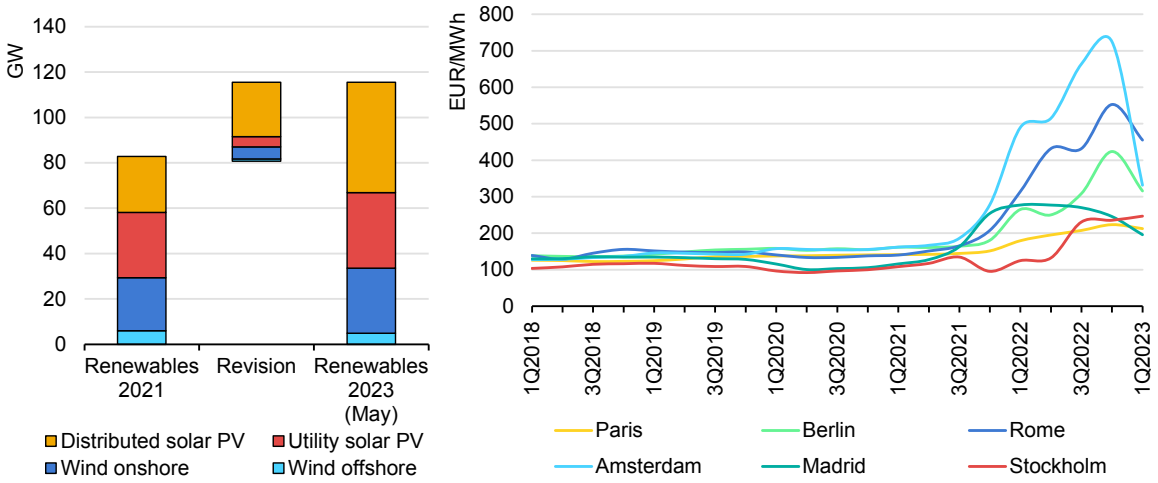
How will the energy crisis affect EU renewable energy deployment in 2023 and 2024?

Russia's invasion of Ukraine has pushed the accelerator on renewable energy deployment in the European Union, impacting short-term deployment especially, as the bloc urgently needs to reduce its dependence on Russian natural gas imports. As a result of policy actions in many European countries, we have revised the forecast for renewable capacity additions for 2023 and 2024 upwards by 38% compared with IEA expectations before the war in December 2021.

Rapid distributed solar PV growth is the main reason for the upwards forecast revision

In the European Union, residential and commercial solar PV systems account for 74% of the increase to our forecast, with the majority (82%) of the rise coming from six key markets: Germany, Spain, the Netherlands, France, Italy and Sweden. Two main developments are driving this transformation: the first is the increasingly attractive business case for self-consumption since January 2021.

EU capacity additions in 2023-2024 (left) and average household electricity prices for selected capital cities (right)



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Notes: Retail prices for households exclude taxes and value-added taxes. Household prices consider new tariff offers. Quarterly data are an average of the months. The price trend in capital cities are considered a proxy for that country.
Source: (right) Household Energy Price Index (HEPI) by Energie-Control Austria, MEKH and VaasaETT, © 2023 VaasaETT Ltd.

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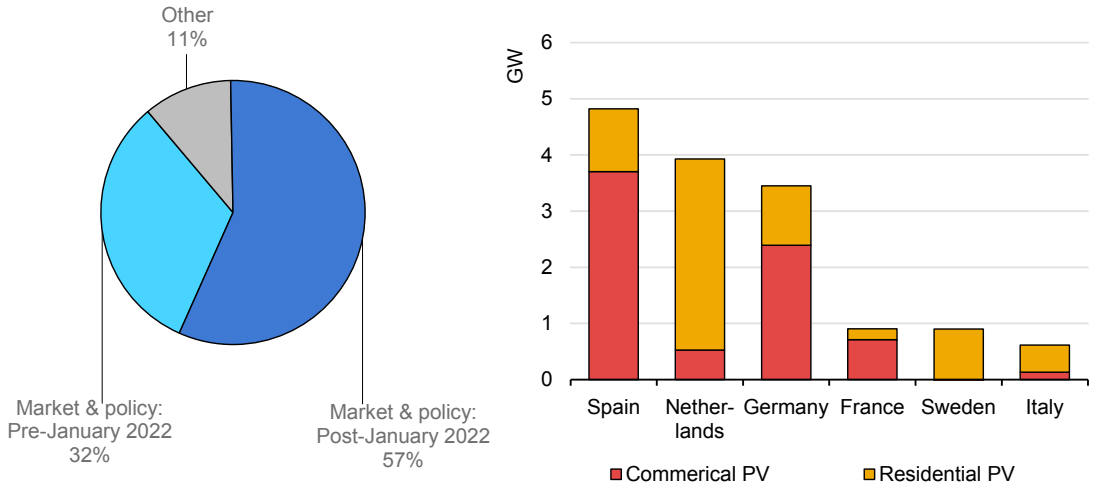
Rising gas and coal prices during the economic rebound from Covid-19 caused retail electricity prices in the European Union[1] to climb approximately 60% between January 2021 and January 2022, making self-consumption more economically appealing. This accounts for 32% of the upwards revision for distributed solar PV.

The second reason for this transformation is the new market conditions triggered by Russia's invasion of Ukraine and the policy response of some countries to incentivise distributed solar PV deployment. Higher retail prices and concrete policy action in Europe explain almost 60% of the distributed solar PV forecast revision. Following Russia's invasion of Ukraine, European electricity prices increased another 40% from February to October 2022 due to gas supply restrictions. Policy makers acted swiftly to accelerate distributed PV deployment to help mitigate the burden of energy cost increases for consumers.

Revisions to the distributed solar PV forecast (2023-2024) due to policy and market changes (left) and by major country (right)



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Note: "Other" refers to the share of remaining EU countries in the revised forecast for net distributed PV (Poland, Italy, Portugal, Greece, Austria, Finland, Denmark, Belgium, Ireland, Lithuania, Romania, Croatia, Hungary, Bulgaria, Estonia, Cyprus, Luxembourg, Slovenia, Slovakia, Latvia, the Czech Republic and Malta.).

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

Note by all the European Union member states of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the government of the Republic of Cyprus.

For instance, Germany offered more direct financial support, raised existing remuneration levels and introduced further incentives (premiums) to sell all generation to the grid. The prolongation of tax rebates in Italy and net metering in

[1] Data for the European Union is from the Household Energy Price Index (HEPI) for Europe by Energie-Control Austria, MEKH and VaasaETT, © 2022 VaasaETT Ltd. Released March 31, 2023.

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the Netherlands, which were both due to expire before the war began, are also driving faster distributed solar PV uptake. Meanwhile, Spain's regulatory reforms to expedite the environmental permitting process and to free up grid capacity for self-consumption are also prompting faster expansion. In France, the government modified auctions to retroactively increase awarded capacity by 40% for large commercial installations.

These policy actions, combined with higher retail prices, underpin the upwards forecast revisions for these markets. However, even in the absence of concrete policy change, consumer action to reduce electricity bills remains a key driver of accelerated residential solar PV growth in Sweden, France and Spain where retail prices remain above pre-war levels. While electricity prices have begun to fall since January 2023 in most European markets, they remain approximately 80% higher than January 2021. Permitting challenges and limited participation in competitive auctions prevent faster growth of utility-scale wind and solar PV.

Permitting challenges and limited participation in competitive auctions prevent faster growth of utility-scale wind and solar PV

Utility-scale growth for 2023 and 2024 has also been revised up, but to a much lesser extent due to permitting challenges, auction undersubscription and long development timelines. While European countries and the European Commission are moving quickly to streamline permitting (see "How are European countries addressing permitting challenges to accelerate renewable energy development?"), the impact on deployment in 2023-2024 is expected to be limited.

Developers face multiple challenges, including rising equipment costs, inflation, and supply chain constraints, which have made them less eager to participate in competitive auctions. Part of this is due to relatively low ceiling or reference prices, as well as fixed contract prices that are not indexed to inflation. Some governments have taken steps to modify auction designs to better reflect the changing pricing environment: for instance, Germany raised its auction ceiling prices and Portugal has adjusted contract prices for inflation. We have accordingly revised the forecast for utility-scale solar PV upwards for these markets.

Meanwhile, Spain's corporate PPA market growth is also resulting in revised utility-scale deployment for that country, but the upside potential for other markets is more uncertain (see "Will market forces now drive the expansion of wind and solar PV plants, or is policy still key?"). For onshore wind capacity, the upward revision results from delayed projects coming online after supply chain constraints and cumbersome permitting procedures lengthened project lead times.

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How are European countries addressing permitting challenges to accelerate renewable energy development?

Most countries in Europe have introduced policies to address the challenges posed by slow and complex permitting procedures for renewable energy projects. In fact, more policies and regulatory changes have been instituted in the last 18 months to ease permitting than over the entire previous decade.

The time required to obtain permits can vary significantly from one EU country to the next, ranging from one to five years for ground-mounted solar projects and from three to nine years for onshore wind projects. Delays resulting from complex and slow authorisation procedures are leading to limited participation in renewable energy auctions, increasing project risks and costs and ultimately weakening project economics and the bankability of power plants.

Permitting has finally become a key policy focus in Europe

Today at least 59 GW of onshore wind capacity (four times the capacity commissioned in 2022) is held up in various permitting procedures in Europe. For solar PV, the average length of permitting procedures is shorter than for wind, but there could be a significant number of projects awaiting permitting. For example, solar PV projects waiting for construction and generation permits in Portugal amount to more than 4 GW, which is almost five times the capacity commissioned in 2022.

Although long permitting timelines remain a major challenge in many countries, they became a key policy focus in the European Union following Russia's invasion of Ukraine. In May 2022, the European Commission released recommendations on permitting in the communication package of its REPowerEU Plan. The European Council also agreed to member states' identification of renewable energy "go-to areas" where low environmental risk and suitability for renewable power plants could allow shortened and simplified permitting to be applied.

Mostly following the EU guidelines, half of the EU member states and the United Kingdom have made important policy changes to streamline permitting procedures. These policies focus on three major areas: simplifying permitting procedures and/or setting clear permitting timelines (adopted by 10 countries); identifying preferential areas for renewable energy projects to fast-track permitting

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(adopted by 2 governments); and removing certain permitting requirements for small renewable power projects or increasing the minimum capacity requirement for environmental impact assessments (adopted by 4 countries). These changes aim to reduce permitting lead times, increase project bankability, and ultimately accelerate the deployment of renewable energy in Europe.

Policy changes on renewable energy permitting in EU and other countries following Russia's invasion of Ukraine

Country / Region	Month and year	Technology	Category	Description
European Union	May 2022	All renewables	1) Simplify permitting procedures 2) Identify priority areas 3) Revisit threshold for permitting	The recommendation on permitting under the REPowerEU Plan identifies best practices and provides guidance to speed up permit-granting procedures for renewable energy projects.
	Dec 2022	All renewables	1) Simplify permitting procedures 2) Identify priority areas 3) Revisit threshold for permitting	The European Council agreed on targeted amendments to the Renewable Energy Directive. Member states will design dedicated "go-to areas" for renewable energy development, with shortened and simplified permitting processes in areas with lower environmental risks. Member states are also required to ensure public involvement to address social acceptance issues, and to exempt PV equipment on buildings from environmental impact assessments (EIAs).
Austria	Jan 2023	Solar PV	1) Simplify permitting procedures	In Austria, EIAs for solar PV projects will be accelerated given their special public interest status, while projects that receive no complaints will not have to be halted.
Czech Republic	Apr 2023	Solar PV	1) Simplify permitting procedures	The Czech Republic approved an amendment to the construction law to create a simplified permitting procedure for solar panel installation with fixed deadlines.
Estonia	Feb 2023	Wind	1) Simplify permitting procedures	To speed up permitting procedures in Estonia, wind farm developers have the opportunity to waive the second stage of planning in the case of special planning of the state and local government.
Finland	Aug 2022	All renewables	1) Simplify permitting procedures	Certain renewable energy projects in Finland are to be given temporary priority until the end of 2025 in regional administrative agencies' processing of permits.

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Country / Region	Month and year	Technology	Category	Description
France	Feb 2023	All renewables	2) Identify priority areas	France adopted a law empowering local authorities to create preferred “go-to” and “no-go” areas for renewable energy development.
Germany	Apr 2022	Offshore wind	1) Simplify permitting procedures	As a part of the Easter Package, Germany has prioritised offshore wind in maritime spatial planning and streamlined permitting procedures.
	Dec 2022	Onshore wind	1) Simplify permitting procedures	Germany relaxed air radio navigation rules to accelerate the permitting process for onshore wind.
Ireland	Oct 2022	Solar PV	3) Revisit threshold for permitting	Ireland’s revised law on exemptions for rooftop solar panel installations removed the requirement for planning permission and extended the exemptions to new building categories.
Italy	Mar 2022	All renewables	1) Simplify permitting procedures	Italy began bypassing regional authorities to permit some renewable energy projects. The government also simplified permitting processes to install commercial rooftop PV systems.
	Feb 2023	Solar PV	1) Simplify permitting procedures	A new law simplifies the PV installation process and sets a limit of 150 days on the permitting process.
Lithuania	Apr 2022	Solar PV Wind	3) Revisit threshold for permitting	Lithuania abolished solar PV and wind production permits for self-consumption (power plants of up to 30 kW currently do not require them).
Luxembourg	Jan 2023	Solar PV	1) Simplify permitting procedures	Luxembourg adopted a regulation to limit the permit-granting time to less than three months for solar PV installations and co-located energy storage systems.
Portugal	Apr 2022	All renewables	1) Simplify permitting procedures 2) Identify priority areas	Portugal’s exceptional measures to simplify procedures for renewable energy projects exempt developers from securing an operating licence/certificate, provided that the network operator confirms conditions for grid connection. They also simplify EIA procedures as long as projects are not located in sensitive areas.
	Dec 2022	Solar PV Wind	3) Revisit threshold for permitting	Portugal scrapped EIA requirements for solar PV installations occupying less than 100 hectares and for wind stations located more than 2 km apart.
Spain	Mar 2023	Solar PV Wind	3) Revisit threshold for permitting	Spain has enabled an accelerated temporary procedure until 2024 to grant environmental approvals for wind power plants of less than 75 MW and solar parks not exceeding 150 MW.

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Country / Region	Month and year	Technology	Category	Description
Sweden	Nov 2022	All renewables	1) Simplify permitting procedures	To strengthen its energy supply, Sweden proposed a list of budgetary investments that includes streamlining permitting processes for grid connection.
United Kingdom	Sep 2022	Onshore wind	1) Simplify permitting procedures	The United Kingdom has presented measures to relax planning rules for approving onshore wind projects and to streamline EIAs.

In last year's Renewables 2022 report, we determined that addressing a number of barriers, including permitting challenges in Europe, could result in 30% more renewable energy deployment than what was detailed in the main forecast for 2022-2027.

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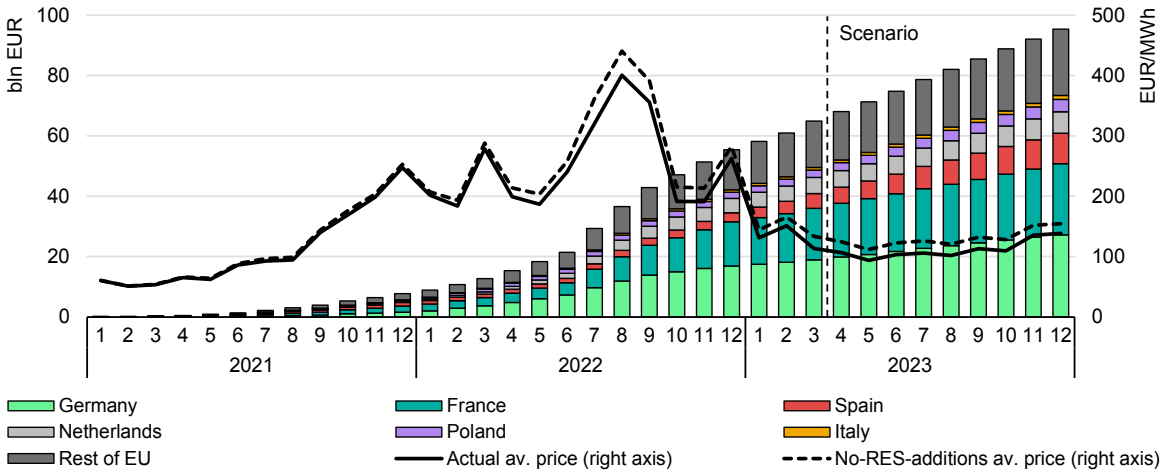
How much less money is the European Union spending on expensive electricity thanks to additional renewable energy capacity?

EU electricity consumers are expected to save an estimated EUR 100 billion during 2021-2023 thanks to additional electricity generation from newly installed solar PV and wind capacity. Low-cost new wind and solar PV installations have displaced an estimated 230 TWh of expensive fossil fuel generation since Russia's invasion of Ukraine, leading to a reduction in wholesale electricity prices on all European markets. Without these capacity additions, the average wholesale price of electricity in the European Union in 2022 would have been 8% higher.

Cumulative electricity costs decrease due to PV and wind additions, and average EU wholesale spot electricity price, actual and in no-RES-additions scenario, 2021-2023



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Notes: RES = renewable energy source. The no-RES-additions scenario assumes no PV or wind capacity additions in 2021-2023.
Source: IEA analysis based on ENTSO-E Transparency Platform (accessed April 2023).

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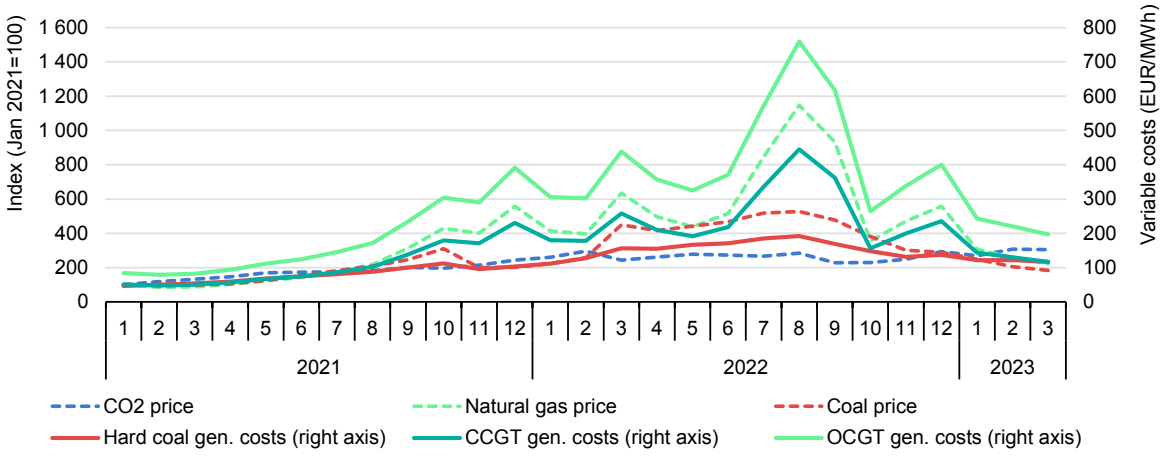
Reduced Russian natural gas supplies and multi-year lows in hydro and nuclear output led to an unparalleled increase in the EU wholesale electricity spot price

Following Russia's invasion of Ukraine, Russian natural gas deliveries to the European Union by pipeline decreased by 80% from 2021 to 2022. This sharp drop coincided with multi-year lows in European hydro and nuclear power output. Between January 2021 and August 2022, the average monthly natural gas price increased ten-fold and the price of hard coal quintupled. As a result, the cost of power generation from natural gas, which usually sets the electricity price in most EU wholesale markets, increased to unparalleled levels, reaching almost 800 EUR/MWh for open-cycle gas turbines (OCGTs) and 500 EUR/MWh for combined-cycle gas turbines (CCGTs).

EU CO_2 emissions allowances, natural gas prices, coal price index, and variable electricity generation costs, 2021-2023



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Notes: CCGT = combined-cycle gas turbine. OCGT = open-cycle gas turbine. Natural gas price – TTF index; hard coal price – API2 index; CO_2 price – EEC index. Gen: generation
Source: Bloomberg LP Terminal (accessed April 2023).

In the European Union, the wholesale electricity spot market is the benchmark for most electricity supply contracts, driving prices up for all consumers. The price is set by the most expensive generator needed to fill demand at any given moment. Due to the steep increases in natural gas and coal prices in 2021-2022, consumers in the wholesale market such as retailers or large companies with limited fixed-contract energy portfolios and without strong hedging positions had to purchase electricity at rates of up to 15-20 times the averages of 2015-2020.

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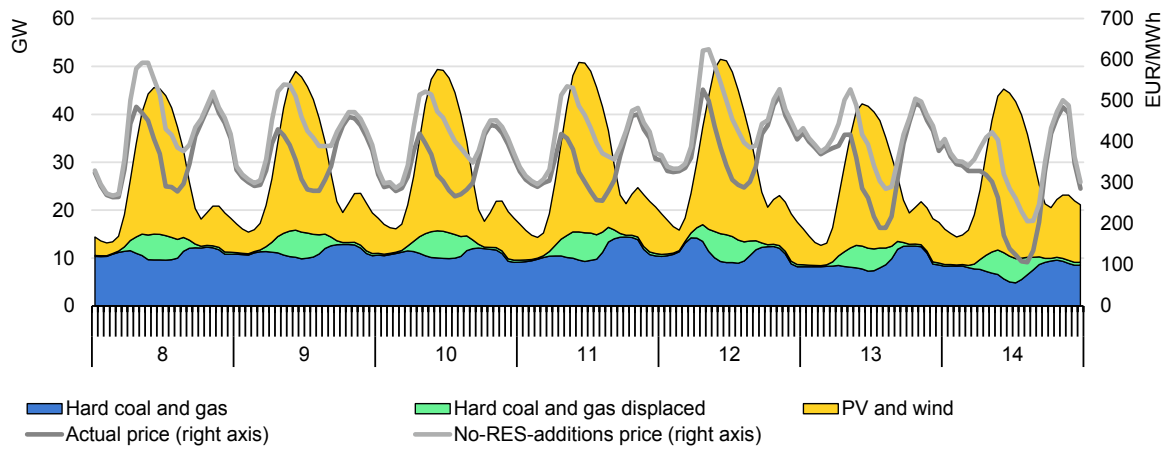
Germany hourly generation from hard coal and natural gas, and from PV and wind, and hourly wholesale electricity spot price, actual and in no-RES-additions scenario, 8-14 August 2022



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Note: RES = renewable energy source. The no-RES scenario assumes no PV or wind capacity additions in 2021-2023.
Source: IEA analysis based on ENTSO-E Transparency Platform (accessed April 2023).

New PV and wind capacity is expected to provide savings of EUR 100 billion since the beginning of the energy crisis

In 2021 and 2022, the European Union added nearly 90 GW of PV and wind capacity. This capacity has displaced almost 10% of hard coal and natural gas generation, pushing the most expensive power plants out of the market and effectively reducing the price for all consumers. In addition, another 60 GW of solar PV and wind is expected to come online in 2023, increasing displacement to almost 20% this year.

Based on the historical relationship between hourly generation from hard coal and natural gas, and wholesale electricity spot prices for several large EU economies in 2021 and 2022, we modelled a scenario for 2023 to estimate the further savings possible with additional wind and solar PV capacity. The results show that without PV and wind capacity growth in 2021-2023, average wholesale electricity prices would be higher by about 3% in 2021, 8% in 2022 and 15% in 2023, raising the cost of electricity supply for the entire European Union by roughly EUR 100 billion.

For instance, new renewable energy capacity in Spain offers saving of 60% more than the country's allocated budget of EUR 6.3 billion for an EC-approved temporary intervention to reduce wholesale electricity prices. For Germany, savings gained through new renewable generation capacity would pay for the government's recent proposal to support electricity prices for energy-intensive industries until 2030.

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Accelerating annual renewable energy deployment since 2021 has provided a cost-effective solution to the energy crisis' economic challenges. Long-term contracts secured through policy mechanisms and regulations provide stable prices for most wind and solar PV power generators in Europe, limiting their exposure to volatile electricity prices. They can also help shelter consumers from rising electricity prices. The total investment cost of deploying PV and wind capacity over 2021-2023 is expected to amount to about EUR 200 billion. Almost 50% of this investment cost will likely be returned in the form of savings on power consumers' bills by as early as the end of 2023, while these power plants will continue to provide benefits for the next 20-25 years.

According to the IEA accelerated case forecast, savings could have been about 15% higher if EU capacity had been increased more rapidly, through quicker implementation of policies supporting the deployment of technologies with short lead times (i.e. distributed solar PV) and a reduction in red tape for projects at the advanced stages of permitting.

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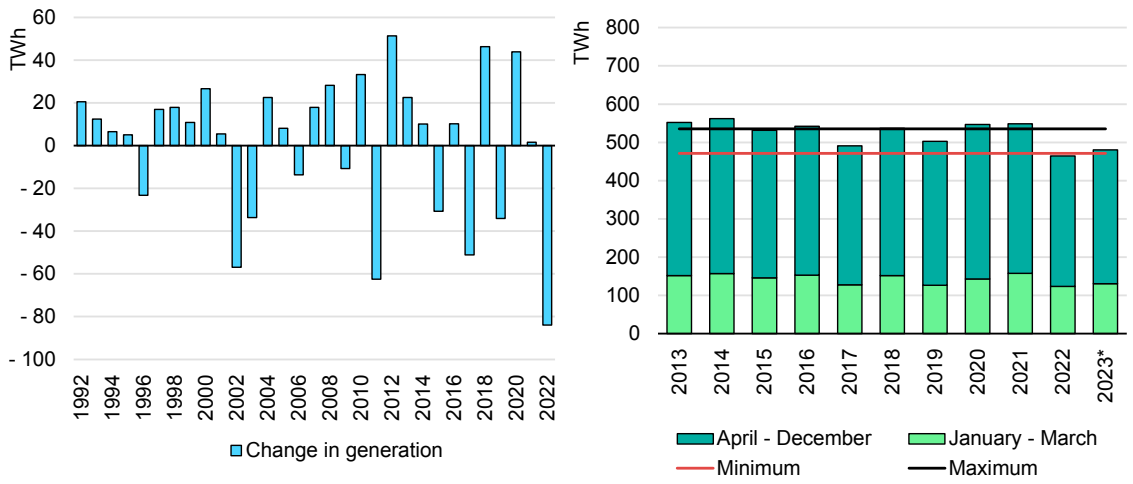
Will hydropower in Europe recover in 2023 following a severe drought last year?

European hydropower generation declined by 15% (80 TWh) in 2022 to 460 TWh, dropping to its lowest level since 2004. Variations in hydropower output are common due to natural fluctuations in rainfall, but last year's drop was the largest annual decline in the region since 1990. Four consecutive below-average rainy seasons led to drought conditions and lowered reservoir levels.

The reduced hydropower output resulted in an estimated additional 13-14 bcm of natural gas being used to generate electricity last year. This exacerbated the already high electricity prices the region was experiencing due to reduced gas supply caused by Russia's invasion of Ukraine and nuclear plant outages in France. Some large hydropower operators in Europe suffered financial losses as they had to buy back power at higher prices to meet their electricity delivery commitments.

Annual year-on-year change in hydropower generation in Europe (1992-2022) and historical and forecast (2013-2023)



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Notes: 2023*= forecast. Minimum = the lower bound for the 2023 forecast and Maximum = the upper bound.

In 2023, hydropower electricity generation is forecast to increase by 3% year-on-year (16 TWh), based on preliminary data for the first three months of this year. First quarter data in Europe is up 5% year-on-year compared to 2022, thanks to higher output from the Iberian and Balkan regions. Generation for January through March in Spain and Portugal was up 60% and 140% respectively, as high

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precipitation in January helped fill reservoirs to above average levels for the first quarter. Heavier than average rainfall along the Danube also boosted annual output from run-of-river plants in Romania, Croatia, and Slovenia by about 40%.

While generation in 2023 is expected to increase to 480 TWh, this is still 9% below the 10-year average (530 TWh) as drought conditions in key markets continued during the past winter. First quarter generation is down year-on-year in France, Italy, and Greece following low rainfall. In the Alps, warmer winter temperatures and less snowfall are expected to result in below average snowmelt for the remainder of the year. Output will also depend on whether operators decide to fill reservoirs or generate.

However, generation will depend on how much precipitation Europe gets from April to December, a key uncertainty for the forecast. Seasonal precipitation patterns are becoming increasingly unpredictable and can exhibit different trends compared to the first quarter. For instance, after the three consecutive months of year-on-year growth in January to March 2023, hydropower generation in Spain dropped 15% in April compared to 2022. Lower precipitation levels across several markets could result in Europe's hydro generation falling to 470 TWh, though this is still above last year's levels. Conversely, should some markets receiver higher precipitation, such as Italy where rainfall was heavier in May than previous months, Europe's generation could exceed 535 TWh. This upside potential of around 50 TWh could contribute to displacing around 9-10 bcm of additional natural gas in Europe.

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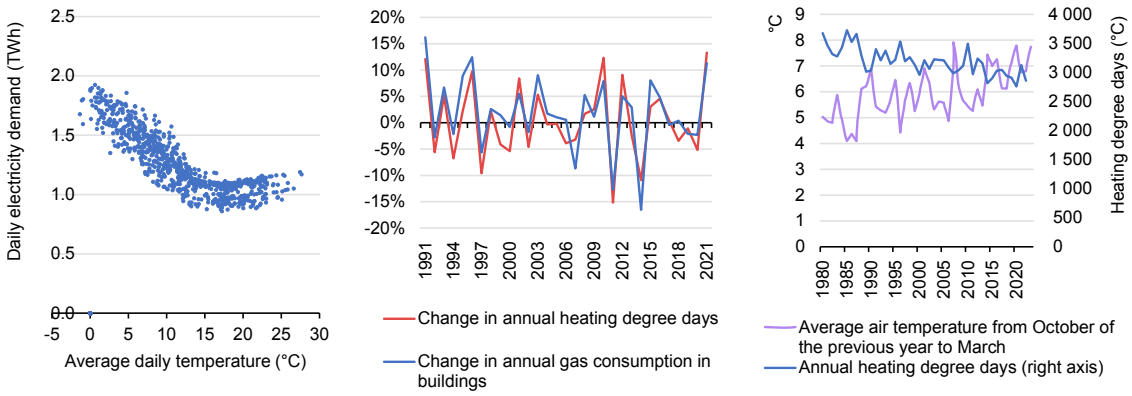
To what extent can renewable energy use displace gas consumption in EU buildings in 2023 and 2024?

With heating and cooling being the largest energy end-users in the EU buildings sector, air temperature is the primary short-term determinant of the bloc's buildings sector energy demand. Direct and indirect use of renewable energy through electricity, in addition to greater energy efficiency and energy sobriety, can play a key role in reducing EU gas demand in the short term.

Annual EU buildings natural gas demand, including indirect consumption, has ranged from 150 bcm to 210 bcm since 2010. The number of heating degree days has largely influenced this demand along with prices and consumer behaviour. The 2022/23 heating season was the second warmest on record for the European Union, with the average air temperature 1°C above the previous ten-year average, and 9% fewer heating degree days.

Sensitivity of total final electricity consumption to temperature in France, 2021-2022 (left), correlations between annual heating degree days and final consumption (direct use) of natural gas in buildings in the EU, 1991-2020 (centre), and EU long-term average air temperature and variability during the heating season, 1980-2022 (right)



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Note: The heating degree days series was calculated based on a reference temperature of 18°C with a 15°C threshold.
Sources: Eurostat (2023), Heating and cooling degree days - statistics; IEA (2022), Energy Balances; Entsoe (2023), Transparency Platform; IEA (2023), Weather for Energy Tracker.

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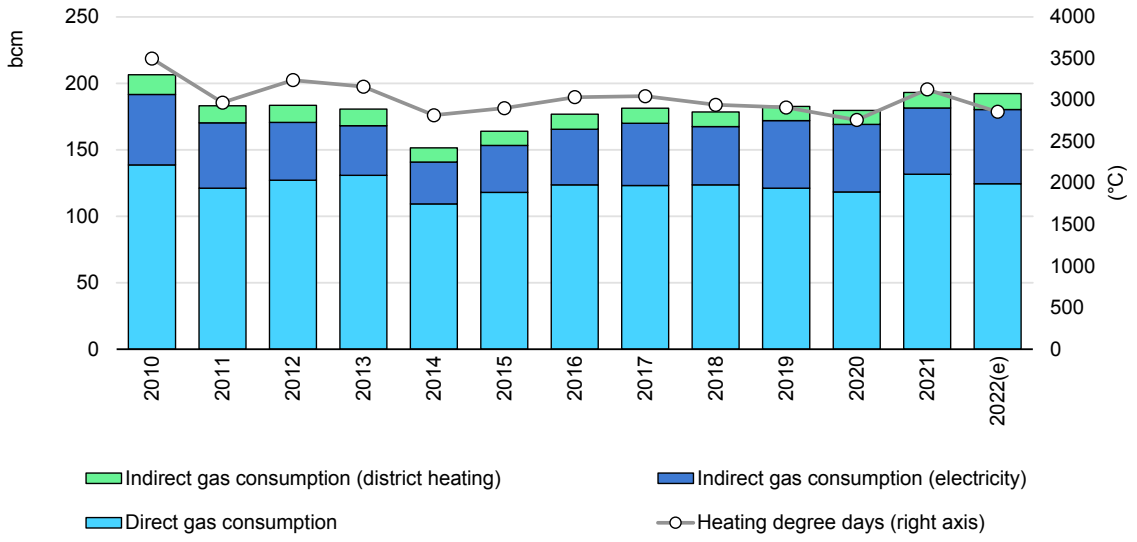
All other things being equal, such mild winter conditions alone would entail an estimated 7% drop in gas consumption in buildings from previous winters. This mild weather therefore eased pressure on EU gas markets considerably in the winter of 2022/23.[2]

While long-term climate trends point to an overall temperature rise, a harsh winter and a hot summer could intensify EU buildings sector heating and cooling demand in the short term.

EU historical gas consumption in the buildings sector, 2010-2022



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Note: The heating degree days series was calculated based on a reference temperature of 18°C with a 15°C threshold.
Sources: Eurostat (2023), Heating and cooling degree days - statistics; IEA energy balances (2023); IEA (2023), Weather for Energy Tracker. 2022e: 2022 estimate

The rapid expansion of renewable energy technology use in buildings can ease EU natural gas demand and contribute to the bloc's energy security in the short term. Projected cumulative new developments in direct use of renewable heat and expansion of renewable electricity post-2022 would displace almost 8 bcm of EU buildings-related gas consumption annually in 2023 and more than 17 bcm in 2024.[3] This is equivalent to avoided emissions of more than 50 Mt CO_2 in 2023-2024.

[2] In addition to weather, behavioural factors (i.e. a drop in space heating as a result of voluntary efforts or in reaction to high gas prices) also helped reduce gas demand in the EU buildings sector.
[3] These calculations take into consideration hourly demand profiles and generation patterns of each renewable electricity technology at the country level.

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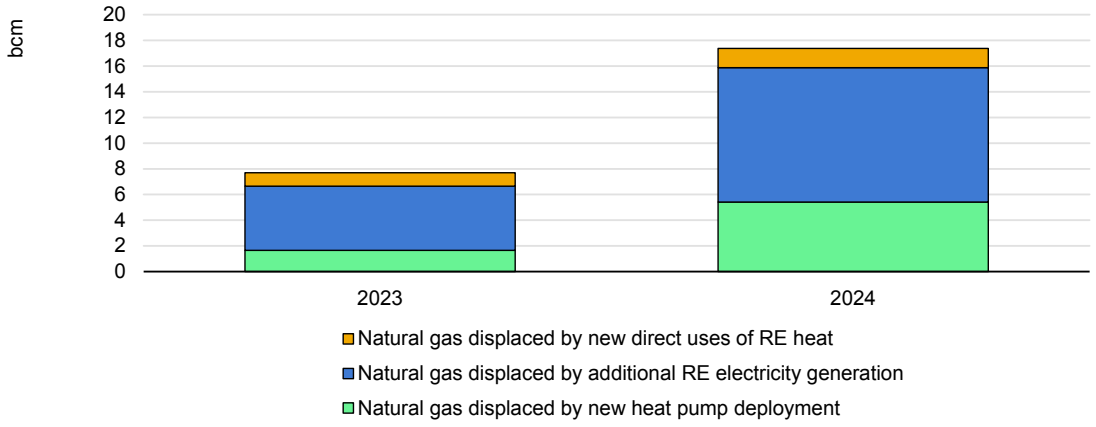
Natural gas consumption displaced by projected additional renewable energy supply in the European Union in 2023 and cumulative in 2024



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Notes: RE: renewable energy.

The largest contribution to gas displacement in buildings is expected to come from projected development of renewables in the electricity sector, with additional renewable generation compared to 2022 substituting 5 bcm of gas consumption for buildings electricity consumption in 2023 and more than 10 bcm in 2024. Countries for which growth in electricity generation is projected to displace the most gas cumulatively in 2023-2024 are Spain, Italy, Netherlands, Germany and France. Spain and Italy have important shares of gas in their electricity mixes and they benefit from well-matched demand-supply profiles with solar PV generation patterns accommodating summer cooling demand.

The sustained growth of annual heat pump sales driven by policy incentives in many countries is anticipated to represent another quarter of the gas displaced in buildings (7 bcm cumulatively by 2024). Limited biomass stoves and boilers, solar thermal and geothermal developments in buildings yield only marginal gas savings by 2024 (less than 3 bcm cumulatively). While these renewable energy contributions will help ease potential tensions on gas markets, the potential of renewable heat technologies is still largely untapped, both in buildings and industry. Harnessing their potential would, however, require sustained and comprehensive policy action to improve consumer awareness, reduce high upfront costs and split-incentive challenges, alleviate supply chain challenges, expedite permitting procedures, establish training programmes and support R&D to further improve technologies.

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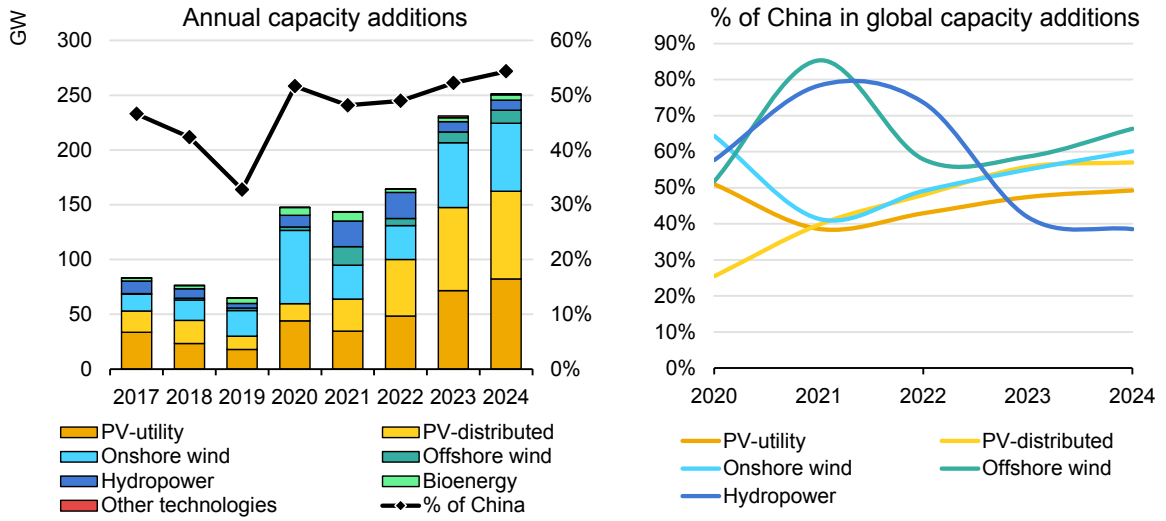
Will China's role in global renewable energy deployment decline in 2023 and 2024?

China's ambitious target of net zero emissions by 2060, its strong and continuous policy support for renewable energy, and the large size of its domestic manufacturing industry for all renewable technologies consolidate China's position as the undisputed leader in global renewable energy deployment in 2023 and 2024.

China's contribution to global renewable capacity additions is expected to increase in 2023 and 2024 thanks to distributed solar PV and wind

In 2022, China accounted for 49% of global renewable capacity additions, due mostly to acceleration in solar PV growth, particularly for distributed systems. Following the phaseout of solar PV subsidies, the Chinese government has transferred the focus of its renewable energy deployment strategy to two principal areas that underpin the forecast for 2023 and 2024.

China net renewable capacity additions (2017-2024) and its share in global deployment



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China's first aim is to develop large-scale mega projects far from demand centres that can provide power at prices equal to or lower than provincial benchmark coal

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electricity prices. Second, the government is incentivising distributed solar PV projects through capacity targets for public institutions and large state-owned enterprises for self-consumption, and for smaller residential systems through subsidies to promote rural economic development.

Owing to rising industrial electricity prices and government policy support, distributed PV applications are the main source of China's renewable capacity expansion in 2023 and 2024, with the country's share in global expansion reaching almost 55%. Higher module prices over the last 12-18 months have affected the competitiveness of distributed applications less than that of utility-scale projects, for which profit margins remain tight and modules account for a larger share of total system costs.

Our forecast expects onshore wind to rebound strongly in 2023 compared with last year, as China deployed almost 30% less wind energy than was anticipated in the IEA *Renewables 2022* report. As movement restrictions due to the Covid-19 outbreak in 2022 delayed the completion of multiple onshore and offshore wind projects, we now expect these installations to become operational in 2023 and 2024, pushing China's share in global onshore and offshore wind expansion to over 60%.

Considering that the central government phased out direct financial incentives in 2021, the strengthening role of China in global wind growth indicates greater competitiveness and strong provincial support, motivated by the economic benefits of rural deployment.

China's increasing solar PV and wind manufacturing capabilities will maintain a strong domestic demand

China's demand and supply policies for wind and solar PV technologies are well established, and its industrial policies have been designed holistically to produce competitive clean energy equipment for both domestic demand and exports. In 2022, China's annual manufacturing capacity for solar PV equipment continued to expand much more quickly than global demand. Last year, manufacturing capacity increased 40-50% for wafers, cells and modules and almost doubled for polysilicon.

Today, utilisation rates of Chinese solar PV manufacturing facilities range from 20% to 40%, and the country is expected to double its PV manufacturing capacity again by the end of 2024, significantly swelling the supply glut. Thus, strong domestic demand in China remains essential to maintain or increase manufacturers' utilisation rates in 2023 and 2024.

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For wind, China is expected to expand onshore and offshore manufacturing facilities almost 20% by 2025, especially for offshore wind. More than 90% of domestic demand is met by Chinese companies and their exports are limited, highlighting the importance of a strong domestic market.

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Will the US inflation Reduction Act impact wind and PV deployment in the short term?

The impact of the IRA on wind and solar PV deployment in 2023 and 2024 will be limited. While federal tax credits under the IRA provide unprecedented investment certainty for renewable energy projects up to 2032, installations due to come online within the next two years have already qualified for previous tax incentive schemes. Thus, pre-IRA policies as well as developments concerning supply chain constraints and trade measures affect our short-term capacity forecast.

Trade and supply chain concerns led to lower capacity additions in 2022, but wind and PV expansion will accelerate this year

In 2022, the US anti-dumping and circumvention investigation involving solar panels from several Southeast Asian countries in March and the Uyghur Forced Labour Act in June delayed the delivery of PV products. In addition, higher commodity prices and continuous supply chain challenges for renewable equipment parts coming from China pushed wind turbine and solar panel prices up.

For solar PV, the impact of trade measures on deployment and prices was much larger than for wind. In 2022, the solar PV market contracted 15% due to uncertainty over trade restrictions, which paused imports and slowed project development. However, an interim order published in June 2022 addressed some trade issues and, as a result, the market is expected to expand in the next two years. In fact, solar PV additions could break new records, reaching more than 30 GW in 2024 – a 50% increase from 2022 – thanks to accelerated utility-scale project deployment. Meanwhile, distributed solar PV additions, which benefit from the Investment Tax Credit (ITC) and local net metering provisions, remain stable at around 8 GW.

However, two important policy developments counteract one another to prevent higher total annual solar PV additions. While changes to California's net metering law could slow down deployment in the largest distributed PV market in the United States, commercial solar PV is expected to start benefitting from new IRA incentives such as eligibility for community solar and economic adders in 2023, making commercial solar PV more economically attractive.

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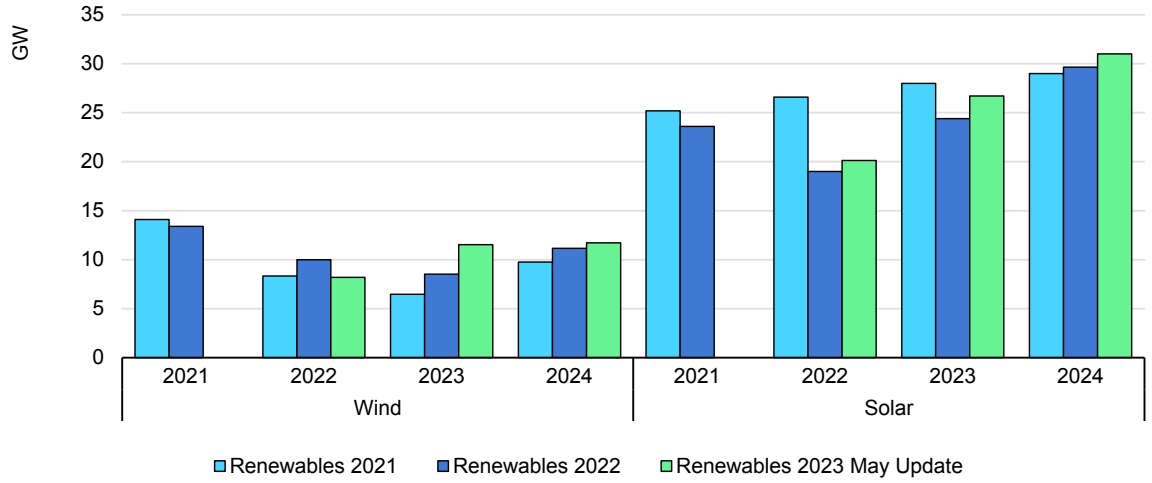
The US onshore wind market added 8 GW of new capacity in 2022 – a 40% fall from 2021 and a 50% drop from record-level expansion in 2020. This decline was expected with the reduction and eventual expiration of the pre-IRA production tax credit policy, but supply chain constraints and inflationary pressure also caused project commissioning delays last year. As a result, the commissioning of delayed projects will mean 40% higher additions this year than in 2022.

However, due to lower production tax credit rates under the previous tax policy, onshore wind additions are forecast to decelerate again in 2024. Nonetheless, the commissioning of roughly 2 GW of large-scale offshore projects is expected to keep annual US wind capacity additions stable at around 12 GW in 2023 and 2024.

Net solar PV and wind capacity additions by year, 2021-2024



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The Inflation Reduction Act's impact on renewable energy technology deployment will become evident in 2025

For both solar PV and wind projects, long-term tax incentives under the IRA are a game-changer. Considering the deployment timelines for large-scale installations, the IRA's impact will become visible mainly beginning in 2025. Under the act, solar PV projects are once again eligible for the production tax credit if construction begins before 2025, providing an alternative driver for new capacity additions beyond the ITC.

After 2025, multiple technologies, including for wind and solar PV, will be eligible for the Clean Energy Production Tax Credit. While the IRA's long-term credit visibility will create steadily increasing demand for renewable energy, it will also place greater pressure on permitting, transmission and distribution grids, and supply chains.

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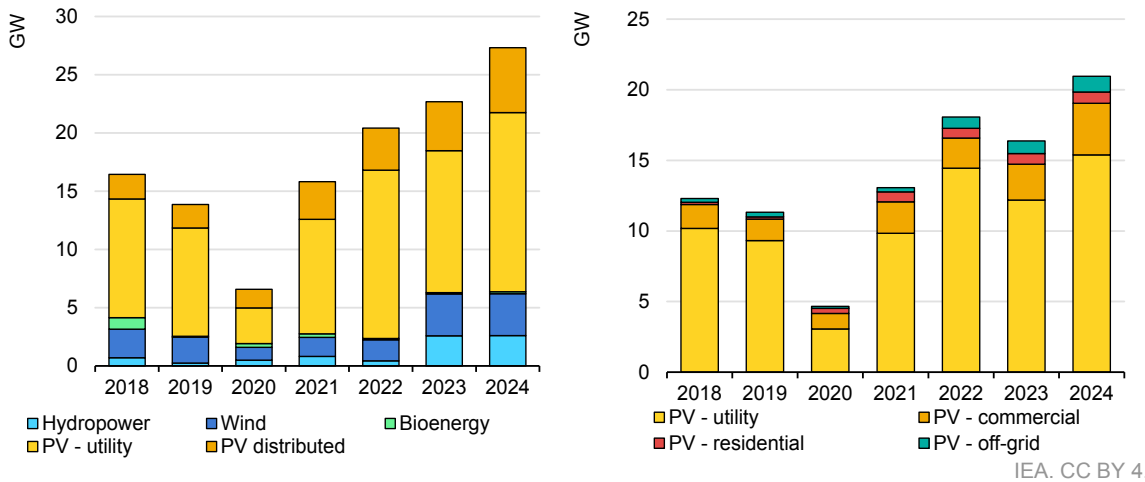
Will India's renewable energy deployment boom in 2023 and 2024?

India's renewable capacity additions are expected to increase again in 2023 and 2024 owing to faster onshore wind, hydropower and distributed solar PV deployment. However, annual additions for utility-scale projects, India's largest renewable electricity growth segment, are expected to slow briefly this year due to supply chain challenges, preventing renewable energy growth from truly booming in the short term.

Higher prices, lower auction volumes and trade policies weigh on short-term PV deployment

In 2022, India's utility-scale solar PV capacity additions (made up mainly of capacity awarded in auctions) reached a record-breaking 14 GW, accounting for over two-thirds of renewable energy growth in the country. For 2023, however, lower auction volumes and supply chain challenges indicate that a slowdown of almost 20% is probable, with a possible recovery in 2024.

India net renewable capacity additions by technology, 2018-2024



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In 2022, auction volumes dropped by one-third, with only 10 GW_{AC} awarded, the lowest amount since 2017 and significantly below the volumes required to reach the national target of 500 GW of non-fossil capacity by 2030. Average solar PV

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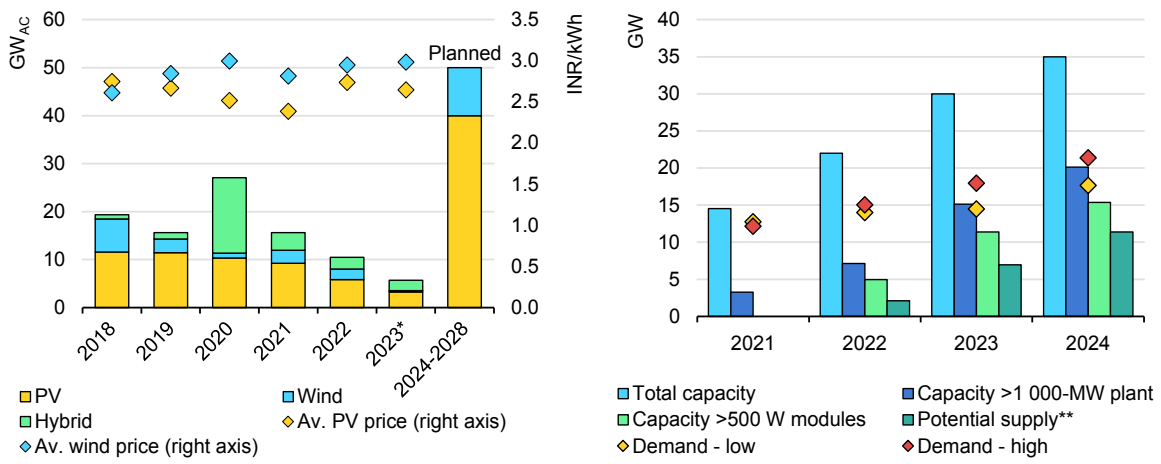
tariffs from 2022 auctions were 15% higher than in 2021, which discouraged distribution companies (DISCOMs) in poor financial health from signing contracts.

In addition, some states that had fulfilled their Renewable Purchase Obligations neglected to organise further auctions, and federal agencies were putting more emphasis on hybrid tenders. Lower awarded capacity is expected to translate into a slowdown in capacity additions in 2023-2024. To improve the situation, in March 2023 the Indian government ordered federal agencies to increase auction capacity to 50 GW_{AC} annually starting in FY 2023-2024, which should lead to higher deployment beyond 2025.

India renewable capacity awarded in auctions, 2017-2023 (left) and PV module supply and demand, 2021-2024



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* Data for January-April only.

** Indicates a potential annual supply of over 500 W of modules by producers with over 1 GW of manufacturing capacity.

Note: Planned 2024-2028 capacity indicates targeted annual auction awards.

Sources: (left) Bridge to India (2023), India RE Navigator (accessed April 2023); BNEF (2023), Q1 2023 Global Auction and Tender Results and Calendar. (right) PV InfoLink (2023), Supply and Demand Database (accessed April 2023); Ministry of New and Renewable Energy (February 2023), Approved List of Models and Manufacturers.

Large-scale PV manufacturing is emerging, but it creates short-term demand and supply mismatches

India's push to expand domestic manufacturing is triggering a supply-demand mismatch and higher prices in the short term, affecting PV expansion in 2023 and 2024. Historically, India has imported almost 90% of its solar PV modules from China. However, the government's production-linked incentives (PLIs) for PV manufacturing aim to increase India's domestic manufacturing capabilities to

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reduce or eliminate imports. The two rounds of the PLI subsidy scheme should allow India to become fully self-sufficient in terms of solar PV supply in the next four to five years.

In the short term, however, demand for high-capacity modules from large-scale top-tier manufacturers exceeds supply. Although the list of government-approved manufacturers (ALMM) in February 2023 implied total manufacturing capacity of 22 GW, only less than 5 GW were declared by large producers offering modules with over 500 W of power. Developers demand these high-quality top-tier modules for their cost efficiency and to more easily secure low-cost financing.

Along with supply-demand mismatches, the introduction of higher import tariffs on PV modules and cells in April 2022 led to a 30-40% increase in module prices in the second half of 2022. This reduced project bankability, forcing developers to either cancel or delay projects while waiting for PV prices to fall. In response, the government postponed ALMM requirements for all projects commissioned by April 2024 and extended the commissioning deadlines.

Although government actions have mitigated some challenges, our forecast nevertheless expects that the temporary supply-demand mismatch for top-tier PV modules will prevent rapid utility-scale PV expansion in 2023 and 2024. However, the Indian market should experience a real deployment boom beyond 2025, with higher auction volumes and lower prices.

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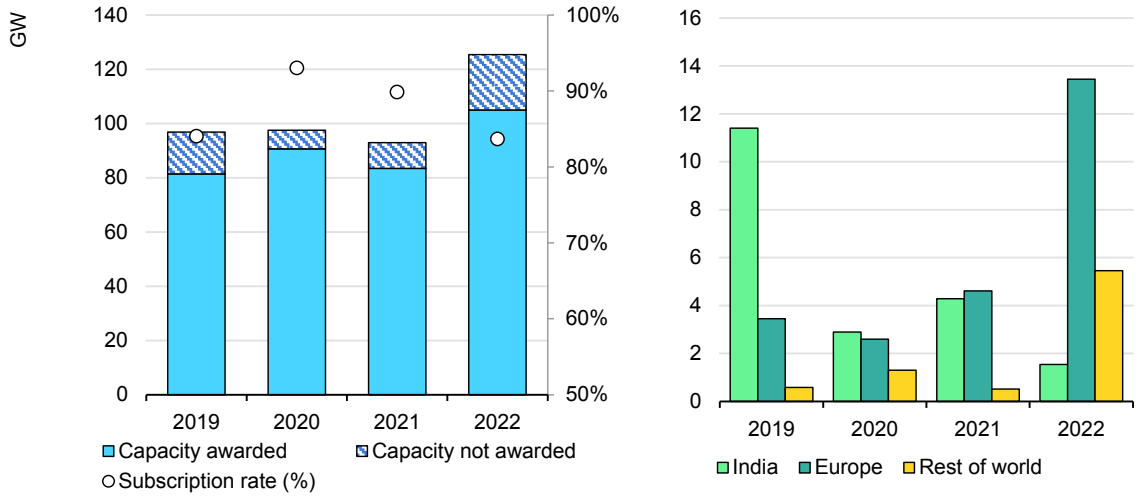
Are competitive renewable energy auctions increasingly undersubscribed?

In 2022, competitive renewable energy auctions resulted in governments awarding a record-breaking 100 GW of capacity. However, unallocated capacity also reached its highest-ever level last year (20 GW) with only close to 85% of proposed capacity being awarded, the lowest rate ever.

The energy crisis has negatively affected participation in European auctions

In 2022, Europe accounted for two-thirds of global unallocated capacity in competitive renewable energy auctions, triple the volume of the previous year. Meanwhile, India's auction allocation rates have been improving since 2019 thanks to policy changes. However, outside of these two markets in which competitive auctions drive utility-scale renewable energy development, 9% of auction volumes remained unallocated in 2022. If China is excluded, unallocated volumes rise to 23%, a more than ten-fold increase from 2021 in absolute value.

Global renewable energy auction results (left) and volumes of unawarded auction capacity by region (right)



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India's auction volumes for renewable capacity decreased in 2022, with the country offering as well as awarding less than half of what it had annually during

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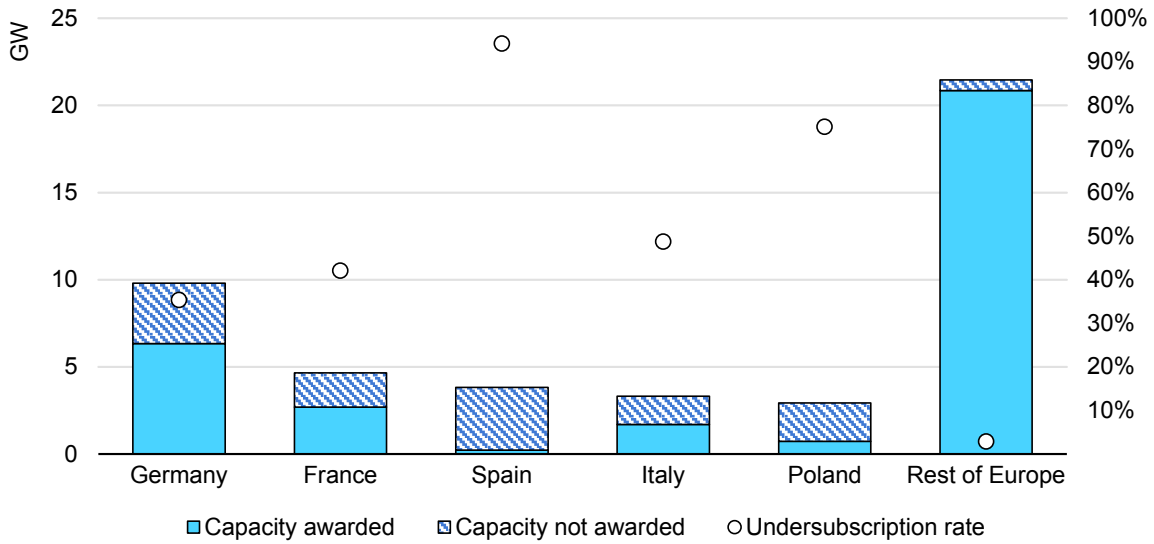
2019-2021. Auction volumes dropped because state-level tenders prioritise the signing of previously awarded power purchase agreements, and because developers are currently focused on completing construction of a large-scale project pipeline.

In 2022, India awarded almost 90% of auctioned capacity thanks to policy improvements to reduce offtaker risks. Contrary to historical trends, last year the central government offered more capacity than the financially challenged state DISCOMs did, and rapid implementation of the solar park programme facilitated land procurement and grid connection.

Europe experienced the opposite trend. The reason for record-level undersubscription in European auctions is an increase in investment costs for wind and solar PV compared with previous years, combined with an unchanged auction ceiling and static reference prices. Furthermore, some developers have found corporate power purchase agreements and wholesale market opportunities to be more economically attractive than auctions, allowing them to tap into higher prices. Price volatility in commodity markets, rising interest rates and inflation have all added to uncertainty over project economics. As most European contract prices from competitive auctions were not indexed to address rising costs, developers were reluctant to participate.

Unawarded capacity in renewable energy auctions in Europe, 2022



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In Germany, sluggish permitting procedures and rising auction volumes have left record amounts of capacity unallocated. In fact, the country allocated only two-thirds of offered capacity in feed-in-premium auctions, sustaining the trend of rising undersubscription that began in 2020. To address these challenges, in 2022 Germany increased the ceiling price of tenders for the first time since 2020.

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Spain's third auction for 3.3 GW in 2022 was undersubscribed due to a combination of factors. Rising costs, low ceiling prices, and long-term contracts without inflation indexing were suggested as a main reason that only 5% of the offered capacity (3.3 GW) was awarded. Developers may have also found corporate PPAs and merchant projects offer more suitable economics or contractual arrangements. Similarly, Poland experienced a record-high 75% undersubscription rate in 2022, significantly higher than the usual rate of less than 10% in previous years.

Italy conducts three technology-neutral auction rounds per year under the FER programme, with each round rolling over unallocated capacity from the previous one. In 2022, however, it allocated only half of the capacity initially targeted and rolled over capacity from the previous year. For the past two years, all tenders had undersubscription rates of more than 70%, resulting in a large amount of capacity being rolled over and even extension of the FER programme into 2023.

In South Africa, grid access challenges in areas of high wind potential resulted in 3 GW of wind projects remaining unallocated in recent auctions. In Chile, a successful 1-GW auction in 2021 was followed by a 2022 auction of similar size that allocated only 15% of the capacity offered, as the auction prices did not address challenges associated with rising costs and interest rates.

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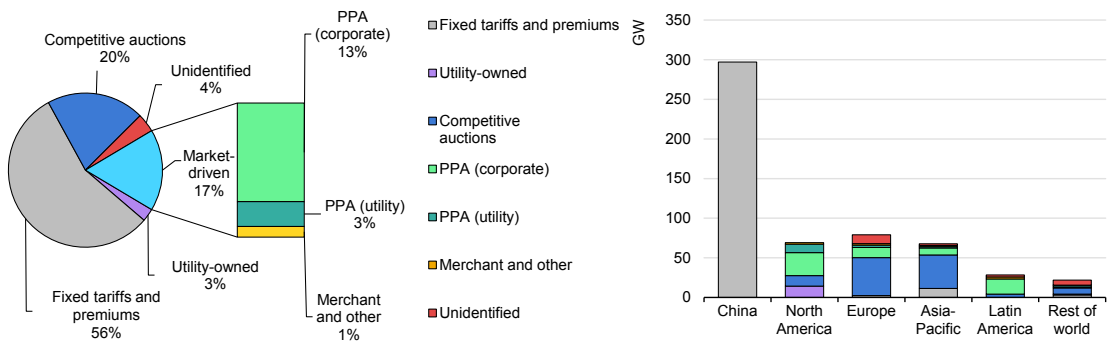
Will market forces now drive the expansion of wind and solar PV plants, or is policy still key?

Market-driven procurement is expected to account for one-fifth of utility solar PV and wind capacity expansion between 2023 and 2024, and almost twice as much (36%) when China is excluded. Market-driven procurement is a business model that allows for renewable power price discovery between buyers and sellers. Modes include bilateral contracts (PPAs) between IPPs and corporate consumers or utilities; merchant projects; and remuneration from certificate schemes.

Conversely, policy-driven procurement refers to models in which government decisions affect the price signal for investment. It can take the form of policy support, such as the setting of volumes or controlling of prices, or regulatory measures, which directly affect competition. The two most prominent policies have been administratively set tariffs for remuneration (wherein the government decides on a fixed tariff to offer developers) and competitive auctions (wherein the government puts a set amount of capacity up for bid and sets a limit on what it will pay for the power). Utility-owned projects in regulated markets constitute a third policy-based procurement method, as the price signal is effectively absent by default of the regulatory environment.

Solar PV and wind forecast by primary procurement type, 2023-2024



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Notes: This analysis only covers procurement methods for the sale of electricity; it excludes any additional subsidies on investment costs such as tax credits, accelerated depreciation, rebates, grants, etc.). PPA = power purchase agreements are defined in this report as contracts that are bilaterally negotiated. "other" (left graph) includes renewable certificates and capacity dedicated to renewable hydrogen production. "Rest of world" (right graph) refers to the Middle East and North Africa, Eurasia and sub-Saharan Africa. "Unidentified" refers to countries for which the breakdown by procurement was not applied.

Globally, almost 60% of utility-scale solar PV and wind deployment in the next two years will be developed under policies with administratively set remuneration

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policies such as fixed tariffs, premiums, and utility-owned projects. However, most of this deployment will be in China, where developers receive tariffs set at the provincial benchmark electricity price now that renewable energy feed-in tariffs have been phased out. Excluding China, less than 15% of the world's utility-scale solar PV and wind capacity additions are expected to be procured through administratively set tariffs.

The largest growth is in the United States, from utility-owned projects in regulated markets, followed by the Asia Pacific region, from feed-in tariffs in Japan, Chinese Taipei and Viet Nam. In Europe, growth in administratively set procurement is mostly in onshore wind in France, where a feed-in premium exists for small projects, and from feed-in tariffs in the Republic of Türkiye (hereafter "Türkiye").

Competitive auctions are the largest source of policy-driven growth outside of China, accounting for almost half, led by Europe and followed by India, the United States, Korea, the United Arab Emirates and Brazil. The main motivations for auction-based growth are policy actions to meet climate goals (in the European Union), utility choice (in the United States) and economic attractiveness (in the Middle East and North Africa).

Market-driven growth, which accounts for 17% of the world's utility solar and wind expansion, is dominated mostly by corporate PPAs. The United States leads expansion in corporate PPAs, followed by Brazil, Australia, Spain and Sweden, all motivated by the economic attractiveness of these technologies, the opportunity to hedge against rising and volatile power prices, and sustainability goals. Unsolicited bilateral contracts with utilities (PPAs with utility offtake) are prominent mostly in regulated markets, while some growth is expected from merchant projects in Chile, the United States, Denmark and Spain.

Outside of China, Europe leads most of the policy-driven renewable capacity expansion, while market-driven growth remains very important in the United States and North America in general. How each of these markets evolves over the next two years will depend on the wholesale electricity price environment and on regulatory and policy decisions.

Economic attractiveness and consumer demand drive PPA growth in the United States

Over half of US utility-scale solar and wind growth is expected to come from bilateral contracts for either corporate or utility offtake, spurred by both economic attractiveness and corporate demand to meet sustainability goals. Corporate PPAs are forecast to account for the largest share (40%), mostly in the form of

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virtual PPAs[4] in deregulated wholesale markets. Over 80% of the virtual PPAs signed between 2021-2023 were in the ERCOT, MISO and PJM service areas.

However, rising PPA prices do pose a downside risk. Climbing interest rates, equipment price increases and interconnection queues have driven up costs for developers, while supply chain delays slowed supply amid rising demand. As a result, CPPA prices rose an estimated 11% in the ERCOT, PJM and MISO service areas between Q4 2022 and Q1 2023.

Nonetheless, consumer demand for virtual PPAs is expected to remain strong, in part because of the cost savings they can offer consumers by aggregating demand across multiple locations. For developers, the economics of PPAs are expected to remain appealing with the IRA extending the ITC, and with new opportunities for 10% premiums for projects being developed in energy communities starting in 2023. Additional revenue from renewable energy certificates (RECs) in some markets also strengthens the business case.

The remaining 60% of US renewable capacity expansion over 2023-2024 is mostly from utility-owned plants, competitive auctions, and PPAs with utilities. These are the dominant procurement methods in regulated markets in the Southeastern, Southwestern and Northwestern states, but procurement approaches vary across states depending on the regulatory environment and whether utilities have a choice. The main drivers for growth are consumer demand for renewable power (sometimes in the form of green tariffs), the economic attractiveness of PV and wind systems compared with a utility's existing fleet, and the need to comply with a government's renewable energy targets.

Competitive auctions drive European growth in 2023-2024, but the pace will depend on policy responses to volatile wholesale prices and rising costs

The leading procurement method in Europe is competitive auctions, accounting for at least 60%[5] of renewable capacity growth between 2022 and 2024. Almost half of this growth will be from auctions for two-way fixed contracts for difference,[6] led by Poland, the United Kingdom, France, Italy, and Spain. Türkiye use one-way

[4] Virtual PPAs are a financial contract for difference between a wholesale electricity price and the PPA price. As virtual PPAs require access to the wholesale market, the majority of the corporate PPA growth will occur in deregulated markets.
[5] The value represents deployment in Germany, Spain, France, the United Kingdom, Poland, the Netherlands, Sweden, Italy, Denmark, Belgium, and Türkiye, which account for 85% of Europe's growth. The value would be higher if competitive auctions from the remaining European countries are included.
[6] In this model, developers receive a subsidy from the government when the wholesale price is below the strike price and will pay back any revenues that exceed the strike price.

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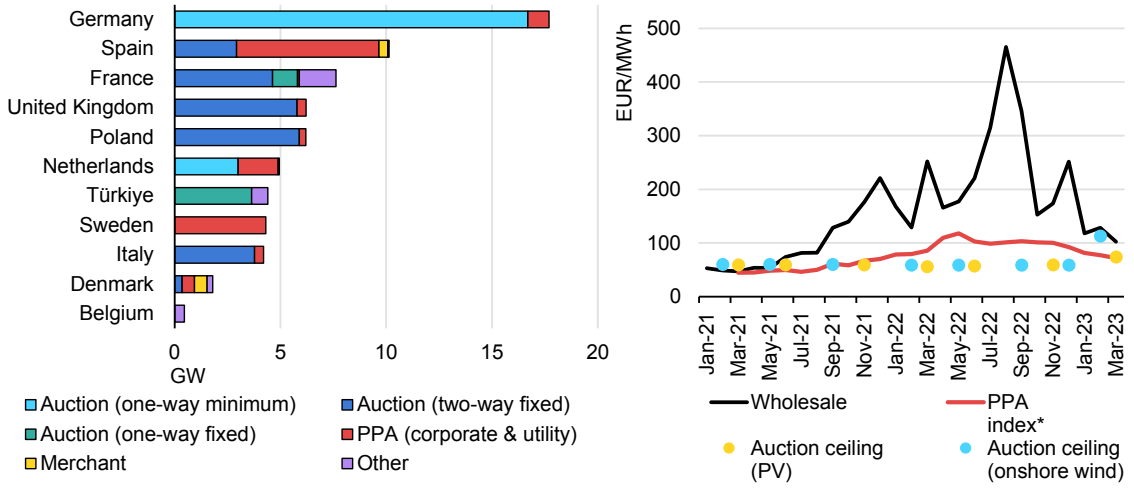
fixed-tariff auctions with price indexation, wherein the strike price is the contractual price irrespective of the wholesale market price.

Meanwhile, Germany, the Netherlands, the Czech Republic and Slovenia use a one-way floor that guarantees developers the minimum strike price and an uncapped maximum from the wholesale market.[7] In September 2022, the European Union agreed to begin taxing wholesale market revenues of more than 180 EUR/MWh in an attempt to reduce the burden on consumers, with some member states implementing even lower thresholds.

Europe solar and wind forecast (2023-2024) by policy and procurement type (left) and Germany prices for wholesale electricity, PPAs and auction ceilings (right)



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Notes: PPA = power purchase agreement. August 2022 data were not published, so the figure is estimated as the average between July and September 2022. * Refers to Pexapark's index.

Sources: (right) Pexapark (monthly reports from 2021,2022,2023), Bloomberg New Energy Finance (accessed May 2023), and Bundesnetzagentur (accessed May 2023).

However, uncertainty over future capacity growth in Europe's auctions is mounting because they have been increasingly undersubscribed due to permitting challenges, and more recently due to the rising costs developers are facing from commodity prices, equipment costs, interest rates and inflation. As a result, developers are wondering whether they should turn to wholesale markets and direct PPAs with corporations and utilities with the prospect of higher remuneration. For instance, auction ceiling prices in Germany at the end of 2022 were just EUR 60/MWh, compared with corporate PPA of almost EUR 100/MWh and wholesale prices over 250 EUR/MWh.

[7] New regulations to protect consumers have introduced temporary wholesale and gas price caps in multiple European countries.

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Going forward, unsubsidised projects in the form of PPAs and merchant plants are expected to account for 22% of Europe's capacity expansion. The majority of this will be corporate PPAs, led by Spain, Sweden, Germany, the Netherlands, and Denmark, with projects emerging in the United Kingdom, Italy, and Poland. While installations being developed on a fully merchant model are likely to constitute a minority, PPA projects are expected to stack revenues by combining a merchant tail.

Nonetheless, the pace of growth for unsubsidised projects in the Europe is also somewhat uncertain. Ambiguity over how long high wholesale prices will persist, especially with the share of marginal-cost PV and wind increasing, poses a downside risk to plants relying solely on merchant revenue. In addition, signed PPA volumes in Europe were down 20% in 2022 compared to 2021, as developers raised contract prices to account for rising costs, while buyers were hesitant to lock in higher tariffs.

The primary factor affecting procurement methods in Europe will be countries' policy and regulatory responses to the risks developers face. For competitive auctions, some governments have already begun to take action to accelerate growth by adjusting auction designs and contracts to reflect developers' cost uncertainties. In 2023, Germany raised its auction price ceilings by 90% (to EUR 113/MWh) for onshore wind and by 25% (to EUR 74/MWh) for solar PV. As a result, solar PV auctions were oversubscribed for the first time since 2021. Portugal, meanwhile, will adjust the strike prices of its last three years of projects to account for inflation and rising equipment prices, and France will allow non-operational auctioned projects to sell electricity on the spot market for 18 months prior to the contract start date.

Our forecast also expects corporate PPA growth to resume. PPA prices in March 2023 have fallen around 30% from November 2022, and the European Commission's draft of electricity market reforms suggests PPAs may play a more prominent role in the future. The March 2023 draft proposes that auctions be changed to two-way contracts and that auction bidders be allowed and encouraged to also enter into bilateral PPAs with other offtakers. While a final proposal will not be approved until 2025, developers may begin to devise business models in anticipation.

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Is the renewable energy industry's financial health improving?

Despite challenges associated with energy security concerns, volatile commodity prices, supply chain constraints and trade measures, the renewable energy industry has shown financial resilience. This is evident across various segments of the industry, including among major equipment manufacturers, developers and investors. In the short term, strong policy support in major economies, increasing demand and falling commodity prices can improve the financial performance of renewable energy companies, although challenges and risks will persist.

Multiple challenges have tested the financial health of renewable energy companies since 2019

Prior to the Covid-19 pandemic, the renewable energy industry had been surpassing most major market indices and the energy sector overall in equity markets. In the first half of 2020, however, wind turbine and solar equipment manufacturers recorded negative earnings before interest, taxes, depreciation and amortisation (EBITDAs) as revenues temporarily fell due to Covid-19 impacts. In 2021, rising commodity prices led to higher solar PV module and wind turbine costs. Then in 2022, Russia's invasion of Ukraine triggered a global energy crisis, leading to a further increase in input costs (including for electricity, raw materials and transportation), higher interest rates and continued supply chain disruptions.

Despite the challenges posed by energy security concerns, volatile commodity prices, supply chain constraints and trade measures, the renewable energy industry has demonstrated remarkable financial resilience. This is especially true for the solar PV sector, which has recorded stable profits in recent years. One of the reasons for this is the increasing market share of Chinese integrated companies since the early 2010s, thanks to China's industrial policy and growing global demand. These companies have achieved cost efficiencies through integration and their ability to absorb price shocks, allowing them to produce the world's lowest-cost solar PV equipment.

In the last two years, tight polysilicon supplies and rising PV demand have led to a more than fourfold increase in polysilicon prices, the highest level since the early 2010s. This has improved manufacturers' net margins, and polysilicon producers are posting record profits.

In contrast with the stable profits seen in the solar PV sector, the wind industry has faced significant financial challenges in recent years. Western wind

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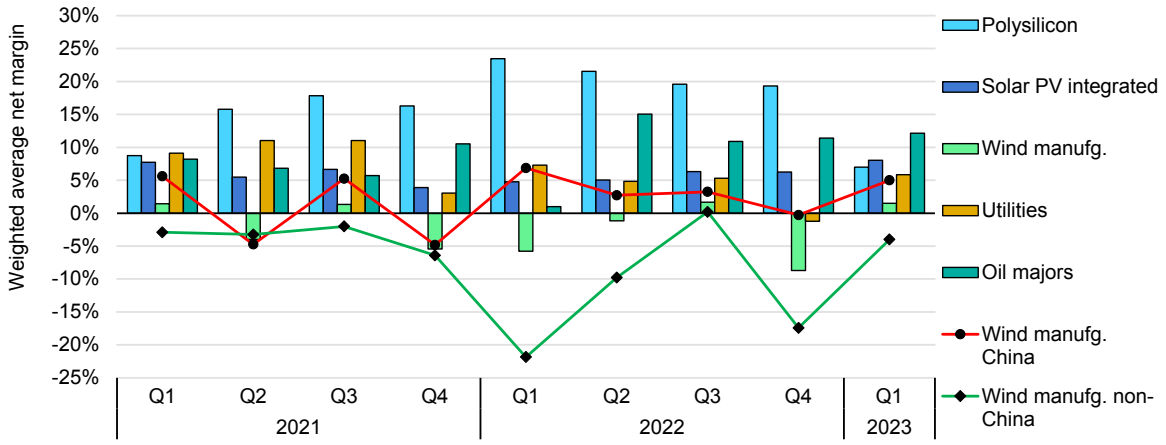
manufacturers have registered negative net margins for eight consecutive quarters since 2019, due to factors such as volatile global demand, supply chain and logistical challenges, and rising costs. These challenges have impacted their profitability, particularly for contracts signed with developers through competitive auctions during 2017-2020. These manufacturers have been unable to pass their cost increases on to developers.

Chinese wind turbine manufacturers have been less affected by commodity price volatility, and strong domestic demand has supported their financial health. This is partly because large Chinese manufacturers are also important project developers, which gives them greater control over project costs and enables them to absorb price shocks more effectively.

Quarterly weighted average net margin of renewable energy companies, large utilities and oil majors, 2021, 2022 and 2023 (Q1)



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Note: Wind manufg. = wind equipment manufacturing companies.
Source: IEA analysis based on annual financial reports.

The financial health of utilities is crucial for the sustainable growth of the renewable energy industry, but the global energy crisis has posed challenges to their financial performance and profitability. While large global utilities reported very high revenues, they were also exposed to volatile gas and electricity prices, which increased their energy procurement costs and sales. Their profitability was dependent on their retail exposure and on hydropower and nuclear output, and European utilities found it challenging to pass on the higher generation costs resulting from existing or new regulatory measures to protect vulnerable customers.

Furthermore, some large utilities incurred hedging losses by contracting energy at high prices, especially for Q4 2022 when electricity prices began to decline from

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peak levels. European utilities also registered higher taxes than in previous years because of taxation on windfall revenues/profits, which affected their overall profitability.

Meanwhile, medium- to large-sized global utilities made marginal profits or losses thanks to their geographical diversity, which allowed them to compensate for losses in certain markets by gaining profits in others. In the United States, utilities reported 2022 to be one of the best years for new renewable energy resource growth thanks to incentives such as accelerated depreciation and income tax credits. Some utilities used hedging strategies, long-term contracts and market trading activities to gain profits by selling supplies at higher market prices. The better-performing utilities had a significant share of renewables in their generation mix, which also allowed them to take advantage of favourable weather conditions in some regions and markets.

A bright future for the financial health of the renewable energy industry is on the horizon, but it requires governments and the industry to tackle multiple challenges

For the solar PV manufacturing sector, increasing annual capacity additions in 2023 and 2024 and government ambitions in the long term provide a positive outlook for demand growth. In the short term, integrated manufacturers, mostly based in China, will benefit from lower commodity prices, cost efficiencies and limited competition to maintain healthy profitability. However, the high profitability of polysilicon producers could be short-lived because global polysilicon capacity is expected to double by 2024, and price declines have already begun.

Overall, solar PV demand is not expected to grow as quickly as supply in the short term, leaving capacity utilisation of all manufacturing segments relatively low. In the past, this situation has led to negative margins for the industry but did not result in major bankruptcies for Chinese manufacturers. However, new manufacturing investments in India, the United States and Europe are also moving ahead and will contribute to the supply glut. While trade measures are expected to shelter new markets from competition, it will be difficult for these new facilities to maintain long-term profit sustainability.

Wind equipment manufacturers are expected to benefit from lower commodity, electricity and freight prices, which could improve their margins as demand expands in the short term. However, turbine prices are likely to remain relatively high, especially for Western manufacturers, due to uncertainties regarding commodity prices, interest rates and policies. Moreover, current supplies in

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Europe and the United States may not keep up with growing demand over the medium term because manufacturers' poor financial health is preventing them from investing in new facilities.

To improve the financial health of companies, it is crucial that government policies address permitting challenges, raise auction volumes and change tender designs with contract price indexation. In China, competition in local markets has lowered turbine prices even though commodity prices remain high, reducing company profitability. While lower prices create opportunities for Chinese manufacturers to increase their global market share, their success will depend on their financial sustainability.

Despite challenges stemming from electricity price volatility, most large utilities have decided to strengthen their renewable energy portfolios. However, rising interest rates and policy uncertainties threaten the ability of utilities to increase their investments in renewables.

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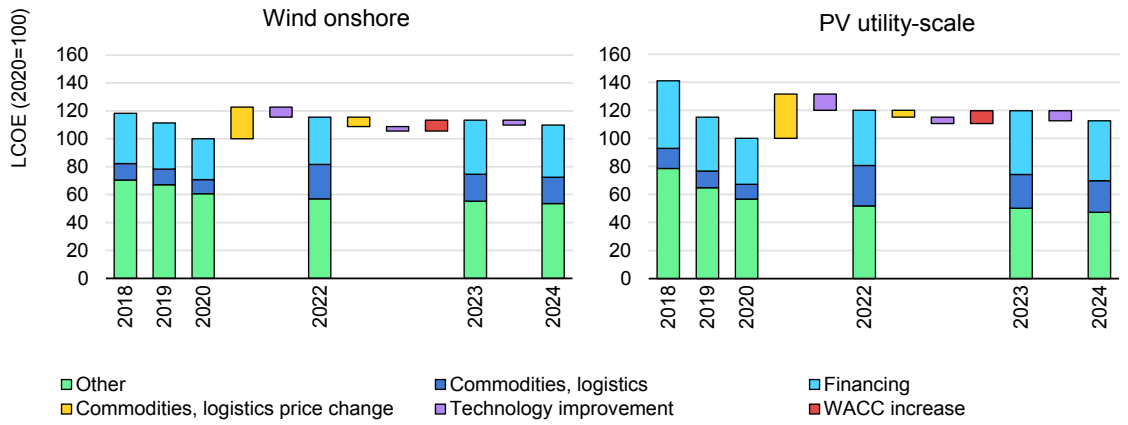
Will solar PV and wind costs finally begin to fall again in 2023 and 2024?

Electricity generation costs from new utility-scale onshore wind and solar PV plants are expected to decline by 2024, but not rapidly enough to fall below pre Covid-19 values in most markets outside China. Although commodity and freight prices have dropped from last year's peaks, they remain elevated. At the same time, developers' financing costs have increased due to rising interest rates. As a result, global average levelised costs of energy (LCOEs) for onshore wind and solar PV are expected to remain 10-15% above 2020 levels in 2024.

Solar PV and wind LCOE index based on average annual input costs, 2018-2024



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Notes: "Other" includes remaining investment costs, including other commodities, labour, energy, manufacturing processes, construction etc. LCOE = levelised cost of energy. WACC = weighted average cost of capital. LCOE index calculations are based on WACC of 4.5% in 2020-2022 and 5.5% in 2023-2024. Analysed commodities include steel, copper, aluminium and polysilicon. Technology improvement impact is based on historical trends. The data excludes China.

Initial investment accounts for the majority of solar PV and wind power plant generation costs, as operations and maintenance expenditures are low. In late 2020, the prices of major inputs such as steel, copper, aluminium and polysilicon began to rise sharply, as did freight and land transport costs, due to supply chain challenges and growing demand during the post Covid-19 global economic rebound.

At its highest point in 2022, the average monthly price of polysilicon – a crucial material for crystalline silicon solar PV cell production – was four times higher than at the beginning of 2020. The price of steel, the main construction material for both utility-scale PV and onshore wind plants, increased 75% in China, 160% in the

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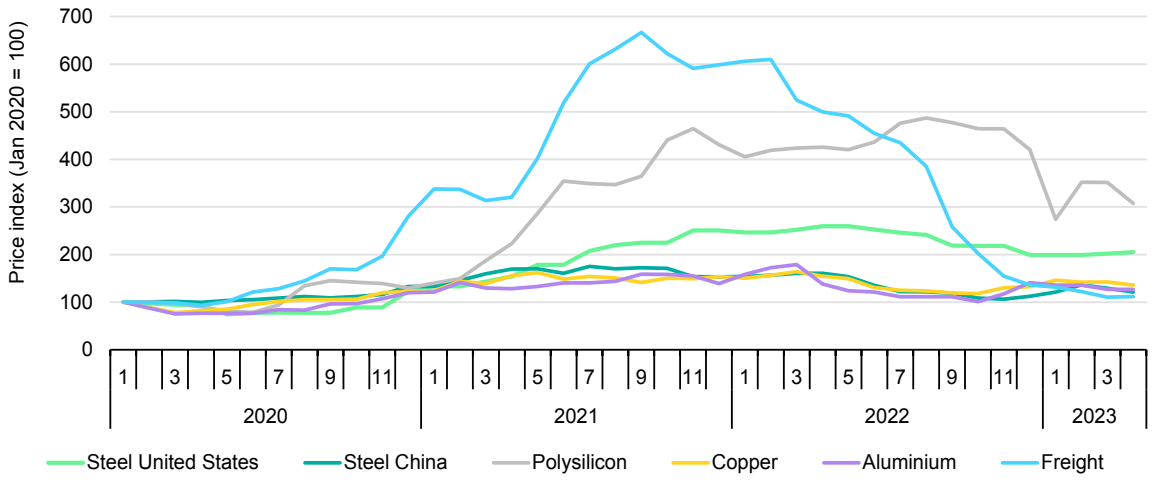
United States and 270% in Europe, while copper and aluminium became 60-80% more expensive. The highest growth was in freight rates, which rose almost sixfold.

In 2022, the share of main commodities and costs associated with transportation accounted for an estimated 30-35% of overall CAPEX for utility-scale and wind projects, twice as much as in 2020. Taking the full impact of higher prices on project development costs into account, and the usual annual cost reductions from continued technological innovation, the resulting LCOE increase for 2022 is estimated at 15-20% for these technologies.

Monthly commodity and freight price indexes, 2020-2023



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Notes: Steel United States: North America steel plate spot price ex-works. Steel China: China domestic 20-mm steel plate average spot price. Polysilicon: BNEF solar-grade silicon spot price. Copper and aluminium: London Metal Exchange 3-month forward contract price. Freight: WCIDCOMP Index.

In 2023, commodity prices have fallen significantly below their peaks, but they remain elevated compared with 2020. Average prices in Q1 2023 compared with January 2020 were higher by over 200% for polysilicon; by 100% for steel in the United States and Europe; and by 20-40% for aluminium, copper and freight. In many cases, commodity price changes have not yet been directly reflected by equipment manufacturers because of their supply contracts. However, many suppliers may attempt to recover their increased costs by raising prices in upcoming years, leading to higher investment costs.

In addition, macroeconomic risks in the global economy – associated with rising inflation, higher interest rates and the energy crisis caused by Russia's invasion of Ukraine – lead to a higher cost of capital, including for renewable energy projects. In real terms (i.e. excluding the impact of inflation), the weighted average cost of capital (WACC) is expected to increase in most large solar PV and wind markets, excluding China. The higher cost of capital could offset most of the cost

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decreases resulting from lower commodity prices and further technology innovation in the next two years. Consequently, the average LCOE for utility-scale PV and wind could be 10-15% higher in 2024 than it was in 2020.

Although their costs continue to exceed pre Covid-19 levels, solar PV and onshore wind remain the cheapest option for new electricity generation in most countries. Furthermore, power contracts for the end of 2023 and into 2024 in the European Union, the United States, Japan, Australia and India all indicate wholesale electricity prices two to three times above 2020 averages, increasing the economic attractiveness of wind and solar PV. Continued innovation is also expected to reduce costs further, improving competitiveness even with existing fossil fuel-fired plants.

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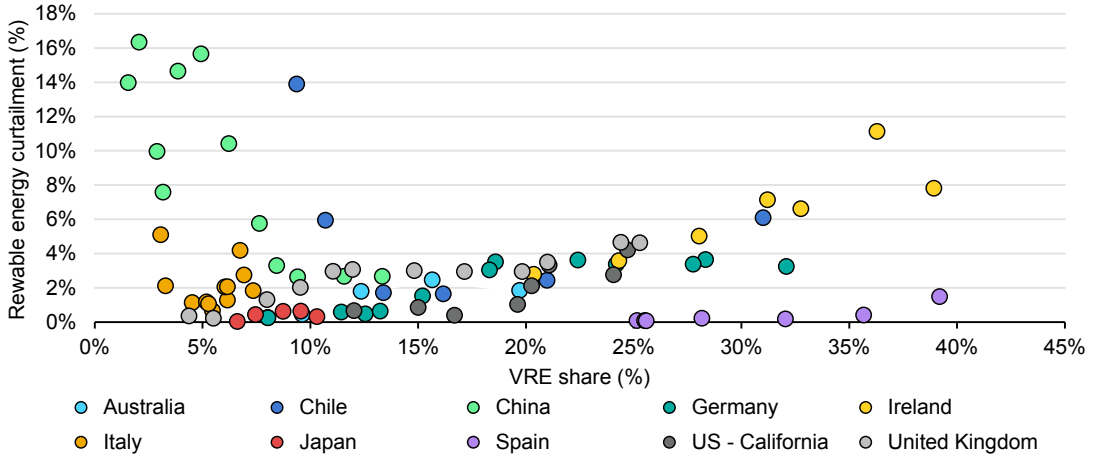
Do higher shares of wind and solar PV generation always imply more curtailment?

As the penetration of variable renewable energy (VRE) increases, the share of curtailed wind and solar PV generation is also on the rise in many markets. This trend is particularly evident in areas where major grid infrastructure investments and/or advanced market design and regulation are not keeping pace with VRE deployment.

VRE shares in generation and technical curtailment for selected countries



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Notes: Data points represent officially reported curtailed or constrained energy and combines various schemes depending on the country. VRE refers to solar PV and wind unless otherwise specified. Italy includes only wind. Spain includes PV, wind, CSP and biomass technologies. The United Kingdom includes only wind. "Technical curtailment" refers to the dispatch-down of renewable energy due to network or system reasons. Dispatched-down energy due to economic or market conditions is not included in this chart.

Sources: Australian Energy Market Operator (AEMO), Quarterly Energy Dynamics (multiple releases); Coordinador Eléctrico Nacional de Chile (CEN), Reducciones de energía eólica y solar en el SEN (multiple releases); National Bureau of Statistics of China (NBS), China Energy Datasheet 2000-2021;); Bundesnetzagentur, Monitoring Report 2022; Gestore Servizi Energetici (GSE), Rapporto attivita 2021; EirGrid, Renewable Dispatch-Down (Constraint and Curtailment) reports (multiple releases); Hokkaido Electric Power Network, Area supply and demand data (multiple releases); Tohoku Electric Power Network, Area supply and demand data (multiple releases); TEPCO Power Grid, Area supply and demand data (multiple releases); Chubu Electric Power Grid, Area supply and demand data (multiple releases); Hokuriku Electric Power Transmission & Distribution, Area supply and demand data (multiple releases); Kansai Transmission and Distribution, Area supply and demand data (multiple releases); Chugoku Electric Power Transmission & Distribution, Area suppy and demand data (multiple releases); Shikoku Electric Power Transmission & Distribution, Area supply and demand data (multiple releases); Kyushu Electric Power Transmission and Distribution, Area supply and demand data (multiple releases); Okinawa Electric Power, Area supply and demand data (multiple releases; Red Eléctrica de España (REE), I3DIA (multiple releases); California Independent System Operator (CAISO), Production and Curtailments data (multiple releases; Renewable Energy Foundation, Balancing Mechanism Wind Farm Constraint Payments.

Although VRE curtailment is increasing overall, the share of curtailed wind and solar PV generation remains relatively low, ranging from 1.5% to 4% in most large renewable energy markets. However, higher VRE shares do not necessarily result

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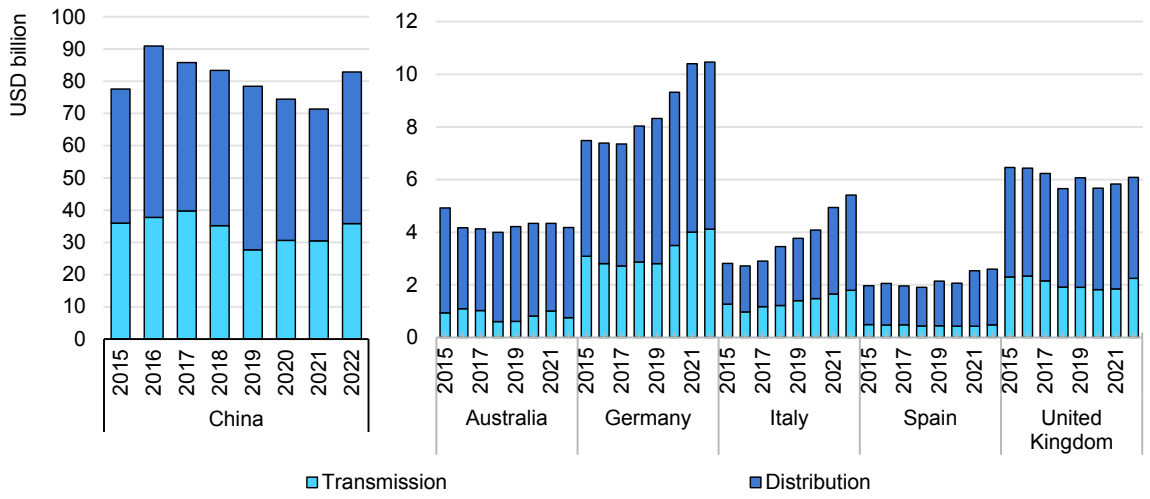
in rising curtailment rates, as countries can effectively manage renewable energy integration challenges with timely measures.

The importance of grid infrastructure

Inadequate investment in grid infrastructure remains a challenge worldwide not only for faster growth in new wind and solar PV capacity, but also for maximising generation potential from existing power plants. China's large-scale investment in grid infrastructure (USD 75 billion on average per year since 2010) has significantly reduced VRE curtailment, decreasing it from 16% in 2012 to less than 3% last year. During this period, China increased the interconnection capacity between wind and solar resource-rich northern and northwestern provinces to load centres in the southern and eastern regions.

Investment in transmission and distribution grids for selected countries



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Source: IEA, World Energy Investment 2023.

Germany has experienced increasing VRE curtailment over the past decade, but this trend has stabilised since 2015. While most of the country's wind capacity is situated in the north, major industries and load centres are in the south, leading to a geographical mismatch between renewable generation and consumption. This mismatch results in curtailment, particularly when the country cannot export its renewable electricity due to limited interconnection capacity.

While major grid investment decisions to strengthen the north-south corridor are still pending, Germany has implemented smaller-scale grid expansions. These have helped the country reduce onshore wind curtailment by 2 percentage points since 2015, but offshore wind curtailment increased from less than 1% to around 8% over the same period.

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In Chile, the geographical mismatch between VRE deployment and demand has resulted in high curtailment rates. The country's strong solar and wind potential is located primarily in the north, whereas most demand is concentrated in the centre. To address this mismatch, Chile merged its central and northern electricity systems in 2017, resulting in an initial reduction from 14% curtailment that year to 2% a few later. However, this trend was not sustained, with VRE curtailment reaching almost 6% in 2022, as wind and solar PV capacity more than tripled since 2017, while the commissioning of additional grid capacity faced delays.

In 2022, the United Kingdom generated one-fourth of its electricity from wind power, mainly from onshore wind farms in Scotland and offshore installations. However, most electricity demand is in the country's southeast. This has led to increased curtailment, with the amount reaching almost 4 TWh in 2022. Curtailment rates remained stable at around 3% in the second half of the 2010s but have since increased due to limited transmission capacity at the Scottish-English interface. To address this challenge, the national energy regulator plans to build an high-voltage direct current (HVDC) link on the east coast to increase interconnections.

Policy and system planning

To successfully manage rising VRE integration, it is crucial to not only make physical changes to the power system, but to adjust system planning. China's success in reducing curtailment stems not only from grid capacity expansion but from the government changing FIT remuneration rates to provide higher incentives in provinces with limited system integration challenges, among other measures.

As lead times for grid investment can be long, policies promoting electricity storage systems can also be useful to relieve high curtailment rates. Chile's 2022 law on electricity storage and electromobility aims to tackle renewable energy curtailment by incentivising installation of batteries and enabling electric vehicles to inject energy into the distribution grid. Meanwhile, Ireland has allocated budgetary funds for storage infrastructure in its Renewable Electricity Support Scheme (RESS) and has begun to award projects through auctions by providing them long-term revenue certainty and reduced financing costs.

Market design and operation

Integrating VRE sources such as wind and solar PV has necessitated changes to traditional power markets, both in their design and technical regulation.

Some countries are updating their market design to facilitate the VRE participation in their power markets, for instance by shortening the imbalance settlement period, reducing the gate closure time, and increasing the geographical granularity of the market. Furthermore, renewable energy generators could also be included in

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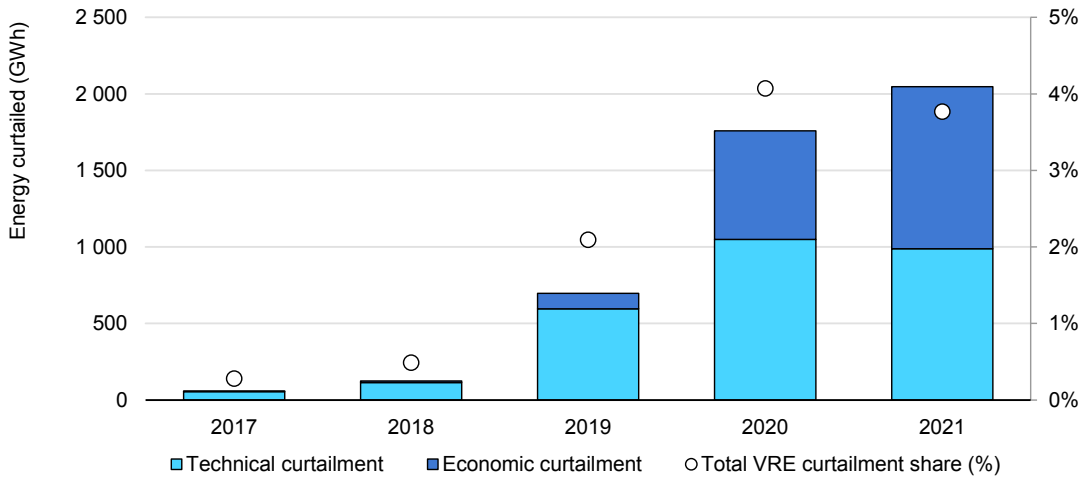
intraday markets (or balancing markets). Operational measures to increase system flexibility involve lowering the thermal fleet's minimum operational requirements and enhancing forecasting methods.

Ireland has increased its System Non-Synchronous Penetration limit and reduced minimum negative ramping reserve requirements while offering wind farms financial incentives to voluntarily reduce their output during high-generation periods. Chile is also considering options to further reduce thermal plants' minimum operation requirements to increase system flexibility.

Australia technical and economic curtailment



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Notes: "Technical curtailment" refers to the dispatch-down of energy due to network or system reasons; "Economic curtailment" refers to the quantities bid out of dispatch in balancing and intraday markets. Spain includes PV, wind, CSP and biomass technologies.

Sources: Australian Energy Market Operator (AEMO), Quarterly Energy Dynamics (multiple releases).

Enabling VRE to compete in balancing markets would provide additional income for renewable generation, while exposure to imbalance penalties would incentivise producers to smooth their output and improve forecasting. California has introduced an Energy Imbalance Market (EIM) to balance supply and demand to curb rapidly increasing curtailment rates. This approach relates to the concept of economic dispatch-down, wherein generators may bid out of dispatch during times when high levels of renewable energy are available and demand is low, which could result in zero or negative prices. For instance, economic curtailment in Australia has increased since 2017 and was responsible for the majority of curtailment in 2021.

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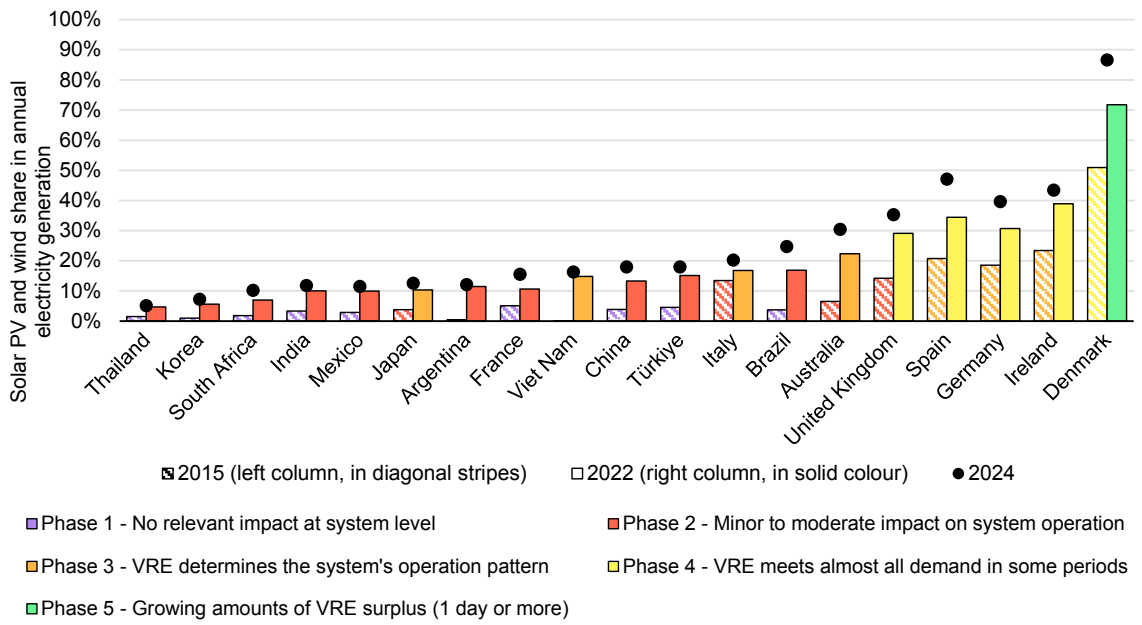
How are higher shares of wind and solar PV challenging power systems?

Rapid wind and solar PV capacity expansion is presenting new power system challenges, but IEA analysis of system integration phases for variable renewable energy (VRE) is helping governments identify relevant difficulties and prioritise measures to facilitate integration. Since 2015, accelerating VRE deployment has prompted system integration phase shifts in many countries, amplifying challenges for power system operators and regulators.

While VRE generation did not have a relevant impact (phase 1) on the power system of Viet Nam in 2015, today wind and solar PV output is determining the operation patterns (phase 3). Wind and solar PV capacity surged from less than 500 MW in 2018 to 25 GW in 2022 thanks to the country's generous FIT policy, causing the nation to jump two phases and resulting in rising wind and solar PV power generation curtailment. However, after experiencing power system challenges (including curtailment) following this unprecedented expansion, Viet Nam phased out all incentives and VRE penetration is not expected to increase any further by 2024.

Variable renewable energy shares and phases for selected jurisdictions, 2015, 2022 and 2024



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The United Kingdom also jumped two phases in the same period as a result of rapid offshore wind and solar PV growth, transitioning from VRE having a minor to moderate impact on system operations (phase 2) to periods when VRE makes up almost all generation (phase 4). Multiple European countries (e.g. Germany, Spain and Ireland) also reached phase 4 in 2022, for them a one-phase increase from 2015. Accelerating wind and solar PV power generation in these countries following Russia's invasion of Ukraine indicates that VRE share increases for 2024 will be higher than previously expected.

For instance, Spain's annual VRE share is forecast to increase by nearly 15 percentage points to almost 50%, enlarging its VRE surplus, which can be only partially exported to the rest of Europe due to limited interconnection capacity with France. Denmark's power systems have been managing an over-50% VRE share since 2015 thanks to the country's high interconnection capacities with Sweden, Norway, Germany and the Netherlands. However, the forecast for 2024 indicates that Denmark's VRE share could reach almost 90%, intensifying system integration challenges. Considering the country's size relative to its interconnections, its ability to tackle upcoming challenges will also depend on the VRE situation in neighbouring countries.

The trajectory of European countries in the IEA assessment of system integration phases highlights the importance of addressing upcoming integration challenges as soon as possible. Many major economies, including Brazil, China, France and Türkiye, have multiplied their wind and PV capacity by four to five times since 2015 and have begun to experience moderate system operation impacts. As all these large countries have ambitious VRE expansion plans, they will need to plan for additional flexibility investments to accommodate greater net load variability.

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Will global solar PV and wind technology manufacturing capacity be adequate to meet Net Zero demand in 2030?

Global solar PV manufacturing capacity is expected to reach almost 1 000 GW in 2024, adequate to meet annual IEA Net Zero by 2050 demand of almost 650 GW in 2030. However, wind equipment manufacturing continues to expand more slowly, such that it may not be able to keep pace with demand growth under this scenario through 2030. While China will dominate global wind and solar PV manufacturing capacity in the short term, PV project announcements indicate supply chain diversification.

With PV manufacturing capacity to more than double by 2024, the industry is rushing headlong into a supply glut

China reaffirmed its dominant position last year. In 2022, global solar PV manufacturing capacity increased by over 70% to reach almost 450 GW, with China accounting for over 95% of new facilities throughout the supply chain. In 2023 and 2024, global solar PV manufacturing capacity is expected to double, with China again claiming over 90% of this increase. Meanwhile, the forecast expects significant wafer, cell, and module manufacturing expansion in the ASEAN region through investments from Chinese manufacturers. For the first time, a relatively large deployment of manufacturing plants is also forecast for India and the United States, thanks to industrial policies introduced last year.

Announced new PV manufacturing in India, the United States and Europe reaches 30 GW for polysilicon and 100 GW for module assembly, with signs of diversification emerging

Governments in the United States, Europe and India have begun to prioritise solar PV supply chain diversification, implementing policies such as India's Production Linked Incentive (PLI) scheme and the US Inflation Reduction Act (IRA) to provide

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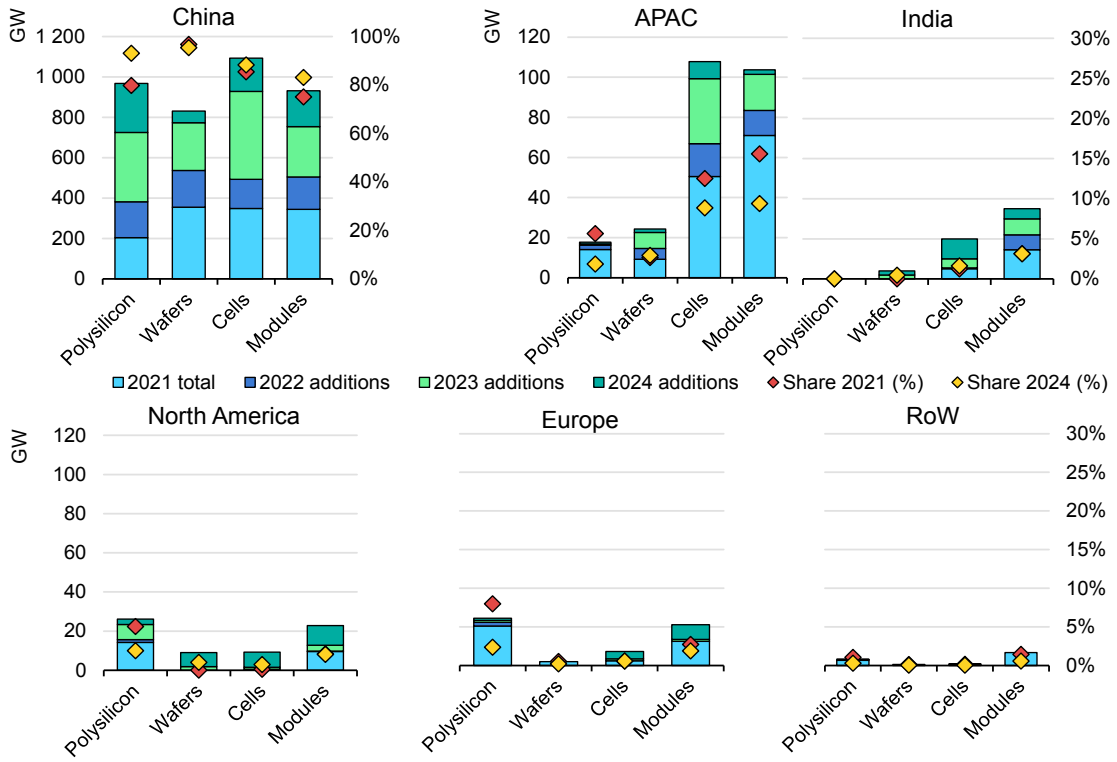
direct financial incentives for domestic manufacturers to increase their competitiveness with Chinese ones. As a result, over 120% more new solar PV manufacturing projects were announced from November 2022 to May 2023, to potentially create national PV supply chains with over 20 GW of capacity in each region.

Solar PV manufacturing capacity by region and component, 2021-2024



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Notes: APAC = Asia Pacific region excluding India and China. RoW = rest of world. Manufacturing capacity in 2027 is the value expected based on announced policies and projects. Manufacturing capacity refers to a nameplate year-end value.

Sources: IEA analysis based on BNEF, Solar PV Equipment Manufacturers database (accessed April 2022), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

However, differences in policy design between India and the United States have led to the promotion of different PV production segments. While India's PLI focuses on integrated facilities, the IRA provides tax credits for various PV segments, leading to mostly segment-specific project announcements.

New manufacturing capacity in the European Union makes up just 14% of announcements tracked by the IEA since August 2022. The EU Green Deal Industrial Plan for the Net-Zero Age and the Net-Zero Industry Act target specific percentages of domestic solar PV manufacturing, but do not yet include specific incentives. In addition, high industrial power prices have made it more expensive to manufacture solar PV equipment in EU countries. Without a manufacturing

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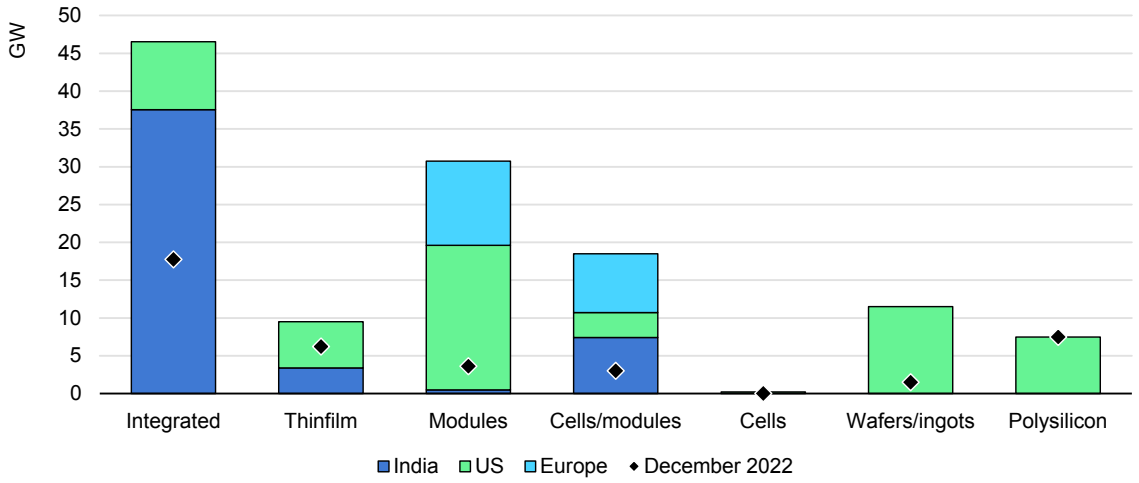
policy or domestic-content premiums, manufacturing solar PV equipment in the European Union is less competitive than in India or the United States.

Announced solar PV manufacturing capacity by region and component, 2022-2023



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Notes: "Integrated" indicates three or more manufacturing processes in one single plant. The budget for India's PLI scheme was announced in February 2022, with project capacities for the second phase awarded in March 2023.

Integrated, module and thin-film manufacturing plants make up nearly 85% of new facilities, while capacity lags for dedicated manufacturing for new cells (less than 1%), ingots and wafers (9%) and polysilicon production (6%). Integrated manufacturing plants produce three or more components, but nearly 80% of this announced capacity does not include dedicated polysilicon production. In addition, while new module assembly plants will have a capacity of nearly 30 GW, this amount is not matched by capacity announced for other components, especially cells and polysilicon. These new plants will therefore still need to import cells and other components from China.

China leads sluggish growth in wind equipment manufacturing as Western equipment suppliers struggle financially

In 2022, manufacturing capacity for the main wind power components (nacelles, towers and blades) remained relatively stable at 110-120 GW. However, global production capabilities are anticipated to increase in line with demand over the next three years, resulting in approximately 120-140 GW of capacity by 2025, about one-third of what is required in 2030 to meet annual IEA Net Zero by 2050 demand.

Unlike solar PV manufacturing, wind equipment production is less concentrated geographically, as suppliers prefer to locate production plants close to demand

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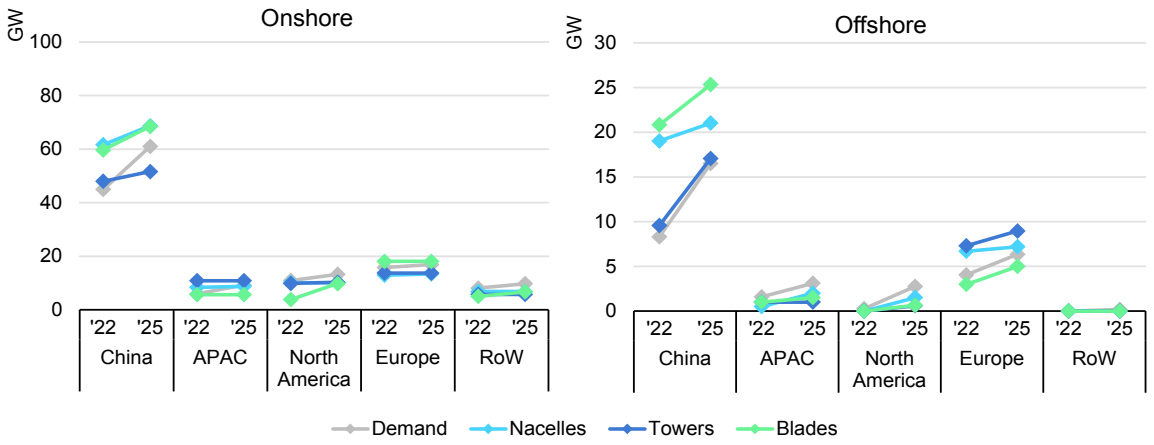
centres due to the high costs and risks associated with transporting large and fragile components over long distances.

Until 2025, China is expected to remain the largest manufacturing hub for all main wind energy components, commensurate with its growing demand. However, the United States' first manufacturing plants for offshore wind equipment are also anticipated to come online in this period to support planned offshore wind farm deployment.

Wind equipment manufacturing capacity by region and component, 2022-2025



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Notes: APAC = Asia Pacific region excluding India and China. RoW = rest of world. Manufacturing capacity refers to a nameplate year-end value.

Source: IEA analysis based on BNEF and Wood Mackenzie.

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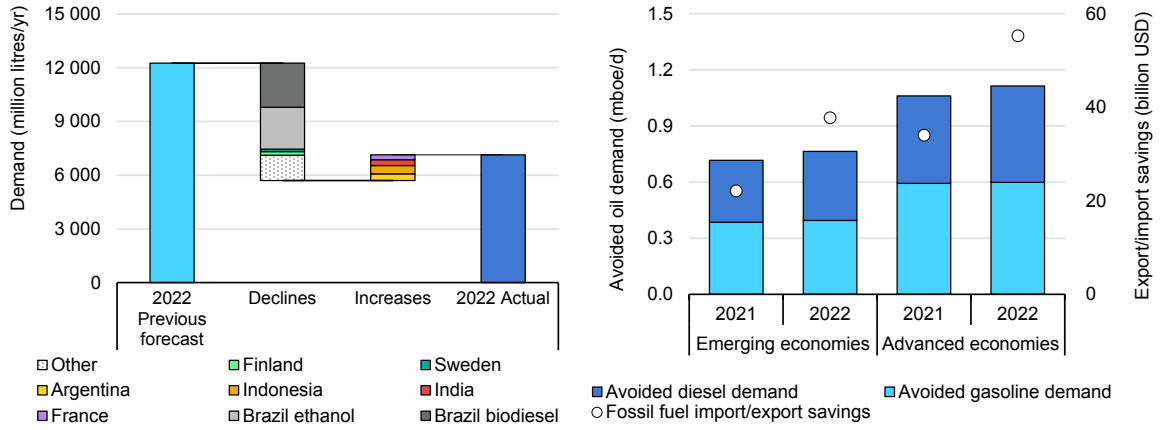
Where were governments able to rely on biofuels to secure energy supplies during the 2022 energy crisis?

Biofuel production expanded in countries with readily available, affordable feedstocks, spare production capacity and flexible policy instruments. For instance, Argentina, India and Indonesia all accelerated biofuel use in 2022 helping reduce fossil fuel imports. However, in many countries biofuel prices climbed more quickly than gasoline and diesel prices, contributing to higher transportation costs. To mitigate increases in transport fuel costs, Brazil, Sweden and Finland delayed planned increases to biofuel blending obligations in 2022.

Forecast changes to biofuel demand growth, 2022 (2021 forecast vs. current forecast) (left) Avoided gasoline and diesel demand and fossil fuel import savings, 2021-2022 (right)



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Notes: Amounts of avoided gasoline and diesel demand are based on energy content for domestically produced biofuels. Gasoline and diesel import savings are estimates based on average annual pre-tax market prices for gasoline and diesel in 2022. Estimates include any export revenues from additional oil sales for oil-exporting countries. In this case, countries benefited from additional oil exports due to less domestic demand.

Globally, biofuels helped avoid consumption of 2 million barrels of oil equivalent per day (mboe/d) in 2022, which accounts for 4% of global transport sector oil demand. Most of these fuels were produced domestically, allowing countries to save on import costs. As a result, countries avoided oil import costs of USD 90 billion in 2022, up 70% from 2021. Domestic production of biofuels in emerging markets alone (mainly Brazil, India and Indonesia) avoided USD 38 billion of import costs. These estimates do not account for the relative prices of biofuels and

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fossil fuels in each of these countries, nor the benefits of increased local economic activity that domestic biofuel production can stimulate, including in the agriculture sector. Biofuels also continued to deliver greenhouse gas (GHG) reduction benefits, helping countries maintain the pace of their clean energy transitions in the transport sector.

Some markets increased biofuel production to mitigate high prices and address supply concerns…

Argentina, India and Indonesia all accelerated their biofuel production in 2022 because of their readily available domestic feedstocks, affordable biofuel supplies, available capacity, flexible policy instruments and high dependence on fuel imports. The Argentinian government, for instance, responded to concerns of diesel shortages by increasing its biodiesel blending rate and offering incentives. These measures boosted biodiesel use 80% from 2021 to 2022, offsetting an estimated 6.5% of Argentina's diesel demand. In Indonesia, higher-than-expected diesel demand prompted the government to increase its biodiesel allocation, expanding biodiesel supplies by 6% above planned biodiesel allocations from earlier in 2022.

In India, ethanol supplies expanded more quickly than previously expected, climbing to 10% of total gasoline supply in 2022. Ethanol in India is produced mostly from molasses and sugar cane, for which prices did not rise as much as for other biofuel feedstocks. In Europe, France also expanded its ethanol usage through a combination of generous tax breaks for high ethanol blends (E85) and financial support for conversion kits to allow existing vehicles to run on E85. These efforts helped boost E85 share of gasoline use by 2 percentage points in one year, driving a 10% increase in ethanol consumption.

… but overall biofuel demand growth declined by 40% during the energy crisis

By the end of 2022, however, five governments had delayed planned policy measures to increase biofuel use over concerns these policies would increase transport costs. These five changes (Brazil, Sweden, Finland, Croatia and Latvia) account for the majority of the 40% drop. Biofuel consumption still grew 5% in 2021-2022, similar to annual growth over the last decade but well below our expectations for 2022 before the energy crisis. Brazil's delay in implementing higher biodiesel blending rates is the main factor: in 2021 and again in 2022, it delayed a five-percentage-point increase to its biodiesel blending mandate,

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keeping blending at 10%. It now plans to slowly increase the blending mandate to 15% by 2026. Finland and Sweden also froze their respective policies until 2023.

Last year's forecast had also expected Brazil's ethanol demand to be higher. Although the country did maintain its 27% ethanol blending mandate, securing a portion of ethanol demand, discretionary blending declined because ethanol was more expensive than gasoline at some points during the year. Brazil also modified its fuel tax rates to keep gasoline prices low, which provided less support for ethanol than usual.

In 2022, the United States approved the use of 15% ethanol blends year-round in an effort to reduce pump prices. However, the impact on ethanol use was limited because only a few pumps could handle the 15% ethanol blend.

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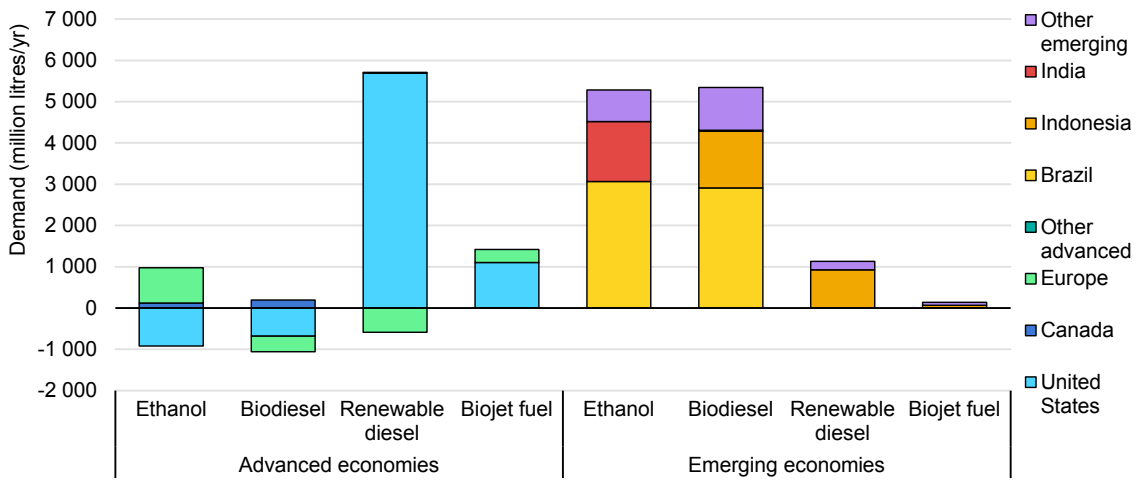
Will energy security concerns drive biofuel growth in 2023-2024?

Energy security returned as a primary rationale for expanding biofuel policies last year. Similar to the forecast before Russia's invasion of Ukraine, our updated forecast expects 11% (18 000 million litres) of new demand by 2024, supported by policies with energy security objectives. However, as in 2022, only a few markets are actively trying to accelerate deployment by 2024. In advanced markets, new policies are not likely to influence production until after 2024, and high prices, feedstock concerns and technical constraints limit additional growth beyond our 2021 forecast.

Emerging markets to lead growth in 2023-2024

Nearly two-thirds of biofuel demand growth will occur in emerging economies, primarily India, Brazil and Indonesia. All three countries have ample domestic feedstocks, additional production capacity, relatively low production costs and a package of policies they can leverage to increase demand. Policies in all three countries are also rooted in energy security considerations, as greater biofuel use will offset some oil imports. India imported 87% of its crude oil supply and Indonesia net imports made up 20% of supply in 2021. Brazil is a net crude exporter but still imported 19% of its gasoline and diesel in 2021.

Biofuel demand growth by fuel and region, 2022-2024



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Indonesia also announced two initiatives to accelerate biofuel deployment at the end of 2022. First, it plans to increase its biodiesel blending mandate to 35% in 2023, up from 30% in 2022. Second, it released an Ethanol for Energy Security strategy to increase ethanol use, but implementation details remain limited.

Brazil plans to reinstate a climbing biodiesel blending target to reach 15% blending by 2024, up from 10% in 2022. Ethanol demand will expand as well, but more slowly than anticipated in our 2021 pre-energy-crisis forecast because sugar prices have risen. Depending on which option is more profitable, sugar producers in Brazil can switch some production from sweeteners to ethanol or the reverse. The country is also considering a 2.5% increase to its mandatory ethanol blending requirement, but no date has been released.

In 2022, India did not announce any new biofuel policies. However, the country is still committed to its target of achieving 20% ethanol blending by 2025, which will drive demand growth in upcoming years.

Renewable diesel growth remains strong in advanced economies, but overall biofuel demand expansion will not accelerate by 2024

Biofuel demand is projected to rise by 6% or 5 700 million litres between 2022 and 2024 in advanced economies, with most of the increase occurring in the United States and Europe. The Renewable Fuel Standard and the Inflation Reduction Act in the United States are intended to achieve various goals, including enhancing energy security. Meanwhile, the EU Renewable Energy Directive (RED), which member states' governments have implemented through domestic policies, aims to achieve 14% renewable content in transport fuels by 2030.

One of the reasons for the RED's initial implementation in 2003 was to decrease oil import reliance to strengthen EU energy security. In 2022, this rationale was reiterated, with the RED additionally considered a measure to reduce both energy prices and EU dependence on imported fossil fuels.

Nevertheless, we do not expect biofuel demand to accelerate in response to energy security concerns in either the European Union or the United States during 2023-2024.

Although the European Union is planning to increase its targeted share of renewable energy in transport from 14% to 29% by 2030, a final agreement has yet to be reached, and member governments would need time to align their domestic targets. Ethanol, biodiesel and renewable diesel prices also remain above those of gasoline and diesel (see next section), so biofuel use can be less expensive for consumers only if it is subsidised. Furthermore, over 40% of the

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European Union's biodiesel (or the feedstocks to produce it) were imported in 2022. Renewed concerns over the difficulty of verifying the sustainability credentials of these imports presents additional doubts about increasing blending requirements.

In the United States, the IRA provides production support to 2027 and investment support to 2031. We do not, however, expect a notable change in production or demand to 2024, since projects take more than two years to complete and we had assumed the biodiesel blending credit available in 2021 would remain in place. The Environmental Protection Agency (EPA) has released proposed volume obligations for 2023 through 2025, but the amounts for biodiesel and renewable diesel are lower than our current forecast. If the proposed values stand, it will likely lead to a decrease in our forecast. The EPA noted that "feedstock limitations are more likely [than capacity] to limit renewable diesel supply".

Biofuel policies and energy security rationale by region, with influence on forecast

Country/region	Energy security policy links and changes	Production change in 2023-2024 compared to 2021 forecast	Explanation
United States	With the Renewable Fuel Standard (RFS), congress intended the renewable fuel programme to provide greater US energy security. The intent of the Inflation Reduction Act (IRA) is to take the most aggressive action ever to confront the climate crisis, strengthening the US economy and energy security. On 28 April, the US government provided an emergency waiver for year-round E15 blending.	No change	The 2021 forecast assumed the biodiesel blender credit would continue to 2024 as it had been extended several times in the past. The IRA is therefore unlikely to drive additional volumes in the forecast time horizon. The RFS has not yet been set to 2024. Proposed values for biodiesel and renewable diesel, if implemented, would likely downgrade our forecast.
Brazil	Brazil introduced its first ethanol blending requirement in 1976. Since then the biodiesel blending programme has aimed to reduce diesel use and effectuate savings sustainably while promoting social inclusion, guaranteeing competitive prices, quality and supplies, and enabling biodiesel production from various oil sources in different regions. The RenovaBio programme recognises the strategic role of all biofuels in contributing to energy security, market predictability and the mitigation of GHG emissions.	Decline	The 2021 forecast included 15% biodiesel blending in 2024, which the Brazilian government had delayed to 2026. We revised the ethanol forecast down slightly to reflect lower blending in 2022 and the potential for high sugar prices in 2023, which would divert some sugar to sweetener manufacturing rather than ethanol production.

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Country/region	Energy security policy links and changes	Production change in 2023-2024 compared to 2021 forecast	Explanation
European Union	In 2023 the EU Parliament and Council agreed to new Renewable Energy Directive (RED) targets, including a 14.5% GHG or 29% renewable energy share target for transport by 2030. The overall aim of the RED is to reduce energy prices as well as EU dependence on imported fossil fuels. However, Sweden announced its intention to reduce its blending obligation to 6%, down from 7.8% for gasoline and 30.5% for biodiesel.	Decline	RED III has not yet been finalised and it is unlikely that member governments will be able to incorporate new targets that would raise demand by 2024. We also assume Finland return to its initial target as planned. Sweden reduces blending obligation to 6% by January 2024 for gasoline and diesel.
Indonesia	Indonesia launched its biodiesel blending programme in 2006 to ensure the country's energy supply security, and in 2023 it increased its biodiesel blending mandate to 35% to reduce diesel imports and expenses. Indonesia also announced an Ethanol for Energy Security Strategy in 2022.	Increase	Indonesia has set an allocation for additional biodiesel and has the production capacity to support this level growth. It also has surplus palm oil stocks. We did not increase ethanol blending since there are no details on the Ethanol for Energy Security Strategy.
India	India launched its National Policy on Biofuels as one part of a five-pronged strategy to meet energy security objectives, with the primary energy security aim of reducing imports.	Increase	In 2022 India officially adopted a target of 20% ethanol blending by 2025. It also increased guaranteed ethanol prices, which contribute to a higher forecast.

The United States has additional ethanol capacity, and ethanol prices are currently close to gasoline prices. To promote sales, the US government issued an emergency waiver in 2022 allowing for year-round 15% ethanol sales, and has done so again for 2023 to help reduce gasoline prices. However, ethanol consumption cannot be boosted quickly because compatible infrastructure is required for higher ethanol blends.

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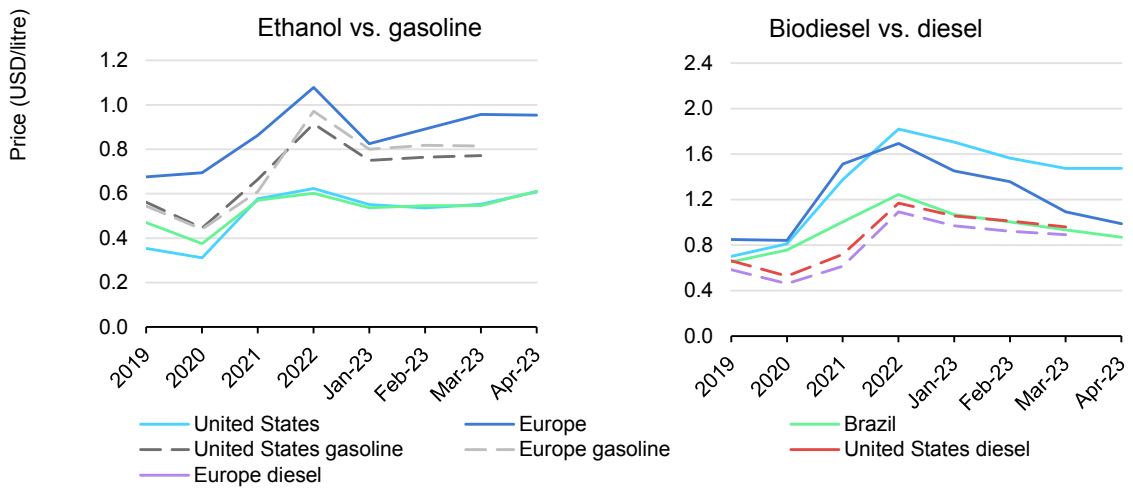
Will we see lower biofuel prices in 2023-2024?

Biofuel prices peaked in 2022 and have since declined, but we expect them to remain above pre-war levels in most markets in 2023-2024. In 2022, biodiesel prices rose by up to 160% and ethanol prices by up to 75% from 2019 levels. These price increases resulted from a combination of factors, including trade disruptions, high energy prices, high fertiliser costs, and weather-related supply interruptions for primary biofuel feedstocks.

In the first four months of 2023, ethanol prices declined 7-16% from the 2022 average and biodiesel prices dropped 15-28% (depending on the market). In 2023, US ethanol prices are expected to climb due to slightly higher-priced corn, which is the country's primary feedstock for ethanol production. In Brazil and India, decade-high sugar prices are likely to put upward pressure on ethanol prices, since ethanol production in both countries relies primarily on sugar.

Meanwhile, even though vegetable oil prices for biodiesel production have fallen 27% from record highs in 2022, supplies remain tight, limiting the pace and scale of price declines in the next two years. The risk of higher prices due to Russia's invasion of Ukraine continues to be a concern, as the conflict may disrupt international agricultural trade again this year.

Ethanol and gasoline prices (left) and biodiesel and diesel prices (right) in selected markets, 2019-2023



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Notes: Gasoline and diesel prices are based on reported IEA data and exclude taxes. Ethanol and biodiesel prices are based on Argus, IHS Markit and IEA analysis.

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Advanced biofuel imports drive down biodiesel costs in Europe

As of April 2023, biodiesel prices had fallen by more than 40% since 2022 for several reasons, including lower vegetable oil prices and increased imports of lower-priced advanced biofuels and feedstocks. Advanced biodiesel is produced from used cooking oil, tallow, palm oil mill effluent, and other residues.

In the first three months of 2023, imports of advanced biofuels and used cooking oil from China increased 18% from the same time last year. In many EU markets, each litre of advanced biofuel can be counted twice towards blending obligations, displacing two litres of conventional biodiesel, reducing overall biodiesel demand and contributing to more significant price declines.

Ethanol prices have also declined from peaks in 2022 but remain 40% above 2019 levels. High sugar prices, a poor harvest of sugar beets (used to make ethanol) and still-high farming input costs for natural gas and fertiliser are contributing to higher prices. Ethanol demand is also expected to increase by 12% to 8 billion litres by 2024 as countries continue to pursue biofuel obligations and GHG targets in the transport sector.

Renewable diesel growth supports higher vegetable oil prices in the United States

We expect biodiesel prices to decline slightly in 2023/24 from their highs in 2022 owing to drops in vegetable oil prices. The cost of soybean oil, for instance, is 12% lower this year than it was in 2022. This decline is still below the global average, however, partly because expanding renewable diesel production is boosting domestic demand while soybean oil supplies have not increased. The USDA expects rising renewable diesel demand to displace exports, reducing them by 75% in 2023.

Ethanol prices are still high compared with historical levels and are expected to remain elevated in 2023. The USDA foresees a 9% drop in corn production from 2021/22 to 2022/23 while demand remains stable, supporting 10% higher corn prices. Prices are then expected to decline over 2023/24. Corn is the dominant ethanol feedstock in the United States.

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High Brazilian sugar and soybean production supports domestic and international demand increases

In Brazil, ethanol prices are expected to increase in 2023 due to higher international sugar prices and rising domestic demand. Globally, sugar prices soared to 10-year highs in the first four months of 2023 because key producing regions such as India had lower output while global demand remained stable. Ethanol produced from corn, 15% of Brazil's production, may offer relief if production prices remain below those of sugarcane ethanol.

Brazil's biodiesel prices are down 30% from last year and the country expects a record soybean crop, which should keep prices low. However, raising of the country's biodiesel blending mandate will command an additional 7 Mt of soybeans (5% of estimated total production in 2023 and 9% in 2024), contributing to higher domestic demand. Brazilian soybean exports are also expected to increase 17% (13 Mt) from last year, making up for a 60% year-on-year drop in Argentinian production. Droughts in Argentina, the world's largest soymeal and soybean oil exporter, have left its soy crushers searching for new supplies, prompting increased imports from Brazil.

Price drivers per biofuel by country/region

Country/ region	Ethanol		Biodiesel	
	Price pressure	Drivers	Price pressure	Drivers
United States	Increase then decrease	Corn prices are expected to rise 10% in 2023 because of lower production and stable demand, and to return to below 2021/22 values in 2023/24.	Decrease	Vegetable oil prices are expected to decline slightly in 2023/24, although greater renewable diesel demand could raise prices. Higher final renewable fuel standard volume obligations for renewable diesel and biodiesel could also influence prices.
Brazil	Increase	Sugar prices are up 40% from December 2022 and are expected to stay high in 2023 because of production declines in India. Ethanol demand is also expected to be 11% higher in 2024 than in 2022. Brazil is expecting a 6% production increase this year to help cover ethanol demand and export	Decrease	Prices for soybean oil, Brazil's dominant biodiesel feedstock, are down 27% year-on-year and production is at record levels. Demand increases from the biodiesel mandate and higher exports, but prices are expected to decline overall.

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Country/ region	Ethanol		Biodiesel	
	Price pressure	Drivers	Price pressure	Drivers
		expansion, and it is also considering a 2.5% increase to its ethanol blending requirement, which would boost demand.		
European Union	Increase	Although agricultural input costs are still well above pre-energy-crisis levels, they are down considerably from 2022 peaks, helping reduce feedstock costs. However, sugar prices have nearly doubled from 2022, raising the price of sugar beets, a dominant feedstock for EU biofuel production.	Decrease	Increases in advanced biofuel imports from China, which count double under the Renewable Energy Directive, have reduced used cooking oil prices by 28%, contributing to a 40% decline in biodiesel prices. However, high import levels have raised concerns that supplies do not meet sustainability requirements. Validation of these concerns could slow the pace of price declines.

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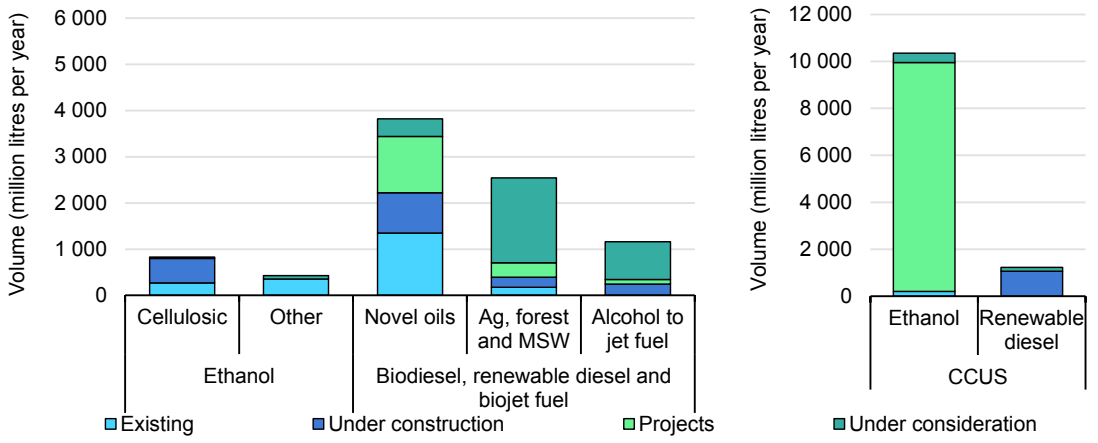
What are governments and companies doing to avoid a supply crunch, and is it enough?

The number of planned projects using unconventional feedstocks is not enough to avoid a feedstock supply crunch over the medium term. Even if every proposed project is built on time, new production potential amounts to just 4% of existing biofuel production globally. Nevertheless, thanks to policies in major biofuel markets, these planned facilities could more than triple existing capacity of plants using unconventional feedstocks by 2030. Beyond investing in new projects, the renewable energy industry is also helping expand feedstock supply chains by enlarging the use of new oilseeds.

Existing and planned biofuel capacity using non-conventional feedstocks and incorporating CCUS, 2021-2030



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Notes: CCUS = carbon capture, utilisation and storage. MSW = municipal solid waste. "Existing" projects are those with operational capacity as of the end of 2022. "Under construction" are projects being built as of Q1-2023. "Projects" are those with announced final investment decisions or otherwise highly likely to move forward as of Q1-2023. "Under consideration" covers all other announced projects with planned operation dates as of Q1-2023.

The feedstock supply crunch

In Renewables 2022, we found that raising biodiesel, renewable diesel and biojet fuel production would likely require most available supplies of used cooking oil and animal fats as well as a sharp increase in vegetable oil supplies to 2027. Although ethanol feedstocks such as sugar and corn are under less pressure, feedstock diversification is ultimately necessary for all biofuel pathways on a net zero trajectory.

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Broadly, governments and companies have four options to reduce feedstock pressure while expanding production of sustainable biofuels:

1. Enlarge production from existing feedstocks by intensifying crop production, investing in supply chains and improving waste and residue collection.
2. Expand crop production to areas where there is no competition from food or feed crops.
3. Use biofuel technologies that can process alternative feedstocks such as woody organic residues.
4. Reduce the GHG intensity of fuels so that emissions reduction targets can be met with lower biofuel volumes.

Government policies and market reactions are encouraging the largest-ever expansion in new biofuel technologies

Planned projects using unconventional feedstocks would more than triple existing production, with government policies and industry reactions to market demand helping drive investment. Government programmes and policies fall into three broad categories:

1. **Strategic planning:** Many jurisdictions use roadmaps and strategic plans to address feedstock limitations. For example, three of the six action areas of the US SAF Grand Challenge Roadmap focus on expanding feedstock supplies, as do China's bioeconomy plan and Brazil's Fuel of the Future Programme.
2. **Regulatory design:** Regulatory design can also prompt feedstock diversification. The EU Renewable Energy Directive (RED), for instance, limits the contribution of crop-based feedstocks, used cooking oil and animal fats, and also allows certain feedstocks (Part A of Annex IX) to count double to help stimulate demand. Meanwhile, California's low-carbon fuel standard requires GHG intensity reductions for transport fuels, such that fuel producers receive financial benefits per unit of GHG reduction delivered (rather than per volume of fuel), helping achieve the same policy objective with lower feedstock demand.
3. **Financial support:** Production and investment incentives in the form of tax credits, guaranteed pricing and grants are also helping drive investment. For instance, the IRA in the United States provides tax credits through the Second-Generation Biofuel Incentive, the Advanced Energy Project Credit and the Tax Credit for Carbon Sequestration. While Canada provides funding for feedstock diversification, India is offering support for cellulosic ethanol projects.

These policies and programmes, in addition to historical efforts to date, are helping spur new project development. For biodiesel, renewable diesel and biojet fuel, new projects are being dedicated to alcohol-to-jet fuel, thermal treatment of

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agricultural and forest residues and municipal solid waste streams, and to novel oils that do not compete with food or feed crops. In fact, eights projects involving major biofuel producers investing in novel oil supply chains have been announced in 2022-2023. All planned projects would introduce 7 billion litres of new capacity – four times the existing capacity from these types of projects – but half of them are currently just proposals with no firm production date.

Meanwhile, new cellulosic ethanol projects, mostly in India and Brazil, would triple existing production capacity. Although they would cover only a small fraction of new ethanol demand, these developments are the most significant cellulosic buildout in a decade.

Biofuel production combined with CCUS can also reduce pressure on feedstock supplies in jurisdictions such as California that have GHG intensity targets.

While not in the figure above, biofuel producers are also expanding their conventional supply chains. In North America, crushing capacity (to produce oils from oilseeds) is expected to increase by up to 40% by 2025 for soybeans alone, helping biofuel producers access more local vegetable oil supplies.

More efforts are needed to expand feedstock supplies

While the scale of new projects is impressive, it is not yet at a level that would avoid a feedstock supply crunch, and the feasibility of most new projects is uncertain. Even if every project is built, combined they would represent only 16% of new production expected by 2024. In most cases these projects will also not replace existing demand.

Nevertheless, these projects could lay the groundwork for speedier deployment if successful approaches are demonstrated and economies of scale are established. Higher feedstock prices, which would indicate scarcity, will also prompt investment in new supplies. In addition, many options do not require the construction of new facilities, just access to new feedstocks and/or modifications to existing plants. Change can therefore happen quickly with the right incentives.

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General annex

Abbreviations and acronyms

AEMO	Australian Energy Market Operator
ASEAN	Association of Southeast Asian Nations
CAISO	California Independent System Operator
CCGT	Combined-cycle gas turbines
CCUS	Carbon capture, utilisation and storage
CEN	Coordinador Eléctrico Nacional de
CSP	Concentrated solar power
DISCOM	Discouraged distribution companies
EBITDA	Earnings before interest, taxes, depreciation and amortisation
EIA	Environmental impact assessments
EIM	Energy Imbalance Market
EPA	Environmental Protection Agency
FIT	feed-in tariff
GHG	greenhouse gas
GSE	Gestore Servizi Energetici
HEPI	Household Energy Price Index
HVDC	High-voltage direct current
IRA	Inflation Reduction Act
ITC	Investment Tax Credit
LCOE	Levelised costs of energy
OCGT	Open-cycle gas turbines
PLI	Production-linked incentives
PPA	power purchase agreement
REC	Renewable energy certificates
RED	Renewable Energy Directive
RESS	Renewable Electricity Support Scheme
RFS	Renewable Fuel Standard
TRNC	Turkish Republic of Northern Cyprus
VRE	Variable renewable energy
WACC	Weighted average cost of capital

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Units of measure

bbl	barrel
bbl/d	barrels per day
bcm	billion cubic metres
bcm/yr	billion cubic metres per year
cm/s	centimetres per second
EJ	exajoule
GJ	gigajoule
Gt/yr	gigatons per year
$GtCO_2$	gigatonne of carbon dioxide
$GtCO_2$/yr	gigatons of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
MLPY	million litres per year
MW	megawatt
MWh	megawatt hour

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