

iea



International  
Energy Agency

# Renewables

## 2022

Analysis and forecast to 2027

# INTERNATIONAL ENERGY AGENCY

---

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 31 member countries, 11 association countries and beyond.

This publication and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

## IEA member countries:

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

The European Commission also participates in the work of the IEA

## IEA association countries:

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

# Abstract

Renewables 2022 is the IEA's primary analysis on the sector, based on current policies and market developments. It forecasts the deployment of renewable energy technologies in electricity, transport and heat to 2027 while also exploring key challenges to the industry and identifying barriers to faster growth.

The current global energy crisis brings both new opportunities and new challenges for renewable energy. Renewables 2022 provides analysis on the new policies introduced in response to the energy crisis. This year's report frames current policy and market dynamics while placing the recent rise in energy prices and energy security challenges in context.

In addition to its detailed market analysis and forecasts, Renewables 2022 also examines key developments and trends for the sector, including the more ambitious renewable energy targets recently proposed by the European Union; the issue of windfall profits; the diversification of solar PV manufacturing; renewable capacity for hydrogen production; and a possible feedstock crunch in the biofuels industry and viable ways to avoid it.

# Acknowledgements, contributors and credits

This study was prepared by the Renewable Energy Division in the Directorate of Energy Markets and Security. It was designed and directed by Heymi Bahar, Senior Analyst.

The report benefited from analysis, drafting and input from multiple colleagues. The lead authors of the report were, Yasmina Abdelilah, Heymi Bahar, Trevor Criswell, Piotr Bojek, François Briens, Jeremy Moorhouse and Laura Mari Martinez, who was also responsible for data management. The report also benefited from analysis and drafting from Kazuhiro Kurumi and Kartik Veerakumar.

Paolo Frankl, Head of the Renewable Energy Division, provided strategic guidance and input to this work. Valuable comments, feedback and guidance were provided by other senior management and numerous other colleagues within the IEA, in particular, Keisuke Sadamori and Laura Cozzi.

Other IEA colleagues who have made important contributions to this work include:

Abdullah Al-Abri, Ana Alcande Bascones, Carlos Alvarez Fernandez, Elisa Asmelash, Praveen Bains, Jose Miguel Bermudez Menendez, Stéphanie Bouckaert, Davide d'Ambrosio, Syrine El Abed, Astha Gupta, Ilkka Hannula, Ciarán Healy, Pablo Hevia-Koch, Joerg Husar, Kevin Lane, Stefan Lorenczik, Rita Madeira, Yannick Monschauer, Brian Motherway, Francesco Pavan, Uwe Remme, Luis Fernando Rosa, Brent Wanner.

Timely data from the IEA Energy Data Centre were fundamental to the report, with particular assistance provided by Pedro Carvalho, Luca Lorenzoni, Taylor Morrison, Nick Johnstone, Julian Prime and Roberta Quadrelli.

This work benefited from extensive review and comments from the IEA Standing Group on Long-Term Co-operation, IEA Renewable Energy Working Party, members of the Renewable Industry Advisory Board (RIAB) and experts from IEA partner countries and other international institutions. The work also benefited from feedback by the IEA Committee on Energy Research and Technology, IEA Technology Collaboration Programmes (IEA TCPs).

Many experts from outside of the IEA provided valuable input, commented and reviewed this report. They include:

## Countries

Argentina (Ministry of Energy), Brazil (Empresa de Pesquisa Energética), Canada (Natural Resources Canada), China (Energy Research Institute – ERI), Denmark (Ministry of Climate, Energy and Utilities), European Union (European Commission – DG Energy), Finland (Ministry of Economic Affairs and Employment), Japan (Ministry of Economy, Trade and Industry - METI), Spain (Institute for Energy Diversification and Energy Saving - IDAE).

## Technology Collaboration Programme (TCPs)

Bioenergy TCP, Heat Pump Centre (HPC) TCP, Hydropower TCP, Photovoltaic Power Systems (PVPS) TCP, Solar Heating and Cooling TCP, SolarPaces TCP, Wind Energy TCP.

## Other Organisations

Archer Daniels Midland Company (ADM), Australian Energy Market Operator (AEMO), Enel, Energy Information Administration (EIA), European Commission, European Heat Pump Association (EHPA), European Renewable Ethanol Association (EPURE), European Solar Thermal Industry Federation (ESTIF), Global Wind Energy Association (GWEC), Iberdrola, National Renewable Energy Laboratory (NREL), Natural Resources Canada, Neste, Ørsted, Siemens Gamesa Renewable Energy, Solar Energy Corporation of India Ltd. (SECI), Solar Power Europe, Solrico, SPV Market Research, The Energy and Resources Institute (TERI), US Grains Council, Vestas, WindEurope, World Bank, World Bioenergy Association.

The authors would also like to thank Kristine Douaud for skilfully editing the manuscript and the IEA Communication and Digital Office, in particular Jon Custer, Astrid Dumond, Jad Mouawad, Barbara Moure, Jethro Mullen, Julie Puech, Robert Stone and Therese Walsh for their assistance. In addition, Ivo Letra from the Office of Management and Administration supported data management.

Questions or comments?

Please write to us at [IEA-REMR@iea.org](mailto:IEA-REMR@iea.org)

# Table of contents

<b>Renewables 2022</b> .....	<b>1</b>
<b>Analysis and forecasts to 2027</b> .....	<b>1</b>
Abstract .....	3
Acknowledgements, contributors and credits .....	4
Table of contents.....	6
Executive summary.....	10
Chapter 1. Renewable electricity .....	17
Forecast summary .....	17
China .....	28
United States .....	30
Europe.....	34
Asia Pacific.....	56
Latin America .....	70
Middle East and North Africa .....	76
Sub-Saharan Africa .....	81
Chapter 2. Transport Biofuels.....	84
Forecast summary .....	84
Demand, supply and trade .....	92
Chapter 3. Renewable heat .....	108
Recent trends and policy update .....	108
Outlook to 2027 .....	110
Chapter 4. Trends to watch.....	117
Question 1: Is the European Union on track to meet its REPowerEU goals? .....	117
Question 2: Is renewable energy capacity in the European Union making windfall profits from high wholesale prices? .....	129
Question 3: Will new PV manufacturing policies in the United States, India and the European Union create global PV supply diversification? .....	135
Question 4: Is the biofuel industry approaching a feedstock crunch? .....	141
Question 5: How much will renewable hydrogen production drive demand for new renewable energy capacity by 2027? .....	146
Question 6: Is the energy crisis really making the business case for heat pumps? .....	151
General annex.....	156
Abbreviations and acronyms.....	156
Units of measure .....	157

## List of Figures

Figure 1.1	Upward revisions to renewable capacity expansion forecasts from Renewables 2021 to Renewables 2022.....	17
Figure 1.2	Renewable capacity growth in the main and accelerated cases, 2010-2027 .....	18
Figure 1.3	Quarterly average utility-scale solar PV and onshore wind auction contract and wholesale power prices in selected European countries, 2018-2022.....	19
Figure 1.4	Renewable capacity growth outside of China, main and accelerated cases, 2010-2027.....	20
Figure 1.5	Renewable annual net capacity additions by technology, main and accelerated cases, 2015-2027 .....	21
Figure 1.6	Renewable capacity auctioned by region, Q1 2018 to Q3 2022.....	23
Figure 1.7	Auction contract prices for utility-scale solar PV (left) and onshore wind (right) by region.....	24
Figure 1.8	Cumulative power capacity by technology, 2010-2027.....	26
Figure 1.9	Global electricity generation by technology, 2015, 2021 and 2027 .....	26
Figure 1.10	Hydropower electricity generation absolute year-on-year change, 2018-2022 .....	27
Figure 1.11	China renewable capacity additions, 2010-2027 (left) and shares of renewables in electricity generation, 2015-2027 (right).....	28
Figure 1.12	United States annual renewable capacity additions by technology, 2020-2027 (left) and total renewables capacity growth, 2010-2027 (right) .....	31
Figure 1.13	United States solar PV capacity additions, 2019-2027 (left) and median time between solar PV interconnection request and plant commissioning for selected system operators, 2013-2021 (right).....	32
Figure 1.14	United States onshore wind capacity additions and maximum PTC credit rate, 2020-2027 (left) and offshore wind project status (right).....	33
Figure 1.15	Europe renewable electricity capacity additions, 2022-2027 (left) and wholesale electricity prices for selected markets (right).....	35
Figure 1.16	Germany renewable capacity additions, 2022-2027 (left) and 2030 targets for cumulative installed capacity in EEG2021 and EEG2023 vs installed capacity today (2021) .....	39
Figure 1.17	Historical feed-in premiums (2014-2021) and new rates under the EEG2023 with full feed-in premium (2023-2024).....	40
Figure 1.18	France capacity additions by technology, 2010-2027 (left) and project pipeline vs annual commissioning, 2016-2021 (right).....	44
Figure 1.19	Spain renewable capacity additions by technology, 2010-2027 (left) and annual auctions vs deployment targets, 2022-2026 (right).....	45
Figure 1.20	The Netherlands renewable capacity additions, 2020-2027 (left) and capacity to solar PV and other technologies in SDE+ and SDE++ (right).....	47
Figure 1.21	Belgium renewable capacity additions by technology, 2010-2027 (left) and Denmark renewable capacity additions by technology, 2010-2027 (right).....	50
Figure 1.22	Italy renewable capacity additions, 2010-2027 (left) and results of FER renewable energy auctions (right).....	51
Figure 1.23	United Kingdom renewable capacity additions, 2010-2027 (left) and CfD auction results, capacity limits and projects pipeline in Renewable Energy Planning Database (right).....	53
Figure 1.24	Poland renewable capacity additions, 2010-2027 (left) and quarterly distributed PV capacity additions, 2019-2022 (right).....	55
Figure 1.25	Asia Pacific renewable capacity additions by technology, 2010-2027 (left) and annual capacity additions by country, 2019-2027 (right) .....	57
Figure 1.26	India renewable capacity additions, 2010-2027 (left) and renewable capacity awarded in auctions, 2017-2022 (right).....	58
Figure 1.27	India awarded and commissioned renewable capacity, 2017-2022 (left) and DISCOM energy market shares by integrated rating, 2015-2021 (right) .....	60

Figure 1.28	Japan renewable capacity additions, 2010-2027 (left) and FIT-approved capacity and prices for solar PV and onshore wind, 2012-2021 (right).....	63
Figure 1.29	Korea renewable capacity additions, 2010-2027 (left) and fixed-price solar PV capacity and average revenue per MWh by technology, 2017-2022 (right) .....	64
Figure 1.30	Australia renewable capacity additions, 2010-2027 (left) and quarterly distributed PV capacity additions, 2017-2022 (right).....	66
Figure 1.31	ASEAN renewable capacity additions, 2010-2027 (left) and annual capacity additions by country, 2019-2027 (right).....	68
Figure 1.32	Brazil renewable capacity additions, 2020-2027 (left) and utility-scale solar PV and onshore wind capacity by market registration (right) .....	71
Figure 1.33	Chile renewable capacity additions, 2020-2027 (left) and capacity and prices awarded in Chilean energy auctions (right).....	72
Figure 1.34	Colombia renewable capacity additions, 2020-2027 (left) and installed renewable capacity in REMR2022 forecast vs Colombia's National Energy Plan (right).....	73
Figure 1.35	Mexico renewable capacity additions, 2010-2027 (left) and Argentina renewable capacity additions, 2010-2027 (right).....	75
Figure 1.36	Middle East and North Africa renewable capacity additions, 2010-2027 (left) and renewable additions by technology and country, 2022-2027 (right) .....	76
Figure 1.37	Middle East and North Africa renewable capacity additions dedicated to hydrogen production, 2010-2027 (left) and project status for electrolyzers using dedicated renewables with commissioning planned by 2027 (right) .....	80
Figure 1.38	Sub-Saharan Africa renewable capacity additions, 2010-2027 (left) and renewable additions by technology and country, 2016-2027 (right).....	82
Figure 2.1	Biofuel demand growth by fuel and region, 2021-2022 .....	84
Figure 2.2	Ethanol and gasoline prices (left), and biodiesel and diesel prices (right), 2019-2022 .....	85
Figure 2.3	Global biofuel demand (left) and growth for advanced and emerging economies (right), main case, 2021-2027 .....	86
Figure 2.4	Forecast growth by country (left) and biofuel share of transport demand (right), main case, 2021-2027.....	87
Figure 2.5	Global biojet fuel demand and supply growth, 2022-2027.....	89
Figure 2.6	Demand growth by country (left) and total demand (right), accelerated case, 2021-2027.....	91
Figure 2.7	United States five-year biofuel growth, main and accelerated cases, 2016-2027 ...	93
Figure 2.8	Brazil five-year biofuel growth, main and accelerated cases, 2016-2027.....	96
Figure 2.9	Europe five-year biofuel growth, main and accelerated cases, 2016-2027 .....	98
Figure 2.10	Indonesia five-year biofuel growth, main and accelerated cases, 2016-2027 .....	101
Figure 2.11	India five-year biofuel growth, main and accelerated cases, 2016-2027 .....	102
Figure 2.12	Other markets five-year biofuel growth, main and accelerated cases, 2016-2027	104
Figure 3.1	Global increase in renewable energy consumption and share of total heat demand in buildings and industry, 2010-2027 .....	110
Figure 3.2	Increase in renewable heat consumption in industry and share of renewables in industrial heat demand, selected regions, 2016-2027 .....	111
Figure 3.3	Contribution of different factors to renewable electricity consumption growth in industry and buildings, selected regions, 2022-2027 .....	113
Figure 3.4	Buildings sector increase in renewable heat consumption and share of renewables in heat demand, selected regions, 2016-2027 .....	114
Figure 4.1	Renewable electricity shares in main case (left), and average annual additions for solar PV (middle) and wind (right) in the main and accelerated cases (2022-2027) .....	119
Figure 4.2	European Union renewable energy share in transport, main case (left) and accelerated case (right), 2020-2030 .....	123
Figure 4.3	Share of renewables in heating and cooling, historical average annual progress and proposed targets for EU member states .....	127



Figure 4.4	European Union shares of installed renewable capacity by exposure to wholesale market price, based on member country policy schemes .....	130
Figure 4.5	Revenue and EBITDA comparison of major European utilities for the first halves of 2022 and 2021 (left) and their shares in installed generation capacity mix (right). 132	
Figure 4.6	Total manufacturing costs for mono PERC c-Si solar components by input, 2022	136
Figure 4.7	India PLI subsidies and investment cost difference with lowest cost manufacturing (left) and US c-Si manufacturing costs with and without IRA Manufacturing Production Tax Credit, compared with China and ASEAN (right).....	137
Figure 4.8	Solar PV manufacturing capacity outside China and total investment by 5-year periods, 2017-2027 .....	139
Figure 4.9	Solar PV manufacturing capacity and production by country and region, 2021-2027 .....	140
Figure 4.10	Total biofuel production by feedstock (left) and growth by region (right), main case, 2021-2027 .....	141
Figure 4.11	Biofuel demand shares of global crop production (left) and wastes and residues (right), main case, 2010-2027 .....	143
Figure 4.12	Total renewable capacity dedicated to hydrogen production in the main and accelerated case globally (left) and for main case by region (right), 2021-2027 ...	146
Figure 4.13	Europe dedicated renewable capacity in the main case by country, 2021-2027 (left), and proposed EU targets for renewables of non-biological origin in transport and replacing non-renewable with renewable hydrogen use in industry (right).....	148
Figure 4.14	Levelised cost of heating for air-to-water heat pumps and gas boilers for selected countries, and fuel-price sensitivity .....	154

## List of Tables

Table 1.1	Renewable energy targets by Australian state .....	66
Table 2.1	Summary of Inflation Reduction Act provisions for biofuels.....	94
Table 2.2	Policy and assumption summary, main and accelerated cases .....	105
Table 4.1	Summary of renewable energy benchmarks by sector in REPowerEU plan and in main and accelerated cases .....	118
Table 4.2	Transport renewable energy shares with and without multipliers, main and accelerated cases .....	124
Table 4.3	European Union proposed targets for renewable heating and cooling.....	125
Table 4.4	Selected European countries that have introduced or announced a windfall-profit tax .....	134
Table 4.5	Planned solar PV component manufacturing expansion in the United States and India in 2022.....	137
Table 4.6	Liquid biofuel production pathways, costs and feedstock potential .....	145
Table 4.7	Change in residential consumer prices for electricity and gas between H1 2021 and H1 2022 (left) and marginal cost of heating with residential heat pumps and gas boilers under different energy cost assumptions (right), selected countries.....	152
Table 4.8	Prevalent public investment support for heat pumps by policy type, selected countries, 2022.....	153

# Executive summary

## Energy security concerns and new policies lead to largest ever upward revision of IEA's renewable power forecast

**The first truly global energy crisis, triggered by Russia's invasion of Ukraine, has sparked unprecedented momentum for renewables.** Fossil fuel supply disruptions have underlined the energy security benefits of domestically generated renewable electricity, leading many countries to strengthen policies supporting renewables. Meanwhile, higher fossil fuel prices worldwide have improved the competitiveness of solar PV and wind generation against other fuels.

**Renewable capacity expansion in the next five years will be much faster than what was expected just a year ago.** Over 2022-2027, renewables are seen growing by almost 2 400 GW in our main forecast, equal to the entire installed power capacity of China today. That's an 85% acceleration from the previous five years, and almost 30% higher than what was forecast in last year's report, making it our largest ever upward revision. Renewables are set to account for over 90% of global electricity capacity expansion over the forecast period. The upward revision is mainly driven by China, the European Union, the United States and India, which are all implementing existing policies and regulatory and market reforms, while also introducing new ones more quickly than expected in reaction to the energy crisis. China's 14th Five-Year Plan and market reforms, the REPowerEU plan and the US Inflation Reduction Act are the main drivers of the revised forecasts.

## Renewables will transform the global power mix through 2027, becoming the largest source of electricity

**Renewables become the largest source of global electricity generation by early 2025, surpassing coal.** Their share of the power mix is forecast to increase by 10 percentage points over the forecast period, reaching 38% in 2027. Renewables are the only electricity generation source whose share is expected to grow, with declining shares for coal, natural gas, nuclear and oil generation. Electricity from wind and solar PV more than doubles in the next five years, providing almost 20% of global power generation in 2027. These variable technologies account for 80% of global renewable generation increase over the forecast period, which will require additional sources of power system flexibility. Meanwhile, the growth of dispatchable renewables including hydropower,

bioenergy, geothermal and concentrated solar power remains limited despite their critical role in integrating wind and solar PV into global electricity systems.

**Solar PV's installed power capacity is poised to surpass that of coal by 2027, becoming the largest in the world.** Cumulative solar PV capacity almost triples in our forecast, growing by almost 1 500 GW over the period, exceeding natural gas by 2026 and coal by 2027. Annual solar PV capacity additions increase every year for the next five years. Despite current higher investment costs due to elevated commodity prices, utility-scale solar PV is the least costly option for new electricity generation in a significant majority of countries worldwide. Distributed solar PV, such as rooftop solar on buildings, is also set for faster growth as a result of higher retail electricity prices and growing policy support to help consumers save money on their energy bills.

**Global wind capacity almost doubles, with offshore projects accounting for one-fifth of the growth.** Over 570 GW of new onshore wind capacity are forecast to become operational over the 2022-27 period. However, onshore wind additions will only break their annual record, set in 2020, by the end of the forecast period because of lengthy permitting procedures and lack of improvements to grid infrastructure. Offshore wind growth accelerates globally, while Europe's share of installed offshore capacity declines from 50% in 2021 to 30% in 2027 as China's provincial policies support faster expansion and the United States becomes a sizeable market at the end of the forecast period.

## Improved policies can narrow the gap to net zero by 2050

**Our accelerated case shows global renewable capacity can expand by an additional 25% compared with the main forecast if countries address policy, regulatory, permitting and financing challenges.** Most advanced economies face challenges to implementation, especially related to permitting and grid infrastructure expansion. In emerging economies, policy and regulatory uncertainties still remain major barriers to faster renewable energy expansion. Finally, in developing economies, weak grid infrastructure and a lack of access to affordable financing hamper the timely commissioning of projects in our main forecast. Should countries address those challenges, global renewable capacity could expand by almost 3 000 GW. This faster increase would significantly narrow the gap on the amount of renewable electricity growth that is needed in a pathway to net zero emissions by 2050.

## Russia's invasion of Ukraine is a turning point for renewables in Europe

**The war is expediting Europe's clean energy transitions.** The energy crisis hit the EU while it was already discussing ambitious renewables targets under the Fit

for 55 package. After Russia invaded Ukraine in February 2022, energy security emerged as an additional strong motivation to accelerate renewable energy deployment. At the EU level, the European Commission's REPowerEU plan released in May 2022 proposes ending the bloc's reliance on Russian fossil fuels by 2027. Among other goals, the plan aims to increase the share of renewables in final energy consumption to 45% by 2030, exceeding the 40% previously under negotiation.

**Europe's renewable electricity expansion doubles over the 2022-2027 period as energy security concerns add to climate ambitions.** Many European countries passed or proposed action plans to further raise their ambitions, increased policy support and addressed non-financial challenges. Our forecast for growth in the EU has been revised upward significantly (by 30%) from last year's report, led by Germany (50% higher) and Spain (60% higher). Germany has increased renewable electricity targets, introduced higher auction volumes and improved remuneration for distributed PV while reducing permitting timelines. Spain has streamlined permitting for solar PV and wind plants, and increased grid capacity for new renewable energy projects.

**Sluggish growth of renewables in the transport and heating sectors holds back higher renewable energy penetration in the EU.** In our main case, renewables' share of transport energy demand expands from 9% in 2020 to 15% in 2027, which is not in line with the EU's aspirations for 2030. While demand for electric vehicles and biofuel expands, state and EU-level incentives to meet higher renewable shares are not in place in most cases. For heating and cooling, the annual increase in the share of renewables would need to almost quadruple from historical and forecasted growth to be on track with the REPowerEU plan targets.

**Policy improvements can drastically increase renewables expansion and put the European Union in line with REPowerEU goals.** Our main forecast falls short of the modelled goals of REPowerEU plan for all sectors. For electricity, in order to reach the installed capacity needed to generate 69% of electricity from renewables by 2030, average annual net additions need to be 30% higher for solar PV and more than twice as high for wind. Faster acceleration of wind and solar PV would require EU member states to reduce permitting and licensing timelines, extend auction schemes with clear schedules, redesign auctions to reflect the increasing cost of renewables and their energy security benefits, and improve incentive schemes for distributed solar PV generation. If EU governments rapidly implement these changes, the accelerated case sees growth 30% higher, putting the EU on track with its more ambitious REPowerEU modelled goals. For transport, countries would need to implement more ambitious transport decarbonisation programmes, including both biofuels and EVs. In the accelerated case, renewable energy's share in transport climbs to 20% by 2027, narrowing the gap with the EU goal of 29% by 2030. For heating and cooling, accelerating the

rollout of heat pumps will require overcoming high upfront costs through incentives, regulations and low-cost financing for households to facilitate investment.

**Market interventions must shelter citizens from high costs but without hurting the business case for new renewable energy investments.** In October 2022, the European Council passed emergency regulations to protect vulnerable customers from high energy prices, including windfall profit levies on electricity generators. While there is strong rationale behind these interventions, their impact needs to be assessed in terms of the potential harm to renewable developers' capacity to invest in new projects. Current and proposed market interventions in Europe (such as wholesale market caps and windfall-profit taxes) could create uncertainties for renewable energy investments if they are not well designed or co-ordinated across countries. Moreover, the ongoing energy crisis has also sparked new discussions within the European Union concerning possible future electricity market design. These proposed reforms could, in principle, boost market-driven renewable energy deployment, ensure energy security and encourage investment in flexibility resources. However, it is important that any proposals be carefully and transparently prepared, with clear visibility on timing and involving all relevant stakeholders, in order to avoid unintended uncertainty among investors.

## **China, the United States and India all double their renewable capacity expansion in the next five years, accounting for two-thirds of global growth**

**China is forecast to install almost half of new global renewable power capacity over 2022-2027**, as growth accelerates in the next five years despite the phaseout of wind and solar PV subsidies. Policy guidelines and targets in China's new 14th Five-Year Plan on renewable energy are the basis for this year's 35% upward revision on last year's forecast. Very ambitious new renewable energy targets, market reforms and strong provincial government support provide long-term revenue certainty for renewables. In most Chinese provinces, utility-scale renewables are cheaper than regulated coal electricity prices, driving rapid adoption. In the main forecast, China is expected to reach its 2030 target of 1 200 GW of total wind and solar PV capacity five years in advance.

**In the United States, the Inflation Reduction Act is providing unprecedented long-term policy visibility for wind and solar PV projects.** Passed in August 2022, the legislation extended tax credits for renewables until 2032. In addition, 37 out of 50 states have renewable portfolio standards and goals supporting expansion. By 2027, US annual wind and PV capacity additions double compared with 2021. Given that the United States now has clear long-term policy visibility,

any remaining forecast uncertainties relate to supply chain constraints, trade measures, grid infrastructure inadequacy and long permitting lead times.

**In India, new installations are set to double over our forecast period**, led by solar PV and driven by competitive auctions implemented to achieve the government's ambitious target of 500 GW of non-fossil capacity by 2030.

## **New policies in the United States and India can lead to more diversified global solar PV manufacturing**

**Solar PV manufacturing investment in India and the United States is expected to reach almost USD 25 billion over 2022-2027, a sevenfold increase compared with the last five years.** India's Production Linked Incentives (PLI) initiative closes nearly 80% of Indian manufacturers' investment cost gap with the lowest-cost manufacturers in China. Meanwhile, fully monetising manufacturing tax credits in the United States could bring all segments of PV manufacturing to cost parity with the lowest-cost manufacturers. In addition to manufacturing subsidies, tariffs on imported PV equipment and local-content premiums encourage project developers to purchase domestically manufactured products in both India and the United States.

**The global solar PV supply chain is diversifying, but China will continue to dominate manufacturing.** Despite growing investment in the United States and India, China is forecast to invest USD 90 billion over the forecast period, more than triple the expected investment by the rest of the world combined. China's share in global manufacturing capacity could decrease slightly, from 80-95% today to 75-90%, depending on the manufacturing segment. Furthermore, if countries maintain trade policies that limit imports and favour domestically produced PV products, greater geographical distribution of production could result in China's share shrinking more significantly to 60-75% by 2027 depending on the segment. At the same time, investment plans also indicate supply significantly exceeding expected global PV demand even in the most optimistic forecasts by 2027. In the absence of faster growth in global demand, this could result in plant utilisation factors as low as half today's levels for all manufacturing segments in China.

## **Policy efforts are turning hydrogen production from wind and solar PV into a new growth area**

**Global renewable capacity dedicated to producing hydrogen increases 100-fold in the next five years, offering opportunities to decarbonise industry and transport.** Policies and targets introduced in more than 25 countries across all continents are expected to result in 50 GW of wind and PV capacity focused on producing hydrogen over the 2022-2027 period. This expansion is geographically diversified, with China leading the growth, followed by Australia, Chile and the

United States. Together, these four markets account for roughly two-thirds of dedicated renewable capacity for hydrogen production. While renewable capacity dedicated to hydrogen accounts for only 2% of our main forecast, the share is significantly higher at 13% in the Middle East and North Africa and 5% in Latin America because of export opportunities.

## Climate and energy goals underpin robust biofuels forecast

**Total global biofuel demand expands by 35 000 million litres per year (MLPY), or 22%, over 2022-2027 in the main forecast.** The United States, Canada, Brazil, Indonesia and India make up 80% of global expansion in biofuel use, as all five countries have comprehensive policy packages that support growth. Renewable diesel is expected to lead the global expansion for the first time mainly, driven by policies designed to reduce greenhouse gas emissions in advanced economies. Biojet fuel demand expands significantly to 3 800 MLPY in our main forecast – 35 times the 2021 level – to account for nearly 1% of total jet fuel consumption. Recent US tax incentives and the EU's ReFuelEU target propel most of the growth in biojet fuel. Meanwhile, rising ethanol and biodiesel use occurs almost entirely in emerging economies as they aim to reduce oil imports while benefiting the local economy by using indigenous resources.

## Waste and residues are a key growth area for biofuels but require action to prevent a supply crunch

**One-third of new biofuels production is set to come from waste and residues by 2027.** Transport greenhouse gas reduction policies in Europe and the United States are fuelling global demand for waste and residues. The United States' Inflation Reduction Act drives a 20% increase in our biojet and renewable diesel forecast. The policy rewards lower greenhouse gas intensity fuels, driving biofuel producers to focus on waste and residues. In Europe, the existing Renewable Energy Directive and member state policies reward biofuels made from waste and residues. Most biofuel growth in Europe is also for renewable diesel and biojet. Singapore and China are also expanding renewable diesel and biojet production from waste and residues to serve the European and US markets.

**Unprecedented demand growth is straining supply chains, but government policies and innovation may yet provide relief.** Demand for waste and residue oils and fats is expected to nearly exhaust supplies of the most readily available sources by 2027. In advanced economies, supply limits are prompting biodiesel, renewable diesel and biojet producers to secure conventional vegetable oils such as soybean oil and rapeseed oil. Vegetable oil supplies dedicated to biofuel production expand to 23% from 17% over the forecast period. However, higher

prices due to strong demand will prompt companies and governments to improve feedstock supply chains, seek out new supplies and develop new techniques. Policies and innovation can also help unlock untapped supplies and support technology development, enabling the use of more widely available feedstocks for sustainable biofuel production

## Heating with renewables grows but not fast enough to contain fossil fuel use

**Modern renewable consumption for heating purposes is expected to increase by almost one-third during 2022-2027, raising the modern use of renewables in heat from 11% to 14% by 2027.** Renewable heat currently benefits from policy momentum, in particular in the European Union, in response to the energy security concerns fuelled by the current energy crisis. In both the industry and buildings sectors, the combination of rising shares of renewables in the power sector and greater reliance on electricity for heating, including through heat pumps, makes the largest contribution to renewable heat uptake. Nevertheless, renewable heat developments are insufficient to contain fossil fuel-based heat consumption.



# Chapter 1. Renewable electricity

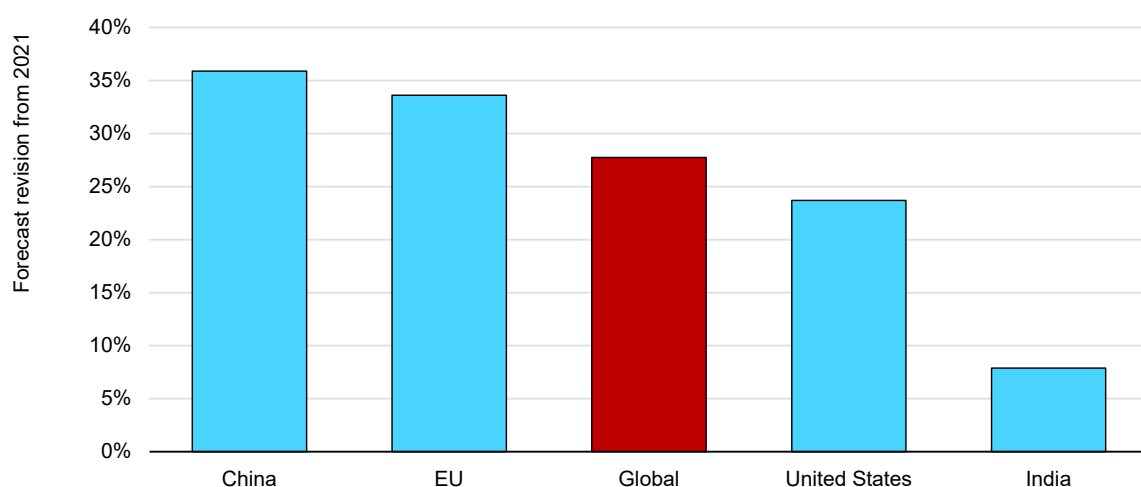
## Forecast summary

### The global energy crisis is pushing the accelerator on renewable energy expansion

Global renewable capacity is expected to increase by almost 2 400 GW (almost 75%) between 2022 and 2027 in the IEA main-case forecast, equal to the entire installed power capacity of the People’s Republic of China (hereafter “China”). Renewables growth is propelled by more ambitious expansion policies in key markets, partly in response to the current energy crisis. This 85% acceleration on the last five years’ expansion rate results primarily from two factors. First, high fossil fuel and electricity prices resulting from the global energy crisis have made renewable power technologies much more economically attractive, and second, Russia’s invasion of Ukraine has caused fossil fuel importers, especially in Europe, to increasingly value the energy security benefits of renewable energy.

This year’s forecast has been revised upwards by almost 30% from last year’s despite energy market turbulence, mainly because China, Europe, the United States and India are implementing existing policies, regulatory and market reforms and new policies more quickly than expected to combat the energy crisis. China’s 14th Five-Year Plan and market reforms, the REPowerEU plan and the US Inflation Reduction Act (IRA) are the foremost policy changes since our last forecast of December 2021.

**Figure 1.1 Upward revisions to renewable capacity expansion forecasts from Renewables 2021 to Renewables 2022**



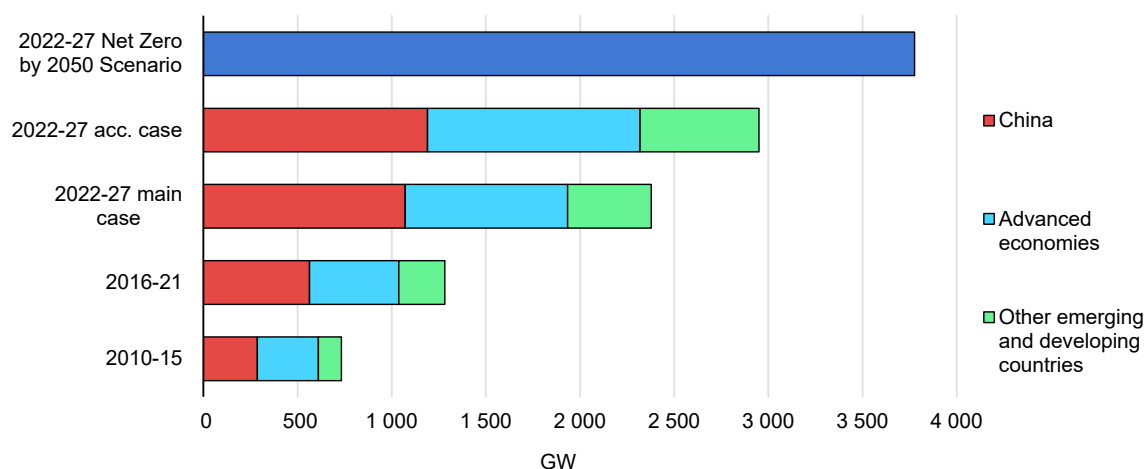
IEA. CC BY 4.0.

The forecast for most advanced economies is based on these countries' ambitious targets and policy incentives, but implementation challenges remain, especially related to permitting and grid infrastructure expansion. In emerging economies, policy and regulatory uncertainties, in addition to implementation challenges, continue to be key barriers to faster renewable energy expansion. Finally, in developing countries, weak grid infrastructure and a lack of access to affordable financing hamper faster commissioning of multiple projects in our main-case forecast. Should countries address those challenges over the next 12-24 months, renewable capacity expansion under the accelerated case is demonstrated to be almost 25% higher than in the main case, producing nearly 2 950 GW in total additions globally.

Globally, the pace of renewable capacity expansion over the forecast period in the main case needs to increase 60% to be in line with the IEA Net Zero by 2050 Scenario. In the accelerated case, however, growth in the next five years (under policies that address challenges and faster implementation of countries' existing plans) narrows the gap for renewable electricity growth needed to achieve net zero emissions by 2050.

Overall, China on its own is forecast to install almost half of new global renewable power capacity over 2022-2027, as growth accelerates in the next five years despite the phaseout of wind and solar PV subsidies. Ambitious renewable energy targets in the 14th Five-Year Plan, market reforms and strong provincial government support provide long-term revenue certainty for renewables. The main-case forecast thus expects China to reach its 2030 wind and solar PV capacity targets in 2025. However, the early achievement of 2030 targets leaves the accelerated case's upside potential relatively limited.

**Figure 1.2 Renewable capacity growth in the main and accelerated cases, 2010-2027**



IEA. CC BY 4.0.

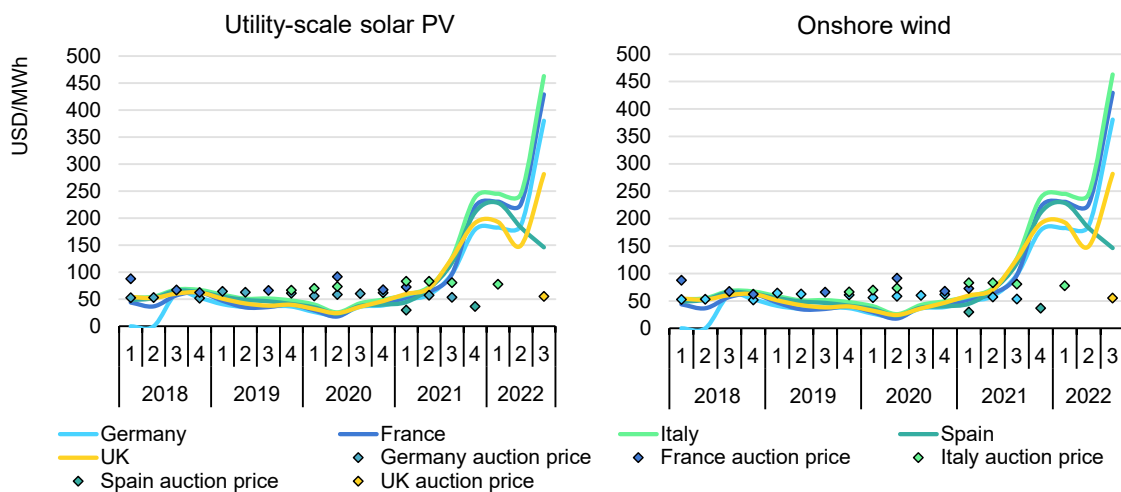
Note: acc. case = accelerated case.

The European Union, the second-largest growth market after China, has had stable renewable capacity expansion in the past five years compared with 2010-2015, but its pace of expansion is expected to more than double during 2022-2027. While several EU member countries had already introduced ambitious targets and policies to accelerate renewable energy deployment before Russia’s invasion of Ukraine, since then the European Union has proposed even more aggressive goals under the REPowerEU package to eliminate Russian fossil fuel imports by 2027. Our forecast thus expects that EU and country-level policies implemented since the beginning of the war will accelerate renewable electricity deployment.

For the EU electricity sector, expanding wind and solar PV power generation remains one of the most effective ways to reduce natural gas consumption. Steep electricity prices resulting from record-high natural gas prices continue to improve the competitiveness of utility-scale renewables with fossil fuel-based alternatives. In fact, from December 2021 to October 2022, average contract prices for long-term wind and solar PV projects were 77% below wholesale market prices. In addition, uptake of distributed solar PV applications is expanding because they can help industrial and residential customers reduce their electricity bills, which have risen significantly since the beginning of 2022.

While these drivers indicate faster expansion in the main case, forecast upside potential is still high and depends on countries resolving pre-existing deployment challenges by simplifying permitting procedures, upgrading and expanding transmission and distribution networks, and providing long-term visibility over policy support for both utility-scale and distributed projects. In fact, accelerated-case modelling shows that the European Union could install over 30% more renewable energy capacity, the largest absolute upside potential of all key countries and regions.

**Figure 1.3 Quarterly average utility-scale solar PV and onshore wind auction contract and wholesale power prices in selected European countries, 2018-2022**



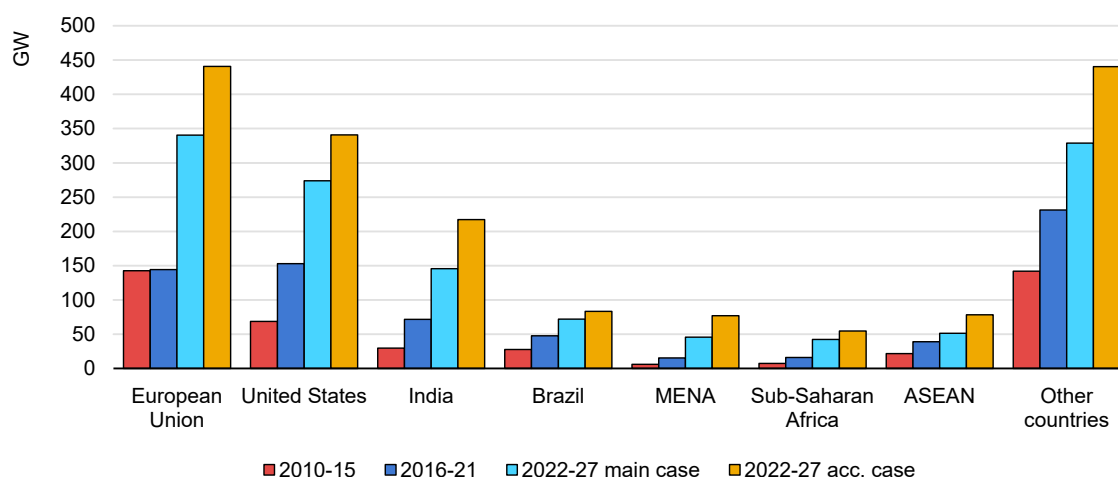
IEA. CC BY 4.0.

Notes: Italy’s spot price refers to the ITA-CSO. Electricity prices in Spain have been lower than in other EU countries due to the introduction of gas price cap.

In the United States, renewable energy expansion almost doubles from the last five years in our main case. The IRA passed in August 2022 extended tax credits for renewables until 2032, providing unprecedented long-term visibility for wind and solar PV projects. In India, new installations are set to double over our forecast period, led by solar PV and driven by competitive auctions implemented to achieve the government’s ambitious target of 500 GW of renewable power by 2030.

In Brazil, forecast growth is based on the booming distributed PV market and the considerable pipeline of utility-scale wind and solar projects contracted through bilateral power purchase agreements outside the government-led auction scheme. Renewable energy expansion also accelerates in the Middle East and North Africa (MENA), sub-Saharan Africa, Association of Southeast Asian Nations (ASEAN) and other regions, owing mostly to policy incentives that take advantage of the cost-competitiveness of hydro, solar PV and onshore wind power.

**Figure 1.4 Renewable capacity growth outside of China, main and accelerated cases, 2010-2027**



IEA. CC BY 4.0.

## Renewable capacity additions reach new record highs through 2027, led by solar PV and wind

Annual additions are expected to ramp up in 2022, ranging from 350 GW in the main case to 400 GW in the accelerated case, with solar PV and wind accounting for almost 90% of all new renewable energy installations. Achieving the higher level of additions this year will mostly depend on the pace of commissioning for utility-scale and distributed PV projects in China and the European Union.

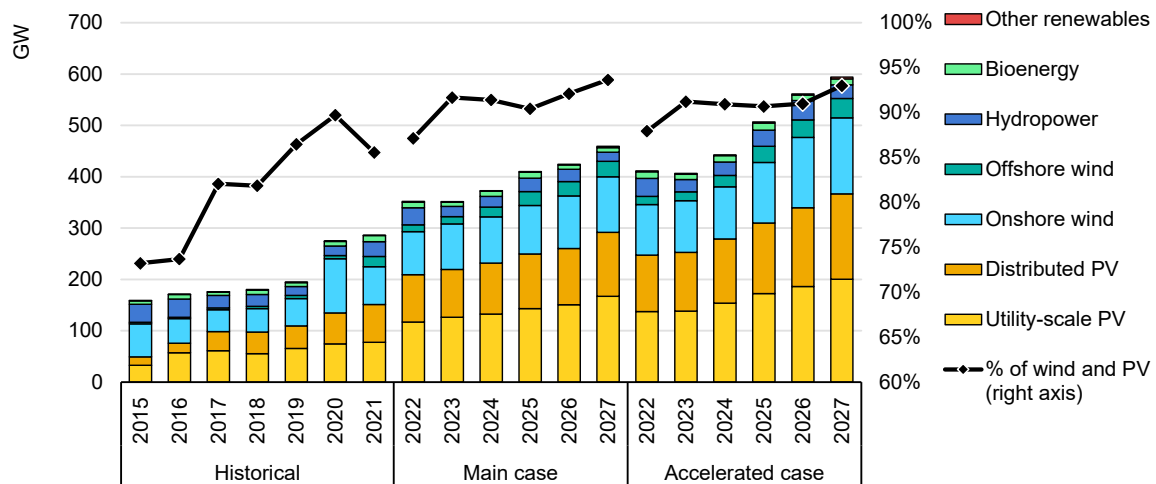
Annual renewable capacity additions are forecast to increase continuously over the forecast period, reaching a record 460 GW in 2027 in the main case, 60%

higher than last year’s growth. At the end of the forecast period, solar PV and wind provide the vast majority of global renewable capacity additions in 2027, accounting for nearly 95% as technology-specific challenges and limited policy support hamper faster expansion of hydropower, bioenergy, geothermal, CSP and ocean technologies.

Solar PV on its own accounts for over 60% of all renewable capacity expansion, setting records for annual additions every year through 2027. Although module prices have increased, utility-scale solar PV is the least costly option for new electricity generation in a significant majority of countries worldwide. Commercial and residential solar PV systems make up 26% of the global renewable capacity additions forecast for the next five years, and the outlook for distributed solar PV applications has been revised upwards because high natural gas prices are raising retail electricity bills.

Distributed PV applications thus remain a key element in faster solar PV growth in the accelerated case, in which annual additions reach almost 170 GW by 2027. Achieving faster solar PV expansion in the next five years also depends on a decline in module prices, which are currently 25-30% higher than in 2020. Greater solar PV affordability therefore underpins the accelerated case, as it would improve economic attractiveness worldwide.

**Figure 1.5 Renewable annual net capacity additions by technology, main and accelerated cases, 2015-2027**



IEA. CC BY 4.0.

Onshore wind additions also increase in our main-case forecast, from 74 GW in 2021 to 109 GW in 2027. This is just slightly above the record growth achieved in 2020, which was propelled by developers in China rushing to complete projects before subsidies were suspended. Onshore wind additions are climbing most quickly in countries that have stable policy frameworks providing long-term

revenue certainty, policies that address permitting challenges and plans for timely grid expansion. However, just a small number of countries, including China, Germany and Spain, have so far made improvements in all three areas.

Similar to solar PV, high commodity and freight prices have led wind turbine manufacturing costs to surge in 2022 to 25-30% above the 2020 level, except in China. Achieving accelerated-case annual onshore wind additions of 145 GW in 2027 will therefore require the resolution of permitting, policy uncertainty and grid expansion concerns worldwide.

In 2022, annual offshore wind capacity additions are forecast to decline more than 30% compared with 2021 because China's record expansion of last year will halve now that developers are no longer rushing to beat subsidy phaseouts. Still, global annual offshore wind installations are expected to increase 50% to over 30 GW in 2027, propelled by policy support in the European Union, the United States and China. Taking long lead times and existing auctions and leasing schedules into consideration, further upside potential is possible but limited. Accordingly, offshore wind capacity growth is 20% higher in the accelerated case, with China claiming the majority.

## **Global competitive auction capacity is expected to break another record in 2022 as a result of Chinese and EU policies**

Competitive auctions remain the main driver of forecast growth, with increasing contributions from corporate PPAs, bilateral contracts and merchant activity. From January to September 2022, 77 GW of new renewable auction capacity was awarded globally, mostly in solar PV and wind. This is a 70% increase from the same period in 2021, with China and Europe accounting for three-quarters of total awarded capacity.

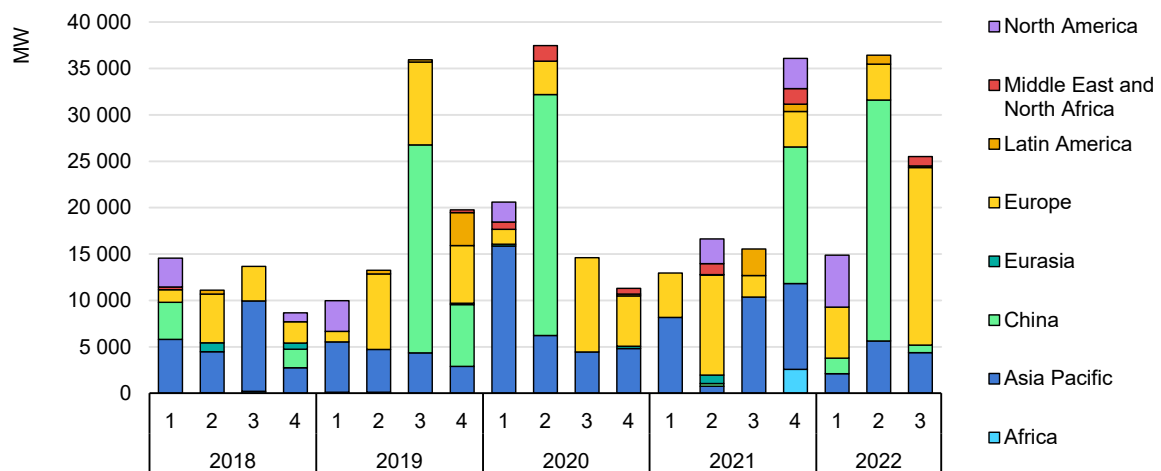
In China, provincial auctions have replaced national tenders and feed-in tariffs, both of which were phased out in 2020 for solar PV and onshore wind and in 2021 for offshore wind. Nine provinces held auctions in Q4 2021, while an additional 13 held auctions in Q3 of 2022. In Europe, auction volumes in the first three-quarters were 60% higher than in the same period in 2021 owing to a record 11 GW of renewable capacity being awarded in the United Kingdom. Excluding the United Kingdom, auction volumes in Europe have remained stable in 2022 because France, Germany and Italy have awarded similar levels of capacity as last year. Poland and Türkiye, which awarded a combined 3.5 GW of renewable capacity last year, have not yet held auctions in the first three-quarters of 2022.

Outside of China and Europe, the world awarded 26% less renewable capacity during the first three-quarters of 2022. In the Asia Pacific region, India awarded

37% less capacity this year than in 2021. Similarly, auctioned volumes in Latin America were 60% lower in the first three-quarters, as moderate power demand from distribution companies reduced auction volumes in Brazil, and Chile’s tender did not allocate as much capacity as expected.

In the Middle East and North Africa, in September 2022 Saudi Arabia launched a 3.3-GW tender for wind and solar projects that has not yet been closed, but it would increase auctioned volumes in the region by more than half if announced capacity is fully allocated by the end of 2022.

**Figure 1.6 Renewable capacity auctioned by region, Q1 2018 to Q3 2022**



IEA. CC BY 4.0.

## After a decade-long downward trend, high commodity prices are causing auction prices to rise

Elevated commodity prices, high freight costs and ongoing supply chain disruptions have caused onshore wind investment costs to increase by 15-25% and solar PV by 10-20% from pre-Covid levels. As a result, auction prices for onshore wind and solar PV rose worldwide in 2022, reversing a decade-long declining trend. Two factors have led to higher contract prices: developers are reflecting price increases in their bidding strategies; and some governments increased reference bidding prices to offer higher remuneration on account of rising investment costs.

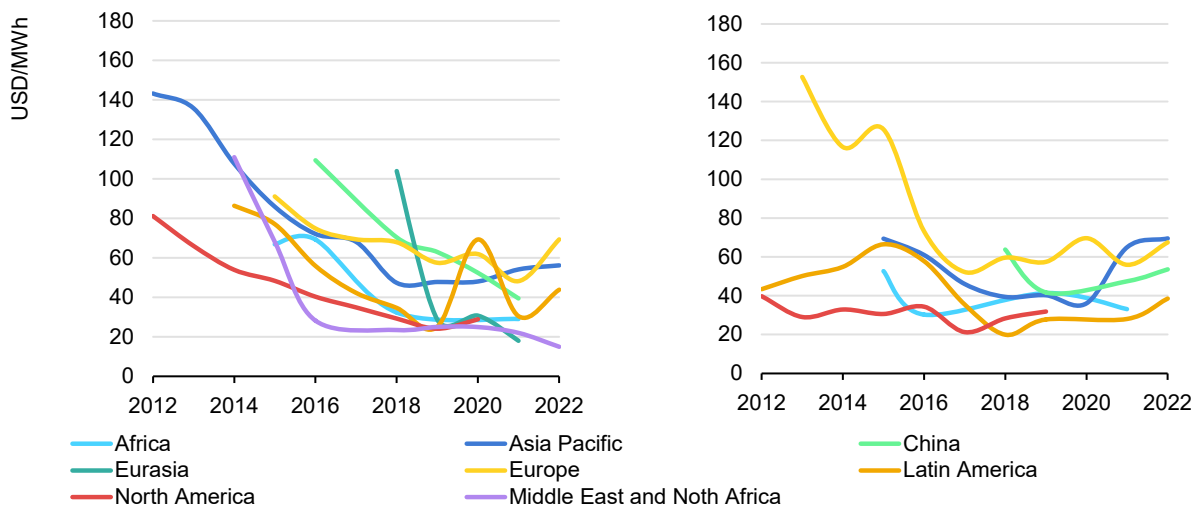
Prices for the primary materials used in wind and solar PV technologies increased drastically from January 2021 to April 2022. For instance, the price of PV-grade polysilicon almost quadrupled, aluminium more than doubled, copper shot up by 90%, steel was 40% higher, and freight fees rose fourfold. Some of these raw materials broke price records, considering total increases since the beginning of the Covid-19 crisis.

Commodity prices have been falling since May 2022, with economic slowdown in China, Europe and the United States resulting from the global energy crisis caused by Russia’s invasion of Ukraine. However, turbine and solar PV module prices are not expected to drop immediately, as companies have been adjusting their business models to ongoing macroeconomic uncertainty. In addition, high power prices, especially in Europe, are raising manufacturing costs, as most plants use electricity for their main industrial processes.

In Europe, average auction prices in 2022 were 44% higher for solar PV and 21% higher for onshore wind than in 2021, in US-dollar terms.

In the Asia Pacific region, average contract prices from government-led auctions in US dollars increased slightly for solar technologies and wind. In India, depreciation of the Indian rupee against the US dollar led to a 1% decrease in average auction prices expressed in US dollars, but a 4% increase in Indian rupee terms. In Latin America, higher reference bidding prices in Brazil and Chile due to higher investment costs led to higher contract prices in the region.

**Figure 1.7 Auction contract prices for utility-scale solar PV (left) and onshore wind (right) by region**



IEA. CC BY 4.0.



## Dispatchable renewables make up just 10% of forecast growth despite growing wind and PV integration challenges

Higher investment costs than for wind and solar PV, a lack of policy support and inadequate recognition of the flexibility value of hydropower, bioenergy, CSP, geothermal and ocean technologies are preventing faster uptake of dispatchable renewable power generation.

For hydropower, annual additions peaked in 2013 with the commissioning of almost 45 GW, but deployment over the forecast period is volatile, ranging from 17 GW to 33 GW according to the commissioning deadlines of large reservoir projects in China, India and Türkiye. These three large markets form the basis of our main-case forecast of 141 GW over 2022-2027, which is slightly lower than deployment achieved in the last five years. Because environmental permitting and construction times are long, the upside potential for hydropower remains limited, with only an additional 40 GW deemed possible in the accelerated case.

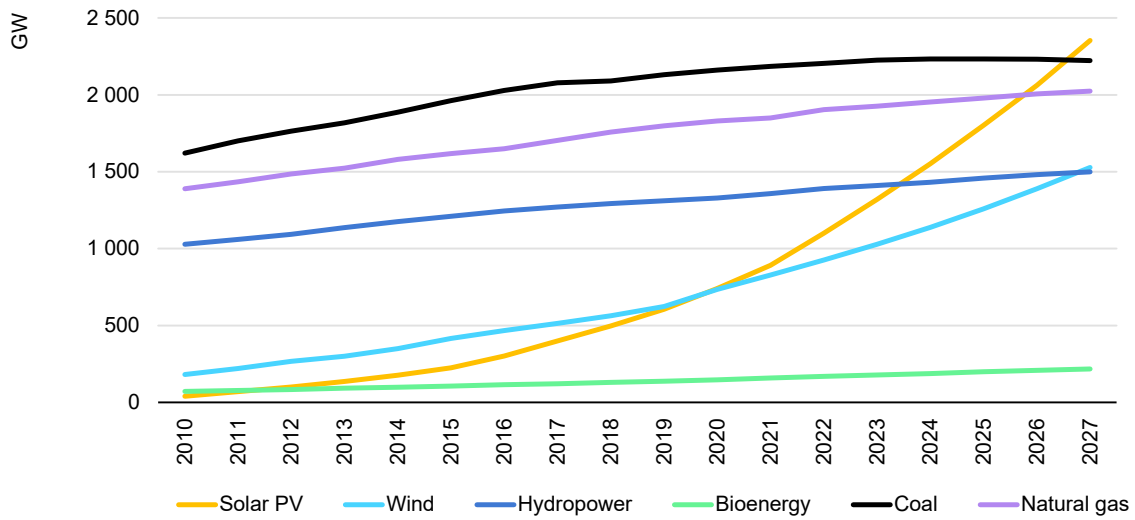
For bioenergy, over 60% of global capacity expansion is in China thanks to its ongoing policy support at the provincial level for waste-to-energy projects. Outside of China, Türkiye promotes bioenergy growth through feed-in tariffs and Brazil has implemented auctions.

Despite geothermal energy's great resource potential, growth is hampered by a lack of policies to address pre-development and resource exploration risks, with anticipated expansion of less than 6 GW over 2022-2027 concentrated in Africa and Southeast Asia. For CSP, relatively high investment costs and limited support to develop storage capabilities result in an increase of almost 5 GW during the forecast period.

## Solar PV claims the most installed power capacity worldwide by 2027, surpassing coal, natural gas and hydropower

Cumulative PV capacity almost triples to over 2 350 GW by 2027 in the main case, surpassing hydropower in 2024, natural gas in 2026 and coal in 2027 to become the largest installed electricity capacity worldwide. Hydropower is falling to third place in terms of installed renewable capacity due to the rapid expansion of wind.

**Figure 1.8 Cumulative power capacity by technology, 2010-2027**

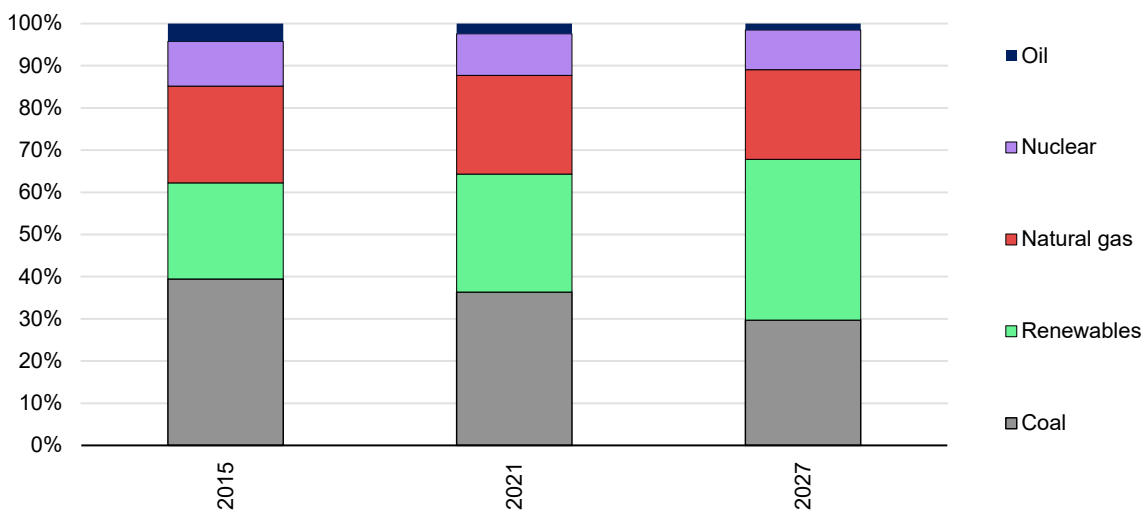


IEA. CC BY 4.0.

Source: IEA analysis based on [World Energy Outlook 2022](#), (2022), Fossil fuel capacity.

Overall renewable electricity generation is expected to increase almost 60% to reach over 12 400 TWh, with hydropower remaining the primary source of renewable electricity generation throughout the forecast period even though its capacity expands less than that of wind and solar PV. The main-case forecast expects renewables to become the primary energy source for electricity generation globally in the next three years, overtaking coal. Renewables account for almost 40% of global electricity output in 2027, making up for declining shares of coal, natural gas and nuclear.

**Figure 1.9 Global electricity generation by technology, 2015, 2021 and 2027**



IEA. CC BY 4.0.

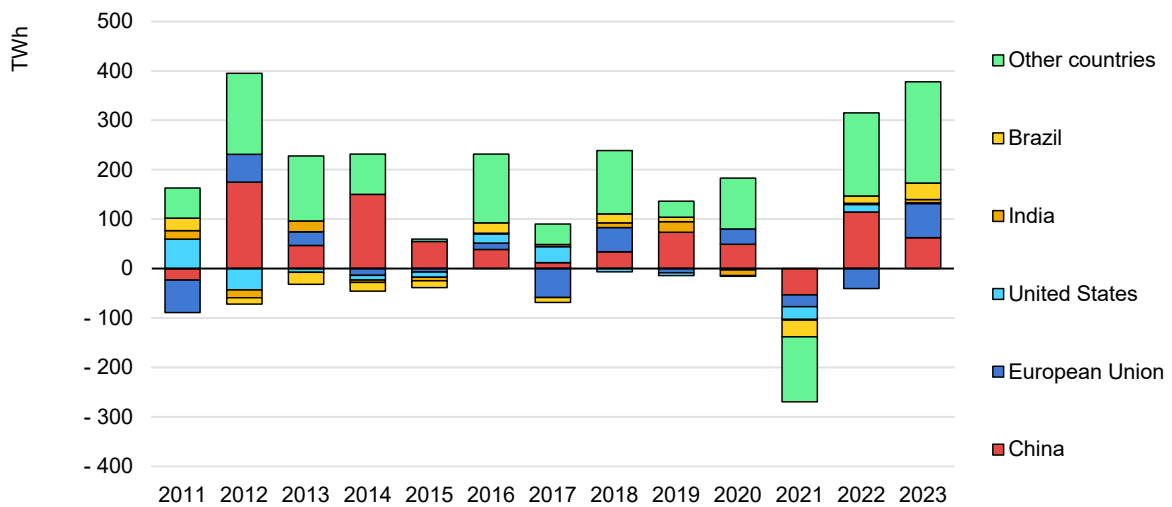
Source: IEA analysis based on [World Energy Outlook 2022](#), (2022), Fossil fuel and electricity generation.

## Large hydropower markets recover slowly from severe droughts in 2021, except in the European Union

Severe drought conditions in Brazil, the United States, China and Türkiye restricted global hydropower generation in 2021, with output declining for the first time in two decades (-3% year-on-year). Although the forecast indicates a 15% drop in EU hydropower generation in 2022, data for the first nine months of this year indicate that hydropower generation in China, the United States and Brazil will be higher than in 2021, with drought conditions easing in other countries as well.

While EU hydropower generation is subject to a high level of uncertainty, historical trends indicate that it could rebound. Given the European Union’s eagerness to displace natural gas generation next winter, higher hydropower output could not only contribute significant additional renewable electricity but improve energy system flexibility.

**Figure 1.10 Hydropower electricity generation absolute year-on-year change, 2018-2022**



IEA. CC BY 4.0.

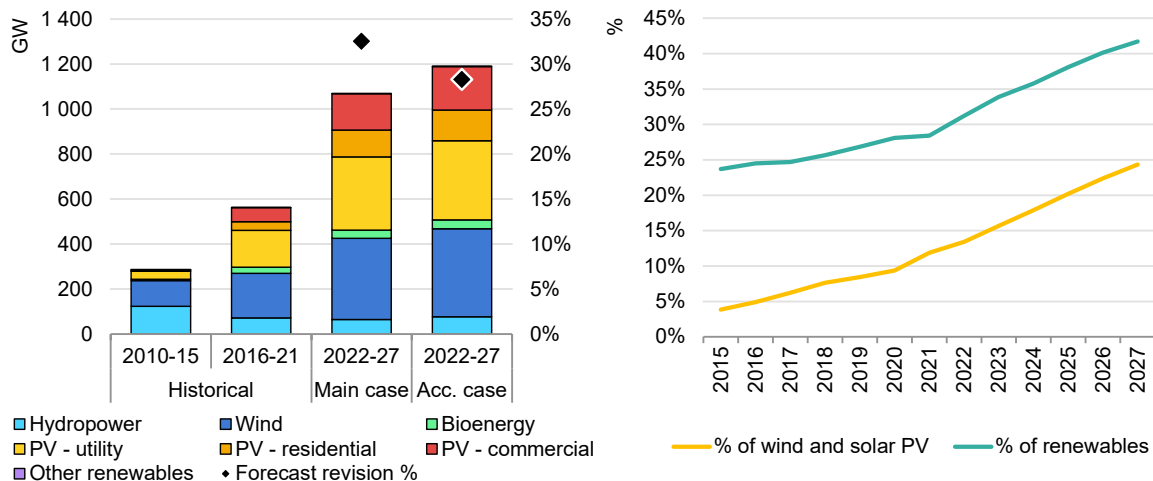
# China

## China is set to surpass its newly announced renewable electricity targets thanks to rapid wind and PV deployment

China’s cumulative renewable power capacity is expected to double during 2022-2027, increasing by almost 1 070 GW. Solar PV and wind account for 90% of renewable energy growth, with hydropower providing most of the remainder. In the main case, China is expected to reach its 2030 target of 1 200 GW of total wind and solar PV capacity five years early. By 2023, solar PV will have surpassed hydropower to have the largest portion of installed renewable capacity in China.

Policy guidelines and targets in China’s new 14th Five-Year Plan on renewable energy (released in June 2022) are the basis for this year’s 35% upward revision on last year’s forecast. For the first time, China has shifted its policy focus from installed capacity to shares of renewable energy sources in electricity generation. Accordingly, the country aims for 33% renewables and 18% wind and solar PV in electricity generation by 2025. Depending on overall power demand growth and hydropower output, China could reach its renewable energy generation targets even earlier.

**Figure 1.11 China renewable capacity additions, 2010-2027 (left) and shares of renewables in electricity generation, 2015-2027 (right)**



IEA. CC BY 4.0.

Informing our forecast for China are the four policy aims of its 14th Five-Year Plan on renewable energy: 1) accelerate large-scale renewable energy deployment; 2) increase the share of renewables in overall energy demand through electrification;

3) shift from subsidy-oriented to market-oriented renewable energy deployment with fixed prices; and 4) promote electricity system stability and security.

China's government has identified large-scale deployment bases for utility-scale PV, with onshore and offshore wind easing project permitting. It has also phased out subsidies for renewable electricity projects because generation costs for mega-sized facilities (i.e. 500-2 000 MW) can easily be lower than for coal-fired generation, especially in provinces with high renewable resource potential.

Utility-scale onshore wind and large-scale solar PV projects with 500 GW of capacity have been announced, to be installed mainly in the Gobi Desert in Xinjiang, around the Yellow River in Inner Mongolia, and in the Hexi Corridor in Gansu. These large plants, most of which are expected to be operational by 2027, are to export power through underutilised ultra-high-voltage (UHV) transmission lines to demand centres. To support large-scale project deployment, the 14th Five-Year Plan also proposes that new UHV lines be built by 2025 to raise power export capacity from east to west from 200 GW to 300 GW.

Recent market reforms enable the use of new business models for solar PV and wind projects, supporting forecast growth. Since November 2021, large commercial and industrial consumers have been exposed to market-based electricity prices, and in the first quarter of 2022 almost half of China's electricity demand was traded in the liberalised market, mostly through provincial long-term contracts.

In addition, the government passed a regulation enabling large consumers to sign clean energy power purchase agreements with new projects developed without subsidies. Thus, developers and consumers can exchange green certificates and environmental attributes in the market. Depending on the agreement, projects receive a premium either from green certificates or environmental attributes on top of market-based prices, improving project bankability.

New government initiatives and regulations are expected to enable faster distributed solar PV expansion over 2022-2027. At the beginning of 2022, commercial and industrial retail electricity prices rose to 10-20% above last year's in most provinces because developers have begun to pass the cost of their higher fossil fuel bills on to consumers under the liberalised market. In our main-case forecast, these higher prices are expected to hasten commercial and industrial PV deployment.

The Chinese government also introduced a new target requiring 50% of all large public buildings and new buildings in industrial parks to have rooftop PV installations. For residential consumers, retail electricity prices remain regulated and relatively low, but provincial incentives from rural economic development programmes continue to support small PV applications.

In the accelerated case, renewable capacity growth in China could be 10% or almost 120 GW higher than in our main case, mainly owing to faster solar PV and wind deployment. Plus, addressing remaining policy and market challenges could lead to stronger uptake of renewables in the electricity sector over 2022-2027.

The pace of implementing large-scale renewable energy bases far from demand centres depends partly on the timely expansion of interprovincial transmission lines. In the absence of subsidies, revenue risks associated with curtailment continue to be a challenge for onshore wind and solar PV projects. Furthermore, rising renewable energy investment costs, especially for solar PV, have reduced the profitability and thus the bankability of some projects.

Developers of utility-scale renewable energy projects will also be increasingly exposed to market price fluctuations for green certificates and environmental attributes. Although volumes are increasing, these markets are still nascent and the interactions among various products remain unclear, especially regarding connections with corporate PPAs. Additionally, new government policy requires commercial and industrial distributed PV applications to maximise self-consumption, but a detailed accounting regime for self-consumption has yet to be released.

## United States

### **Inflation Reduction Act incentives provide unprecedented policy certainty, boosting wind and PV deployment**

Renewable energy capacity in the United States is forecast to increase 74%, or over 280 GW from 2022 to 2027, with solar PV and wind accounting for nearly all renewable expansion. This upwards revision of more than 25% from last year's forecast takes account of new incentives under the IRA, which provides unprecedented long-term policy visibility for multiple technologies.

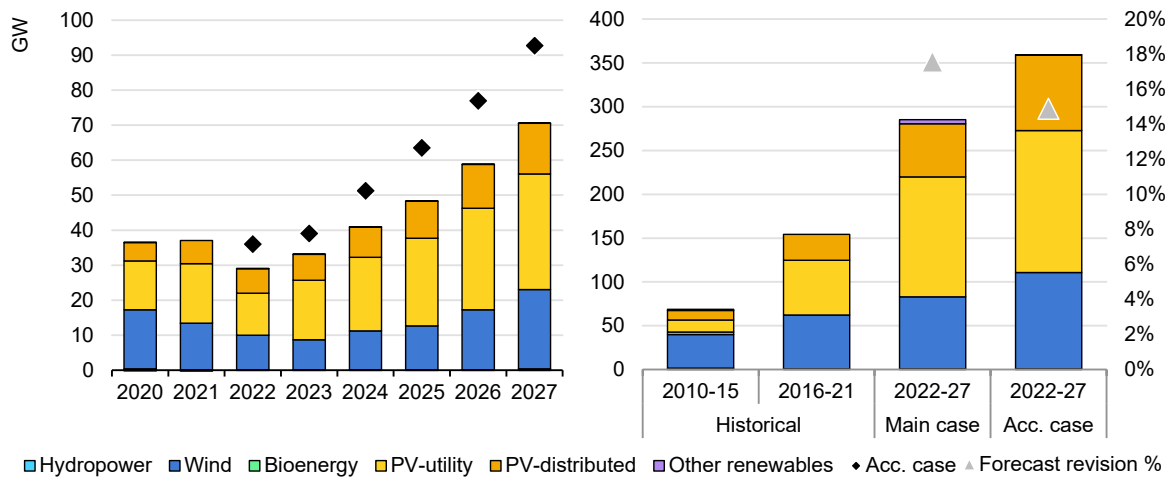
While previous IEA forecasts assumed capacity addition uncertainty or even declining capacity additions because federal tax credits for solar PV and onshore wind developers were declining or expired, the IRA now offers uncapped investment tax credits (ITCs) and production tax credits (PTCs) through 2032. Our updated forecast is therefore more optimistic and will impact deployment beyond 2023.<sup>1</sup>

---

<sup>1</sup> The maximum rate for the ITC is 30%, and for the base PTC rate is USD 0.026/kWh; the PTC is adjusted for inflation. ITC and PTC rates step down in the final years covered by the IRA.

IRA incentives are expected to support the Biden Administration target of 100% carbon-pollution-free electricity by 2035. In addition, 37 out of 50 states have renewable portfolio standards and goals supporting expansion. Given that the country now has clear long-term policy visibility, uncertainties in the US renewable electricity forecast relate to project delays due to supply chain constraints, trade measures, the availability of grid infrastructure and long permitting timelines.

**Figure 1.12 United States annual renewable capacity additions by technology, 2020-2027 (left) and total renewables capacity growth, 2010-2027 (right)**

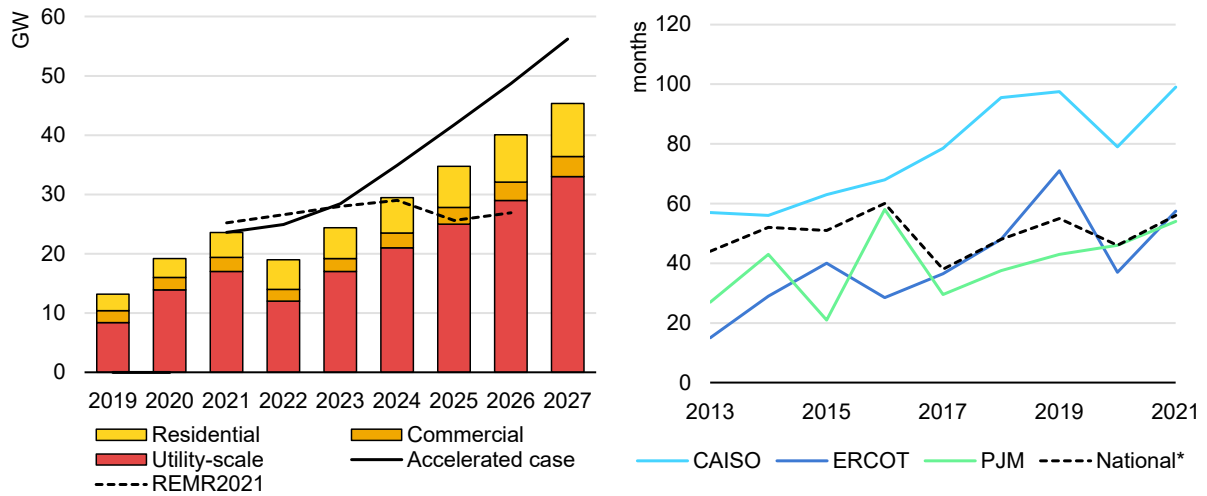


IEA. CC BY 4.0.

Despite the introduction of new incentives, however, US renewable capacity additions are forecast to decrease over 20% in 2022 compared with last year. Overall, utility-scale solar PV and wind projects have been delayed by supply chain challenges and rising costs. In addition to supply chain interruptions, several measures impacting imports have also impeded solar PV project development.

First, the United States started an anti-dumping and circumvention investigation into solar panels from several Southeast Asian exporters in March 2022. While an executive order of June 2022 suspended the investigation for two years, the three-month period of uncertainty stalled decisions throughout the project pipeline. Second, the Uyghur Forced Labour Act came into force in June 2022, requiring imports from China's Xinjiang province to be accompanied by documentation stating that no materials were manufactured using forced labour. Since the act came into force, confirmation and compliance procedures at US ports have delayed the delivery of some PV products to developers.

**Figure 1.13 United States solar PV capacity additions, 2019-2027 (left) and median time between solar PV interconnection request and plant commissioning for selected system operators, 2013-2021 (right)**



IEA. CC BY 4.0.

Note: REMR2021 = Renewable energy market report 2021 (i.e. *Renewables 2021*).

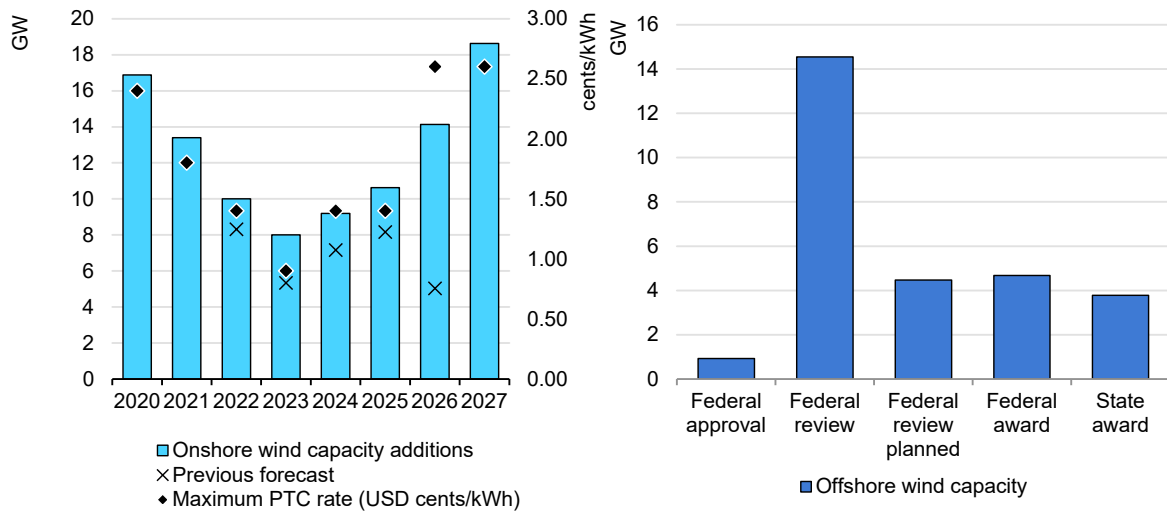
Nevertheless, while trade measures hamper faster solar PV expansion in the short term, IRA incentives induce a more optimistic forecast beyond 2023. Extension of the ITC, the new availability of the PTC, and options for stronger support based on labour and domestic-content bonuses are expected to make the business case more attractive for utility-scale projects. The inclusion of interconnection costs within the ITC and new ways to monetise tax credits are also expected to facilitate rapid uptake.

For distributed PV, the extension of tax credits and attractive economics resulting from net-metering rules in some states drive growth. In fact, net-metering incentives and demand for self-sufficiency resulted in over 4 GW of residential installations in 2021, surpassing previous expectations even before the IRA came into effect. However, ongoing discussions concerning California’s net-metering reforms to switch to time-of-use pricing and apply grid use fees continue to impose forecast uncertainty, as the state remains the largest growth market for residential and commercial installations in the United States.

For onshore wind, last year’s forecast expected a more than 60% decline in annual additions in 2026 compared with 2021 due to the phaseout of tax incentives. However, the long-term tax credit certainty provided by the IRA is now expected to lead to an increase in capacity additions, especially beyond 2023 (the US government’s previous one-year PTC extensions provided little policy certainty, creating boom-bust cycles of additions).



**Figure 1.14 United States onshore wind capacity additions and maximum PTC credit rate, 2020-2027 (left) and offshore wind project status (right)**



IEA. CC BY 4.0.

Notes: PTC values in left figure are base values and exclude inflation adjustment. The PTC will change to a technology-neutral Clean Energy Production Tax Credit beginning in 2024.  
Source: (right) IEA analysis based on information from the [United States Permitting Dashboard for Federal Infrastructure Projects](#) (accessed November 2022).

The US offshore wind forecast expects more than 11 GW of new capacity because projects previously awarded at the state level are entering federal review, leading to their faster commissioning. The forecast thus expects most projects that have been approved (nearly 1 GW) or currently under the federal permitting review process (over 14 GW) to become operational by 2027. Nevertheless, long development timelines remain a key challenge. For instance, Vineyard Wind 1 was awarded its lease area in 2015 while only being granted federal permitting approval in 2021, with construction finally beginning in 2022.

To help achieve the federal target of 30 GW of offshore wind capacity by 2030, federal and state governments have held additional lease auctions and identified new areas for future development. However, several barriers must still be overcome, including long federal and state-level permitting wait times; Jones Act<sup>2</sup> requirements that reduce the number of installation vessels available; and the need for port and transmission infrastructure development.

In the accelerated case, growth is 30% higher if the primary uncertainties affecting utility-scale solar PV and onshore wind expansion in the main-case forecast are addressed. The first challenge is the backlog of grid interconnection applications. The average time from interconnection approval to commissioning is over four

<sup>2</sup> The Jones Act allows only US-built and -operated ships to move goods between US ports. Offshore wind installation vessels are currently under construction in the United States, so the number of vessels available to install turbines is limited.

years (and as high as six to seven for some independent system operators) and has been increasing steadily over the last decade. Growth could therefore be higher if proposed legislation (the Energy Independence and Security Act) to help facilitate transmission expansion is passed. Another forecast uncertainty is how well developers will be able to fully monetise all IRA rate multipliers. If conditions for labour, local content and project location are met, the ITC rate could almost double and the PTC could be five times as high, but the Internal Revenue Service has yet to release further guidance on interpreting these requirements.

## Europe

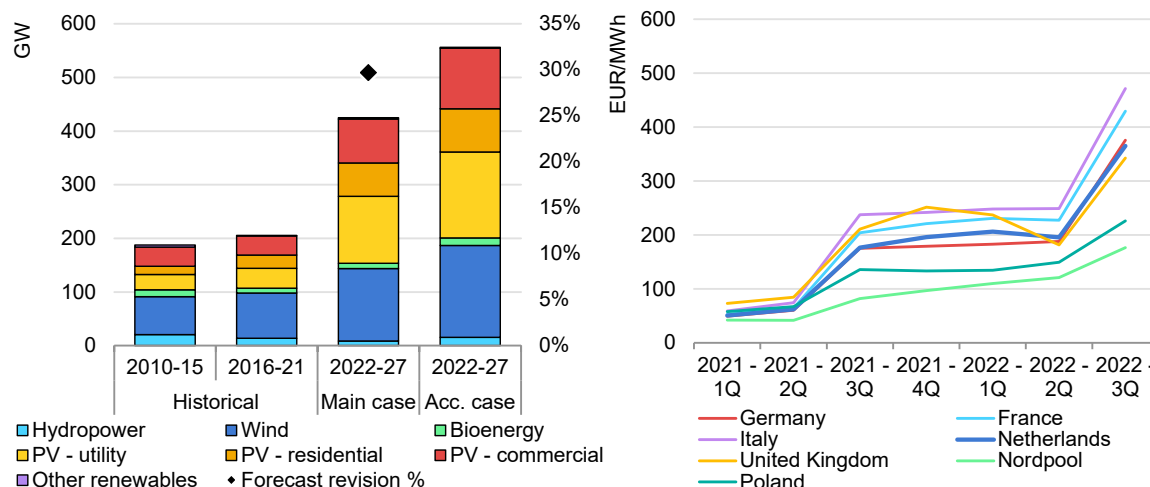
### Europe's renewable capacity expansion doubles as energy security concerns accelerate actions towards climate goals

Cumulative renewable electricity capacity in Europe is expected to increase nearly 60% (+425 GW) between 2022 and 2027, more than twice as much as in the previous five-year period (2016-2021). Solar PV leads growth, followed by onshore wind, offshore wind, bioenergy and hydropower. Three-quarters of European expansion is concentrated in seven countries – Germany, Spain, the United Kingdom, Türkiye, France, the Netherlands and Poland. Europe's main drivers for growth are long-term renewable energy targets and competitive auctions for utility-scale projects.

For distributed solar PV, feed-in tariffs or self-consumption with remuneration for excess generation promote uptake. The increasing attractiveness of projects developed outside of government-led auction schemes, through business models that employ corporate PPAs, revenues from the spot market, or a mixture of both, also spur growth.

This year's main-case forecast has been revised upwards 30% to reflect policy changes made by governments over the last year to accelerate clean energy transitions and reduce reliance on Russian fossil fuels.

**Figure 1.15 Europe renewable electricity capacity additions, 2022-2027 (left) and wholesale electricity prices for selected markets (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

## Policy momentum and market conditions were already signalling faster renewable energy growth before the energy crisis

Even before the energy crisis began, policy actions in 2021 were pointing towards a more optimistic renewable energy forecast for Europe, prompted by policy reforms to accelerate renewable energy growth to reach more ambitious climate goals. Last year, the European Commission released its Fit for 55 policy package and proposed raising the targeted EU renewable energy share from 32% to at least 40% by 2030 to put the European Union on a net zero GHG emissions trajectory for climate neutrality by 2050. The final target is still under negotiation, but once it has been set, member states will have to update their National Energy and Climate Plans (NECPs) during 2023-2024 to reflect new national targets and identify support policies.

By the end of 2021, some member states had already begun to raise their ambitions in anticipation of a higher EU target and had introduced policy and regulatory changes to accelerate the use of renewable energy sources. For instance, Ireland's National Development Plan increased the targeted share of renewables in electricity consumption to 80% by 2030 (up from its current NECP's 70%), and Italy's Ministry of Ecological Transition proposed increasing the share of renewable electricity to 72% (up from 55% in the country's current NECP).

Meanwhile, other countries continued to boost existing support. For example, France raised the size limit for commercial PV eligibility for feed-in tariffs and the

Netherlands extended net metering. Outside of policy action, countries also began to tackle permitting barriers by simplifying procedures: for instance, Greece unveiled a digital one-stop-shop application.

At the same time, favourable market conditions in 2021 were also positioning Europe for faster growth. In many European markets, wholesale electricity prices more than doubled between the first and fourth quarters of 2021, improving the attractiveness of merchant projects. In addition, pipelines of corporate PPA projects expanded in several markets as energy-intensive end users sought to lock in lower tariffs to hedge against possible hikes in retail prices. Higher retail prices also improved the business case for self-consumption.

## Reducing reliance on fossil fuel imports expedites action on Europe's renewable energy plans

Following the February 2022 invasion of Ukraine, energy security emerged as an additional motivation to accelerate renewable energy development. Governments responded by making their targets more ambitious and by fast-tracking policies to facilitate quicker growth. At the EU level, the European Commission's REPowerEU strategy released in May 2022 proposes increasing the share of renewables in final energy consumption to 45% by 2030, exceeding the 40% currently under negotiation. Reaching this target will require almost 600 GW of solar PV<sup>3</sup> and 510 GW of wind capacity by 2030.<sup>4</sup>

The Commission also proposes amending the Renewable Energy Directive with requirements for member states to streamline and shorten permitting processes. While legislation supporting this strategy has not yet passed at the EU level, member states and other European countries have already begun to announce plans, draft legislation, and swiftly implement a raft of reforms to quickly end dependency on Russian gas and mitigate the rising cost of energy to consumers.

These policy actions can be classified into three categories, and the main case considers them on a case-by-case basis depending on the status of the legislative process and country-specific challenges:

- **Raising renewable energy ambitions.** In March 2022, Germany raised its 2030 renewable electricity target from 65% to 80% and accelerated the pace of solar PV and wind expansion, aiming for 350 GW installed by 2030 compared to the previous 191 GW. The United Kingdom proposed a 2030 PV target for the first time in its energy strategy, and Portugal announced plans to meet its 2030 target

<sup>3</sup> Refers to alternating current (AC) as outlined in the [EU Solar Energy Strategy](#).

<sup>4</sup> The [Staff Working Document](#) on investment needs to implement the REPowerEU Action Plan states that 510 GW of cumulative wind capacity and 592 GW of solar are required to reach the target of 45% renewables in final energy consumption by 2030.

by 2026. The forecast is more optimistic in these markets, based on the expectation of draft legislation coming into force within the next five years.

- **Increasing policy support.** Government actions include raising remuneration levels and introducing new financial support. For example, Germany increased feed-in tariffs for distributed PV, the Netherlands eliminated the VAT for residential PV systems, and the United Kingdom unveiled plans to hold annual auctions for the first time. Other countries modified existing schemes (e.g. France adjusted its auction rules so that developers could increase capacity after the auction) or extended current ones (e.g. Cyprus<sup>5,6</sup> allocated additional funding for net metering until 2023). As the main case assumes that these changes, among others, will increase the attractiveness of renewable energy projects, the forecast was adjusted upwards.
- **Addressing non-financial challenges.** Governments have passed regulatory reforms to streamline permitting, make grid connection easier and improve network congestion – three barriers that have lengthened project development times. For instance, Germany overhauled onshore wind siting requirements and streamlined compliance with environmental laws while Spain introduced a simplified permitting procedure and made grid capacity available for renewable energy projects. Portugal eliminated environmental impact assessments for renewable energy projects, while Italy raised the size limit to qualify for licensing exemptions. These changes are expected to raise auction subscription levels and accelerate movement in project pipelines, resulting in stronger growth

While this year's main-case forecast is more optimistic than last year's, non-policy-related barriers threaten the pace of growth. The impact of supply chain disruptions and rising raw material prices on future investment costs continue to impose forecast uncertainty, and a lack of skilled workers to install higher volumes of distributed solar PV is another challenge.

Permitting delays are a key barrier to faster growth for both solar PV and wind in Europe. For onshore wind, [wind turbine orders fell 36% in Q3 2022 compared with Q3 2021](#). In 2021, onshore wind auctions held in Germany, France, Italy and the United Kingdom were undersubscribed because projects could not obtain permits due to authorisation complexity, siting restrictions or social opposition. As a result, the onshore wind forecast for these markets has been revised downwards. Grid congestion, coupled with a lack of investment and long lead times for network upgrades, also constrain renewable energy growth.

---

<sup>5</sup> Footnote 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".

<sup>6</sup> Footnote 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.

In addition, current and proposed market interventions in Europe (such as wholesale market caps and windfall-profit taxes) could create uncertainty for renewable energy investments in the upcoming months if they are not well designed. Moreover, the ongoing energy crisis has also sparked new discussions within the European Union concerning future electricity market design. While reforms could, in principle, boost market-driven renewable energy deployment, ensure energy security and encourage investment in flexibility resources, it is important that any reform proposal be carefully and transparently prepared, involving all relevant stakeholders. Failure in this regard could increase investor uncertainty and slow renewable expansion.

Europe's renewable capacity expansion during 2022-2027 could be 30% higher if accelerated-case conditions are met. Simplified permitting regulations and shorter licensing times would accelerate onshore wind development. This could be achieved if the temporary emergency regulations to address permitting bottlenecks proposed by the European Commission were formally passed and implemented at the country level. In November 2022 the European Commission<sup>7</sup> proposed the designation of renewables as a matter of public interest to benefit from simplified procedures for new permits, and it introduced caps on permitting response times under certain conditions.

Accelerated-case growth is also possible with more grid capacity and faster network improvements to integrate new projects; simplified permitting regulations and shorter licensing times to accelerate onshore wind development; training programmes to increase the number of skilled workers; and greater land availability for new projects to shrink bottlenecks and allow development. Furthermore, an increase in auction volumes would accelerate utility-scale project development while lower investment costs and elevated electricity prices could offer further stimulus for unsubsidised projects.

## Germany

### Germany's swift policy and regulatory response to the energy crisis doubles the pace of renewable energy expansion

Between 2022 and 2027, Germany's renewable power capacity is expected to expand 67% (97 GW), more than twice as much as during the previous five-year period owing to ambitious new renewable energy targets designed to decrease

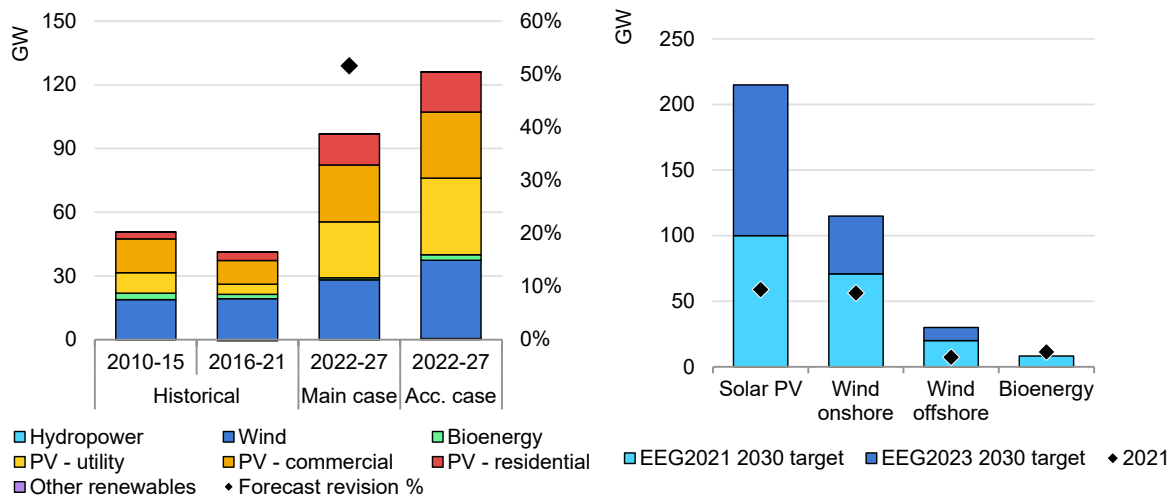
---

<sup>7</sup> In 29 November 2022, EU energy ministers informally agreed to designate renewable energy projects as part of the "overriding public interest" that would be valid for 18 months. However, this regulation proposal is expected to be formally approved by the European Council after the publication of the Renewables 2022 report.

reliance on imported Russian gas and achieve climate goals. This year’s forecast has been revised upwards 52% from last year’s to reflect the passing of policy reforms and support schemes to meet these new targets.

In July 2022, Germany revised its Renewable Energy Sources Act (EEG 2023) just two years after the previous revision (EEG 2021) to raise the share of renewables in electricity generation from 65% to 80% by 2030. The government also increased the 2030 capacity targets for solar PV and wind substantially. Accompanying the target revisions are support policies, including higher auction volumes, increased remuneration for distributed solar PV, and regulations to reduce permitting times for onshore wind. Renewable energy technologies were also legally established as a matter of overriding public interest in the EEG 2023, giving them priority in approval and permitting decisions when evaluated against competing interests.

**Figure 1.16 Germany renewable capacity additions, 2022-2027 (left) and 2030 targets for cumulative installed capacity in EEG2021 and EEG2023 vs installed capacity today (2021)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

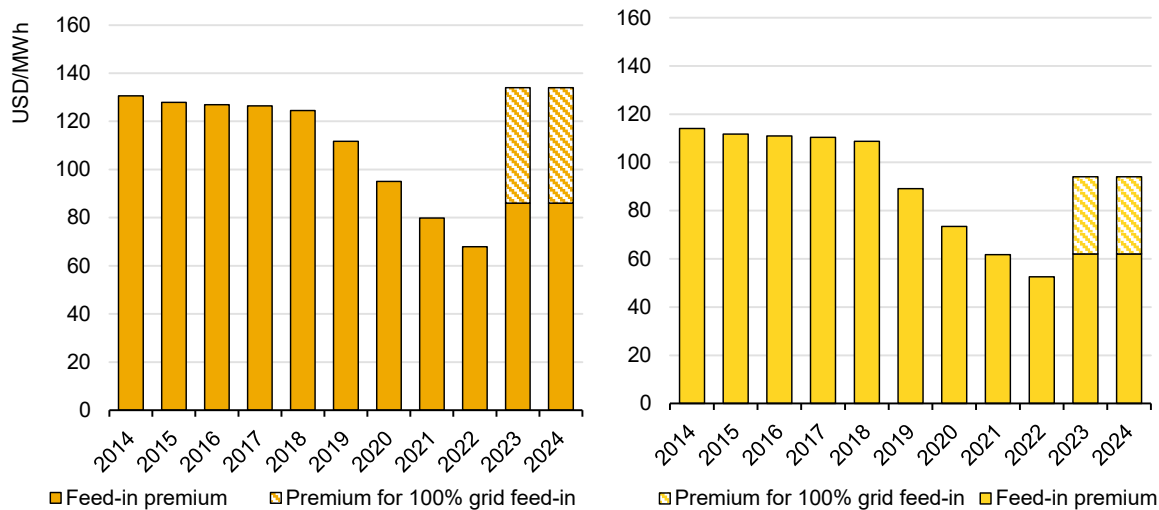
Solar PV accounts for 70% of total forecast growth, led by distributed PV, which is also responsible for half of the upwards revision to this year’s forecast. This year’s forecast for distributed PV is more optimistic than last year’s because the new EEG 2023 offers greater support. For the first time since 2014, feed-in tariffs (FITs) and feed-in premiums (FIPs) will rise in 2023, monthly degressions have been halted until 2025, and the size limit for systems to qualify for the FIP was raised from 750 kW to 1 MW.

In addition, a premium on top of remuneration received through the FIP or FIT was introduced for systems of less than 1 MW that do not self-consume and instead

feed all their electricity into the grid. With this extra benefit, designed to encourage installations on unused roof space, total support would return to levels not seen since 2013 for residential systems and 2018 for commercial ones.

This year’s distributed PV forecast is also more optimistic owing to prospects of a more attractive business case for self-consumption with removal of the EEG surcharge and anticipation of higher retail electricity prices. Utility-scale solar PV growth has also been revised upwards because of greater capacity allocated to auctions under the EEG 2023 and an increase in the amount of land available for development near motorways and agricultural sites.

**Figure 1.17 Historical feed-in premiums (2014-2021) and new rates under the EEG2023 with full feed-in premium (2023-2024)**



IEA. CC BY 4.0.

Notes: In the right graph, feed-in rates for residential refer to systems of less than 10 kW and for commercial are for systems of less than 400 kW. The annual feed-in rate is an average of monthly feed-in rates for that year.

Nonetheless, two main challenges threaten solar PV growth, and resolving them results in near 30% greater expansion in the accelerated case. The first is undersubscribed bid auctions and higher bid prices because of supply chain challenges. For instance, utility-scale auctions in June 2022 were undersubscribed for the first time since the scheme was launched in 2017. Only 62% of the 1.1 GW on offer were awarded, and bid prices increased 6% to 55 EUR/MWh for the first time since 2019. Contract prices for the first two large commercial rooftop auctions in 2022 were also higher, and only 26% of offered capacity was awarded.

The second challenge is labour shortages, which are slowing the pace of distributed PV installation. Naturally, high demand for systems coupled with a shortage of skilled labour raises the forecast’s downside potential. Thus, in the accelerated case, more equipment, fewer delays, an adequate work force and an



attractive business case for corporate PPAs boost growth in annual additions to 19 GW by 2027, in line with the new 2030 target.

For onshore wind, the forecast has also been revised upwards 30% to reflect increased auction volumes, new regulations to make more land available for development, accelerated permitting and less decommissioning. From 2024, the government will double auction volumes to 10 GW per year. However, permitting has been the major challenge for onshore wind development in Germany, with long project approval wait times resulting from social opposition, land development restrictions and nature conservancy requirements. Because of permitting challenges, 14 out of 25 onshore wind auctions have been undersubscribed since 2017, resulting in 5 GW of unawarded capacity.

To address these hindrances, the government passed the Onshore Wind Act (Wind-an-Land-Gesetz) in summer 2022, mandating that each of the federal states dedicate an average 2% of their land to onshore wind development by 2032. Until these targets are reached, rules on minimum distances from residential homes are being suspended and turbines can be permitted in landscape protection areas.

The Species Protection Act was also revised to reduce litigation and facilitate compliance with nature conservancy laws. Species protection assessments have been standardised at the national level, permitting times for species compliance have been reduced from three to two years, and a finite list of endangered bird species has been compiled.

Under the main case, we expect these reforms to make more land available for project development, shorten permitting wait times, and subsequently allow more projects to bid into auctions and be awarded. Although annual additions from auctions in the main case are forecast to reach 5.5 GW by 2027, up from an average of 1.5 GW during 2019-2022, this still falls below the 10 GW on offer annually in the new auction schedule.

The forecast is cautious about full subscriptions, given the rapid increase in auction volumes and the time needed for industry to adjust to the new rules. A lack of available grid capacity is another impediment to rapid deployment of onshore additions, and the pace of grid infrastructure expansion remains a forecast uncertainty. Since 2008, a high-voltage line has been planned to connect wind sites in the north to demand centres in the south, but it has yet to be commissioned. Complications involving permitting across multiple jurisdictions and a shortage of skilled labourers with experience are further barriers to faster grid expansion.

The second reason the onshore wind forecast has been revised upwards is that decommissioning estimates have been lowered: it is now expected that turbines

for which support is expiring will gain sufficient revenue from the spot market or corporate off-takers. In the first half of 2022, [only 100 MW out of 5.6 GW were decommissioned](#) because their FITs expired; the remaining continued to operate thanks to high market prices.

In the accelerated case, onshore wind growth could increase 38% to 32 GW over 2022-2027 if several conditions are met. Permitting reforms would have to be implemented more quickly to shorten lead times and raise auction subscription rates, and network updates would have to be undertaken sooner to reduce congestion and allow for more capacity to be built. Furthermore, the business case for onshore wind systems would have to be made more attractive through corporate PPAs, and there would also have to be less decommissioning of older plants.

For offshore wind, the forecast remains unchanged from last year even though Germany has raised its 2030 target from 10 GW to 20 GW. Because of long project lead times and transmission capacity constraints, the main case does not expect higher 2030 targets to result in stronger growth before 2027. The forecast therefore reflects only the current project development pipeline, which is on track to be commissioned as previously anticipated.

Regarding bioenergy, this year's forecast is more optimistic due higher expectations for biomethane capacity. Compared with biomass auctions, which have been consistently undersubscribed since 2017, Germany's first two biomethane auctions have been fully subscribed and we expect this trend to continue under the new EEG 2023 emphasis on increased auctions.

## France

### **Permitting issues impair deployment, but ongoing policy efforts to shorten development lead times could help unlock faster expansion from auctions**

In the main case, France's cumulative renewable capacity is projected to grow by 50% (31 GW) over 2022-2027, with the greatest annual capacity additions in solar PV (+2.8 GW/year on average) and wind (+2.3 GW/year on average). Overall, France's forecast has been revised downwards from last year mainly because permitting challenges are hampering faster expansion of utility-scale renewable energy projects, particularly onshore wind. Permitting delays and land constraints have caused government-led FIP auctions to be undersubscribed, and long development wait times are widening the gap between the time projects enter the pipeline (i.e. in the announced or permitting phase) and their actual deployment.

The current FIP auction framework offers potential for faster growth for both utility-scale solar PV and onshore wind. Today, project development timelines in France are double those of neighbouring EU countries, with about [four to five years on average for ground PV](#), [seven years for onshore wind and ten years for offshore wind](#).<sup>8</sup> These delays are raising development costs and leading to high project cancellation rates.

To mitigate the economic impacts of lengthy project development timelines, the regulator (CRE) introduced [modified tender specifications](#) in September 2022. Producers now have the option of selling their generation on the market before they receive government support, enabling additional revenues to offset higher technology costs. The CRE also extended the commissioning deadlines for auctioned projects to avoid penalties for developers, and it allows developers to increase project capacity by up to 140% of that secured in tenders.

More recently, the government [announced a new bill](#) to streamline and assure permit delivery and to shorten connection delays, enhancing citizen participation in projects and simplifying access to degraded land for renewable energy projects. However, the effectiveness of regulatory measures and the details of the announced bill to ease permitting are strong forecast uncertainties.

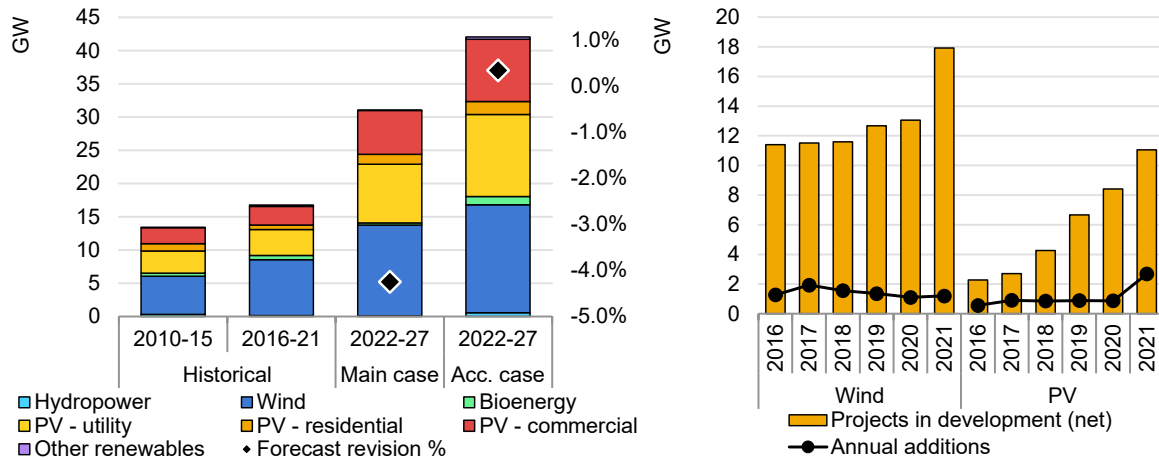
Annual onshore wind additions are expected to step up in 2022, primarily because of rising auction volumes over the past few years. Corporate PPA use is still marginal but expanding, which presents opportunities for both new small-scale plants and the increasing number of projects reaching the end of their 20-year policy support period. In 2022, France launched large-scale offshore wind generation with full commissioning of a 480-MW project at Saint-Nazaire, a full decade after the tendering competition had been held. Cumulative offshore wind capacity is expected to reach 3.6 GW at the end of the forecast period with the commissioning of six other projects from the same tendering scheme.

In 2021, France's annual PV installations more than doubled from 2020 with the commissioning of previously auctioned capacity for utility-scale and commercial PV projects. Modified tendering specifications and an increased threshold for commercial solar PV project eligibility for the on-demand FIT lead to a more optimistic forecast this year, despite ongoing supply chain challenges and rising costs. In addition, high electricity prices and expectations of further increases stimulate demand from residential consumers, who may benefit from new self-consumption support measures the government [announced in September 2022](#). Overall, France's installed PV capacity more than doubles over 2022-2027 in our main case.

---

<sup>8</sup> In comparison, the lead time for ground solar PV projects in Germany is generally [just over one year](#) to [three years](#).

**Figure 1.18 France capacity additions by technology, 2010-2027 (left) and project pipeline vs annual commissioning, 2016-2021 (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Source: Wind and solar PV project pipeline data are from SER (2021), [Panorama de l'électricité renouvelable](#).

Accelerated-case modelling suggests that France's renewable capacity additions over 2022-2027 could be more than one-third higher than in our main case if several conditions are met. For instance, the accelerated case assumes the simplification of land eligibility criteria for projects, which currently encompass multiple regulations at different jurisdictional levels; faster handling of administrative and permitting procedures; re-evaluation of the cost-competitiveness criteria for auctions,<sup>9</sup> especially for the building and rooftop PV segment, in which small projects struggle to compete with large ones, leaving significant PV potential untapped; improvements to the adequacy of network connection capacity; and the securing of a reliable supply chain for equipment.

## Spain

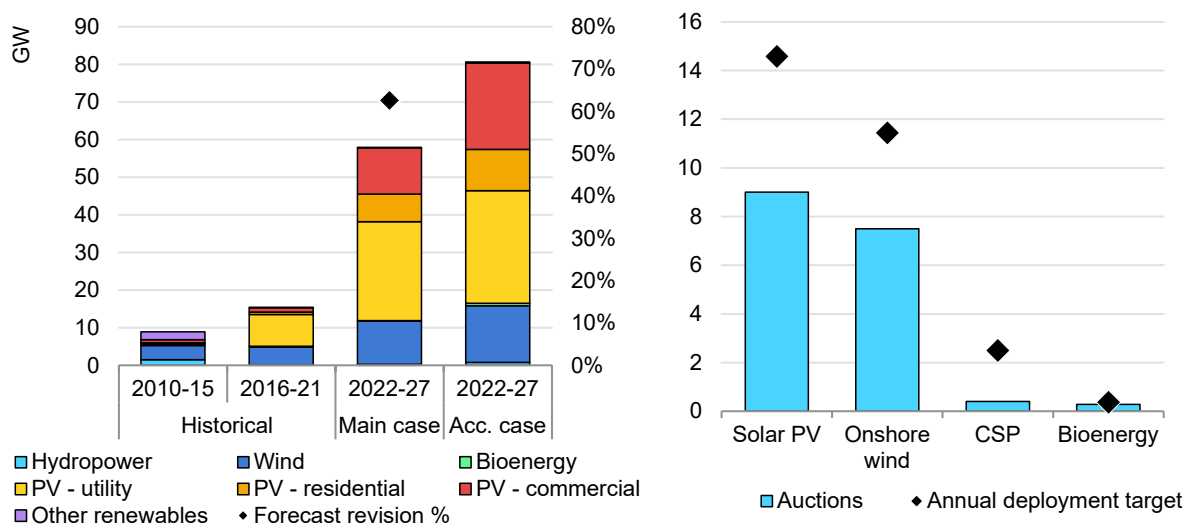
### Renewable power capacity almost doubles thanks to favourable market conditions and reforms to address permitting and grid challenges

Spain's installed renewable electricity capacity is expected to almost double by 2027 as competitive auctions, corporate PPAs and merchant projects add 58 GW of solar PV, onshore wind and pumped-storage hydro. This year's forecast has been revised 63% upwards to reflect a more optimistic outlook for solar PV for two reasons.

<sup>9</sup> Although France's auction design already integrates non-economic criteria to evaluate several environmental dimensions of renewable projects, these criteria are currently accorded relatively lower weight in the final scoring methodology.

The first is an increasingly attractive business case for both unsubsidised utility-scale solar PV and self-consumption in distributed PV. In both segments, growth was stronger than expected in 2021, resulting in total PV additions of 4.7 GW, the highest on record in Spain. The second reason is the passing of regulatory reforms to accelerate renewable capacity growth in response to the war in Ukraine. The reforms streamline permitting for solar PV and wind plants, increase grid capacity for new renewable energy projects, and provide clarity over clawback policies for windfall profits.

**Figure 1.19 Spain renewable capacity additions by technology, 2010-2027 (left) and annual auctions vs deployment targets, 2022-2026 (right)**



IEA. CC BY 4.0.

In March 2022, Spain passed Royal Decree 06/2022 – a series of reforms to address permitting challenges and grid congestion for renewable energy projects. Among their various measures, these reforms underpin a more optimistic forecast by:

- Introducing simplified environmental approvals for solar PV projects of less than 150 MW and wind projects below 75 MW, and by shortening the regulatory response deadline from six to two months.
- Requiring distribution grid operators to earmark 10% of their investment budget for upgrades to facilitate connection for new small-scale renewable power plants.
- Mandating that 10% of transmission capacity be released specifically for large self-consumption projects.
- Announcing an end date for windfall-profit caps for merchant projects and clarifying that projects with fixed-price PPAs would be subject to the clawback only if the contract price is above USD 67/MWh.

Projects outside of the auction scheme account for 50% of the main-case forecast for utility-scale growth. The regulatory reforms clarifying the clawback mechanism, shortening permitting times and increasing grid capacity are expected to address challenges that limited the pace of unsubsidised project expansion in last year's forecast. Accordingly, the utility-scale solar PV forecast has been revised upwards by 60%.

While the reforms are also expected to facilitate onshore wind expansion, their impact is limited because the decommissioning of older plants offsets upwards revisions resulting from the reforms. Not all projects coming to the end of their feed-in-tariff eligibility are expected to gain sufficient revenue in the spot market or from corporate off-takers to maintain operations or repower.

For distributed PV applications, the forecast has been revised upwards, with 88% more expansion in 2021 than expected as self-consumption is increasingly economically attractive and grid reforms will facilitate connection. The Spanish government's 2019 decisions to lift the tax on self-consumption, allow collective consumption and remunerate excess generation have improved the business case for commercial and residential applications, causing capacity additions to increase from 2020 to 2021. The main case expects the prospect of higher retail electricity tariffs to make self-consumption even more financially attractive, while recent regulatory reforms reduce grid congestion and shorten connection queues.

Accelerated-case forecasting indicates that growth could be almost 40% higher than in the main case under two conditions. The first is higher growth from unsubsidised utility-scale projects and distributed PV, encouraged by lower investment costs and sustained or higher electricity prices. The second is the awarding of more capacity through competitive auctions. For solar PV and onshore wind, greater volumes would have to be allocated under the tendering scheme. Current auction volumes do not provide enough annual deployment to meet the 2030 targets, implying that the residual would come from projects contracted outside of the auction scheme.

Higher auction volumes would boost growth and increase the probability of meeting long-term targets, particularly for onshore wind, for which unsubsidised markets are not as attractive as for solar PV. For CSP, raising bidding thresholds could also result in stronger growth. The first auction for 200 MW of CSP in October 2022 awarded no capacity because the bids exceeded the ceiling price of USD 110/MWh.

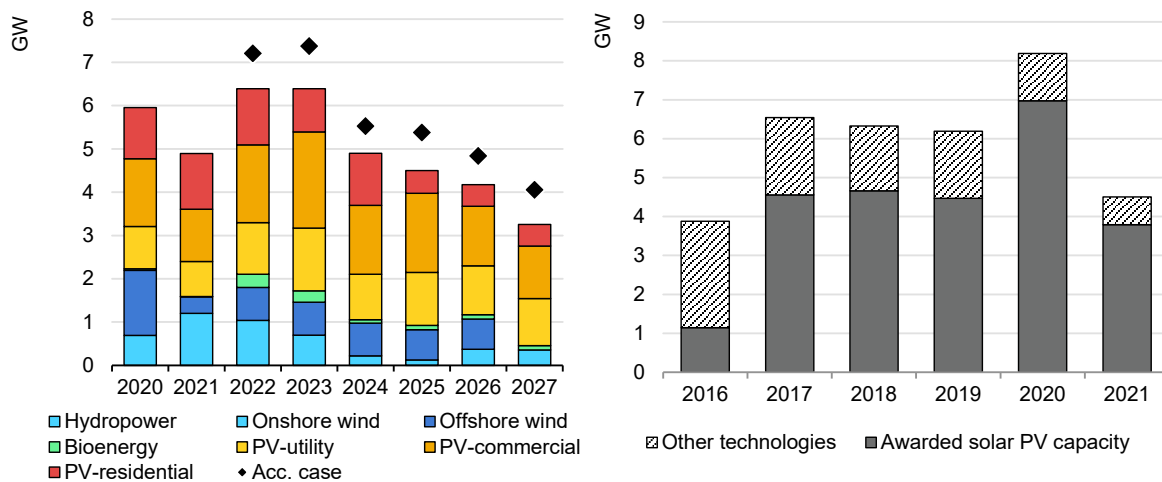
## Netherlands

### Subsidy programmes and net metering encourage solar PV and wind expansion, but grid and roof infrastructure challenges persist

The Netherlands is forecast to add nearly 30 GW of renewable power capacity from 2022 to 2027, led by solar PV and offshore wind. The SDE+ and SDE++ programmes, which provide subsidies for renewable energy generation or CO<sub>2</sub> emissions reductions, prompt onshore wind and utility-scale and commercial solar PV uptake.

Meanwhile, offshore wind capacity expands thanks to tendering schemes, and net metering encourages residential PV growth. The 2022 forecast has been revised 20% upwards from last year because utility-scale and commercial PV projects were deployed more quickly than expected, and the government extended net-metering benefits.

**Figure 1.20 The Netherlands renewable capacity additions, 2020-2027 (left) and capacity to solar PV and other technologies in SDE+ and SDE++ (right)**



IEA. CC BY 4.0.

Source: (right) IEA analysis based on data from the Netherlands Enterprise Agency (accessed October 2022).

Dutch utility- and commercial-scale PV capacity is forecast to increase over 17 GW in 2022-2027. However, annual additions decline because the Netherlands' subsidy scheme now prescribes fewer auctions per year and the [requested SDE++ budget subsidy](#) for solar PV in 2022 is halved compared with last year. In the residential segment, full net-metering benefits were extended to 2024 and will continue to be a major driver of growth before their phasedown

begins in 2025. In addition, the Dutch government recently decided to lift the VAT on residential solar panels starting in 2023, making systems more economically attractive.

Fewer auction bids and low awarded capacity due to grid constraints also affect annual onshore wind capacity additions over the forecast period, with just 2.8 GW of new onshore wind capacity anticipated. Offshore wind additions of over 3.5 GW are expected in previously awarded development zones, including an additional 1.4 GW that will be [tendered this year](#). Although the government increased its 2030 capacity target from 11.5 GW to 21 GW to help [reduce dependency on Russian gas](#), much of the additional capacity has yet to be tendered and is expected to become operational only after 2027.

Three major obstacles challenge expansion. The first is grid constraints, which are rendering some regions [unable to accept new capacity](#) until 2029. The second is future policy uncertainty. Under the EU Climate Agreement, the Netherlands has pledged to generate 35 TWh of electricity from onshore renewables by 2030. The Dutch government [expects](#) that enough onshore renewable capacity will be awarded to achieve this goal by the 2023 SDE++ auction round creating uncertainty about future subsidies for onshore renewables from 2024. The third impediment is rooftop infrastructure, as most large roofs have inadequate [load-bearing capacity](#). From 2022, building owners [must demonstrate](#) a roof's ability to host a solar installation to be eligible for a subsidy; the government is thus [considering policy](#) assistance to help owners retrofit roofs for solar panel suitability.

The accelerated case demonstrates nearly 20% greater additions, assuming the SDE++ scheme continues to award high volumes of onshore renewables beyond 2023. Plus, growth in the residential and commercial PV sectors can be higher if a policy to address roof structure issues is passed. Expanding the use of corporate PPAs, which have been employed in conjunction with SDE subsidies, could also achieve greater capacity increases. Finally, accelerating the pace of grid upgrades to address congestion issues would free up additional capacity for large-scale onshore wind and solar PV projects.

## Belgium and Denmark

### Policy support and high retail prices lead to faster distributed solar PV expansion in Belgium

Belgium is set to add almost 6 GW of renewable capacity over 2022-2027, driven by distributed solar PV and wind in the main case. Forecast growth is slightly lower than in the previous five years due to limited offshore wind expansion. Overall,



four separate green certificate (GC) programmes spur growth: one from the [federal government](#) for offshore wind and hydropower and three regional ones (in [Flanders](#), [Wallonia](#) and [Brussels](#)).

For distributed PV, rebates for residential systems in the Flanders region are being continued. Plus, the federal government has extended the [VAT reduction](#) for residential solar applications to buildings constructed since 2010, as it was previously available for older ones only. The combination of federal and regional incentives has improved the business case for distributed PV, especially in the context of higher retail prices.

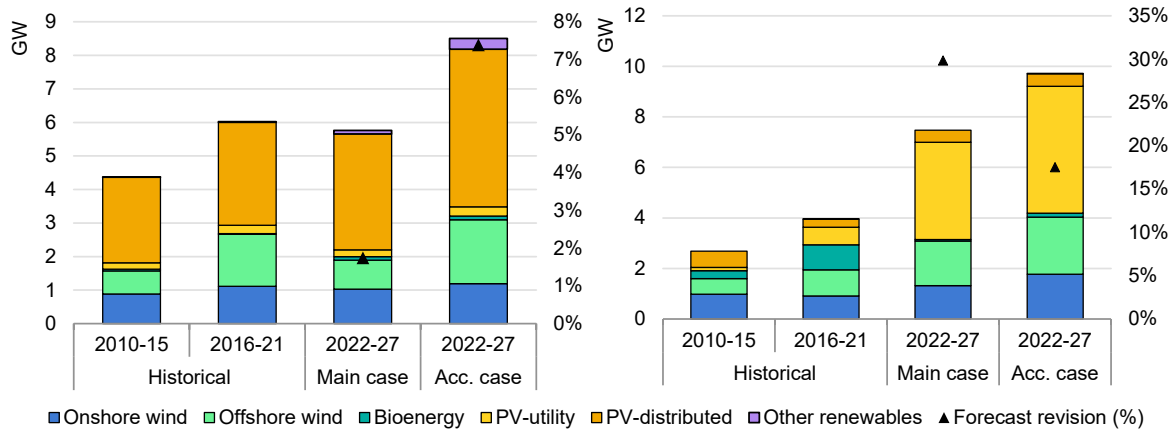
Following Russia's invasion of Ukraine, in March 2022 Belgium's federal government decided to extend the operation of 2 GW of nuclear capacity by ten years. It also introduced a [EUR 1.2-billion](#) financial package to accelerate the country's energy transition and protect consumers from high energy prices. The package's measures include developing new offshore wind zones to expand and accelerate offshore wind deployment, raising the country's wind target from [4 GW to 5.7 GW](#) by 2030.

This new target spurs additional offshore capacity deployment of 800 MW in our main-case forecast. The package also supports accelerated solar PV uptake at national railway stations and on federal buildings, as well as floating PV systems. It also prioritises the shortening of permitting and licensing wait times for onshore wind and solar PV.

In the accelerated case, renewable energy growth is demonstrated to be nearly 50% higher, with offshore wind and distributed PV showing the most upside potential. In May 2022, Belgium, Denmark, Germany and the Netherlands signed the Esbjerg declaration, a EUR 135-billion offshore wind pact to deploy at least 65 GW by 2030 and 150 GW by 2050. Furthermore, Belgium's [national recovery and resilience plan](#) includes EUR 100 million to develop an offshore hub and green hydrogen production.

The accelerated-case forecast thus assumes an early launch of the Energy Island hub with the [North Sea Energy Cooperation](#) and an additional 2 GW of offshore wind capacity by 2027. Plus, faster distributed PV expansion owing to higher retail electricity prices and increased auction capacity in Flanders and other regions leads to 35% higher solar PV deployment.

**Figure 1.21 Belgium renewable capacity additions by technology, 2010-2027 (left) and Denmark renewable capacity additions by technology, 2010-2027 (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

## Subsidy-free projects and bilateral contracts spur renewable energy expansion in Denmark

With stronger ambitions towards 2030, Denmark’s renewable electricity capacity nearly doubles over 2022-2027 in the main case, led by solar PV. This year’s forecast has been revised upwards by 40% because considerable utility-scale solar PV additions are expected, mainly from unsubsidised projects financed through merchant revenues and bilateral contracts.

In the main case, almost 2 GW of offshore wind capacity is commissioned, including the [Thor wind farm](#) awarded last December. Onshore wind expansion includes the repowering of existing capacity, either through competitive auctions or corporate PPAs.

However, renewable capacity growth in the accelerated case is almost 30% higher than in the main case, with more subsidy-free PV projects based on PPAs or direct participation in the electricity market.

Towards the end of 2030, the state is expected to put an additional 9 GW of offshore wind out to tender. Furthermore, faster commissioning of projects in the pipeline and simplified permitting could provide an additional 1 GW of utility-scale solar PV capacity and 1 GW of wind.

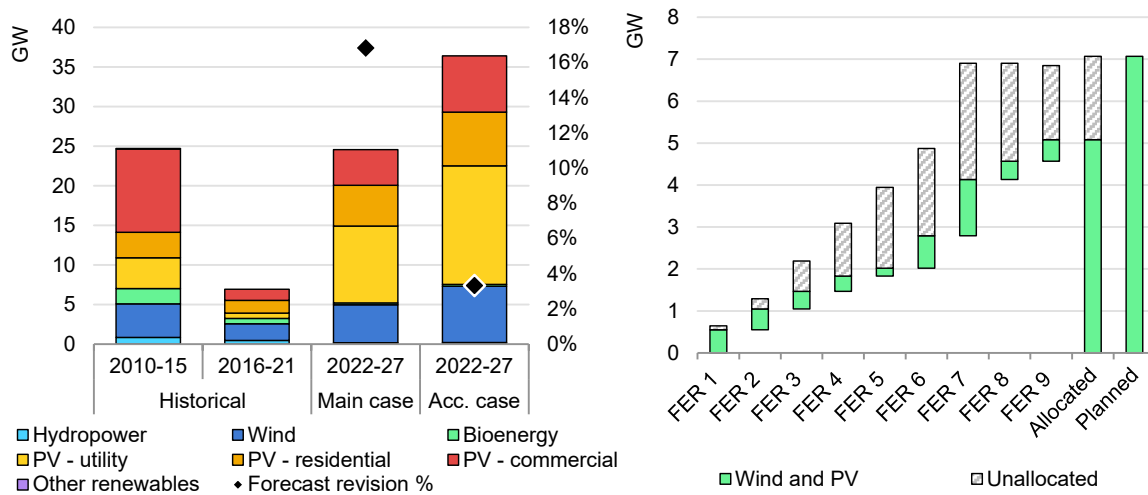
## Italy

### Italy is accelerating renewable capacity deployment in response to the energy crisis, but permitting challenges persist

Italy's renewable capacity is expected to increase 25 GW over 2021-2027 (+40%). Utility-scale and distributed solar PV each account for 40% of growth, with onshore wind providing the remainder. This year's forecast has been revised upwards 17% because stronger distributed PV expansion is expected from Italy's net-billing scheme, generous tax incentives and higher electricity prices, which improve the technology's economic attractiveness.

Meanwhile, the main drivers for utility-scale deployment are competitive auctions with growing contributions from merchant projects and bilateral PPAs. However, while utility-scale solar PV and onshore wind additions accelerate over the forecast period, they expand more slowly than previously expected because permitting challenges persist despite reform attempts.

**Figure 1.22 Italy renewable capacity additions, 2010-2027 (left) and results of FER renewable energy auctions (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Source: (right) IEA analysis based on data from Italy's GSE (Gestore Servizi Energetici), 2022.

Although auctions remain the primary driver of utility-scale PV deployment in Italy, the average allocation rate was just 35% in all rounds. After nine auctions, total awarded capacity had reached 5 GW, while the pipeline of PV and onshore wind projects applying for grid connection at the end of 2020 was 105 GW. A complicated and lengthy permitting process is the main obstacle impeding project development and preventing developers from bidding.

In addition, regulations restricting the participation of projects built on agricultural land significantly limit capacity available for auctions. Although the government introduced new regulations in December 2021 to streamline permitting and facilitate investment on agricultural land, auctions conducted in 2022 remained undersubscribed. Nevertheless, our forecast anticipates an uptick in utility-scale project deployment.

For distributed solar PV, policies introduced in response to the energy crisis should lead to rapid expansion. The new regulations have significantly simplified the permitting process for rooftop PV systems of less than 200 kW on commercial buildings and extended the 110% tax rebate introduced during the Covid-19 crisis by another year. In addition, higher electricity prices have improved the economic attractiveness of distributed PV under the net-billing scheme. Accordingly, distributed PV additions in 2022 will reach almost 2 GW, the highest growth since 2012.

In the accelerated case, Italy could achieve almost 50% higher renewable capacity growth over 2022-2027 than in the main case. Significantly streamlining permitting processes will be crucial to spur development of the huge pipeline of utility-scale PV and wind projects. At the same time, raising support for distributed PV through new tax rebates, subsidies and rooftop PV mandates should incentivise greater consumer investment. In parallel, faster development of power grids and flexibility resources will be necessary to ensure efficient integration of additional variable renewable capacity.

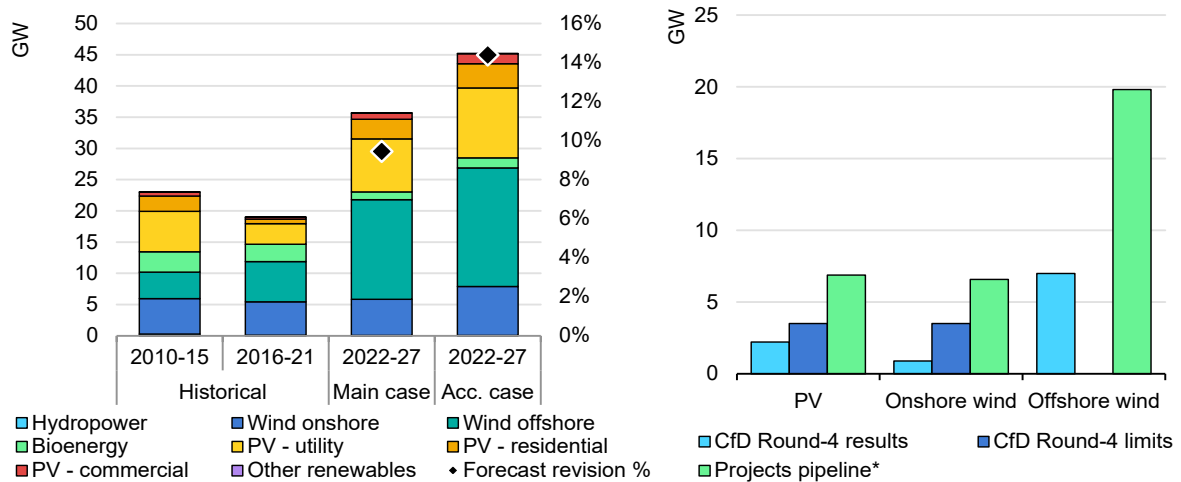
## United Kingdom

### New renewable capacity targets and policies improving permitting lead to a more optimistic forecast

Renewable capacity in the United Kingdom is forecast to increase nearly 70% (36 GW) over 2022-2027, almost doubling the pace of growth of the last five years. Offshore wind accounts for half of this expansion, followed by solar PV and onshore wind. Utility-scale projects lead the surge, spurred by competitive contract for difference (CfD) auctions.

In response to the energy crisis, the UK government increased its 2030 offshore wind target from 40 GW to 50 GW and established a 70-GW solar PV target for 2035 in the new British Energy Security Strategy. This year's forecast has thus been revised upwards almost 10% to reflect recently introduced and anticipated policies.

**Figure 1.23 United Kingdom renewable capacity additions, 2010-2027 (left) and CfD auction results, capacity limits and projects pipeline in Renewable Energy Planning Database (right)**



IEA. CC BY 4.0.

\* Includes projects with “under construction” and “awaiting construction” status in the Renewable Energy Planning Database as of September 2022.

Notes: Acc. case = accelerated case, CfD = contract for difference. “CfD Round-4 limits” reflects the maximum CfD Round-4 capacity available for allocation to PV and onshore wind projects.

Source: (right) IEA analysis based on data from UK Department for Business, Energy and Industrial Strategy, 2022.

The CfD auction conducted in 2022 resulted in the contracting of almost 7 GW of offshore wind projects, and for the first time a 32-MW project with floating foundation won a contract. Currently, the pipeline of offshore wind projects under development represents only 70% of the capacity needed to meet the United Kingdom’s 2030 target. Offshore project development can take up to 13 years, limiting the potential of new projects to be commissioned before 2030. However, the UK government plans to halve development lead times by streamlining administrative procedures. The forecast therefore assumes additional capacity from planned CfD auctions and improvements in permitting.

While the 2022 CfD auction offered an unprecedented 3.5 GW of capacity each for solar PV and onshore wind, only 2 GW of solar and 1 GW of onshore wind were awarded even though the project pipeline for each was at almost 7 GW. Many developers preferred not to participate in the auction, presumably to take advantage of high electricity prices through corporate PPAs or because they wanted to wait for equipment and material prices to fall.

Future auction rounds will be organised annually instead of every two years and will continue to include PV and onshore wind. Auctions remain the main driver of expansion, followed by corporate PPAs, which contribute 0.5-1 GW of additions annually. The government also plans to ease local permitting rules to make a larger portion of the project pipeline eligible for bidding.

For distributed PV, the government's strategy includes introducing design standards to encourage rooftop PV installation on new buildings, increasing the availability of low-cost financing and facilitating permitting. In addition, high electricity prices are expected to make distributed PV more economically attractive. As a result, capacity growth in both the residential and commercial PV segments is expected to increase significantly in the forecast period, exceeding last year's expectations.

In the accelerated case, UK renewable energy deployment over 2022-2027 is 27% higher than in the main case. Onshore wind has the highest upside potential if permitting and consenting rules are streamlined. Meanwhile, allocating more onshore wind and solar PV capacity in future auctions and raising price caps should attract more interest from developers and result in higher deployment of utility-scale projects. Successful implementation of plans to streamline permitting for offshore wind will also be necessary for the timely development of new projects to achieve 2030 targets.

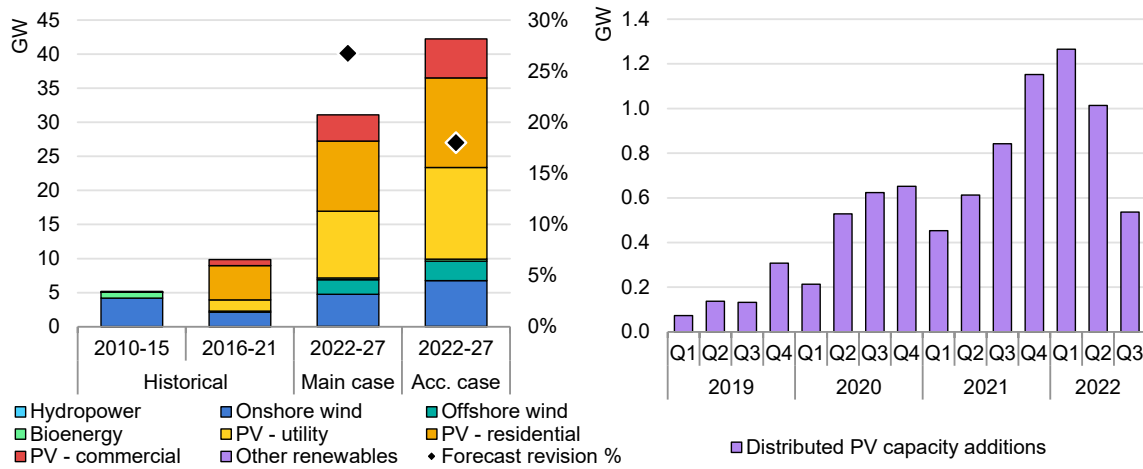
## Poland

### Renewable capacity almost triples by 2027, led by solar PV

Poland is expected to almost triple its installed capacity by adding 31 GW of renewables over 2022-2027, with distributed PV projects accounting for nearly half of all expansion, followed by utility-scale PV. In addition, its first offshore wind capacity will start operation in 2026, adding 2 GW by the end of the forecast period. Competitive auctions are expected to remain the main driver of utility-scale PV and onshore wind deployment.

After a step increase in distributed PV capacity growth in 2021 and the first half of 2022, the annual installation pace will slow with the transition from net metering to net billing, which is less generous. Still, the distributed solar PV forecast for this year is more optimistic than last year's thanks to higher-than-expected deployment over 2021-2022 and elevated electricity prices increasing profitability. Faster rooftop PV adoption is the main reason for Poland's 27% upward forecast revision.

**Figure 1.24 Poland renewable capacity additions, 2010-2027 (left) and quarterly distributed PV capacity additions, 2019-2022 (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Source: (right) IEA analysis based on PTPIREE (2022), [Micro installations in Poland](#).

Investment subsidies, tax rebates and a generous net-metering scheme allowed Poland’s distributed PV capacity to quintuple between 2019 and 2021, exceeding government expectations. As a result, the country already surpassed its 2030 PV target last year. Subsidies were scaled down in 2022 and net billing replaced net metering in April 2022, as integrating rapidly rising volumes of new capacity into the energy system has been challenging for distribution grid infrastructure. Policy changes led to an almost 60% decrease in installations between Q1 and Q3 2022, but high electricity prices are making rooftop PV investments considerably more attractive, leading to higher-than-expected installations in the second half of 2022.

Auctions are the principal driver of utility-scale capacity expansion, with 6 GW of PV and 5 GW of onshore wind expected to come online as a result of contracts awarded during 2016-2021. The next auctions will be held in December 2022 and the government has published a regulation determining the annual tendering schedule up to 2027. Planned auctions are expected to result in the installation of 9 GW of utility-scale PV and 3 GW of onshore wind. The forecast includes commissioning of some of these projects by 2027.

For offshore wind, Poland awarded 6 GW of capacity in 2021 via contracts for difference, while the next auctions are planned for 2025. Poland has also requested around EUR 3.7 billion in grants and loans through the EU Recovery and Resilience Facility to support development of port infrastructure. The payments have been delayed, however, putting the timely commissioning of awarded projects at risk. Plus, restrictive-distance rules for turbines continue to slow the pace of onshore wind capacity additions, leading to a downward forecast revision for this technology.

In the accelerated-case forecast, Poland achieves 36% higher renewable capacity additions over 2022-2027 than in the main case, with onshore wind having the largest upside potential. While faster onshore wind expansion could be achieved through the prompt easing of turbine placement restrictions, offering higher volumes in planned auctions would lead to faster growth of both onshore wind and utility-scale PV. Extending tax rebates and subsidies for residential PV owners and small companies would accelerate deployment significantly, but greater investment in transmission and distribution grids will be necessary to enable faster wind and solar PV capacity growth. In addition, updating national strategic documents for long-term power sector development would provide greater visibility for renewable energy developers, encouraging investment.

## Asia Pacific

### Solar PV leads deployment thanks to competitive auctions, but better policy support could boost growth

Renewable capacity in the Asia Pacific region (excluding China) is expected to grow by 360 GW (+70%) over 2022-2027. Solar PV accounts for over two-thirds of deployment, followed by wind and hydropower. India leads expansion in the region with more than a 40% share in total growth, thanks to auctions for utility-scale PV and onshore wind capacity and better incentives for distributed PV.

In the ASEAN region, the introduction of competitive auctions in Indonesia and the Philippines (and plans for them in Viet Nam) accelerates renewable capacity growth. However, expansion remains limited by persistent challenges related to the lack of long-term policy support.

In Australia, new state-level auctions and high demand for corporate PPAs have led to significant upward revisions to this year's forecast. In contrast, renewable energy deployment in Japan is expected to slow after 2023 as the transition from a FIT to a FIP leads to fewer capacity awards, while permitting challenges in Korea cause development to stagnate despite prolongation of its attractive fixed-price scheme.

Overall, despite downward forecast revisions for the ASEAN (due to delays in policy implementation) as well as for Japan and Korea, positive developments in India and Australia cause the forecast for Asia Pacific to be 6% higher this year than last.

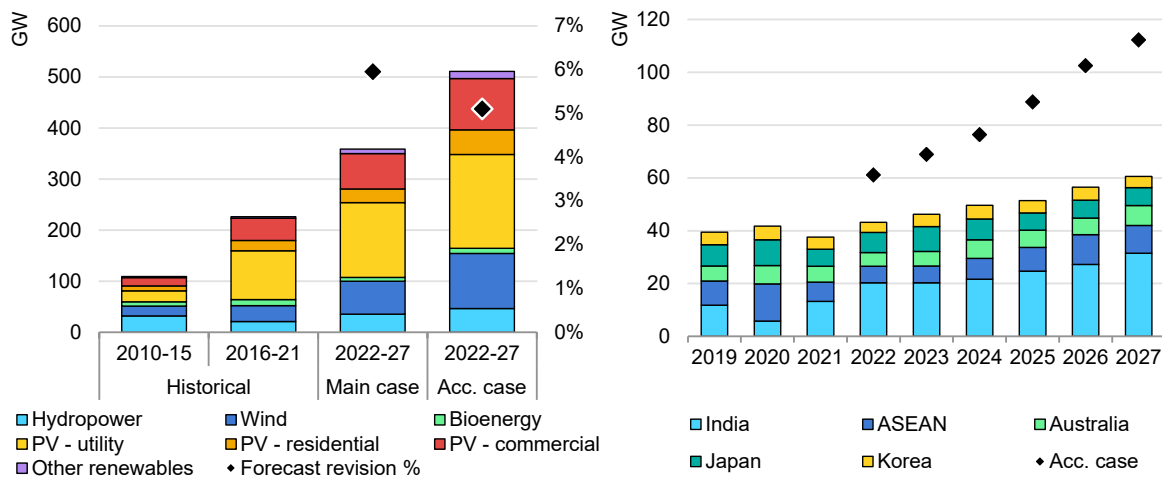
In the accelerated case, renewable capacity growth in the region over 2022-2027 is more than 40% higher than in the main case. Such strong upside potential results mostly from the enlargement of currently limited policy support in the



ASEAN, for example by speeding the implementation of planned competitive auctions in Viet Nam and Indonesia and introducing effective support policies in Thailand.

In addition, relaxing local-content and project ownership rules and improving the bankability of standard PPAs would encourage more international investment. Renewable power development in India could also be accelerated considerably if persistent challenges related to distribution companies' poor financial health and land procurement were solved. In Australia, more auctions, timely investment in grids and rapid development of green hydrogen projects would result in almost 50% faster deployment of renewables. Throughout the region, simplifying permitting, especially in the ASEAN region, Korea and Japan, and boosting investment in grid development will be necessary to accelerate deployment.

**Figure 1.25 Asia Pacific renewable capacity additions by technology, 2010-2027 (left) and annual capacity additions by country, 2019-2027 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. ASEAN = Association of Southeast Asian Nations. Asia Pacific excludes China.

## India

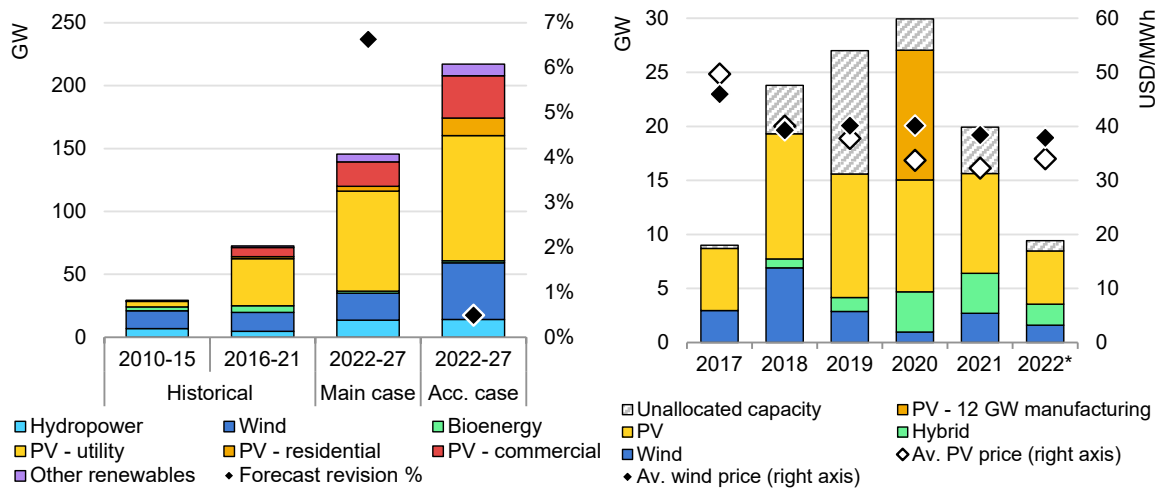
### Consistent policy support and ambitious long-term targets enable India to double its renewable capacity by 2027

With the addition of 145 GW, India is forecast to almost double its renewable power capacity over 2022-2027. Solar PV accounts for three-quarters of this growth, followed by onshore wind with 15% and hydropower providing almost all the rest. Renewable capacity deployment will be dominated by utility-scale plants

contracted through competitive auctions. However, distributed PV is expected to be increasingly important thanks to growing consumer awareness and continued policy support.

This year's forecast has been revised upwards 7% from last year's owing to higher-than-expected PV capacity additions in 2022, the announcement of several ambitious domestic PV manufacturing projects and a planned improvement of auction rules for wind farms. The overarching drivers of renewable energy growth are India's targets of 500 GW of non-fossil installed capacity by 2030 and net zero emissions by 2070, ensuring long-term visibility for renewable energy developers.

**Figure 1.26 India renewable capacity additions, 2010-2027 (left) and renewable capacity awarded in auctions, 2017-2022 (right)**



IEA. CC BY 4.0.

\* Data for January-September only.

Notes: Acc. case = accelerated case. Av. = average. "PV – 12 GW manufacturing" refers to the January 2020 auction linked to national solar PV manufacturing.

Sources: (right) BNEF (2022), 3Q 2022 Global Auction and Tender Results and Calendar; Bridge to India (2022), [India RE Navigator](#) (accessed October 2022).

India's auction volumes declined in 2022, but the participation rate rose thanks to policy improvements. From January to September 2022, India auctioned over 8 GW of renewable capacity, 30% below the average for these months in 2019-2021. This slowdown was caused by auction organisers focusing on finalising PPAs and developers prioritising the execution of projects already under construction.

Almost one-quarter of capacity awarded since 2021 has been contracted through hybrid auctions that require multiple renewable technologies to provide power at specified minimum annual capacity utilisation factors. These auctions usually result in the addition of significantly more capacity than what has been contracted, along with energy storage to ensure compliance with power availability

requirements. Hybrid auctions are thus expected to be an increasingly important growth driver as the penetration of wind and PV technologies in India's power system grows and grid integration challenges emerge.

The undersubscription rate fell to just 10% in 2022, with most auctions significantly oversubscribed. Reducing off-taker risks prompted greater auction participation as the number of auctions held by national rather than state agencies increased and the solar parks programme advanced, facilitating land procurement and grid connection.

On the demand side, higher renewable purchase obligations, which were announced in July 2022 and specify targets for wind, hydro and other renewable energy sources (solar, bioenergy), should further encourage power utilities (DISCOMs) to procure renewable energy. Increasing participation in auctions, an expanding project pipeline and higher renewable energy demand from DISCOMs are all expected to accelerate utility-scale capacity growth in India over 2022-2027.

However, the poor financial health of India's DISCOMs continues to prevent faster renewable capacity deployment. The number of overdue payments to renewable power producers continues to grow, worth almost USD 3 billion in June 2022 – an increase of nearly 60% since January 2021. According to the Ministry of Power's latest annual financial performance report, the share of energy supplied by the lowest-rated DISCOMs increased from 32% in FY 2019-2020 to 70% in FY 2020-2021.

While DISCOM payment delays negatively affect developers' profits and increase project risks, DISCOMs are also often reluctant to support rooftop PV deployment in their grids because they fear losing revenue from energy sales. Although they are obligated to fulfil their renewable purchase obligations and increase renewable energy procurement, they often lack the financial capacity to sign new PPAs with auction winners, resulting in project commissioning delays.

In June 2021, India's government approved another support scheme for DISCOMs, linked with achieving financial and operational improvements worth almost USD 40 billion. So far, about 65% of the planned amount has been earmarked for 38 qualified DISCOMs, but the actual effects of the programme remain to be seen, as previous such incentives (UDAY) did not improve the situation substantially.

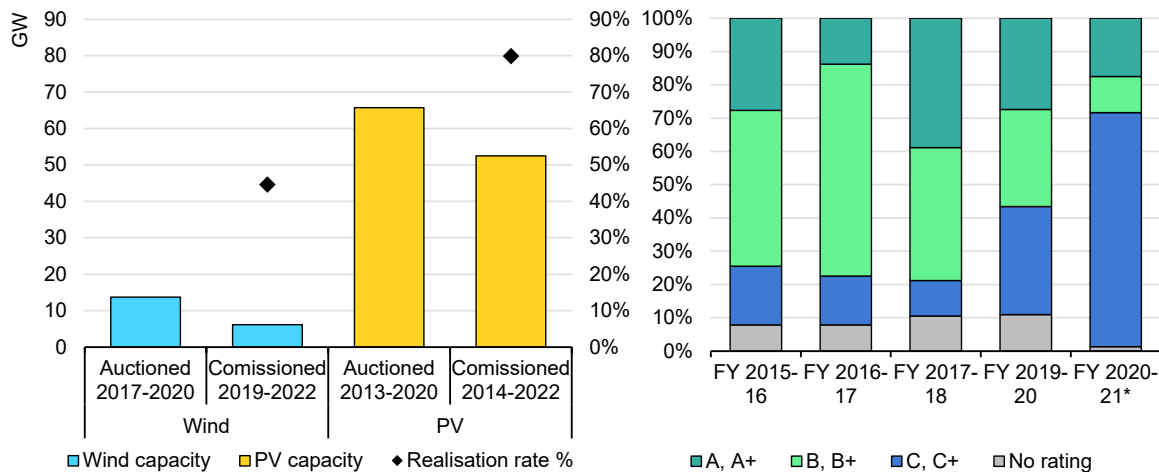
In 2022, the average tariff awarded in PV-only auctions increased by 10% in Indian rupee terms, and is now back at the 2019 level to compensate for higher PV equipment prices since 2021. Moreover, in April 2022 the duty on imports increased from 15% to 40% for PV modules and to 25% for solar cells. Developers prepared for this change by stocking up on PV equipment, leading to record

imports of roughly 10 GW in Q1 2022. This import rush is expected to result in an unprecedented 16 GW of PV capacity additions in 2022, 60% more than in 2021.

However, future projects benefitting from any type of policy support will have to source their supplies from government-approved manufacturers. As of August 2022, the list of authorised manufacturers encompasses about 18 GW of PV module manufacturing capacity, all domestic. Although this is enough to cover India’s demand in upcoming years, the modules offered are often based on outdated technology and are smaller than the top-tier products predominantly used by developers today. The low availability of domestic top-tier modules could raise investment costs and tariffs in the short term.

At the beginning of 2022, the government awarded support for the Production-Linked Incentive (PLI) scheme’s first 9 GW of integrated PV manufacturing capacity, and the second batch of projects is in the allocation process. This programme aims to expand India’s solar PV cell and module manufacturing capacity to over 70 GW in this decade, including 29 GW of manufacturing capacity fully integrated across the whole supply chain. Supply-demand synergy in the Indian PV market is also expected to stimulate capacity growth in the medium term.

**Figure 1.27 India awarded and commissioned renewable capacity, 2017-2022 (left) and DISCOM energy market shares by integrated rating, 2015-2021 (right)**



IEA. CC BY 4.0.

\* In the Tenth Annual Integrated Rating and Ranking of Power Distribution Utilities, the grading scale changed from A+, A, B+, B, C+, C to A+, A, B, B-, C, C-, D. For compatibility with previous reports, grades for FY 2020-21 are grouped as follows: D, C-, C as C, C+; B-, B as B, B+; A, A+ as A, A+.

Sources: (left) IEA analysis based on BNEF (2022), 3Q 2022 Global Auction and Tender Results and Calendar (accessed October 2022); Bridge to India (2022), India RE Navigator (accessed October 2022); (right) IEA analysis based on India, Power Finance Corporation Ltd (2017-2022), [Report on Performance of State Power Utilities](#), editions for FY 2016-17 to FY 2020-2021; India, Power Finance Corporation Ltd (2016-2022) [Annual Integrated Rating and Ranking of Power Distribution Utilities](#), fourth to tenth editions.

Onshore wind deployment in India has been slow in recent years as a result of land procurement and grid connection challenges as well as Covid-19-related supply chain disruptions. In addition, an unexpected increase in material and equipment costs since 2021 has rendered many projects economically unviable. In consequence, a large portion of capacity awarded in auctions has been delayed or cancelled: as of September 2022, only 45% of the 14 GW of wind projects awarded during 2017-2020 had been commissioned.

In July 2022, the Indian government announced it is suspending reverse bidding in wind auctions and is considering limiting the process to closed-envelope submissions. This could raise tariffs for wind energy, which should make projects more feasible. Although DISCOMs may be reluctant to accept higher energy prices, the new renewable purchase obligation for wind should encourage them to sign PPAs. In addition, expanding wind-based power generation has the potential to alleviate some of the grid integration issues faced by DISCOMs that have high shares of solar PV in their systems. These positive policy changes are the basis of our upward wind forecast revision this year.

Annual distributed PV additions doubled in 2021 with the commissioning of many projects delayed by Covid-19-related disruptions. Although expansion slowed in 2022, deployment is expected to accelerate steadily in upcoming years. Public awareness is growing, and the economic attractiveness of investing in distributed PV is becoming apparent for commercial and industrial consumers, especially in times of higher energy costs.

Still, several major obstacles are preventing India from achieving deployment commensurate with its huge potential. While DISCOMs are hesitant to support rooftop PV growth because they fear revenue loss from reduced energy sales and higher grid costs, financing options for small commercial and residential consumers remain limited.

Over one-third of rooftop PV systems added in 2022 were installed in the state of Gujarat, which is home to just 5% of India's population. High deployment in this state was achieved through net billing and subsidies, which exist in most Indian states. This indicates that effective on-the-ground implementation of policies is crucial to achieve faster distributed PV growth in India.

In the accelerated case, India achieves 50% higher renewable capacity deployment over 2022-2027 than in the main case, putting the country firmly on course to meet its 2030 targets. Raising the capability of DISCOMs to procure more renewable energy will be crucial to achieve faster growth.

To this end, improving the financial performance of DISCOMs and increasing penalties for non-compliance with renewable purchase obligations should limit delays in signing PPAs with auction winners, making developers and investors

more willing to undertake new utility-scale projects. In addition, offering DISCOMs financial and regulatory incentives to increase rooftop PV deployment in their grids should encourage them to attract tens of millions of potential prosumers by facilitating investment, thereby tripling main-case distributed PV deployment for 2022-2027.

Achieving faster solar PV growth will also require the timely deployment of manufacturing projects included in the PLI scheme and expansion of competitive auctions. For wind, the rapid implementation of simplified auction rules, more government support in site identification and land procurement, and greater policy support for repowering could double the main case's capacity growth.

## Japan

### Solar PV remains the main source of renewable energy growth, but smooth transition to a feed-in premium is crucial to accelerate expansion

Renewable capacity in Japan is expected to increase 44 GW (+30%) over 2022-2027 in the main case, led by solar PV and wind. The forecast has been revised down slightly (-2%) from last year, mainly because the commissioning of projects previously approved under the FIT scheme has been slower than expected. Uncertainty about capacity awarded under the newly introduced FIP also affects the forecast. Regardless of the challenges, however, the pace of growth expected over 2022-2027 indicates that the country is on track to reach its 2030 renewable generation targets (36-38% of electricity generation) introduced in 2021.

Annual solar PV capacity growth is forecast to be slower over the forecast period than in the previous five years, with projects approved under the FIT scheme ([16 GW as of June 2022](#)) remaining the primary source of expansion. Japan's goal in transitioning from FITs to FIPs is to improve the market integration of renewables and spur utility-scale PV growth. Meanwhile, policy improvements to identify preferential areas, including public buildings and agricultural land, and to promote corporate PPAs, are expected to foster distributed solar PV development.

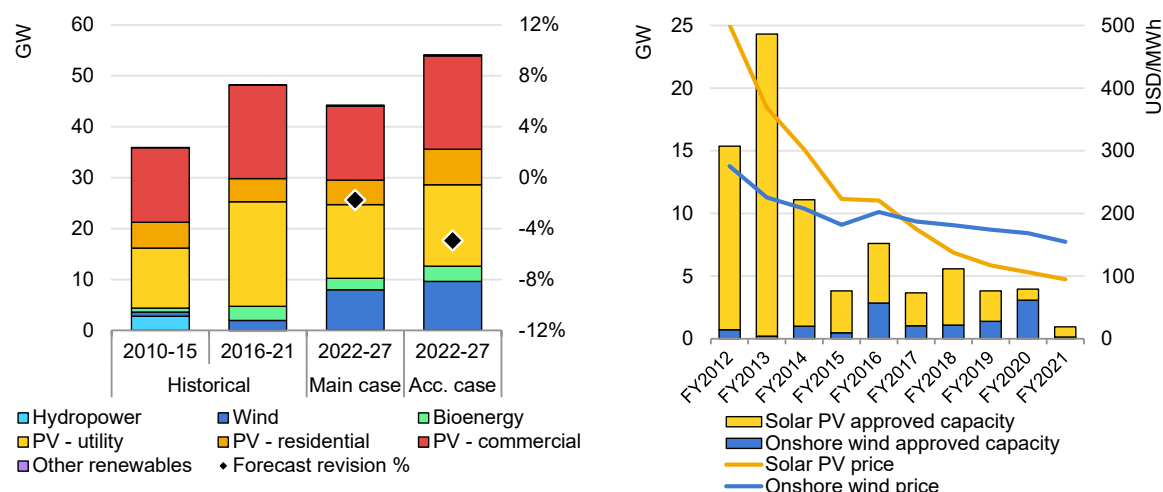
While these policy measures are making the outlook for new projects more optimistic, fewer FIT approvals (an 70% decline for non-residential PV in the past five years) due to lower land availability for large-scale solar PV projects negatively affects the forecast.

Japan's wind forecast remains mostly unchanged from last year, with grid connection and environmental permitting difficulties remaining key impediments to faster wind energy uptake. Capacity additions come mainly from projects previously approved under the FIT scheme ([11 GW as of June 2022](#) – double the 2019 level).

In 2021, the government raised the environmental impact assessment threshold for onshore wind from 10 MW to 50 MW. This policy change could lead to faster commissioning of projects already in the onshore wind pipeline, as half of the FIT-approved projects are below 50 MW.

Meanwhile, offshore wind expansion accelerates during 2022-2027 with over 0.5 GW of capacity commissioned. The Japanese government's policy changes for offshore wind include a FIT, sea area designation and improved community engagement. However, while these policies will promote growth, they will not affect the present forecast because their impact will be pertinent only after 2027, according to current project development timelines. This year's forecast also assumes that some projects will be commissioned before the government-set benchmark dates, thanks to the new auction rule incentivising early commissioning.

**Figure 1.28 Japan renewable capacity additions, 2010-2027 (left) and FIT-approved capacity and prices for solar PV and onshore wind, 2012-2021 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. FY = financial year (April-March). In the right graph, solar PV capacity and price refer to PV systems of more than 10 kW. Solar PV prices between FY 2017 and FY 2021 are the average auction price.

Sources: (right) IEA analysis based on Japan, METI (Ministry of Economy, Trade and Industry) (2022), [78th Procurement Price Calculation Committee](#); METI (2022), [FIT portal site](#) (accessed November 2022).

In the accelerated case, Japan's renewable capacity growth is 22% higher than in the main case. For solar PV, realising the upside potential depends on further approval of projects under the FIT scheme. In addition, smooth transition to the FIP for utility-scale PV projects and the wider use of PPAs could accelerate growth. For onshore wind, greater permitting and grid connection efficiency as well as higher completion of approved FIT projects could enable faster expansion.

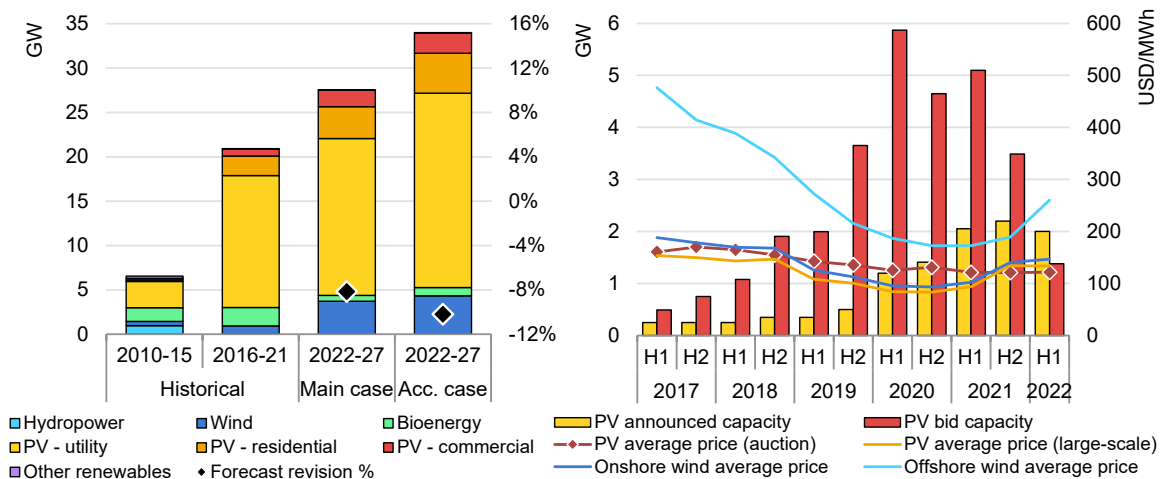
## Korea

### While permitting complications slow PV expansion, new policies ensuring revenue stability for wind improve the forecast

Korea's renewable capacity is expected to double in the main case, expanding by 28 GW over 2022-2027, with solar PV accounting for almost 85% of all expansion. However, this forecast has been revised down slightly (-8%) from last year's because permitting challenges have led to 80% lower bidding capacity for fixed-price PV contracts over the last two years. In addition, the scheme was undersubscribed for the first time since its introduction in 2017 because the government lowered the auction ceiling price even though costs had risen.

Korea's cumulative wind capacity is expected to more than triple by 2027. Although PV expectations are lower, the forecast for wind developments is more optimistic than last year. While higher renewable energy certificate (REC) prices and strong wholesale prices remain key drivers of growth, the new policy introducing 20-year fixed-price contracts (from the second half of 2022) for onshore and offshore wind projects will especially improve their revenue certainty compared with the REC scheme, leading to more optimistic outlook.

**Figure 1.29 Korea renewable capacity additions, 2010-2027 (left) and fixed-price solar PV capacity and average revenue per MWh by technology, 2017-2022 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. In the right graph, average revenues (excluding PV auction) are calculated using the system marginal price (SMP) and weighted REC price. Offshore wind assumes projects with a total interconnection distance of more than 15 km. PV auction prices reflect biannual average awarded prices.

Sources (right): IEA analysis based on Korean New and Renewable Energy Centre (2022), [Results of bidding for solar PV fixed-price contracts](#); KPX (Korean Power Exchange) (2022), [Monthly SMP](#); KPX (2022), [REC spot market trade volumes and prices](#).



In the accelerated case, Korea's renewable market growth could be 23% higher than in our main case. This would result mainly from greater auction volumes if the government adjusts the ceiling price upwards to account for higher costs. Plus, corporate PPA market expansion under the Korean government's K-RE100 initiative could accelerate the development of renewable energy projects of more than 300 kW of capacity. Permitting, social acceptance and land availability obstacles, which remain key impediments to both solar PV and wind expansion, need to be addressed to enable faster commissioning.

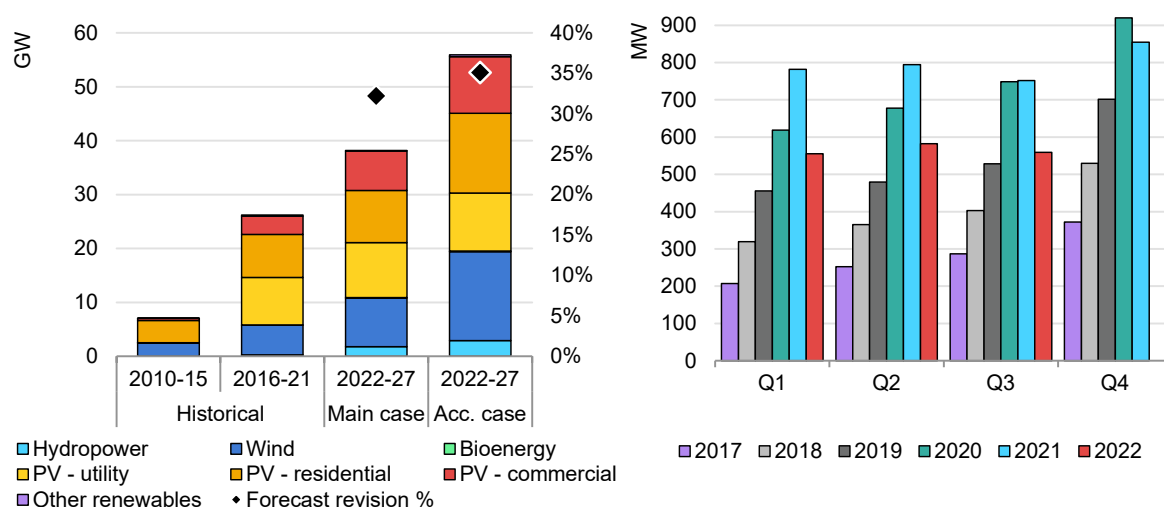
## Australia

### While grid fees and system costs impair distributed solar PV growth, state-level targets and PPAs propel expansion of utility-scale renewables

With nearly 40 GW of new additions expected, Australia's renewable power capacity is forecast to increase more than 85% from 2022 to 2027 thanks to state-level auctions, incentives for distributed solar PV and corporate PPAs. This year's forecast has been revised over 30% upwards from last year's to reflect the announcement of new auctions, continued corporate power purchase activity to meet private sector decarbonisation goals, and new projects associated with renewable energy zones (REZs).

With the federal large-scale renewable energy target (LRET) having been achieved in 2019, states have set additional renewable energy targets. The current government's Climate Bill 2022 pledges to reduce carbon emissions 43% by 2030 from 2005 levels and achieve net zero emissions by 2050. This new law is expected to create an additional impetus for renewable energy growth.

**Figure 1.30 Australia renewable capacity additions, 2010-2027 (left) and quarterly distributed PV capacity additions, 2017-2022 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case.

Source: (right) IEA analysis based on Australia, Clean Energy Regulator (2022), [Postcode data for small-scale installations](#).

Of all renewable technologies, distributed PV deployment expands the most, but annual market growth is expected to slow as new charges for exported power are proposed and higher system prices reduce its economic attractiveness. In Q4 2021, for instance, the quarterly installation pace slowed for the first time since 2015, a trend that has persisted into 2022.

Since 2017, distributed solar PV uptake has grown by over 1 GW annually thanks to net metering, solar FITs and low investment costs. However, the upsurge in self-consumption and power exports resulting from all this new capacity has put pressure on the distribution grid. New market rules were therefore introduced allowing distributors to charge for exporting electricity to the grid.

**Table 1.1 Renewable energy targets by Australian state**

State	Target type	Year	Target
New South Wales	New renewable generation	2030	24 600 GWh
<a href="#">Queensland</a>	Percentage renewable generation	2032	70%
<a href="#">Queensland</a>	Percentage renewable generation	2035	80%
<a href="#">South Australia</a>	Percentage renewable generation	2030	100%
Tasmania	Total renewable generation	2030	15 750 GWh

State	Target type	Year	Target
Tasmania	Total renewable generation	2040	21 000 GWh
Victoria	Percentage renewable generation	2025	40%
Victoria	Percentage renewable generation	2030	50%
<a href="#">Western Australia</a>	Emissions reduction	2030	80%

Note: Targets are from [AEMO Inputs and Assumptions](#), unless otherwise noted.

Utility-scale solar PV and onshore wind growth have both been revised upwards over 35% from last year owing to state-level auctions for new capacity, projects associated with emerging REZs and a growing number of corporate PPAs with governments, utilities and businesses. [Non-price factors](#), such as corporate sustainability goals and emissions or renewable energy targets, are the primary stimulants of corporate PPA market growth.

Meanwhile, rising LRET generation certificate prices resulting from [demand increases](#) provide additional revenue for developers. However, higher amounts of variable renewable energy generation have led to [system integration concerns](#). Connection delays and [curtailment](#) remain key forecast challenges.

The accelerated case forecasts nearly 25% higher additions than the main case, with upside potential enabled by more state-level auctions and faster-than-expected commissioning of REZs. Furthermore, additional coal-fired plant retirements could allow for the deployment of new large-scale renewable energy installations paired with battery storage. For distributed PV, the continuation of high wholesale and retail prices could encourage greater investment. In addition, renewable additions from captive wind and solar PV capacity associated with hydrogen from renewable energy could add over 6 GW of additional capacity over the forecast period.

## ASEAN

### New auction schemes will accelerate deployment in upcoming years, but policy uncertainty remains a challenge

Renewable capacity in the ASEAN region is expected to increase by 51 GW during 2022-2027 (+56%). Solar PV will account for over half of the growth, followed by onshore wind and hydropower. ASEAN is also expected to be a leading region in geothermal power deployment worldwide, responsible for close to one-third of global additions up to 2027. Solar PV leads renewable capacity growth, and the speed of deployment is expected accelerate over the forecast period owing to

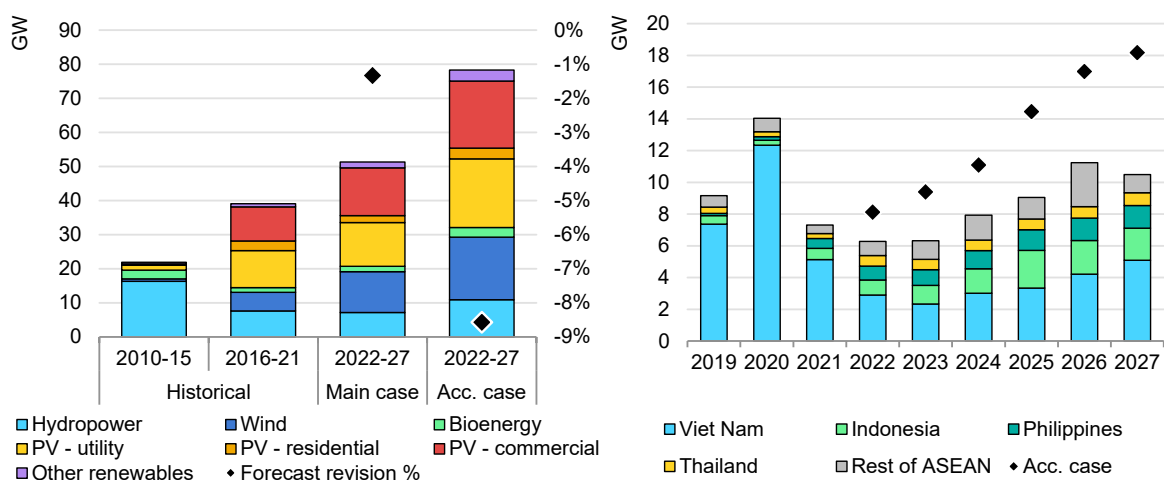
policy improvements, notably new auction and procurement schemes in the Philippines and Indonesia.

Viet Nam leads expansion as its commercial distributed PV deployment accelerates and its planned auction system hastens wind uptake. Renewable capacity expansion, led by PV, will also accelerate in other ASEAN countries over 2022-2027, driven by policy improvements such as the Philippines' and Indonesia's new competitive auction schemes. In addition, a few large-scale hydropower projects are expected to come online in Malaysia and Indonesia. Although the main-case forecast is largely unchanged from last year, the accelerated case has been revised 9% downwards due to delays in implementing new policies in Viet Nam, Indonesia and Thailand.

Although the ASEAN region has the potential for much stronger renewable energy growth, policy uncertainty is the main challenge. In almost all countries in the region, delays in introducing support policies are discouraging investment, while lengthy and complicated permitting procedures are hindering faster project development. Gaps in policy support have led to boom-bust cycles in Viet Nam and Thailand.

Furthermore, low project bankability due to limited risk protection in standard PPAs is curbing the interest of international investors, and strict local-content and project ownership rules further inhibit foreign investment and raise the cost of renewable energy. Under the accelerated case, all these challenges are resolved with focused policies, leading to significantly higher deployment.

**Figure 1.31 ASEAN renewable capacity additions, 2010-2027 (left) and annual capacity additions by country, 2019-2027 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. "Rest of ASEAN" comprises Brunei, Cambodia, Lao PDR, Malaysia, Myanmar and Singapore.

**Viet Nam** is expected to lead ASEAN renewable capacity expansion over the forecast period. While generous subsidies led to deployment booms in utility-scale solar PV projects in 2019, in distributed solar PV in 2020 and in wind in 2021, a significant slowdown in annual additions is expected in 2022-2023 with the phasedown of incentives.

Further deployment of both wind and PV will depend on how quickly Viet Nam's new Power Development Plan (PDP8) and planned auction scheme are implemented. It is expected that auctions will focus on wind, with 20 GW of additions targeted in the draft PDP8 and just 4 GW of utility-scale PV. Rapid capacity growth is forecast for the commercial PV segment, owing to economically attractive self-consumption and new policies facilitating bilateral PPA contracts.

In **Indonesia**, renewable capacity deployment in 2022-2027 is expected to quadruple from the 2016-2021 level. Solar PV accounts for almost half of this growth, followed by hydropower. We also expect the country to add over 1.5 GW of geothermal capacity by 2027, the second-highest addition globally.

A presidential decree of September 2022 introduced competitive auctions, which will be the main impetus for utility-scale PV and onshore wind deployment in the second half of the forecast period. The decree is an important step towards faster renewable energy uptake in Indonesia, but a lack of detailed regulations leads to forecast uncertainty. In addition, several large-scale hydropower projects are to be commissioned by 2027, based on bilateral PPAs with the state-owned utility (PLN).

**The Philippines** is set to add more than 7 GW of renewable capacity over 2022-2027 (almost four times as much as during 2016-2021), mainly in solar PV and wind. In June 2022, the Philippines awarded 2 GW of renewable capacity through its Green Energy Auction Program, and in July 2022 it introduced the National Renewable Energy Program 2020-2040, targeting 35% renewable energy in electricity generation by 2030 and 50% by 2040. The government also plans to double the geothermal share in installed capacity from the current 12% to 24% by 2040.

Competitive auctions are expected to be the main tool used to achieve all these targets. Furthermore, the Philippines' government is considering allowing more foreign ownership of renewable energy assets to encourage international investment, which is assumed to hasten capacity deployment in the main case.

In **Thailand**, commercial PV installations producing power for self-consumption are expected to drive capacity growth over 2022-2027 as policy support for renewable energy technologies remains limited. Although a new power development plan is under consideration, it is unclear which targets and measures for renewable capacity will be included. Auctions and net metering continue to

support growth in utility-scale and commercial PV in **Malaysia**, while the private PPA market will continue to propel rooftop and floating PV uptake in **Singapore**.

In the accelerated case, renewable capacity deployment in ASEAN during 2022-2027 is over 50% higher than in the main case. Solar PV and wind offer the greatest upside potential because their generation costs are the lowest of all renewable technologies and are rapidly becoming more competitive with coal-fired generation. Faster implementation of new auction schemes in Viet Nam and ambitious auction schedules in Indonesia and the Philippines could drive much faster deployment of these technologies.

Increased investment in grid infrastructure, especially in Viet Nam, is also needed to achieve faster solar PV expansion. Simplifying permitting procedures, easing local-content requirements and implementing standardised bankable PPAs should propel international investment. Additionally, reducing delays in updating energy strategy documents with more ambitious renewable capacity targets in Viet Nam, Thailand and Indonesia could provide long-term policy certainty and further boost deployment.

## Latin America

Renewable power capacity in Latin America is expected to increase 45% (+130 GW) during 2022-2027 in the main case. Growth shifts from hydropower to solar PV (+78 GW) and wind (+36 GW), which together make up almost 90% of the region's expansion. Brazil accounts for over 55% of regional growth, though a slowdown in distributed solar PV is expected due to a change in net-metering compensation, leading to a sharp decline in the region's annual additions.

Lower government-led auction volumes in Brazil, Chile, Mexico and Argentina are offset by greater numbers of bilateral power purchase contracts, which increasingly drive expansion. However, in addition to declining auction volumes and participation, the lack of long-term policy certainty remains a key challenge in markets such as Argentina and Mexico, hampering growth in the long term.

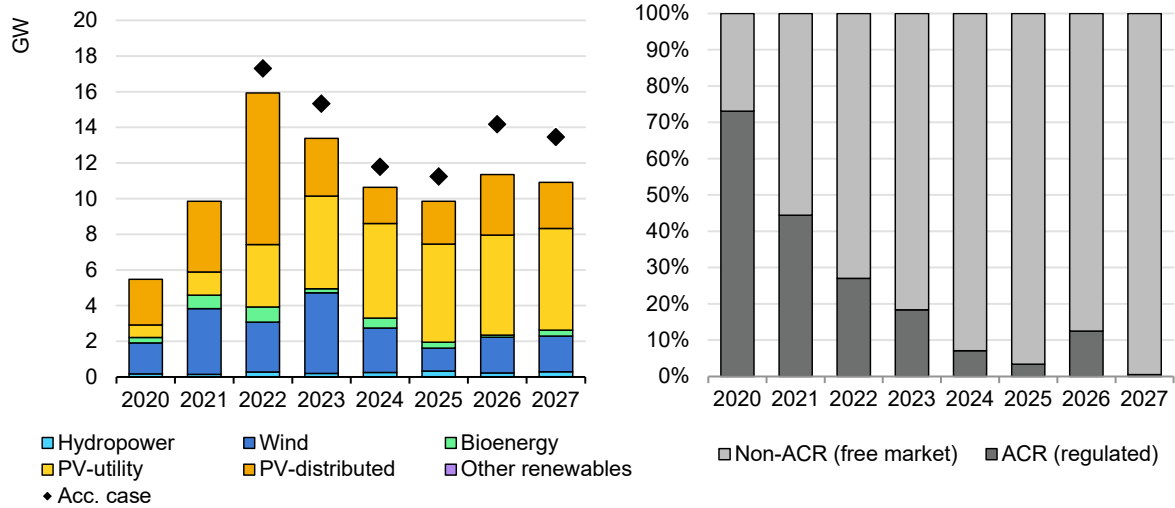
## Brazil

### Deployment outside of the government's auction scheme and net metering prompts over a 60% upward revision to the forecast

Brazil is expected add over 70 GW of new renewable capacity through 2027, with solar PV and wind making up the majority. This year's forecast has been revised

upwards by over 60% to reflect continued utility-scale project growth through the free market, auction deadlines for onshore wind power and a deadline for distributed PV benefits.

**Figure 1.32 Brazil renewable capacity additions, 2020-2027 (left) and utility-scale solar PV and onshore wind capacity by market registration (right)**



IEA. CC BY 4.0.

Note: Values for 2022-2027 are based on projects registered with ANEEL and may not reflect final values.

Source: IEA analysis based on ANEEL (2022), [ANEEL database](#) (accessed November 2022).

For utility-scale solar PV and onshore wind, free-market demand is the main growth driver, supplemented by previously awarded auction capacity. Demand for free-market capacity comes partially from bilateral contracts with retail and industrial customers to help meet corporate decarbonisation goals. In addition, the forecast expects a rush of installations in 2023 before the grid use tariff exemption ends in March 2024.

New distributed PV capacity of more than 20 GW is forecast, with over 8 GW forecast to come online this year (systems installed before January 2023 are eligible for the current generous net-metering scheme, which has provoked an installation rush). New installations will receive less compensation for surplus energy, reducing their economic attractiveness and resulting in lower annual capacity additions over 2024-2027. Still, average market growth of over 2.5 GW per year is expected in the remainder of the forecast period as the business case remains attractive despite lower remuneration.

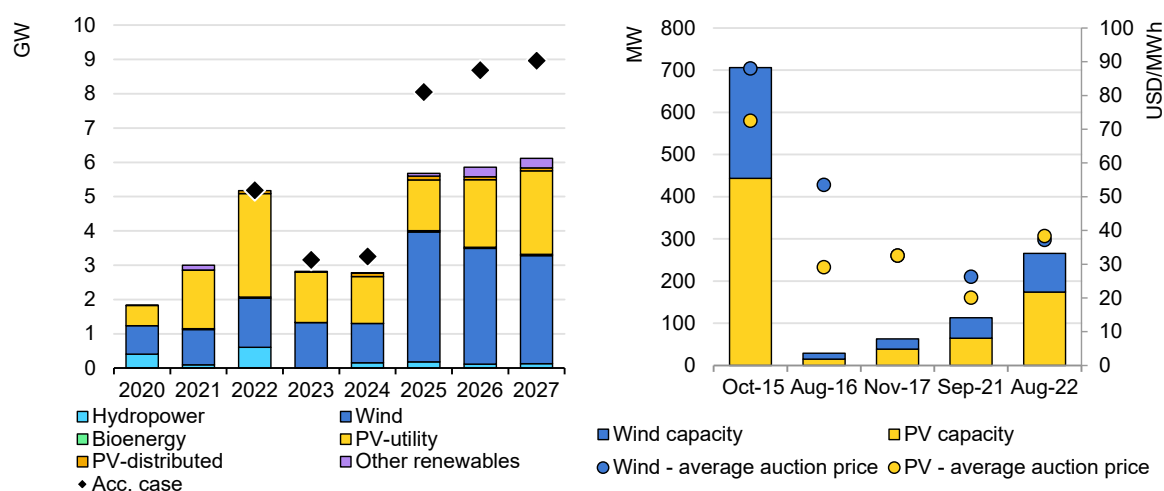
The accelerated case forecasts 16% higher growth, which can be achieved with additional free-market contracts, a slower-than-expected demand drop for distributed PV and higher-than-anticipated auction volumes due to higher consumer demand.

## Chile

### Ambitious renewables-based hydrogen production accelerates wind expansion

Renewable energy capacity in Chile is forecast to more than double by 2027, reaching 45 GW. Onshore wind leads growth, with half of new capacity intended to supply electricity for green hydrogen and ammonia production. Indeed, Chile's ambitious plans to expand renewables-based hydrogen production, combined with solar PV additions in its deregulated market, incite a 46% upward revision from last year's forecast.

**Figure 1.33 Chile renewable capacity additions, 2020-2027 (left) and capacity and prices awarded in Chilean energy auctions (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Source: (right) CNE (Comisión Nacional de Energía de Chile).

Auctions have historically driven utility-scale renewable capacity expansion in Chile. However, the country awarded only 15% of offered energy during its latest auction in August 2022. Despite higher investment costs for onshore wind and solar PV due to elevated commodity prices, auction reference prices remained unchanged. Thus, three-quarters of the bids submitted were not accepted because they exceeded the reference price of USD 42/MWh. While the forecast therefore expects less renewable capacity to come online from auctions, expansion in the deregulated market is accelerating owing to higher prices.

In 2020, Chile announced ambitious plans to ramp up renewables-based hydrogen production, and in December 2021 the Chilean National Development Agency (Corfo) issued a call to finance and leverage green hydrogen projects, awarding a total of USD 50 million to six green hydrogen initiatives. These projects



are expected to be operational in 2025 and will use 100% renewable energy supplied by PV and wind plants (some currently operational, and some planned), as well as employing PPAs. Renewable energy projects dedicated to hydrogen production represent 27% of the main-case forecast, which takes into account the 10-GW H<sub>2</sub> Magallanes project.

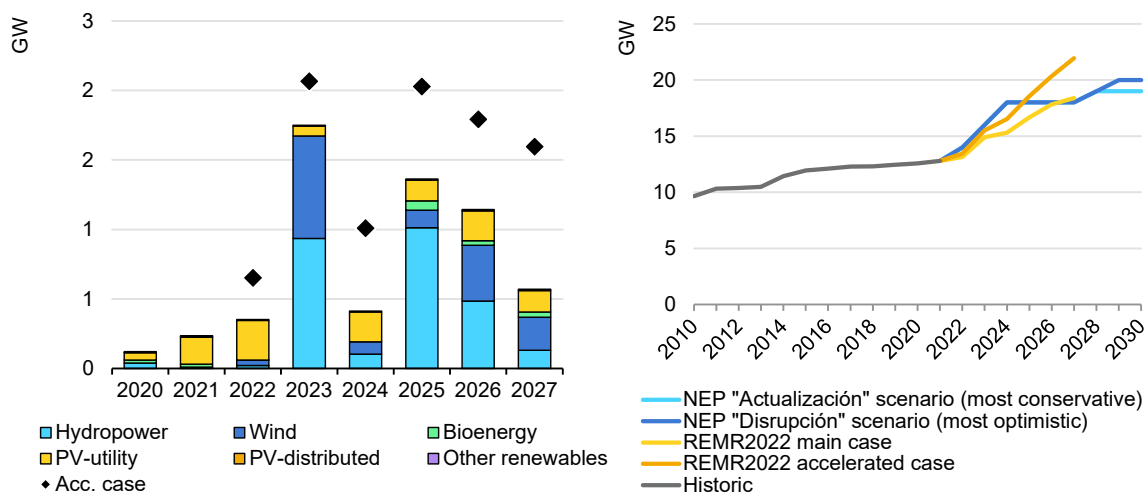
The accelerated case estimates 31% higher installed capacity over the forecast period compared with the main case, led by wind and solar. It assumes additional capacity from potential auctions in upcoming years as well as higher growth from projects participating in the deregulated market. The accelerated case also includes faster expansion of transmission and distribution infrastructure, as bottlenecks have been restricting renewable energy expansion, especially in the north.

## Colombia

### Realising high renewable energy ambitions depends on the timely construction of transmission infrastructure

Colombia's renewable capacity is forecast to expand by more than 5 GW (+44%) during 2022-2027. Hydropower, utility-scale solar PV and onshore wind make up nearly all this expansion. While the largest share of total renewable capacity is currently hydropower, auctions to help meet national targets will enlarge the wind and utility-scale solar PV share to 17% by 2027.

**Figure 1.34 Colombia renewable capacity additions, 2020-2027 (left) and installed renewable capacity in REMR2022 forecast vs Colombia's National Energy Plan (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. NEP = National Energy Plan. REMR2022 = Renewable energy market report 2022 (i.e. *Renewables 2022*).

Source: (right) UPME (Unidad de Planeación Minero-Energética) (2020), Plan Energético Nacional 2020-2050.

The 2.4-GW Ituango hydropower plant is the main source of hydropower additions, as commissioning is to begin in 2023 and it is expected to be fully operational by 2026. Meanwhile, past auctions enable the commissioning of over 1.1 GW of capacity for each solar PV and onshore wind during the forecast period. The country's Long-Term Auction Programme has awarded more than 2 GW of wind and solar capacity combined, with additional auctions planned for 2023. However, slow transmission infrastructure development is impacting the pace of expansion and permitting delays due to community acceptance concerns have resulted in project deferrals of up to three years.

Offshore wind additions of 550 MW in the forecast period come from two projects currently undergoing feasibility studies. In addition, Colombia launched its Offshore Wind Roadmap in May 2022, outlining the potential for 50 GW of new capacity. The government will open tendering in 2023 to help realise this capacity, though awarded projects will not be commissioned within the forecast period.

Renewable capacity growth could be almost 60% higher in the accelerated case with additional renewable capacity auctions and the realisation of more announced projects. In addition, this case assumes that current transmission infrastructure issues will be resolved quickly, enabling faster wind and solar capacity uptake. Finally, Colombia aims to begin producing green hydrogen in 2030 (with 1-3 GW of electrolysis capacity installed), spurring additional development by the end of the forecast period.

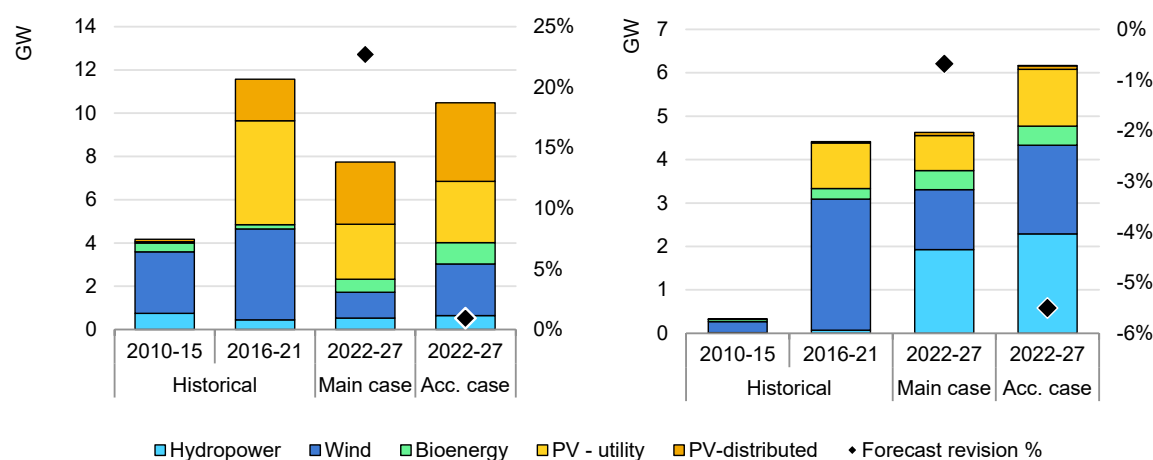
## Mexico and Argentina

### Distributed solar PV leads renewable capacity expansion in Mexico

Mexico's renewable energy capacity is set to expand nearly 8 GW during 2022-2027 in the main-case forecast. At COP 27, Mexico announced its intention to deploy 30 GW of combined wind, solar PV, geothermal and hydropower by 2030. The forecast has been revised upwards by more than 20% to reflect higher distributed solar PV uptake resulting from net-metering and net-billing benefits. Distributed projects of less than 500 kW do not require a generation permit or need to be registered as market participants, enabling faster project deployment.

Outside of government-led efforts for utility-scale expansion, lack of policy certainty remains the main reason for declining additions throughout the forecast period. Growth in utility-scale solar PV capacity (+2.5 GW) and wind (+1.2 GW) is enabled by projects awarded previously through green certificate auctions, corporate PPAs and bilateral agreements.

**Figure 1.35 Mexico renewable capacity additions, 2010-2027 (left) and Argentina renewable capacity additions, 2010-2027 (right)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

### While large hydro projects under construction drive expansion in Argentina, policy uncertainty and growing macroeconomic challenges prompt a downward revision to the wind and PV forecast

Argentina’s renewable capacity is set to increase by almost 5 GW over the forecast period, led by hydropower and followed by onshore wind. Full or partial commissioning of large-scale hydropower projects, including Jorge Cepernic, Presidente Nestor Kirchner and Brazo Aña Cuá, provides almost half of Argentina’s renewable electricity expansion.

Historically, the long-term auction scheme [RenovAr](#) was the primary driver of record wind and solar contracts of more than 4 GW. However, persistent economic challenges and suspension of the fourth round of the RenovAr programme have delayed many projects. As of September 2022, only half of the programme’s projects had been commissioned.

Meanwhile, the government’s fund for the development of renewable energies ([FODER](#)) continues to support project financing at preferential interest rates. The country is also promoting distributed renewable energy generation through real-time self-consumption models. Considering Argentina’s macroeconomic challenges and the absence of long-term renewable energy targets, our forecast expects that only some of the delayed projects will be commissioned by 2027.

In the accelerated case, growth could be over 30% higher if the country addresses challenges of transmission network availability, provides affordable financing, encourages private investment and resumes supply auctions.

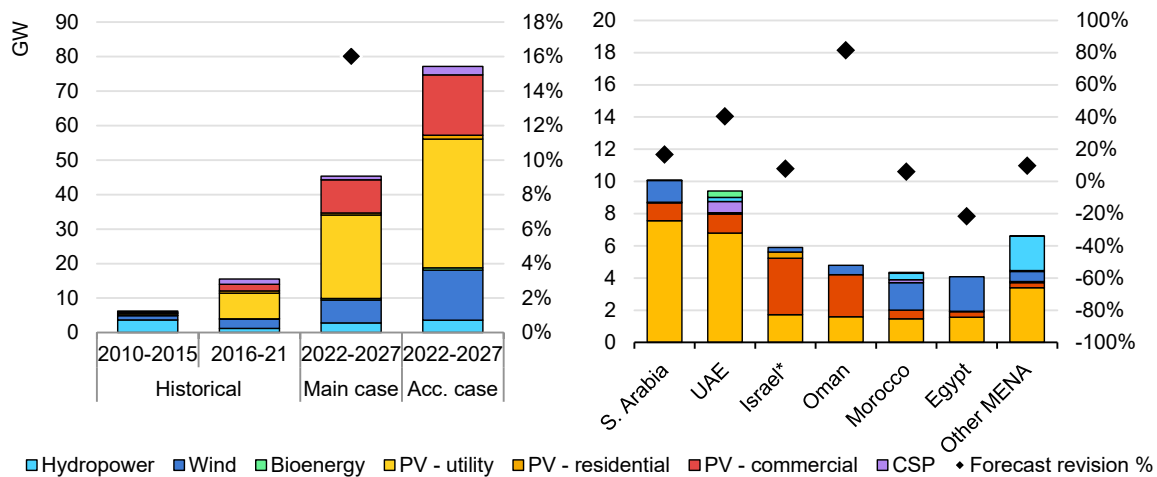
# Middle East and North Africa

## Solar PV dominates expansion because it offers prospects for low-cost power and hydrogen production

Renewable electricity capacity expansion in the MENA is expected to triple in 2022-2027 compared with the previous five-year period, reaching 45 GW. Solar PV makes up three-quarters of capacity growth in the MENA region because of its expansion due to attractive economics for utility-scale projects. Significant solar resource potential and favourable financing conditions in some MENA countries have led to some of the world’s lowest awarded bid prices (i.e. USD 10.4/MWh in 2021 in Saudi Arabia) contracted in competitive IPP auctions.

Onshore wind development, mostly in Morocco and Egypt, accounts for 15% of the region’s growth, while hydropower expansion is concentrated in Iran. The main catalysts for renewable capacity expansion are fast-growing power demand, long-term climate targets, and diversification away from fossil fuels for net-importing countries. Hydrogen and ammonia production are also beginning to drive interest in new renewable power projects.

**Figure 1.36 Middle East and North Africa renewable capacity additions, 2010-2027 (left) and renewable additions by technology and country, 2022-2027 (right)**



IEA. CC BY 4.0.

\*Statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Notes: Acc. case = accelerated case. CSP = concentrating solar power. S. Arabia = Saudi Arabia. UAE = United Arab Emirates. MENA = Middle East and North Africa.

Six markets account for 85% of MENA’s renewable capacity growth between 2022 and 2027: Saudi Arabia, the United Arab Emirates, Israel, Oman, Morocco and

Egypt. Competitive IPP auctions are the key policy mechanism propelling renewable capacity growth in most markets. While this year's forecast has been revised upwards (+16%) because new solar PV auctions have been opened in both the United Arab Emirates and Saudi Arabia, long lead times and uncertainty over the tendering process for onshore wind and CSP are emerging as key challenges to faster growth in the region.

For onshore wind, no new tenders have been announced in Egypt, capacity was cancelled in Round 3 in Saudi Arabia, the announcing of shortlisted bidders in Jordan's Round-3 auction has been delayed and some awarded projects in Morocco have not started construction. For CSP, [Egypt cancelled a 100-MW tender](#), while in Morocco the [winning projects for a tender opened in 2019 have yet to be announced](#), and the commissioning of projects in the United Arab Emirates is taking longer than expected.

In the absence of auctions for onshore wind, developers have been turning to other procurement mechanisms such as selling directly to large consumers when regulations allow (through corporate PPAs) or directly approaching the state utility (unsolicited bilateral contracts).

**Saudi Arabia** is expected to add 10 GW of renewable capacity during 2022-2027, led by solar PV and driven by four procurement mechanisms: competitive auctions, unsolicited bilateral utility contracts, corporate PPAs and state-owned projects. The forecast has been revised upwards from last year to reflect progress made under all four business models.

For competitive auctions, PPAs were signed for one-half of Round 3 projects, and Round 4 opened in September 2022 with higher-than-expected volumes on offer. The country's first corporate PPA project was commissioned in 2021 after the new Private Sector Participation Law came into effect allowing developers to sell directly to consumers for the first time. In our main case, this regulatory change facilitates the growth of future corporate PPA projects.

Furthermore, in the past year the government has announced plans to develop another 2.3 GW through bilateral contracts under the Public Investment Fund and build state-owned projects in industrial cities. Nonetheless, the pace of auctions for onshore wind remains a forecast uncertainty. Round-1 projects took four years to commission and the capacity earmarked for wind in Round 3 was never awarded.

**The United Arab Emirates** is expected to add 9.5 GW of renewable capacity between 2022 and 2027 – quadrupling its current installations. Solar PV leads growth, as competitive auctions for large volumes of utility-scale projects are making it increasingly economically attractive. Bid prices fell from USD 56/MWh for 260 MW in the first tender (held in 2015 in Dubai) to USD 13.5/MWh for 2 GW

in 2020 in Abu Dhabi because solar resources are abundant, economies of scale have been achieved, and financing and land-leasing rates are favourable.

The distributed PV forecast has been revised upwards owing to two consecutive years of over-100-MW growth from Dubai's net-metering programme and an expanding pipeline of large industrial and commercial projects. However, long lead times challenge the forecast for CSP. Projects awarded in the first CSP auction in 2016 were only commissioned in 2022.

**Oman's** renewable electricity capacity is expected to increase 4.8 GW in 2022-2027, with solar PV installations making up most of the expansion. Over half (2.8 GW) of total renewable capacity additions will be dedicated to renewable hydrogen production. Oman's excellent solar and wind resources, its established hydrogen industry and its strategic location along shipping routes encourage renewable hydrogen production and ammonia exports. As result, a pipeline of planned projects situated at ports has emerged, although many are in the early stages of development.

Nonetheless, the main case expects renewable capacity of some of these projects to be at least partially commissioned by 2027 owing to policy support unveiled in the government's new National Hydrogen Strategy. Long-term renewable hydrogen production targets, a dedicated institution to manage state involvement in hydrogen projects, and competitive auctions for leasing earmarked land are expected to facilitate development. The government estimates 16-20 GW of additional renewable capacity is needed by 2030 to achieve the new renewable hydrogen production target of 1-1.25 Mt/year. However, securing financing and off-takers are key forecast uncertainties.

Outside of capacity dedicated especially for renewable hydrogen production, the majority of growth is expected to come from competitive IPP auctions. The state utility [plans to auction and commission 1.9 GW of renewable capacity by 2026](#), but the forecast carries uncertainty because it is not known how quickly the tendering rounds will be conducted. The first 1 GW has been on tender since 2019 but winners have yet to be awarded, and wind auctions depend on the outcome of feasibility studies.

Nonetheless, growth is now also possible outside of auctions. In January 2022, the state utility launched the region's first wholesale electricity spot market, wherein [generators can offer power for sale one day ahead to the sole purchaser, Oman Power and Water Procurement Company SAOC \(OPWP\)](#). Two main challenges to faster renewable capacity expansion in Oman are the high cost of capital and insufficient electricity storage in times of high supply and low demand.

**Israel's**<sup>10</sup> renewable capacity is anticipated to expand by 6 GW, with distributed solar PV growth driven by the country's considerable solar resources, high retail electricity prices and a supportive policy environment. Israel leads the MENA region in installed distributed PV capacity thanks to favourable net-metering and FITs for residential and commercial systems. Competitive auctions are the main driver for utility-scale solar PV growth, but land constraints remain a challenge.

For **Morocco**, 4.4 GW of renewable capacity growth is forecast for 2022-2027, led by solar PV, wind and hydropower. The main impetus for new capacity additions is the government's established competitive IPP auction programme. Corporate PPAs also boost onshore wind development, and solar PV expansion comes from state-owned projects and installations to produce renewable hydrogen.

This year's onshore wind forecast is more optimistic than last year's because Morocco intends to expand existing projects and has announced new corporate PPA projects. However, we are revising the CSP forecast downwards to reflect increasing uncertainty over the government's plans for solar thermal. The last tender was opened in in 2019 but the project has still not been awarded.

Meanwhile, the slow pace of regulatory reform remains an obstacle to distributed PV development. While the new draft law released last year (No. 82-21) makes progress in defining self-producers and introducing procedures for connecting to distribution grids, it may also make the business case for self-consumption less attractive because it proposes to cap excess generation fed into the grid at 10% and introduce a self-consumption surcharge.

**Egypt's** renewable capacity is expected to grow by 4.1 GW between 2022 and 2027, led by onshore wind and followed by solar PV. For utility-scale projects, most of the expansion will be settled through unsolicited bilateral IPP contracts negotiated with the state utility, as deployment under other schemes has slowed or even stalled completely.

Uncertainty over the government's plans for state-owned utility projects and delays in the competitive auction scheme have caused this year's forecast to be revised downwards. Only 26 MW out of 1 GW of planned state-owned projects have been commissioned since they were announced in 2017. Despite plans to organise more competitive IPP auctions, the government has not held competitive tendering since 2013 for solar PV and 2015 for wind.

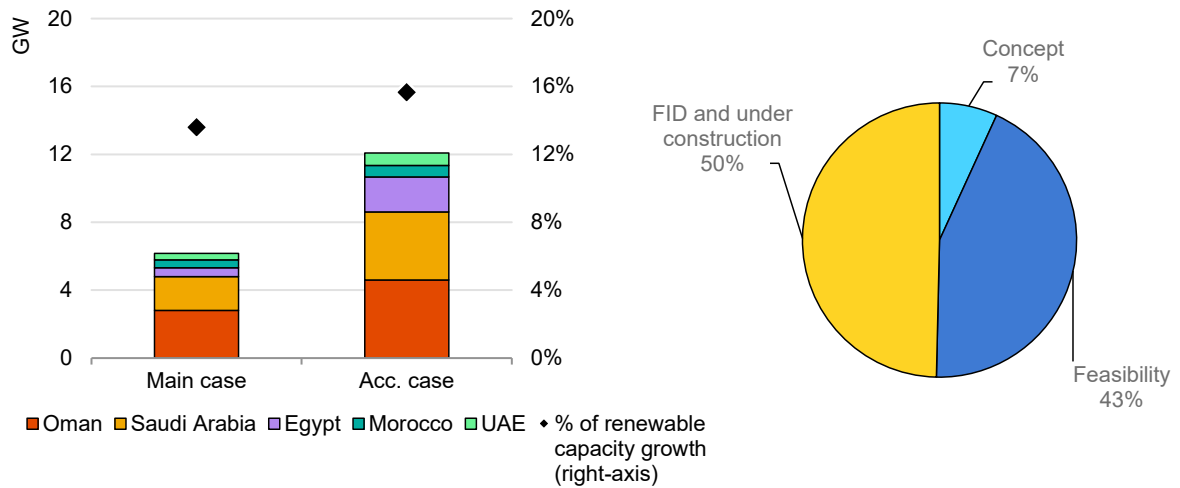
Overcapacity and financing challenges hamper renewable energy development overall. For the 2020-2021 financial year, [peak load reached 32 GW compared](#)

---

<sup>10</sup> Statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

with 59 GW installed, and most projects rely on concessional financing. Nonetheless, the net-metering scheme should continue to encourage distributed PV growth, especially large utility-scale projects for onsite self-consumption in agriculture and the cement industry, and for commercial centres.

**Figure 1.37 Middle East and North Africa renewable capacity additions dedicated to hydrogen production, 2010-2027 (left) and project status for electrolyzers using dedicated renewables with commissioning planned by 2027 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. UAE = United Arab Emirates. FID = final investment decision. Concept = generally refers to projects that are announced. Feasibility = projects where feasibility studies are underway to assess the viability of project.

Source: (right) IEA (2022), [Hydrogen Projects Database](#).

In the main case, we expect 14% (6 GW) of MENA's renewable capacity growth to come from plants dedicated to hydrogen production. Almost 80% of this growth is in Oman and Saudi Arabia, as both countries aspire to become exporters of renewables-based ammonia. Other uses of additional renewable electricity capacity include producing ammonia for shipping fuel and renewable hydrogen for local industries such as petrochemical production and steelmaking.

Almost 75% of dedicated capacity is expected to be solar PV because of its economic attractiveness, which is one of the main motivations for hydrogen development in the region. Since 2015, solar PV-awarded bid prices have fallen from USD 56/MWh in Dubai to USD 10.4/MWh in 2021 in Saudi Arabia owing to the abundance of solar resources, investment cost reductions and beneficial financing conditions.

The forecast is conservative compared with the current pipeline of electrolyser projects announced to be built by 2027. Owing to the region's large amount of available space, its ideal location along international shipping routes and its existing hydrogen use and infrastructure, MENA has announced 4.5 GW of



electrolyser projects powered by dedicated renewable electricity. However, only half of electrolyser capacity has reached final investment decision or started construction.

While our main case does assume some projects in the feasibility stage will be financed thanks to state-backed support, securing financing and off-takers are the main challenges to bringing projects to fruition. In the accelerated case, renewable capacity for hydrogen production could be twice as high (16% of total renewable capacity) if financial close were reached for some of the planned projects.

Furthermore, the accelerated case demonstrates that MENA's total renewable capacity growth could be almost twice as high (77 GW) if auctions proceeded more quickly, PPAs were signed in a timelier manner, and construction was begun on awarded projects. Clarity over regulatory reforms allowing distributed solar PV production and consumption, cost-reflective end-user electricity prices and remuneration of excess generation would also accelerate commercial and residential PV deployment.

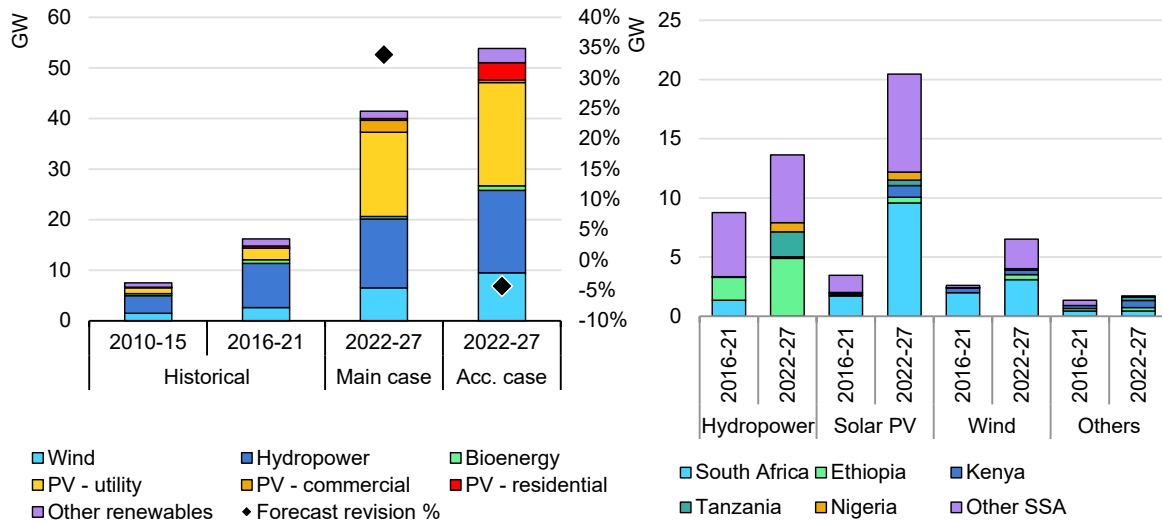
## Sub-Saharan Africa

### Financial guarantees facilitate utility-scale growth while new government programmes boost distributed solar PV

Sub-Saharan Africa's renewable power capacity is expected to almost double with the addition of over 40 GW from 2022 to 2027. Five countries – South Africa, Ethiopia, Tanzania, Angola and Kenya – account for over 60% of all renewable capacity additions. Solar PV and wind make up the majority of capacity growth in the region, marking a technology shift as hydropower accounted for nearly 55% of additions from 2016 to 2021. However, hydropower still continues to expand, enlarging electricity access cost-effectively in many countries.

We have revised our forecast upwards 25% to take account of new and additional wind and PV auction capacity and additional projects reaching financial closure in some markets. Electricity purchase guarantees from state-owned utilities or international development organisations, and concessional financing by international, regional or country-level development banks, facilitate capacity growth in the region.

**Figure 1.38 Sub-Saharan Africa renewable capacity additions, 2010-2027 (left) and renewable additions by technology and country, 2016-2027 (right)**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. SSA = sub-Saharan Africa.

**South Africa's** renewable energy capacity is forecast to expand more than 13 GW from 2022 to 2027. Government-led auctions enable development of over 7 GW of new utility-scale solar PV and more than 3 GW of onshore wind. Additional drivers outside of auctions for utility-scale uptake include municipalities [contracting renewable power](#) from IPPs to reduce the impact of loadshedding. In addition, Eskom is repurposing retiring coal plants as hubs for renewable capacity.

Meanwhile, two policies aid distributed solar PV deployment: the first is the government's increase to the [licensing capacity threshold](#) for small-scale (embedded generation) power stations up to 100 MW, enabling development of larger installations, especially by mining companies. The second is a [proposed feed-in tariff](#) for commercial and residential PV systems. While the details of the FIT have yet to be confirmed, heightened loadshedding and a proposed electricity [price increase](#) are expected to accelerate distributed PV deployment throughout the forecast period as consumers increasingly view self-consumption as a means to maintain power and avoid high bills. Market challenges include delays in the signing of PPAs for awarded auction projects and low grid availability, as both hinder the timely development of new capacity.

**Ethiopia's** renewable capacity will expand more than 125% (+6 GW) from 2022 to 2027. With commissioning of the Grand Ethiopian Renaissance Dam, hydropower provides over 80% of additions. At the same time, the solar PV and wind forecast has been revised downwards 25% due to [project cancellations](#). Government agreements with private firms will lead to utility-scale solar PV additions later in the forecast period, supported by concessional financing, but a

lack of additional tenders and ongoing social and political issues are barriers to further development.

**Kenya's** renewable capacity expands nearly 90% (+2 GW) from 2022 to 2027. PPAs signed under the country's previous FIT policy drive over 1 GW of wind and utility-scale solar PV expansion. Meanwhile, growth in the residential PV segment is spurred by a recently announced [net-metering programme](#) for up to 100 MW of total capacity, although customer fees may hinder uptake. Additionally, the expansion of existing geothermal resources and new developments provide over 500 MW of new capacity. Nevertheless, land-rights issues, interconnection delays, stop-and-go policy and PPA renegotiations lead to [project delays and cancellations](#), lowering investor confidence.

**Nigeria** is forecast to add over 1 GW of renewable capacity from 2022 to 2027, half from hydropower. PPAs enable utility-scale solar PV development, and private capital and development bank financing support the country's prioritisation of solar PV [mini-grids](#) for universities, hospitals and rural electrification. Distributed solar PV deployment increases as consumers install solar PV systems to supplement or replace fossil fuel-fired backup generators to offset rising diesel costs. The lack of enabling policy for large-scale renewables, along with [power outages](#) caused by ageing infrastructure, hinders more extensive development.

Hydropower will make up 70% of **Tanzania's** 3 GW of additions through 2027, while agreements with the national utility (TANESCO) enable nearly 500 MW of new utility-scale solar and wind development. Although low installed capacity and limited transmission and distribution infrastructure challenge additional growth, proposed projects will be built near existing transmission infrastructure, helping ease grid access and increasing utility-scale solar PV capacity during the forecast period. A combination of [grants](#) and government programmes drive off-grid solar PV growth, bringing power to homes and critical infrastructure. Nevertheless, a lack of policies supporting the country's target of 6 GW of renewable energy by 2025 prevents higher growth.

As sub-Saharan Africa has some of the world's highest renewable resource potential, the accelerated case forecasts nearly 30% greater additions, led by solar PV, onshore wind and hydropower. Achieving higher deployment will require firm auction and tendering schedules with the timely signing of PPAs for awarded projects. Plus, additional partnerships between IPPs and governments or development banks for credit enhancement mechanisms to address project financing and off-taker risk could increase investor confidence. Finally, grid upgrades could help facilitate project interconnection and integration, which can sometimes take as long as one year.

# Chapter 2. Transport Biofuels

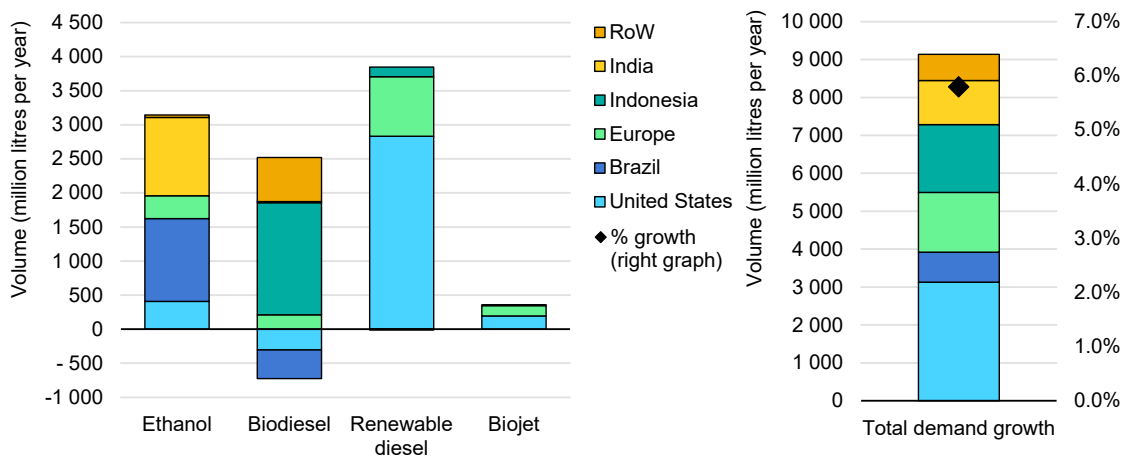
## Forecast summary

### Biofuel use expands in 2022 despite rising costs

Global biofuel demand is expected to be 6% or 9 100 million litres per year (MLPY) higher in 2022 than in 2021. Renewable diesel makes up the largest share of this year-on-year expansion, thanks to attractive policies in the United States and Europe. Blending requirements and financial incentives support demand growth in India and Brazil, and Indonesia’s 30% biodiesel blending requirement also boosts biodiesel use in that country.

Nevertheless, we have revised year-on-year growth downwards 25% from our 2021 forecast, with price and market developments in Brazil, Finland and Sweden responsible for 80% of this downward revision. While high biodiesel prices led the Brazilian government to reduce its biodiesel blending requirements for 2021/22, in Finland high fuel prices prompted the government to temporarily lower its renewable distribution obligation for 2022/23. Sweden [froze 2023](#) greenhouse gas targets for transport fuels at 2022 levels. However, 2030 targets remain unchanged.

**Figure 2.1 Biofuel demand growth by fuel and region, 2021-2022**



IEA. CC BY 4.0.

Note: RoW = Rest of world.

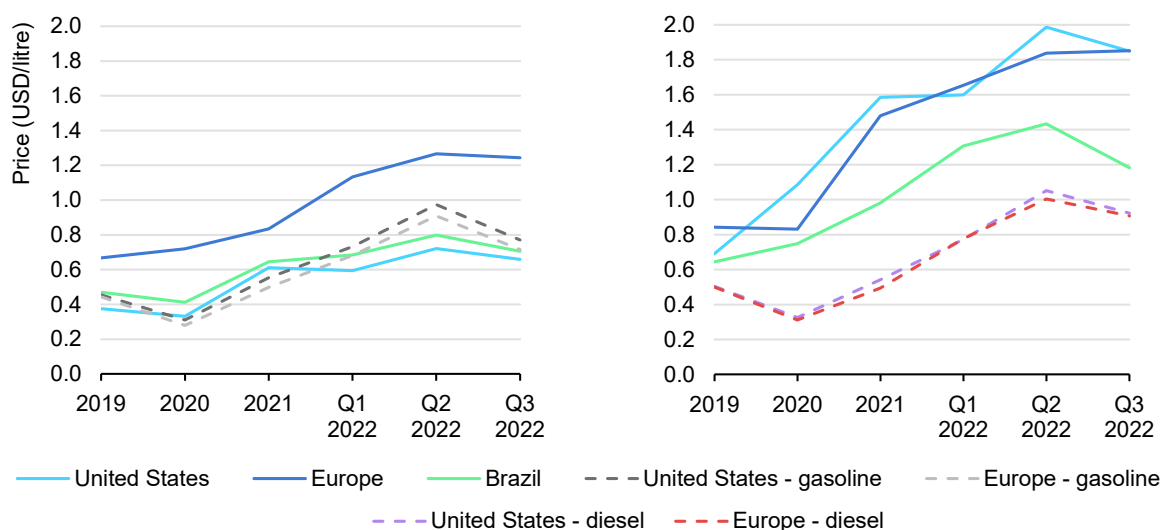
Renewable diesel demand expanded 3 800 MLPY or 40% over 2021-2022. The United States accounted for most of this growth, with state-level low-carbon fuel

standards, the federal Renewable Fuel Standard and the biodiesel production and blending tax credit driving consumption. Domestic production thus expanded 2 800 MLPY to help meet rising demand. In Europe, existing policies in Germany, Spain and France helped boost renewable diesel uptake.

Ethanol demand rose 3 100 MLPY or 3% during 2021-2022, with India accounting for more than one-third of this growth. In 2022, India continued to provide guaranteed pricing for ethanol in pursuit of its 20% ethanol blending target. Meanwhile, consumer ethanol purchases supported a 4% demand increase in Brazil, where the large flex-fuel vehicle fleet allows consumers to choose ethanol over gasoline when prices are advantageous. To date in 2022, the consumer price for ethanol has been 30% lower than for gasoline on average.

Indonesia accounts for almost all the 1 800 MLPY of new biodiesel demand. Its 30% blending target for biodiesel in 2022 and an overall 4% increase in diesel demand have been driving growth.

**Figure 2.2 Ethanol and gasoline prices (left), and biodiesel and diesel prices (right), 2019-2022**



IEA. CC BY 4.0.

Sources: IEA analysis based on Argus America Biofuels and Argus Biofuels (accessed September 2022); IHS Markits, Food and Agricultural Commodities (accessed September 2022); and Bloomberg New Energy Finance (accessed September 2022). Prices are before taxes and averaged annually and quarterly.

Nonetheless, while stronger policies are encouraging demand growth, high prices are slowing its pace. We have therefore reduced this year’s demand forecast by 3 100 MLPY compared with last year’s. In the first half of 2022, diesel prices more than doubled, raising consumer prices and putting pressure on governments to reduce costs. At the same time, biodiesel prices went up in the United States, Europe and Brazil, making it increasingly more expensive than regular diesel.

Biodiesel price increases resulted from vegetable oil export losses from Ukraine, weather-related supply disruptions, high energy prices, high fertiliser costs and export restrictions that pushed agricultural commodity prices to record highs in 2022. In response, Brazil, Finland and Sweden reduced their blending mandates. This evolution accounts for a 2 600 MLPY downward revision to our forecast.

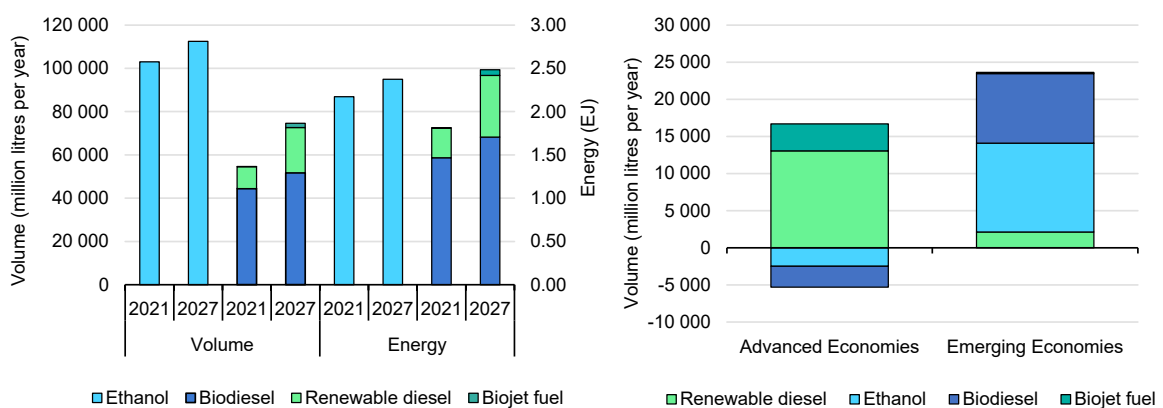
Finland plans to reinstate ascending blending requirements in 2023 and Sweden in 2024. Brazil has not announced when it will re-establish higher biodiesel blending. It had initially targeted 14% blending in 2022.

## Robust growth over the next five years will help meet climate and energy security goals

Total global biofuel demand expands by 35 000 MLPY or 20% over 2022-2027 in the main-case forecast. Growth in renewable diesel and biojet fuel consumption is almost entirely in advanced economies. Here, policies designed to reduce GHG emissions are driving demand because these fuels can be produced with low GHG emissions, blended at high levels and made from wastes and residues. In fact, nearly 70% of renewable diesel and biojet fuel came from wastes and residues in 2021.

Meanwhile, rising ethanol and biodiesel use occurs almost entirely in emerging economies aiming to reduce oil imports while also maximising the use of indigenous resources to benefit the local economy. Plus, biofuel use helps reduce GHG emissions in these countries.

**Figure 2.3 Global biofuel demand (left) and growth for advanced and emerging economies (right), main case, 2021-2027**



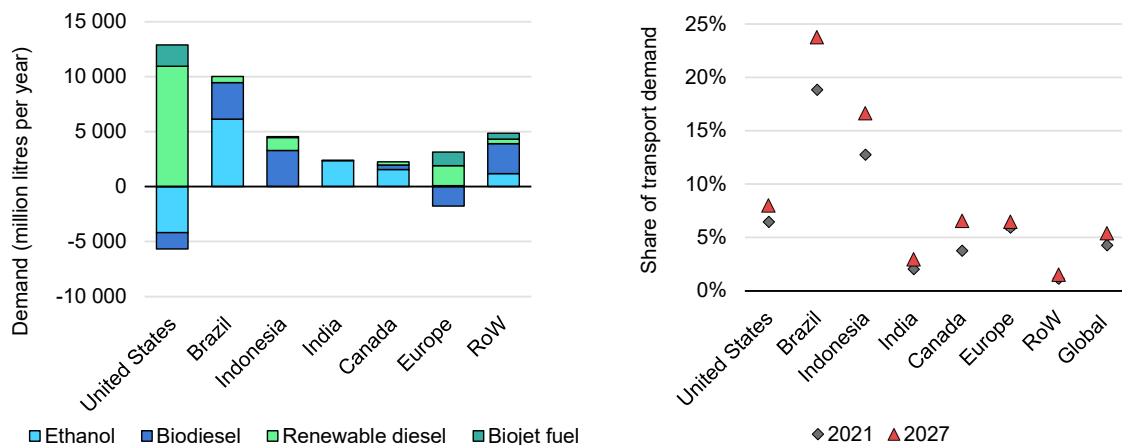
IEA. CC BY 4.0.

Notes: “Advanced economies” covers all OECD member nations plus Bulgaria, Croatia, Cyprus, Malta and Romania. “Emerging economies” encompasses all other countries and regions.

While demand for ethanol is higher than for biodiesel, renewable diesel and biojet on a volume basis, total energy demand met by ethanol is similar in 2021 because the energy content of the three other biofuels, are 60% higher than that of ethanol. By 2027, biodiesel, renewable diesel and biojet fuel demand is expected to reach 2.5 EJ, ahead of 2.4 EJ for ethanol.

The United States, Canada, Brazil, Indonesia and India make up 80% of global expansion in biofuel use, as all five countries have comprehensive policy packages that support growth. In Brazil, Indonesia and India, rising gasoline and diesel use also accelerates demand for biofuels, while in the United States and Canada declining gasoline and diesel demand slow biofuel growth and even reduce the use of some fuels. In Europe, falling transport fuel demand nearly stalls volume growth even though state-level policies are increasingly stringent. Globally, the biofuel share in transport fuel consumption climbs from 4.3% to 5.4% during 2022-2027.

**Figure 2.4 Forecast growth by country (left) and biofuel share of transport demand (right), main case, 2021-2027**



IEA. CC BY 4.0.

Notes: RoW = Rest of world. Renewable diesel, biodiesel and ethanol shares of gasoline and diesel are on an energy basis. Gasoline and diesel demand figures taken from the IEA Oil Information database.

Biofuel demand across Brazil, Indonesia and India expands by 19 000 MLPY over 2022-2027, as all three countries intend to raise blending requirements during this period. In Brazil, we also expect the RenovaBio programme to help reduce the price of ethanol relative to gasoline, prompting greater consumer use. Furthermore, overall gasoline and diesel demand is also expanding in all three countries, accelerating biofuel consumption growth.

The United States and Canada have introduced new national policies to support 9 500 MLPY of new biofuel demand in 2022-2027. In the United States, the

[Inflation Reduction Act](#) includes an [estimated USD 9.4 billion](#) in tax credits and financial support for new production capacity and biofuel infrastructure generally. The tax credits have no financial cap, and we expect these incentives to boost biojet and renewable diesel fuel use over the forecast period. For ethanol, however, an expected 8% decline in gasoline demand over 2022-2027 and static blending levels will cause its use to drop by 4 200 million litres. Overall, the biofuel share in transport energy demand climbs from 6% to 8%.

Canada published its [Clean Fuel Regulations](#) in July 2022, requiring suppliers of liquid road transport fuel to progressively reduce their fuel carbon intensity by 14 g CO<sub>2</sub>-eq/MJ by 2030. We expect greater biofuel use will be required for the regulations to be met. Thus, the total share of biofuels in transport energy demand increases from near 4% to 7% over the forecast period.

Meanwhile, biofuel demand in Europe expands 1 400 MLPY or 5% during 2022-2027, driven by the increasing stringency of existing country-level policies. For instance, blending requirements in France, Finland, Italy, the United Kingdom and Spain – as well as GHG emissions reduction targets in Germany – propel most of the expansion. However, as gasoline and diesel sales decline across Europe, less biofuel will be needed to meet blending mandates and GHG emissions reduction requirements. Still, the biofuel share in transport energy demand expands from 5.9% to 6.5% over the forecast period. This main-case forecast does not include the Fit for 55 programme or the European Commission's REPowerEU proposal.

## Biojet fuel to make up 1-2% of jet fuel globally by 2027

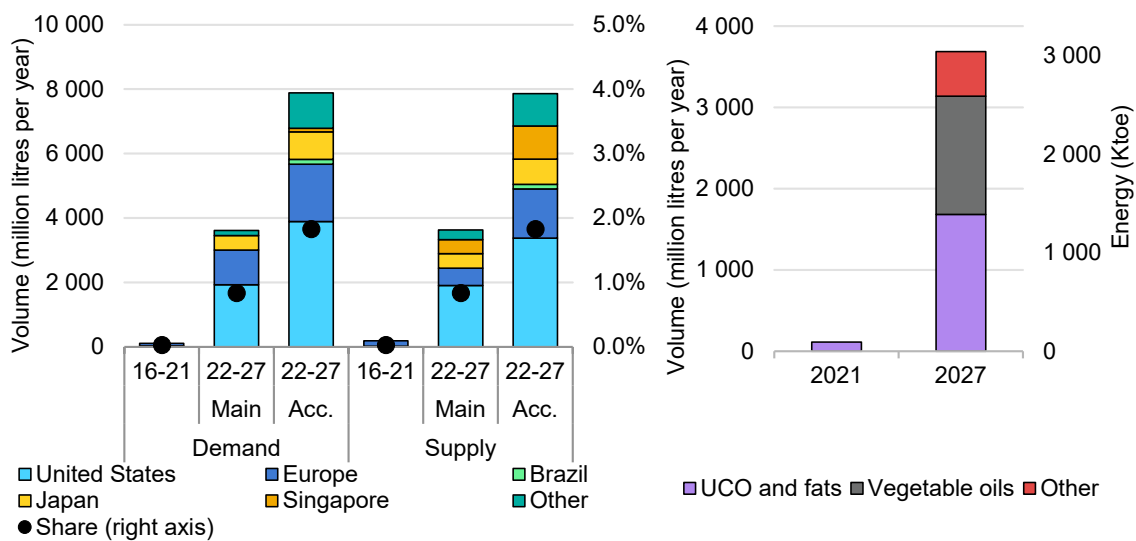
Biojet fuel demand expands to 3 900 MLPY in our main-case forecast – 37 times the 2021 level – to account for nearly 1% of total jet fuel consumption. Recent US and EU policies prompt most of this growth. In the United States, tax credits included in the IRA and measures in the [Sustainable Aviation Fuel Grand Challenge Roadmap](#) boost consumption, while in Europe we expect the [ReFuelEU target](#) of 2% by 2025 to come into force during the forecast period.

Planned capacity additions in Europe and the United States meet most of this increased demand, with additional supplies coming primarily from Singapore. Biojet fuel production depends primarily on the availability of waste and residue oils and fats (52%) and vegetable oils (36%). Ethanol, woody residues and wastes provide the remainder. In Europe, the European Commission is likely to limit the amount of eligible feedstocks available to produce sustainable aviation fuel (SAF), while vegetable oils such as soybean oil will support SAF manufacturing in the United States. In our accelerated case, demand swells to 8 100 MLPY (2% of global jet fuel use) if existing policies as well as those under discussion drive faster growth.



Biojet fuel demand in the United States expands to 2 000 MLPY over 2022-2027, bringing blending levels to 2% for domestic jet fuel in the main case. This forecast includes plans to provide [USD 3.3 billion](#) during 2023-2031 for SAF support, as outlined in the IRA. SAFs include a range of non-fossil fuels such as biojet and non-fossil synthetic fuels made from hydrogen and CO<sub>2</sub>. The majority of this funding (an estimated USD 3 billion) supports a dedicated SAF tax credit that transitions into a clean fuel tax credit, which SAFs are also eligible for.

**Figure 2.5 Global biojet fuel demand and supply growth, 2022-2027**



IEA. CC BY 4.0.

Notes: Acc. = accelerated case. UCO = used cooking oil. "Energy" is the energy value of the fuels made from different feedstocks.

The dedicated SAF credit provides up to USD 1.75 per gallon of fuel produced and sold in the United States in 2023 and 2024, depending on the GHG emissions intensity of the fuel. From 2025 to 2027, SAFs will be eligible for a clean fuel credit of up to 1.75 per gallon – a 75% premium relative to other fuels – if they fall below the maximum GHG emissions intensity. Plus, a further USD 0.3 billion is available to fund new projects and infrastructure, such as blending and storage facilities. The US Sustainable Aviation Grand Challenge Roadmap aims to remove barriers to SAF deployment by co-ordinating government actions, supporting the collection of agricultural, waste and residue feedstocks, promoting production innovation, and strengthening supply chains.

In Europe, biojet fuel demand grows to 1 300 MLPY by 2027 to meet existing SAF blending targets in [France](#) and [Norway](#), planned targets in the [United Kingdom](#) (planned for 2025) and a GHG emissions intensity reduction target in [Sweden](#) (see Policy and Assumption table below). However, the majority of growth depends on the European Union implementing its ReFuelEU targets of 2% SAF use by 2025

and 5% by 2030 (the proposal disallows the use of food and feed crops as feedstock). Biojet fuel is already being produced in Finland, France and Spain, and production is expected next in the Netherlands and Italy.

Elsewhere, [Japan](#) aims for SAFs to make up 10% of the aviation fuel used by its airlines by 2030, and in China the [Civil Aviation Administration of China](#) targets SAF use of 65 MLPY and lower GHG emissions intensity in 2025. Beyond government programmes, airlines have signed agreements to use nearly [35 000 MLPY of SAFs](#) over the next 20 years. The International Civil Aviation Organisation (ICAO) has also established a Carbon Offsetting and Reduction Scheme for International Aviation (CORSA), and in October 2022 it adopted an aspirational goal of [net zero emissions by 2050](#).

Although airline commitments, the CORSA initiative and the ICAO pledge are not considered direct drivers and thus do not affect our forecast, these actions do enable broader SAF development. For instance, airline commitments to purchase SAFs reinforce the business case for new facilities by guaranteeing sales. At the same time, CORSA aims to establish a global market to reduce GHG emissions from aviation, and SAF use is an effective option.

While SAF production is rapidly expanding, high costs, limited policy support and low feedstock availability may slow growth. Biojet fuel [production costs](#) remain more than double those of fossil jet fuel, restricting expansion to just a handful of countries that have tax incentives or mandates. Most SAF production to 2027 will rely on waste and residue oils and fats and vegetable oils. Demand for these products for the manufacture of all biofuels is thus expected to increase 50% over 2022-2027, which will likely keep feedstock costs high (see Chapter 4, Question 4, for more on feedstock availability).

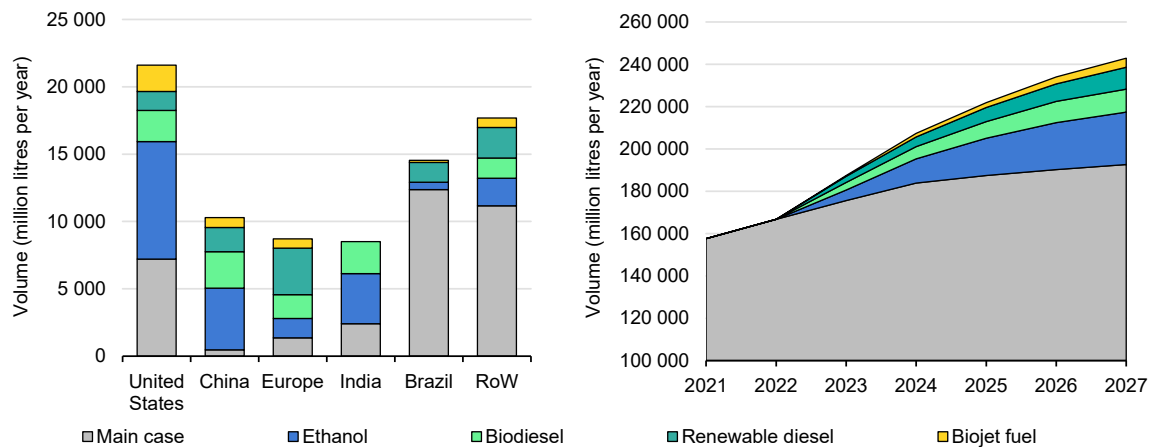
In the accelerated case, demand expands to 8 000 MLPY, bringing the biojet fuel share to nearly 2% of global jet fuel use. The United States has the most significant growth potential in the accelerated case, as we assume existing policies will favour biojet fuel over renewable diesel, enlarging growth prospects. In fact, biojet fuel makes up 4% of US domestic jet fuel use by 2027 in this case.

Meanwhile, development in China is uncertain. The [National Development and Reform Commission](#) says it will “promote the demonstration and application of bio-aviation fuel”, but it has not released targets or policies beyond the 65-million-litre target for 2025. New policies in Brazil and Indonesia, and more stringent policies in Europe, would also help accelerate production, as planned capacity is sufficient to support growth. Although announced biojet fuel plants would raise production capacity to 17 000 MLPY by 2027, this level of expansion is contingent on all facilities being built and feedstock being available.

## The United States, China, Europe and India account for 80% of biofuel consumption growth in the accelerated case

Total biofuel demand reaches 240 000 MLPY in the accelerated case, up 25% from the main case. This level of growth is premised on China, Europe, India and the United States implementing more stringent policies to drive demand, and also assumes that efforts to increase ethanol blending in the United States and India are successful. Furthermore, all four countries must enlarge their supplies of feedstocks, especially wastes and residues, to expand renewable diesel, biojet fuel and biodiesel production.

**Figure 2.6 Demand growth by country (left) and total demand (right), accelerated case, 2021-2027**



IEA. CC BY 4.0.

Note: RoW = Rest of world.

For the United States, demand growth in the accelerated case is more than three times that of the main case, with increases to the Renewable Fuel Standard's blending requirements and strengthening of California's Low-Carbon Fuel Standard boosting biofuel consumption and providing broad support for higher demand. We also assume that 15% ethanol blending is allowed year-round and that fuel dispensers make use of IRA grants to make higher biofuel blends more available. Additionally, greater access to vegetable, waste and residue oils means renewable diesel and biojet fuel production can expand without reducing biodiesel production.

The forecast for China includes new blending requirements to help the country meet its net zero target. However, the [National Development and Reform Commission](#) has committed to "actively promote the use of advanced biofuels" but has yet to release targeted measures. Even modest aims for 2027 would produce

significantly higher biofuel consumption, given China's sizeable gasoline and diesel demand. With China focused on advanced fuels, most production growth will likely be based on wastes and residues, or on energy crops that do not compete with food and feed crops.

Meanwhile, European biofuel demand growth in the accelerated case is six times higher than in the main case because the accelerated case includes the EU-level Fit for 55 target of cutting transport GHG emissions 13% across all countries. Member states are assumed to modify their transport policies to achieve this goal, and the European Commission estimates that these actions would surpass existing transport sector renewable energy targets by two, raising the share of renewables to 28% by 2030.<sup>11</sup> In this case, biofuel producers would also achieve the EU target of 2.2% advanced fuels in total fuel consumption by 2030. Producing these fuels requires feedstocks that are little used today, including wastes and residues other than used cooking oil and animal fats.

In the accelerated case for India, a 3.5% blending target for biodiesel is assumed, leading up to its goal of 5% by 2030, but achieving this aim will require the collection of used cooking oils for feedstock. Ethanol blends also reach 20% in this case, assuming India expands its fleet of compatible vehicles and retrofits those that are currently incompatible. The Indian government is supporting flex-fuel vehicles (for example those that run on 85% ethanol blends) through incentive programmes such as its [Production-Linked Incentive scheme](#).

Brazil's biofuel demand is 30% higher in the accelerated case, owing to a 1% GHG emissions reduction target for aviation and a small increase in the country's biodiesel target. Based on the number of facilities currently planned, renewable diesel would supply most of the additional biofuels blended with diesel. Ethanol demand increases slightly, assuming Brazil's RenovaBio programme makes ethanol more affordable than gasoline.

## Demand, supply and trade

### United States

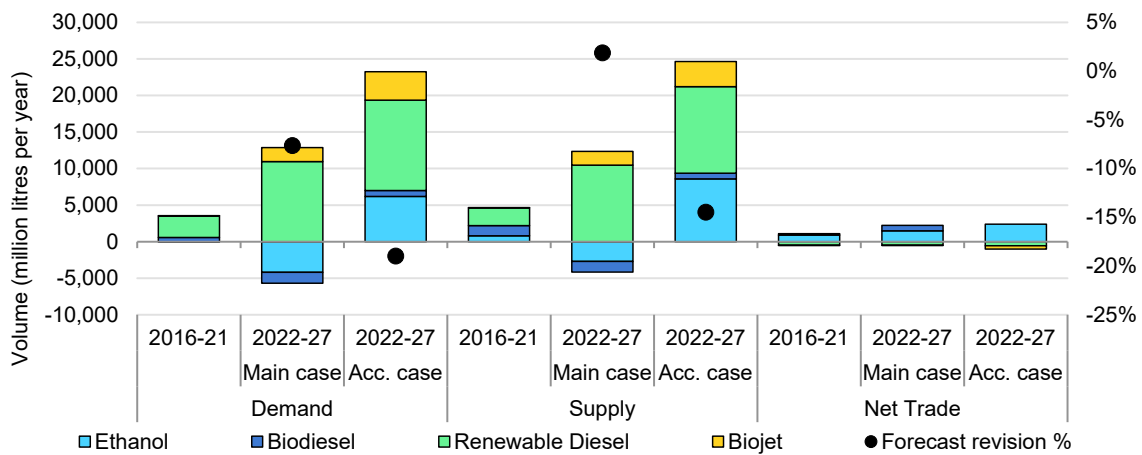
US biofuel consumption expands 11% to 70 600 MLPY in the main case. Greater renewable diesel and biojet fuel demand account for this rise, with the IRA, the Sustainable Aviation Fuel Grand Challenge, the Renewable Fuel Standard and state-level low-carbon fuel standards spurring growth. However, renewable diesel and biojet fuel displace biodiesel, causing its consumption to drop during the forecast period. Ethanol demand also declines because gasoline demand falls and

---

<sup>11</sup> This projection is based on the current Renewable Energy Directive's calculation methodology for renewable energy sources, which includes multipliers for electricity and advanced biofuels.

blending rates remain static. Overall, the main-case forecast is down 8% from last year because of lower ethanol and biodiesel demand, countered by a stronger forecast for renewable diesel and biojet fuel.

**Figure 2.7 United States five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Owing to IRA provisions, the renewable diesel forecast is up 7% and biojet fuel up 130% from last year. The IRA offers an estimated USD 9.4 billion of dedicated biofuel support to 2032,<sup>12</sup> with the majority (an estimated USD 8.6 billion) allocated to biofuel PTCs (their total financial value is not capped). The remaining USD 0.8 billion is for competitive grants to support blending infrastructure, SAF production and biofuel distribution. Renewable diesel and biojet fuel will also continue to benefit from state-level low-carbon fuel standards and the federal Renewable Fuel Standard. Additionally, the United States has an [SAF production goal](#) of 11 000 MLPY by 2030.

<sup>12</sup> Total estimated by the congressional budget office for Sections 13201, 13202, 13203, 13404, 13704, 22003 and 40007. The fuel infrastructure tax credit (Sec. 13404), tax credit for carbon dioxide sequestration (Sec. 13104) and the extension of the advanced energy project credit (Sec. 13501) are not included in the total, although biofuel producers will likely access some portion of these tax credits (Congressional Budget Office [2022], Estimated Budgetary Effects of H.R. 5376, the Inflation Reduction Act of 2022, [https://www.cbo.gov/system/files/2022-08/hr5376\\_IR\\_Act\\_8-3-22.pdf](https://www.cbo.gov/system/files/2022-08/hr5376_IR_Act_8-3-22.pdf)).

**Table 2.1 Summary of Inflation Reduction Act provisions for biofuels**

Tax credit / grant	Time period	Value	Eligible fuels	GHG requirements
Extension of the Biodiesel and Renewable Diesel Credit	2022 – 2024	USD 0.26 per litre (USD 1 per gallon)	Biodiesel and renewable diesel	At least 50% less than average diesel GHG emissions intensity on a lifecycle basis
New Sustainable Aviation Fuel Credit	2023 - 2024	Minimum USD 0.33 per litre (USD 1.25 per gallon). Up to USD 0.46 per litre (USD 1.75 per gallon) for lower GHG intensity	SAFs	
New Clean Fuel Production Credit	2025 - 2027	Qualified facilities USD 0.26 per litre (USD 1 per gallon) times the fuel emission factor	Any fuel	
New Clean Fuel Production Credit – SAFs	2025 – 2027	Qualified facilities up to USD 0.46 per litre (1.75 per gallon) times the fuel emission factor	SAFs	
Extension of the Second-Generation Biofuel Incentive	2022 – 2025	USD 0.27 per litre (USD 1.01 per gallon)	Second-generation biofuels <sup>13</sup>	
Extension of the Alternative Fuel Infrastructure Tax Credit	2022 – 2032	A 30% credit up to USD 100 000 for fuelling pumps	At least 85% ethanol blends and 20% biodiesel blends	None
New Biofuel Infrastructure and Agriculture Product Market Expansion Grant	2022 – 2031	USD 500 million total available for competitive grants for infrastructure projects that support higher blending	Ethanol blends greater than 10% and biodiesel blends greater than 5% SAFs	None
New Alternative Fuel and Low-Emission Aviation Technology Program	2022 – 2026	USD 297 million for competitive grants for projects that produce, blend or store SAFs or develop low-emission aviation technologies		Must lead to lower GHG emissions
Extension and Modification of Tax Credit for Carbon Sequestration	2022 - 2033	USD 60-180 per metric tonne, depending on carbon sequestration approach and use	Any biofuel facility with labour requirements, but limits with double-counting with other credits	None
Extension of the Advanced Energy Project Credit	2023 – 2031	30% of the qualified investment for a given year. Total available credits USD 10 billion	Any biofuel facility, but limits with double-counting with other credits	None

The extent to which this mix of incentives favours renewable diesel over biojet fuel is unclear, however. Biofuel producers using hydroprocessed esters and fatty acids (HEFA), the primary renewable diesel and SAF product considered in this forecast, can optimise its production for use as either renewable diesel or biojet fuel, depending on revenue prospects. Producer decisions will hinge on several factors, including tax credit values, feedstock costs, GHG emissions intensity,

<sup>13</sup> Lignocellulosic or hemicellulosic and cultivated algae, cyanobacteria or lemna.

biofuel plant design, interactions with other policies and the value of diesel and jet fuel relative to renewable diesel and biojet fuel.

Regarding ethanol, demand is expected to fall 8% (by 4 200 MLPY) following an 8% decline in gasoline demand over 2022-2027. This downward revision from our previous forecast reflects this year's lower estimated gasoline demand. As gasoline demand falls, so does that of ethanol, and production therefore declines. The IRA does offer support for infrastructure to help raise blending rates, but long-term approval for year-round 15% ethanol blending remains uncertain. Nevertheless, ethanol producers can still benefit from the IRA by accessing the carbon sequestration credit to help reduce their emissions, or by claiming the clean fuel production credit for those fuels already associated with relatively low emissions.

We expect a 24% decline in biodiesel demand and production over the forecast period. Consumption was already down 8% as of June 2022 compared with the same period last year, and a 6% decline from 2020 had already been registered in 2021. These drops are the result of feedstock restrictions, unfavourable policy design and less-than-optimal fuel properties.

As renewable diesel, biojet fuel and biodiesel are all competing for the same feedstocks, including vegetable and waste and residue oils, our main-case forecast would require a 12-million-tonne increase in bio-oils and fat availability for biofuel production – a more than 100% increase in just six years. The [USDA](#) already expects a decline in soybean oil exports to accommodate growth in 2022-2023, and biofuel demand has been keeping prices high in 2022.

US energy policies are more supportive of renewable diesel and biojet fuel than of biodiesel. For example, renewable diesel receives a higher credit (1.7 credits per gallon) in the Renewable Fuel Standard compared with biodiesel (1.5 credits per gallon). Biojet fuel will also receive a higher tax credit (USD 0.46 per litre) than biodiesel (USD 0.26 per litre) under the IRA. Furthermore, renewable diesel can be blended at higher levels than biodiesel and, like biojet fuel, be made in retrofitted refineries. This situation is already reducing biodiesel demand.

However, other policy decisions will likely be made during the forecast period that could increase demand. For instance, California is reviewing its [Low Carbon Fuel Standard](#) and considering more stringent GHG emissions intensity targets for 2030. While the federal government has not yet announced its Renewable Fuel Standard objectives for 2023, higher targets would lead to additional biodiesel demand.

In the accelerated case, biofuel demand growth is three times higher than in the main case, totalling 23 300 MLPY. A stronger Renewable Fuel Standard, a more stringent Low-Carbon Fuel Standard in California and fewer feedstock constraints

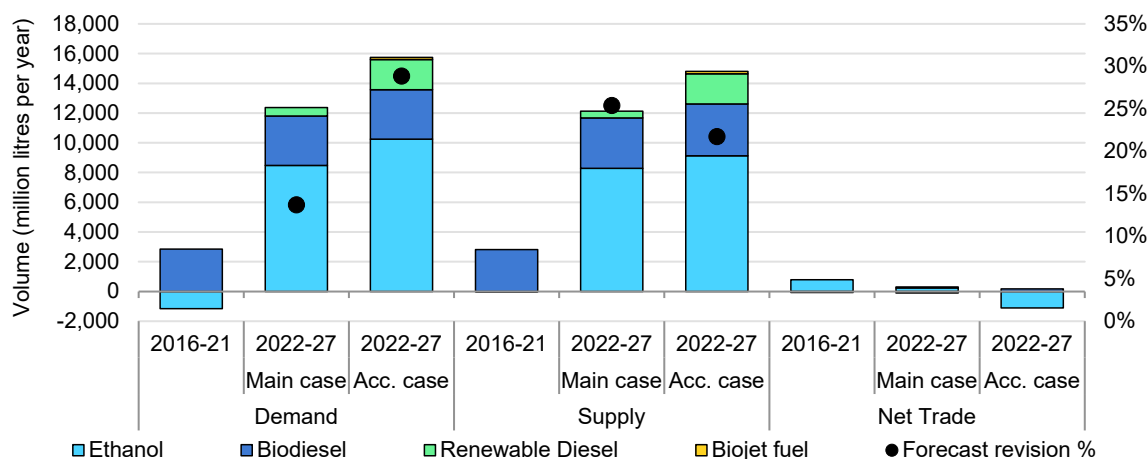
would help support this level of growth. Ethanol accounts for 30% of this increase, assuming infrastructure provisions for higher blending in the IRA allow ethanol blending to increase to 12.5%.

Renewable diesel and biojet fuel demand and production expand as well, provided that a larger share of announced projects come online and feedstock constraints lighten. Biojet fuel demand and production are twice as much as in the main case, bringing blending to 4% in aviation, one-third of the way to achieving the US Sustainable Aviation Grand Challenge goal. Renewable diesel demand expands an additional 10% and biodiesel remains constant, instead of declining.

## Brazil

Brazil's biofuel demand grows 40% to 47 000 MLPY, and production climbs to 49 000 MLPY over 2022-2027. Ethanol accounts for 70% of this expansion, with the rest coming from biodiesel and renewable diesel. Brazil's ethanol and biodiesel mandates, discretionary blending, the RenovaBio mechanism (a carbon intensity reduction scheme), and increasing diesel and gasoline demand drive biofuel expansion.

**Figure 2.8 Brazil five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

We expect ethanol demand to expand 8 500 MLPY over the forecast period. Brazil's 27% compulsory ethanol blending mandate, a 3% increase in gasoline consumption, the RenovaBio programme and discretionary blending support this growth. We estimate discretionary ethanol purchases will account for 23% of gasoline and ethanol sales by volume in 2022 and 34% by 2027. Brazil has a large



flex-fuel vehicle fleet, which allows drivers to choose high- or low-ethanol-blended gasoline depending on the price. In 2022, ethanol prices hovered around the level at which consumers would choose ethanol over gasoline.

Over the forecast period, we expect more discretionary blending to result from continued tax incentives and rising GHG emissions intensity targets under the RenovaBio programme. Existing and planned ethanol production capacity will be more than sufficient to meet expected demand. We also anticipate a decline in ethanol exports as Brazilian consumption increases and demand growth outside of Brazil is met by domestic production.

The higher cost of biodiesel relative to diesel led Brazil to reduce its blending mandate from 13% to 10% in 2021, and to maintain it at 10% in 2022. Assuming the price differential narrows, we expect Brazil to achieve 15% blending in 2024 and thereafter, one year behind its initial schedule. Renewable diesel and biojet fuel consumption expand little in the main case since there are no specific targets or support programmes. To help address this issue, Brazil announced its [Fuel of the Future Program](#) last year to expand biofuel blending in aviation fuels and diesel. It also released technical specifications for renewable diesel, but further support policies have yet to be announced.

The accelerated case assumes Brazil supports both biojet fuel and renewable diesel, achieving 2% biojet blending and expanding its biodiesel blending to 18% by 2027. This is consistent with statements that Brazil is considering mandating a 1% cut to aviation GHG emissions in 2027.<sup>14</sup> We also assume Brazil's own production will satisfy domestic demand, given its soybean and palm oil feedstock potential and its focus on internal ethanol and biodiesel development in the past. Ethanol consumption rises slightly, based on a 3-percentage-point increase in discretionary blending, and production outpaces domestic demand to take advantage of growing export opportunities.

## Europe

Biofuel demand across Europe expands 5% to 29 200 MLPY over 2022-2027. Renewable diesel and biojet fuel lead growth while biodiesel demand declines. Ethanol consumption remains near the 2021 level, as state-level policies encourage expansion even though gasoline and diesel demand fall 13% over the forecast period.

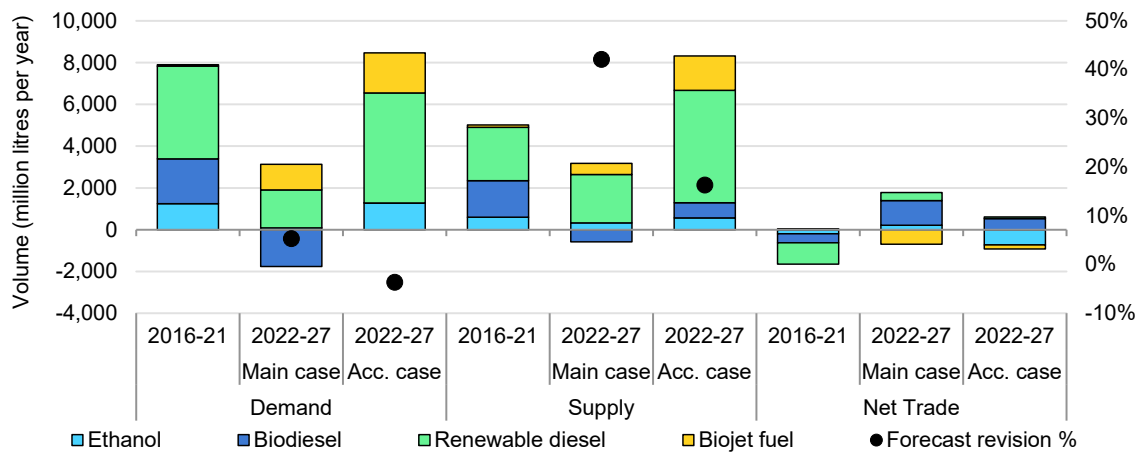
This year's demand growth forecast remains near last year. Although there are regional and fuel changes because of modifications to Germany's feedstock eligibility rules and lower estimated transport fuel use over the forecast period. In

---

<sup>14</sup> Ministry of Mines and Energy (2022), Statement from Renato Dutra, head of biodiesel and other biofuels.

the accelerated case, demand rises more strongly because we assume that EU member states incorporate the Fit for 55 transport targets into their domestic policies.

**Figure 2.9 Europe five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Europe’s renewable diesel demand expands by 1 800 MLPY over 2022-2027, with France, Finland and Germany accounting for 80% of this growth. France targets 8% biodiesel blending (including renewable diesel) by 2027, [Finland](#) aims for 30% renewable energy sources in transport by 2027 and Germany targets a 14.5% GHG emissions intensity reduction in transport by 2027. Renewable diesel production expands in France, Sweden, the Netherlands, Finland and Spain to supply the volumes required for proposed projects in these countries.

Biojet fuel consumption expands to 1 200 MLPY by 2027, as the ReFuelEU Aviation proposal requires 2% SAF blending by 2025 and 5% by 2030. We expect this policy to be implemented over the forecast period, supporting the SAF forecast. SAF targets in the United Kingdom and Norway also indicate rising biojet fuel demand.

Meanwhile, ethanol demand remains steady over the forecast period. The most significant growth is in the United Kingdom, where consumption expands 55% or 400 MLPY during 2022-2027 to meet the UK Renewable Transport Fuel Obligation supported by 10% ethanol-blended gasoline availability across the country. Ethanol demand rises in France as well, thanks growth of its flex-fuel vehicle fleet.

Across the European Union overall, however, ethanol demand peaks mid-forecast and then falls to 2027. This decline results from a 10% drop in gasoline consumption over the forecast period as vehicles become more efficient and electric vehicles are adopted. Lower gasoline demand thus means less ethanol is needed to meet blending targets.

EU biodiesel consumption declines 3% to 13 900 MLPY over 2022-2027 as demand for regular diesel drops 14%. Additional biodiesel blending is not an option for many countries, since they are already near the 7% blending limit set in the EU Fuel Quality Directive. France, Germany, the Netherlands and Spain all reach this limit over the forecast period, but Italy has considerable growth potential because it achieved just 2.2% biodiesel blending in 2021.

The combination of declining gasoline and diesel demand as well as feedstock limitations put additional downward pressure on the forecast. For instance, in September 2021 [Germany](#) reduced its cap on crop-based fuels from 6.5% to 4.4% and limited the employment of used cooking oil and animal fats to 1.9% on an energy basis. These feedstock caps will likely be reached during the forecast period when gasoline and diesel demand declines. Volume growth would therefore be limited to fuels made from wastes and residues, which rely on non-commercial conversion technologies or feedstocks available in just small quantities today.

The EU Renewable Energy Directive also limits crop-based fuels to a one-percentage-point increase above 2020 levels and to no more than 7% on an energy basis. Used cooking oil and certain animal fats are capped at 1.7%,<sup>15</sup> and IEA analysis indicates this limit will likely be reached across the European Union during the forecast period.

In the accelerated case, biofuel demand grows by 8 500 MLPY (six times the main case), assuming the European Union implements its revised Renewable Energy Directive as outlined in the Fit for 55 package. The revised directive calls for a 13% decline in transport GHG emissions intensity by 2030, 2.2% advanced fuel use and 2.6% use of renewable fuels from non-biological sources.<sup>16</sup>

As the revised Renewable Energy Directive is still under negotiation, there is potential for higher targets as proposed by the European Parliament and Council. The European Commission estimates the revised Renewable Energy Directive would achieve 28% renewable content in transport fuels by 2030, double the current target.<sup>17</sup> This does not mean that biofuel demand and production will

<sup>15</sup> This refers to feedstocks in the [Renewable Energy Directive](#) Annex IX, Part B.

<sup>16</sup> This can include synthetic fuels made from CO<sub>2</sub> and hydrogen.

<sup>17</sup> Both the current 14% target and the 28% goal are based on the Renewable Energy Directive's calculation methodology, which includes multipliers for specific fuels.

double, however. The same blending limits, feedstock constraints and declining gasoline and diesel demand will still limit growth potential. Nevertheless, if all planned facilities are built, there would be an additional 1 700 MLPY of production from plants using advanced feedstocks.

Biofuels are also only one option for policy compliance. Electricity, biogas and renewable fuels from non-biological sources such as hydrogen will also contribute. Additionally, the transport targets of Germany, Finland and Sweden are already more ambitious than in the revised directive, reducing potential for additional growth.

## Indonesia

Indonesia's biofuel consumption and production are expected to expand 50% during 2022-2027 in the main-case forecast. Biodiesel accounts for 70% of this increase and renewable diesel makes up the remaining 30%, while new renewable diesel capacity will also add a small amount of biojet fuel production. Combined, bio-based diesels<sup>18</sup> account for a 35% share of transport diesel demand in Indonesia by 2027, up from 30% in 2021. We expect no additional ethanol production despite existing targets, as no incentives or other regulations are in place or planned to support it.

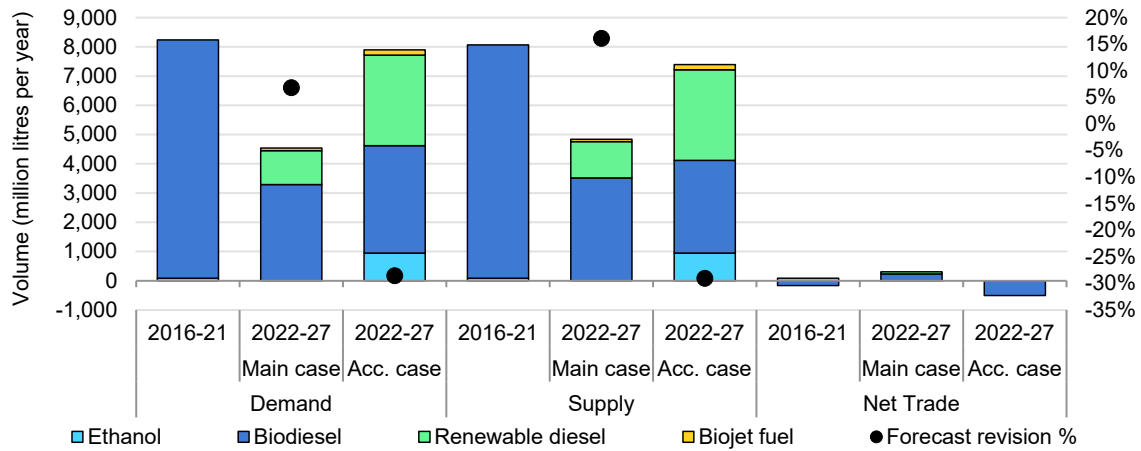
The country's biodiesel blending target, combined with financial incentives, remains the primary driver of biodiesel production and demand. Indonesia provides subsidies to ensure a market for palm oil producers, reduce diesel import dependence and curb GHG emissions. Although in 2022 the government intends to keep biodiesel blending at the same rate as in 2021 (30%), we expect volumes to increase relative to 2021 because diesel demand is rising and Indonesia has expanded the share of biodiesel used for non-transport purposes.

This expansion of biodiesel blending for non-transport use is the basis of our upward forecast revision. Blending levels in non-transport sectors such as electricity and industry are currently at 20%, and the Indonesian government targets 30% blending for these uses by 2025. Total biodiesel production in 2022 is thus expected to be near 11 000 MLPY, a 20% increase from 2021.

---

<sup>18</sup> Bio-based diesels include renewable diesel, biodiesel and biojet fuel.

**Figure 2.10 Indonesia five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Indonesia’s ultimate goal of 40% biodiesel blending in transport fuels is expected to be implemented in some regions in 2025. However, meeting this target across the country will be challenging overall, and technical trials carried out by the Indonesian government have revealed that 40% biodiesel blending could compromise engine performance. Renewable diesel is a viable alternative, since it can be used at higher blend levels without threatening engine integrity, but planned capacity would expand blending by only an additional 3 percentage points.

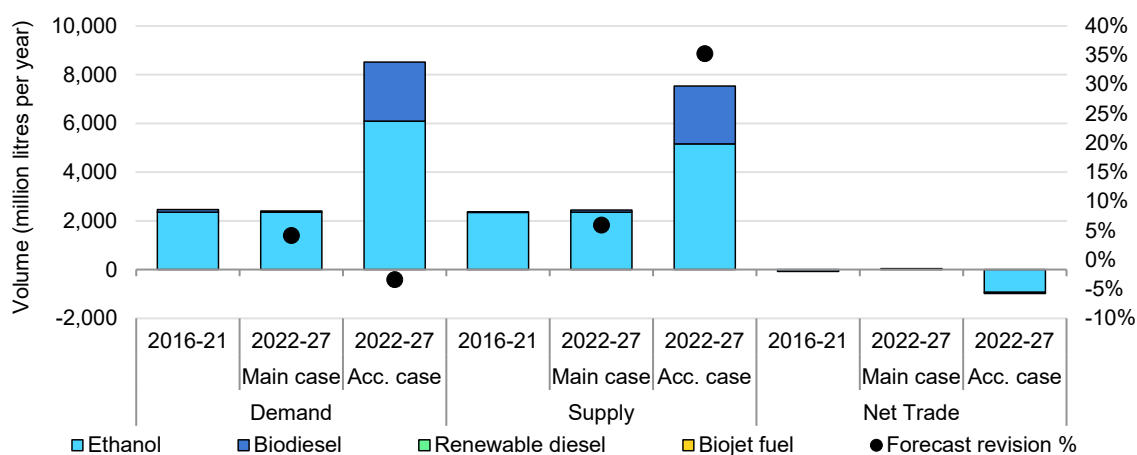
Exports offer another growth path, but we expect little expansion in this domain because of the European Union’s planned phaseout of palm oil for biofuel production and incompatibility with the US Renewable Fuel Standard. Imports are also likely to remain limited, as Indonesia’s production capacity is sufficient to meet internal demand. We also expect little growth in ethanol or biojet fuel production without government support programmes.

In the accelerated case, production and demand increase 90% during 2022-2027, assuming Indonesia supports ethanol and biojet fuel demand and production and expands renewable diesel consumption to meet its 40% blending target. However, forecast growth is down 30% for both production and demand because of a higher 2021 baseline this year (we revised the 2021 baseline upwards to incorporate new data on biodiesel blending in non-transport sectors). Nearly 20% of Indonesia’s biodiesel demand in 2021 came from non-transport sectors.

## India

India's biofuel demand and production increase 70% or 2 400 MLPY over 2022-2027 in the main case, thanks primarily to its goal of reaching 20% ethanol blending by 2025 and buoyed by rising gasoline demand. The government requires that ethanol demand be met with domestic production, and in its updated National Biofuel Policy it has reiterated its aim to blend biodiesel at a rate of 5% by 2030. It is also exploring biojet fuel opportunities but has introduced no specific requirements or incentives to stimulate demand and production, limiting growth prospects. Overall, this year's main-case forecast is similar to last year's.

**Figure 2.11 India five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Ethanol demand and production increase by 70% or 2 360 MLPY, with India supporting its 20%-by-2025 ethanol blending target with guaranteed ethanol pricing per feedstock and offering financial support for new ethanol production (these policies already boosted blending from 4% in 2017 to more than 9% in 2021). Gasoline consumption also rises 8% over the forecast period, contributing to ethanol demand growth. Already, in 2022 we expect ethanol demand and production to increase by 35%, or 1 200 MLPY.

India's ethanol prices have remained low relative to other regions because it makes ethanol primarily from surplus sugar and molasses. While the average sugar price in 2022 was 50% higher than 2019, the cost of corn rose 80%.<sup>19</sup>

<sup>19</sup> Based on USDA data for world raw sugar prices and US corn prices.

Nevertheless, several challenges may impair ethanol uptake in India. For instance, a significant portion of India's vehicle fleet, especially two-wheelers, may [be incompatible with E20 blends](#). Although India is working to expand its number of new compatible vehicles, replacement time is a forecast uncertainty. Furthermore, while the country has ample feedstocks to support the level of ethanol expansion envisioned, grain-based production capacity has yet to be enlarged to supplement sugar-based ethanol manufacturing. India [estimates](#) grain-based ethanol will provide 46% of its supplies.

For biodiesel, renewable diesel and biojet fuel, a lack of policy support limits growth in our main case. We therefore assume biodiesel blending remains below 1%, following the historical average, and no use or production of renewable diesel or biojet fuel is planned. While India does endorse 5% biodiesel blending by 2030 in its updated [National Biofuel Policy](#), it has yet to announce specific policies to achieve this target. Should it pursue this goal, it could draw on its potentially considerable supply of collectable used cooking oil, which could support 2.5% blending.<sup>20</sup>

In the accelerated case, biofuel demand expands by 8 500 MLPY, more than triple the main case. In this scenario, ethanol blending reaches 20% because India expands its grain-based ethanol production capacity, allows some imports and overcomes vehicle compatibility issues. Biodiesel blending reaches 3.5% with the use of used cooking oil, and biojet fuel demand reaches 0.5% thanks to blending.

## Other markets

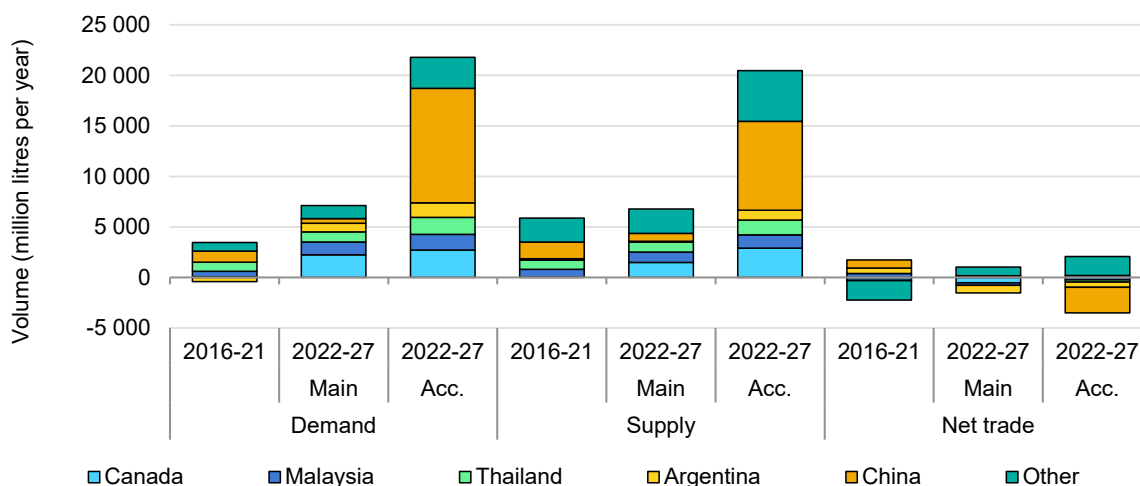
Demand in other markets<sup>21</sup> grows 35% to 26 700 MLPY over 2022-2027 in the main case, with Canada's Clean Fuel Standard and strengthened blending requirements in Malaysia, Thailand and Argentina driving expansion. In emerging markets, growing demand for gasoline and diesel also accelerates biofuel use. While production expands in these countries to satisfy domestic demand, imports are also necessary in some. For instance, Canada's imports nearly double over the forecast period while greater production in Singapore and China permits exports to European and North American markets.

---

<sup>20</sup> India has an estimated 1.5 million tonnes of used cooking oil collection potential, which could meet 2.5% of India's diesel demand in 2027.

<sup>21</sup> Remaining countries account for 15% of global supply and demand. The top five in demand in 2021 were China, Canada, Thailand, Argentina and Malaysia.

**Figure 2.12 Other markets five-year biofuel growth, main and accelerated cases, 2016-2027**



IEA. CC BY 4.0.

Note: Acc. = accelerated case.

In July 2022, Canada released the final version of its Clean Fuel Regulations, requiring fuel producers and importers to reduce the carbon intensity of their fuels by 14 g CO<sub>2</sub>-eq/MJ by 2030. This policy alone will prompt around 2 300 MLPY of new demand.

Meanwhile, Malaysia plans to roll out its 20% biodiesel blending target for transport at the end of 2022. This mandate, combined with growing diesel demand, doubles biodiesel use by 2027.

In Thailand, pursuit of its 20% ethanol target and 10% biodiesel target, combined with increasing gasoline and diesel demand, drive a 30% increase in biofuel demand.

In 2022, Argentina temporarily allowed biodiesel blending of up to 12.5% to help guard against diesel shortages in the country, which created a sharp doubling in biodiesel demand this year. We therefore assume a 10% blending rate for the remainder of the forecast period.

In China, biofuel consumption increases 10% to 5 400 MLPY, primarily because of higher gasoline and diesel demand. Meanwhile, biojet fuel demand expands to meet the Chinese Civil Aviation Administration’s 50 000-tonne (62.5-million-litre) [biojet fuel target](#). China also reiterated its commitment to develop advanced fuels in the [National Development and Reform Commission](#)’s May 2022 bioenergy plan.

Although biofuel production in all these countries expands to supply growing domestic use, both Singapore and China raise renewable diesel and biojet fuel production by 60% to also satisfy export market demands in the main case. Most of these fuels are made using wastes and residues to meet European policy



stipulations as well as the low GHG emissions requirements of California’s Low-Carbon Fuel Standard and Canada’s Clean Fuel Regulations.

In the accelerated case, demand and production growth are three times higher than in the main case. China alone accounts for more than half of this potential: if its blending requirements are consistent with the IEA’s Net Zero Emissions by 2050 Scenario, growth jumps to 11 300 MLPY over the forecast period.

There is also scope for greater demand growth in Malaysia, Argentina and Thailand if these countries pursue more stringent policies (see Policy and Assumption table below). Production in these countries would also expand to satisfy domestic usage. At the same time, renewable diesel and biojet fuel production also increase, especially in Singapore and Paraguay, assuming global consumption increases enough to justify new projects to serve export markets in Europe and North America.

**Table 2.2 Policy and assumption summary, main and accelerated cases**

Country or region	Main- and accelerated-case policies, assumptions and blending levels
United States	<p><b>Main case:</b> No significant changes to the Renewable Fuel Standard or other existing policies. Includes IRA provisions as outlined in the table above. Ethanol blending stays near 10% and exports remain around 2021 levels for the forecast period. Renewable diesel expands according to planned capacity additions for projects in advanced development stages. Renewable diesel blending reaches 8.5% in 2027. Biodiesel blending declines to 2.7% while biojet fuel supply and demand reach 2% blending for domestic jet use. Biojet fuel makes up almost 15% of renewable diesel production in 2027.</p> <p><b>Accelerated case:</b> An accelerated version of the Renewable Fuel Standard boosts domestic biofuel demand, with ethanol reaching 12.5% blending and biodiesel expanding to 4%. Renewable diesel blending increases to 9.5%, requiring additional production capacity beyond projects in advanced development stages. Biojet fuel blending expands to 4%, just over one-quarter of the way to meeting the Sustainable Aviation Grand Challenge goal. Ethanol production increases to meet both domestic and net export demand using existing ethanol-manufacturing capacity.</p>
Brazil	<p><b>Main case:</b> Brazil maintains mandatory ethanol blending, and hydrous ethanol purchases expand so that total blending reaches 57% by 2027. Biodiesel remains at B10 for 2022, climbing to B15 by 2024 and onwards. There is a small amount (0.8%) of renewable diesel blending by 2027 based on planned project additions. The forecast assumes soybean oil prices decline from 2021/22 highs.</p> <p><b>Accelerated case:</b> Brazil achieves its B15 blending target as in the main case but also accepts renewable diesel and co-processing so that additional growth flows to renewable diesel for 3% blending in 2027. Ethanol blending expands marginally more quickly, to 59% in 2027. Part of total ethanol blending is a continuation of blending requirements of 25% (premium gasoline) and 27% (regular gasoline). Hydrous ethanol sales (100% ethanol) make up the remainder of ethanol demand. Brazil produces enough ethanol, biodiesel, renewable diesel and biojet fuel to serve domestic consumption. Ethanol production increases further to meet export demand.</p>
India	<p><b>Main case:</b> India achieves 12% ethanol blending on average across the country by 2027 and all fuel ethanol is produced domestically. E20 is available starting in 2023. The forecast assumes vehicle incompatibility limits ethanol uptake. Biodiesel blending remains near 0.4%.</p> <p><b>Accelerated case:</b> India achieves its 20% ethanol blending mandate in 2025 and makes progress towards its 5% biodiesel blending ambitions, reaching 3.5% by 2027. This assumes India addresses vehicle compatibility concerns and establishes used cooking oil collection. It continues to support domestic production and allows fuel ethanol imports of up to 20% of demand.</p>

Country or region	Main- and accelerated-case policies, assumptions and blending levels
China	<p><b>Main case:</b> No significant changes to ethanol or biodiesel policy. Ethanol blending remains near 2% and biodiesel at 0.5%. Ethanol imports stay around 2020/21 levels. Biodiesel exports are close to 2020 levels and renewable diesel exports expand according to planned project additions in advanced development stages.</p> <p><b>Accelerated case:</b> China implements policies aligned with its bioeconomy plan, including blending targets of 4% for ethanol, 3% for biodiesel and hydrotreated vegetable oil (HVO), and 1% for SAFs in domestic aviation by 2026. China continues to allow ethanol imports of up to 10% of demand from the United States and other countries. Exports continue for biodiesel but drop to zero for renewable diesel and biojet fuel. Production of both fuels is used to satisfy domestic demand.</p>
Indonesia	<p><b>Main case:</b> Biodiesel blending increases to 35% by 2027 for transport and to 30% for non-transport uses. The main blending source is biodiesel at 32%, followed by renewable diesel at 3% blending. Biodiesel use remains at 30% because of compatibility issues, and renewable diesel is limited to planned projects. There is no ethanol or biojet fuel production or use. Exports remain near 2020 levels.</p> <p><b>Accelerated case:</b> Indonesia meets the B40 mandate for transport and non-transport fuel consumption, with the 40% blend broken down as 32% biodiesel and 8% renewable diesel. This requires additional renewable diesel manufacturing capacity. Indonesia also enforces SAF blending of 2% by 2025 and 3% by 2027. Exports decline by 2027, as nearly all production is directed towards domestic demand.</p>
Europe	<p><b>Main case:</b> EU member countries implement the Renewable Energy Directive II or achieve domestic targets if more stringent, and non-EU countries achieve domestic targets. Biojet fuel use expands to meet the ReFuelEU's 2%-by-2025 target. As per the ReFuel proposal, feed and food crop-based fuels are not eligible and fuels must otherwise meet the requirements of Renewable Energy Directive II Annex IX, Part A or Part B.</p> <ul style="list-style-type: none"> <li>• Germany's GHG emissions reduction target climbs to 14.5% by 2027, up from 6%. Biodiesel and ethanol blending remain steady, while renewable diesel expands to 3%.</li> <li>• France meets its 8.6% ethanol and biodiesel blending targets. Ethanol blending increases to 12.7%, biodiesel blending remains flat, renewable diesel blending expands to 3% and biojet fuel reaches 2.3% by 2027.</li> <li>• In Spain, ethanol and biodiesel blending remain flat but renewable diesel blending expands to 3% and biojet fuel to 2.7%.</li> <li>• Finland, the Netherlands and the United Kingdom all achieve near-10% ethanol blending. Sweden reaches 3% biojet fuel blending. In Italy renewable diesel blending expands to 5%.</li> <li>• The United Kingdom makes progress towards its target of 10% SAF blending by 2030, with the mandate starting in 2025. Norway continues working towards its 0.5% SAF target.</li> </ul> <p><b>Accelerated case:</b> The European Union moves more quickly towards its 2030 6% biojet fuel-use target. Germany focuses on non-biogenic renewable fuels in aviation instead of biojet fuel. The European Commission also implements proposed changes to the Renewable Energy Directive II to reduce the transport sector's GHG emissions intensity by 13%, as proposed by the Fit for 55 package. Member states implement this standard. The European Union maintains and strengthens sustainability requirements for biofuels, which limits some imports. The United Kingdom establishes a 1%-by-2025 SAF target.</p>

Country or region	Main- and accelerated-case policies, assumptions and blending levels
Other countries	<p><b>Main case:</b> Canada implements its Clean Fuel Standard in 2023. Malaysia’s B20 mandate is delayed until 2023. Thailand makes progress on its E20 target, reaching 15% blending by 2027, while biodiesel use expands to 10% based on government support plans. Singapore’s renewable diesel and biojet fuel production expand to fill domestic shortfalls in the rest of the world. Argentina’s biodiesel blending climbs to 10%, and ethanol to 12%. Colombia returns to 10% ethanol blending by 2022, while biodiesel blending rises to 12% over the forecast period. Japan pursues 10% SAF use by 2030.</p> <p><b>Accelerated case:</b> Canada follows the United States in supporting SAFs. US SAF blending reaches 4%. Malaysia expands biodiesel blending for the industrial sector to 20%. Colombia pursues 13% biodiesel blending. Thailand achieves 20% ethanol blending by 2026 and allows 10% ethanol imports.</p>

# Chapter 3. Renewable heat

Heating is the world's largest energy end use, accounting for almost half of global final energy consumption. Industrial processes are responsible for 53% of the final energy consumed for heat, while another 44% is used in buildings for space and water heating and, to a lesser extent, cooking. The remainder is used in agriculture, primarily for greenhouse heating. The heating sector is largely dominated by fossil fuels, with renewable energy sources meeting less than one-quarter of global heat demand in 2021 (and the traditional use of biomass makes up half this amount).

## Recent trends and policy update

With the global economy rebounding in 2021, heat consumption increased by 4% year-on-year, exceeding the pre-pandemic level and reaching a record-high 219 EJ. Excluding the traditional use of biomass, modern renewables<sup>22</sup> fuelled just 13% of this growth, leaving the share of modern renewables in global heat consumption almost unchanged from the previous year's 11%.

Modern bioenergy made the largest contribution to the increase in renewable heat consumption, owing essentially to rebounding activity in industry, followed by renewable electricity as heat pump deployment in the buildings and industry sectors accelerated. Annual heat-related CO<sub>2</sub> emissions rose by almost 0.6 Gt CO<sub>2</sub> to 14.1 Gt CO<sub>2</sub>, representing 39% of global energy-related CO<sub>2</sub> emissions.

The rise in policy attention renewable heat is gaining worldwide is due not only to environmental considerations but to acute energy security concerns in the context of the current global energy crisis. Major recent heat-related policy updates include the US [Inflation Reduction Act](#) passed in August 2022, which allocates an estimated USD 22 billion (out of an estimated USD 369 billion for overall energy and climate change spending) for home energy supply improvements. The bill includes substantial rebates (of up to USD 8 000 for a space heating heat pump for low- and moderate-income households) and ten years of consumer tax credit

---

<sup>22</sup> In this report, "modern renewable energy" excludes traditional uses of biomass. Modern renewable heat covers the direct and indirect (e.g. through district heating) final consumption of bioenergy, solar thermal and geothermal energy, as well as renewable electricity for heat based on an estimate of the amount of electricity used for heat production (including through heat pumps) and on the share of renewables in electricity generation. Although credited as a renewable heat source, ambient heat harnessed by heat pumps is not considered in this report due to data insufficiency, especially for the industry sector. For the sake of simplicity, "modern renewables" is shortened to "renewables" in the remainder of this report.

(30%, or up to USD 2 000) for heat pumps, geothermal heating and electric heating appliances (e.g. stoves and clothes dryers) as well as high-efficiency biomass stoves and boilers.

The [REPowerEU plan, communicated in March](#) and published in May 2022, aims to reduce EU dependency on Russian gas and proposes to revise the EU target for renewables in total final consumption from 40% to 45% by 2030 under the Fit for 55 package. In addition to a solar PV strategy, it contains provisions for industry sector decarbonisation through (among other measures) electrification, the use of large-scale heat pumps and renewables-based hydrogen, and the deployment of other renewable energy sources, including by integrating solar thermal and geothermal technologies into district heating systems.

The plan also proposes the cumulative installation of 10 million new hydronic heat pumps in the next five years and 30 million units in the buildings sector by 2030. This would mean a more than 20% annual increase in hydronic heat pump installations in the European Union throughout this decade, from a starting point of 1.1 million units in 2021. To align with the ambitions of the REPowerEU plan, ongoing negotiations on the revision of the European Renewable Energy Directive include proposals to strengthen member state's targets for renewable heat deployment in the buildings, industry and district heating sectors.

In November 2022, the European Commission proposed [a new temporary emergency regulation](#) to accelerate permit-granting for heat pumps by introducing a three-month deadline and simplifying the grid connection procedure for smaller units.

Meanwhile, the targets of China's [14th five-year energy plan](#) to 2025, released in March 2022, include a 20% non-fossil-fuel share in the energy mix by 2025 and 60 million tonnes of coal equivalent (about 1.8 EJ) of non-electric use of renewables (i.e. for heating and transport). [A total budget of RMB 27.5 billion](#) will be allocated to clean heating and air pollution control measures.

In Chile, the [National Heat and Cold Strategy](#) of 2021 targets 40% GHG emissions reductions in the heating and cooling sector by 2030 and 65% by 2050, and aims for 45% sustainable energy in heating and cooling by 2030 and 80% by 2050. The plan promotes renewable energy sources, particularly solar thermal and biomass, as well as district heating projects.

Several other countries, including France, Denmark, Canada, the United Kingdom, Luxembourg, Austria and Malta, have also implemented new financial incentives for renewable heating and cooling or have extended or enhanced existing ones since 2021. Heat pumps have received particular attention, with most support in the form of tax incentives and grants.

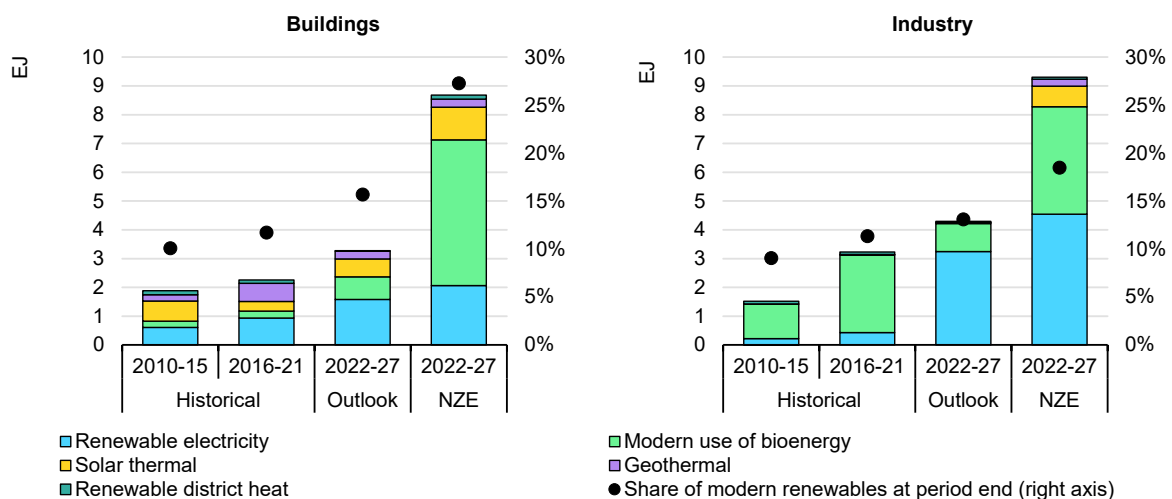
## Outlook to 2027

Given the policy landscape as of September 2022, global heat consumption – excluding ambient heat harnessed by heat pumps – is projected to grow almost 14 EJ (+6%) during 2022-2027. Increasing industrial activity drives this trend, with China and India together representing 60% of industrial heat demand growth, while energy efficiency improvements allow building heat consumption to decline 4% globally. The traditional use of biomass is anticipated to decline by more than 3 EJ (-13%) over the outlook period, mostly in China and India, owing in part to the deployment of improved biomass cookstoves.

Modern renewable heat consumption is expected to increase by almost one-third during 2022-2027, raising the modern use of renewables in heat from 11.4% to 14% by 2027. In both the industry and buildings sectors, using renewable electricity for heating contributes the most to renewable heat uptake over the outlook period, owing to the combination of greater use of electricity for heating, including through heat pumps, and rising shares of renewables in the power sector.

Nevertheless, renewable heat developments are insufficient to contain fossil fuel-based heat consumption, which expands in industry and leads to a 7% (+1 Gt CO<sub>2</sub>) growth in total annual heat-related CO<sub>2</sub> emissions by 2027. For comparison, to align with the IEA Net Zero Emissions by 2050 Scenario, renewable heat consumption would have to advance 2.4 times more quickly, and wide-scale behavioural change and much larger energy and material efficiency improvements would be required to reduce heat demand in both buildings and industry.

**Figure 3.1 Global increase in renewable energy consumption and share of total heat demand in buildings and industry, 2010-2027**



IEA. CC BY 4.0.

Note: NZE = Net Zero Emissions by 2050 Scenario.

Source: IEA (2022), [World Energy Outlook 2022](#).

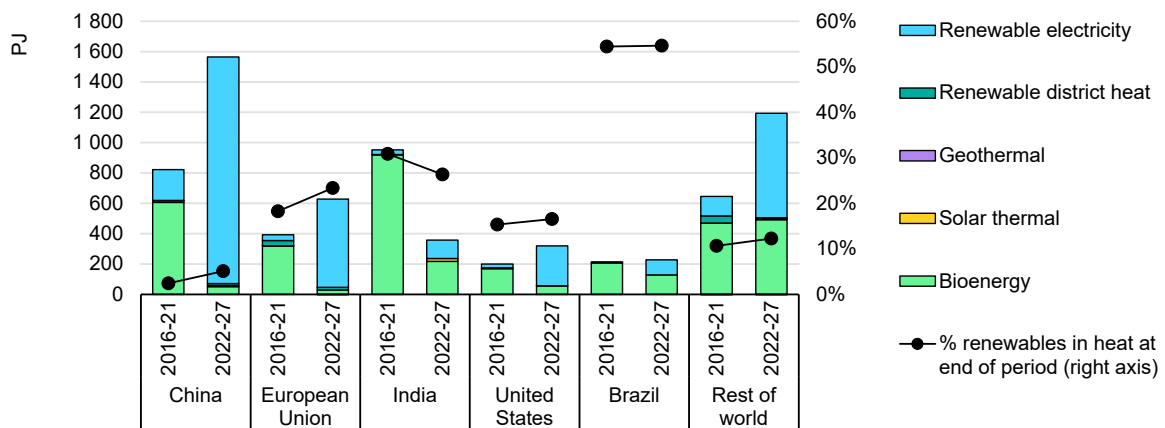
## Industry

### Electrification of thermal processes gains traction, but demand growth outpaces renewable heat progress

Annual industrial heat consumption is projected to rise 17 EJ during 2022-2027, with chemical manufacturing contributing the most to this increase. Renewable energy sources are expected to fuel only one-quarter of this growth, with their share in industrial heat demand rising to 13% by 2027, less than a two-percentage-point increase from 2022. Thus, decarbonising industry will require greater renewable heat uptake and significantly faster energy and material efficiency improvements.

China, which accounts for more than 40% of industrial heat demand growth, also makes the most progress in renewable heat consumption, followed by the European Union, India and the United States. Together, these regions are responsible for two-thirds of renewable heat developments in industry over the outlook period.

**Figure 3.2 Increase in renewable heat consumption in industry and share of renewables in industrial heat demand, selected regions, 2016-2027**



IEA. CC BY 4.0.

Source: IEA (2022), [World Energy Outlook 2022](#).

Renewable electricity becomes the largest contributor to renewable heat progress in industry globally, accounting for three-quarters of growth. The acceleration of process heat electrification is the main driver globally, with electricity being used to produce 9% of industrial heat consumed by 2027, up from less than 4% in 2021. Most electricity demand growth comes from both greater reliance on heat pumps and direct electricity use in non-energy-intensive industries and chemical production, and to a lesser extent from the expansion of scrap steel recycling using electric arc furnaces. After China, the largest increases in renewable electricity

use for process heat are expected in the European Union, the United States and India. Together, these four regions account for three-quarters of global developments.

Bioenergy is expected to remain the foremost renewable heat source in industry, with its consumption expanding by almost 1 EJ over the outlook period – the second-largest absolute increase after renewable electricity. More than one-third of this growth takes place in India and Brazil – the two largest industrial bioenergy consumers – owing primarily to greater use of bagasse in the sugar and ethanol industries as well as biomass in the food and beverage subsectors. In the latter, the trend is partly driven by [a few large multinational companies](#) seeking to reduce their fossil fuel consumption to meet their voluntary carbon reduction targets. Another quarter of the growth takes place in West-, middle- and Eastern African countries, due partly to expanding waste use in the cement subsector. Biogas injected into the gas grid or directly consumed represents only a marginal share of bioenergy use, but developments continue to gather momentum.

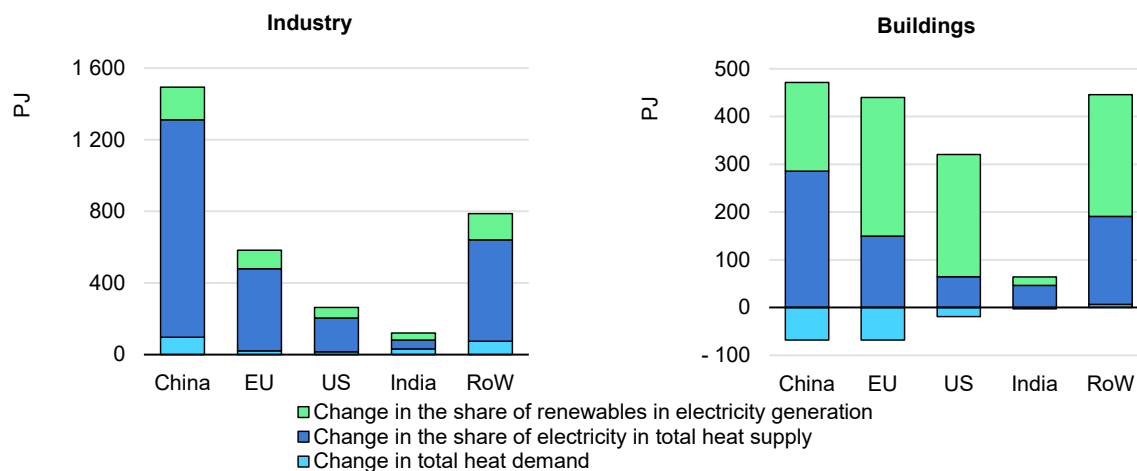
Meanwhile, solar heat for industrial processes (SHIP) remains a niche market, accounting for less than 0.02% of global industrial heat consumption. A few large-scale projects dominate the sector in terms of installed capacity, with the world's largest SHIP plant – the Miraah in Oman, dedicated to enhanced oil recovery – on its own accounting for more than one-third of global capacity.

Yet, interest in SHIP continues to grow, with at least [71 new projects installed worldwide in 2021](#), raising total operational capacity by 5% to nearly 826 MW<sub>th</sub>. France, China and Spain led capacity additions in 2021, while Mexico, the Netherlands and Austria were the most dynamic markets in terms of number of new plants. While the main SHIP application sectors are currently mining, food and textiles, [large-scale developments are also envisaged in the aluminium subsector](#).

“Heat-as-a-service” business models for SHIP are also emerging, with France and Mexico having launched the first large systems with heat purchase agreements in 2021. The use of concentrating solar heat for industrial applications is also expanding strongly, with [Spain in the lead](#) thanks to grants available under the [Thermal Energy Production scheme](#). By 2027, the industrial use of solar heat is projected to increase more than twofold globally. Well suited to a variety of industrial applications with low- to medium-temperature heat requirements, the global potential for solar heat in industrial processes is still largely untapped, owing partly to lack of awareness and low policy support.



**Figure 3.3 Contribution of different factors to renewable electricity consumption growth in industry and buildings, selected regions, 2022-2027**



IEA. CC BY 4.0.

Note: RoW = rest of world.

Source: IEA (2022), [World Energy Outlook 2022](#).

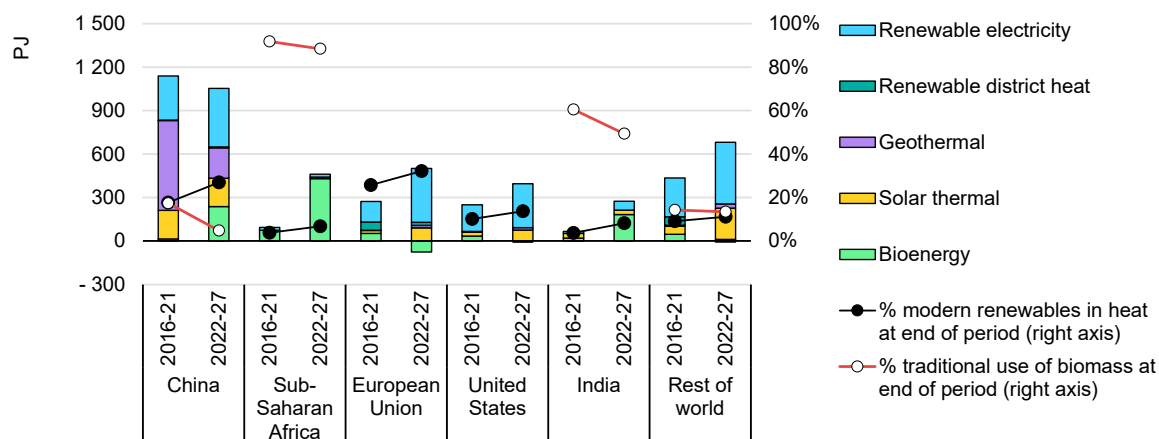
## Buildings

### Heat pump market expansion and the rollout of improved biomass stoves boost modern renewable heat use in buildings

Although building stocks are expanding worldwide, global consumption of heat in buildings (excluding ambient heat) is projected to drop 3.6 EJ during 2022-2027. This decline results mostly from a decrease in the inefficient traditional use of biomass (especially in China and India), efficiency improvements to buildings and heating appliances, and the deployment of heat pumps. China and the European Union demonstrate the largest absolute reduction in building heat consumption, together accounting for more than 80% of the total, followed by Russia, the United States and India.

Over the same period, the modern use of renewable heat in buildings is anticipated to grow almost 30% (+3.2 EJ) globally, with its share in total heat consumption rising from 12% in 2021 to near 16% by 2027 – excluding ambient heat. China alone is responsible for one-third of this growth, while sub-Saharan Africa, the European Union and the United States together contribute almost 40%.

**Figure 3.4 Buildings sector increase in renewable heat consumption and share of renewables in heat demand, selected regions, 2016-2027**



IEA. CC BY 4.0

Source: IEA (2022), [World Energy Outlook 2022](#).

Almost half the growth in renewable heat use in buildings globally is expected to result from a stronger renewable electricity presence as the share of renewables in power generation expands and electric heat pump deployment accelerates. China, the European Union and the United States together account for two-thirds of the 1.6-EJ increase in the use of renewable electricity for thermal purposes in buildings over the outlook period.

In 2021, the European Union registered [record 34% growth in heat pump sales](#), with France, Italy, Germany, Spain and Sweden leading in unit sales, bringing total units in operation in Europe by the end of the year to an estimated 17 million. Heat pump uptake gained further traction in the first half of 2022, with sales [up one-quarter in Germany](#), [80% in Finland](#), 96% in Poland and [114% in Italy](#) (for hydronic heat pumps).

In addition to high gas prices and [growing consumer willingness to reduce dependency on Russian gas](#), policy support for electric heat pumps in the European Union and the United States is expected to significantly boost deployment in these markets. However, strategic co-ordination and robust, diversified supply chains for components, as well as job-training programmes, will be needed to avoid bottlenecks and secure the skilled manufacturing and installation labourers needed to enable rapid market expansion.

The second-largest increase in renewable heat consumption in buildings comes from modern bioenergy use, which represents nearly one-quarter of growth in the outlook period. Most developments in this domain are expected in China, India and sub-Saharan Africa, where improved biomass stoves displace the traditional use of biomass. In contrast, even though wood pellet heating appliances sales

expand, bioenergy consumption in historically large markets such as Europe and the United States stagnates or even declines slightly owing to building efficiency improvements and falling heat demand.

Following seven consecutive years of decline, the global solar thermal market rebounded in 2021 with a [3% increase in installed collector area](#), representing 25.6 GW<sub>th</sub> of new installations and 21 GW<sub>th</sub> of net capacity additions. Growth was made possible by the stabilisation and slight upturn of the Chinese market, which is by far the largest one, representing 83% of global additions, with India, Türkiye and Brazil primarily responsible for the remaining fraction. In relative terms, Italy, the United States, Greece and Poland also experienced remarkable year-on-year market growth.

Small-scale domestic water heaters are the most common solar thermal applications globally, followed by solar combi systems. However, these technologies are facing increasing competition from heat pumps and solar PV systems in large parts of Europe and China. By 2027, solar thermal heat consumption in the buildings sector is projected to increase nearly 40% (+0.6 EJ). One-third of this growth occurs in China alone, while the Middle East, the European Union and the United States together account for half.

Meanwhile, a one-quarter increase (+0.3 EJ) in geothermal heat consumption in buildings is expected during 2022-2027, with China accounting for more than three-quarters of new developments. While the upfront expenses of geothermal heating systems are generally high, recent innovative techniques for [installing underground heat exchangers](#) could reduce their cost while limiting disruption for customers. Together with the development of alternative business models (e.g. heat-as-a-service), these new methods could accelerate expansion in geothermal heat use.

## District heating

In 2021, district heating networks supplied 3% more heat than in the previous year, furnishing 6% of total heat consumed globally. However, the decarbonisation potential of district heating networks remains largely untapped because fossil fuels still dominate district heat production, especially in China and Russia, the world's largest markets.

Renewables (mostly bioenergy, including biogenic waste) were used to produce 8% of district heat supplies globally in 2021, and the use of solar thermal resources, though still limited, continues to progress, with almost [300 solar district systems](#) (total capacity of 1.6 GW<sub>th</sub>) in operation worldwide at the end of 2021 (+10% year-on-year). China has led solar district system developments since the Danish market – historically the largest – collapsed in 2020 following a shift in

policy. Beyond China, solar thermal district systems are garnering increasing interest in Germany, Sweden, Austria, Poland and France.

[Other innovative technological combinations](#) are also being developed, based on the integration and coupling of distributed reversible heat pumps, thermal storage and variable renewables in efficient low-temperature networks. These systems offer promising options to optimally supply heating and cooling to buildings across an entire neighbourhood in densely populated areas.

The share of renewables in district heating is expected to remain stable globally during 2022-2027, while district heat consumption expands 4%. Two-thirds of projected growth in renewable district heat consumption is in the European Union, as greater bioenergy use and the integration of large-scale heat pumps raise the share of renewables by two percentage points to 37%. Most of the remaining growth is expected to take place in China, where district heat consumption – most of which is in the industry sector – expands 13% over the outlook period.

## Chapter 4. Trends to watch

### Question 1: Is the European Union on track to meet its REPowerEU goals?

The REPowerEU plan's aim is to rapidly reduce dependence on Russian fossil fuels by 2027, and the European Commission estimates that this will require significant expansion of renewable energy shares in the electricity, transport and heating sectors. Although the use of renewable energy does increase in all three of these sectors by 2027 in our main-case forecast, in none of them are levels consistent with the REPowerEU plan.

While the share of renewables in electricity expands to almost 55% by 2027 in our main case, this is well below the 69% share the European Commission estimates is needed to support the REPowerEU plan. To enable further increases, governments across the European Union will need to minimise policy uncertainty, simplify permitting procedures and accelerate transmission and distribution network upgrades. Ramping up renewables-based power generation is also essential to expand renewable energy uptake in the transport and heating sectors, as renewable electricity can power electric vehicles and heat pumps and be used to produce green hydrogen.

For transport, a renewable energy share of 16% by 2027 in our main case is less than half the estimated REPowerEU requirement. Member states will need to align their domestic policies, accelerate biofuel deployment and reinforce conservation and efficiency programmes to contain or reduce energy demand and enlarge the share of renewables in final energy consumption.

Meanwhile, renewable energy shares in heating and cooling expand 0.9 percentage points annually up to 2027 – one-third faster than during the last decade, but well below the 2.3-percentage-point annual increases needed to match REPowerEU ambitions. To accelerate deployment, more aggressive policies will be needed to strengthen heat pump supply chains; increase labour availability for installations; integrate renewable energy sources in district heating networks; scale up biomethane production; streamline permitting regulations for large-scale renewable heat projects; and support alternative business models for heating.

Should government and industry overcome deployment challenges in the electricity, transport and heating and cooling sectors, REPowerEU goals appear to be within reach, at least in terms of renewable energy.

**Table 4.1 Summary of renewable energy benchmarks by sector in REPowerEU plan and in main and accelerated cases**

Segment	RePowerEU benchmarks, 2030 <sup>23</sup>	Main case / accelerated case benchmarks, 2027
<b>Electricity<sup>24</sup></b>	69%	54% / n/a
Solar capacity	592 GW	396 GW / 471GW
Wind capacity	510 GW	290 GW / 316 GW
<b>Transport*</b>	32%	16% / 20%
<b>Heating and cooling</b>		
Share of renewable energy in heating and cooling	2.3-percentage-point average annual increase to 2030	0.9-percentage-point average annual increase to 2030**
Share of renewable energy in industry		
Share of renewable energy in buildings sector final energy consumption	1.9-percentage-point average annual increase to 2030	0.9-percentage-point average annual increase to 2030**
	60%	32%**

\* Including RED II multipliers.

\*\* Excluding ambient heat harnessed by heat pumps.

## The REPowerEU plan

The European Commission's [REPowerEU](#) plan, released in May 2022 in response to energy market disruptions from Russia's invasion of Ukraine, aims to rapidly reduce dependence on Russian fossil fuels by 2027. It builds upon existing initiatives, including the Recovery and Resilience Facility, and increases the renewable energy target of the proposed Fit for 55 package (launched in 2021) from 40% to 45%.

This higher aim for renewable energy use, combined with other REPowerEU provisions to reduce energy demand, implies significant increases in renewable capacity shares across the electricity, transport and heating and cooling sectors. The Commission estimates that renewable energy in electricity would need to climb to 69% by 2030, to 32% in transport, and in heating/cooling should expand at least 2.3 percentage points annually.

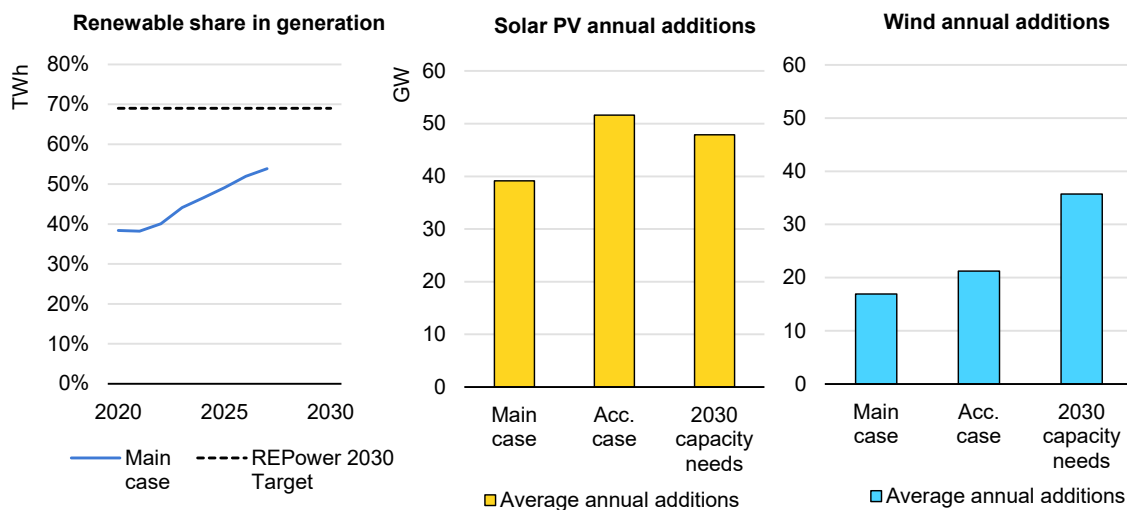
<sup>23</sup> The REPowerEU plan targets a 45% renewable energy share across the European Union as well as numerous other objectives and spending commitments. The European Commission modelled the programme package to determine renewable energy shares likely necessary in electricity, transport and heating (see [Implementing the REPowerEU Action Plan](#), p. 23). While the benchmarks for electricity and transport are based on these modelled outcomes, the heating and cooling annual growth benchmarks are targets in the REPowerEU plan, not just modelled outcomes.

<sup>24</sup> Electricity and transport shares are not REPowerEU targets. Rather, they are European Commission estimates of shares needed to achieve REPowerEU goals.

## Renewable electricity

In our main-case forecast, solar PV and wind capacity expansion are insufficient to reach the REPowerEU plan’s renewable electricity objectives for 2030. According to the latest [European Commission Staff Working Document](#), capacities of 592 GW<sup>25</sup> of solar PV and 510 GW of wind are required by 2030 to achieve the 69% share of renewable electricity modelled by the Commission. This would require average annual additions of 48 GW for solar PV and 36 GW for wind. In comparison, our main case foresees average annual net additions of only 39 GW for solar PV and 17 GW for wind during 2022-2027. This results in a 54% share of renewables-based generation in the electricity sector, 15 percentage points below the 69% desired three years later. Thus, to reach the installed capacity needed to generate 69% of electricity from renewables by 2030, average annual net additions need to be 22% higher for solar PV and more than two times greater for wind.

**Figure 4.1 Renewable electricity shares in main case (left), and average annual additions for solar PV (middle) and wind (right) in the main and accelerated cases (2022-2027)**



IEA. CC BY 4.0.

Note: Acc. case = accelerated case.

Europe’s renewable capacity expansion is limited by three main challenges: inadequate support schemes; lengthy and complex permitting procedures; and the slow pace of transmission and distribution network upgrades.

- **Insufficient or limited policy support** – For utility-scale projects, the uncertainty created by an absence of competitive auctions or limited visibility over future ones in some countries constrains the level of annual additions in

<sup>25</sup> Refers to alternating current (AC) as outlined in the EU Solar Energy Strategy.

the main case. Moreover, most current EU auction designs use bid price as the only selection criterion, which has led to very low or negative bids reducing profitability for both developers and manufacturers. For distributed PV, ambiguity regarding the extension of current support schemes challenges growth in some countries. Insufficient remuneration also prevents faster uptake for self-consumption in some segments.

- **Permitting challenges** – Permitting difficulties are the primary reason auctions have been undersubscribed in Europe for both solar PV and onshore wind. Developers often need a permit to enter an auction, but obtaining it is not always a guarantee. Furthermore, regulations forbid installing renewable energy systems on certain types of land (e.g. agricultural) or set distance limitations for siting turbines near buildings, and social opposition and litigation also lengthen permitting wait times. In addition to building permits, some jurisdictions require permits for transport and for building roads close to construction sites. In many markets, permitting is time-intensive because the complex process involves several steps and institutions (which sometimes lack digitalisation), the response deadline for the approving authority can be long or even unlimited, and understaffing at permitting offices creates backlogs. These challenges lengthen project lead times, drive up costs, and limit the pace of deployment in the main-case forecast.
- **Grid congestion** – Many transmission and distribution networks have insufficient capacity to connect new solar PV and wind plants. System operators therefore need to reinforce existing infrastructure and, in some cases, install new lines. However, permitting complexity, a lack of skilled labour, social opposition and high costs limit the pace of upgrades. Local populations often oppose the construction of overhead lines, and permitting new lines across multiple jurisdictions is a lengthy process. Because it can take years to complete grid improvement projects, developers face long wait times for grid connection approvals, which slows project development.

Addressing some of these challenges could increase the pace of solar and wind deployment in the European Union by 30% between 2022 and 2027. In fact, our accelerated case assumes that increased policy support, regulatory reforms and faster infrastructure development boost average annual solar PV additions to 52 GW, in line with what is needed to reach the REPowerEU target.

For utility-scale solar PV, reaching this level would require countries lacking auction schemes (i.e. Sweden and Belgium) to implement them. Countries already using competitive auctions would have to extend their current scheme (the Netherlands), provide schedules for planned auctions (Italy and Denmark), allocate higher volumes (Spain and Poland) and improve auction design to ensure full subscription (France). Furthermore, countries could consider modifying their auction rules to reflect higher investment costs and ongoing supply chain



challenges, improving the business case for solar PV and wind developers. They could also include non-price criteria (e.g. the security benefits of renewable energy) in the selection process.

For distributed solar PV, if expiring support schemes are extended and remuneration levels raised to make the business case for self-consumption more attractive, annual growth could reach 35 GW by 2027, a pace that would be sufficient to meet the 2030 target. The accelerated case for solar PV also assumes local manufacturing and job-training programmes would ease the logistical and labour constraints currently preventing faster solar PV project development. Equipment delays and higher freight costs on solar cell and module imports have stifled competition in auctions, resulting in undersubscriptions and price hikes, while the shortage of skilled workers has slowed the installation pace for distributed PV systems.

For wind, however, average annual additions still fall below the REPowerEU modelling exercise's 2030 installed capacity objectives despite stronger policy support, regulatory reforms and grid expansion. In the accelerated case, average annual wind additions increase to only 21 GW by 2027, 40% less than the 36 GW needed to achieve the 2030 goals.

For onshore wind, persistent permitting challenges hinder faster growth in the accelerated case. While some countries have announced plans to streamline processes and have formed institutional working groups to propose reforms, the only ones to implement substantial legislative changes for onshore wind permitting over the last year are Germany and Spain. More widespread regulatory changes would be needed to advance onshore wind development such as the temporary emergency regulations proposed by the European Commission to address permitting bottlenecks. In November 2022, the Commission proposed the designation of renewables as a matter of public interest to benefit from simplified procedures for new permits, and it introduced caps on permitting response times under certain conditions. If these were formally passed by the European Council<sup>26</sup> and implemented rapidly at the member-state level, onshore wind development times would be significantly shortened. Uncertainty over the business case for repowering also limits the pace of growth in the accelerated case.

For offshore wind, long lead times and grid connection difficulties continue to be the main impediments to achieving faster growth by 2027. While many countries have raised their ambitions for offshore wind expansion and announced auction plans, the pace of implementation hinges upon new site selection and increasing transmission capacity. Excessive prerequisites for grid connection and for

---

<sup>26</sup> In 29 November 2022, EU energy ministers informally agreed to designate renewable energy projects as part of the "overriding public interest" that would be valid for 18 months. However, this regulation proposal is expected to be formally approved by the European Council after the publication of the Renewables 2022 report.

expanding transmission networks lengthen project lead times and limit the pace of deployment in the accelerated case.

In addition to the technology-specific challenges that hamper faster expansion of renewables, protecting vulnerable consumers through current and proposed market interventions (such as wholesale market caps and windfall-profit taxes) will affect renewable energy investments in the upcoming months. Moreover, the ongoing energy crisis has also sparked new discussions within the European Union concerning future electricity market design. While reforms could, in principle, boost market-driven renewable energy deployment, ensure energy security and encourage investment in flexibility resources, it is important that any reform proposal be carefully and transparently prepared, involving all relevant stakeholders. Failure in this regard could increase investor uncertainty and slow expansion.

## Transport

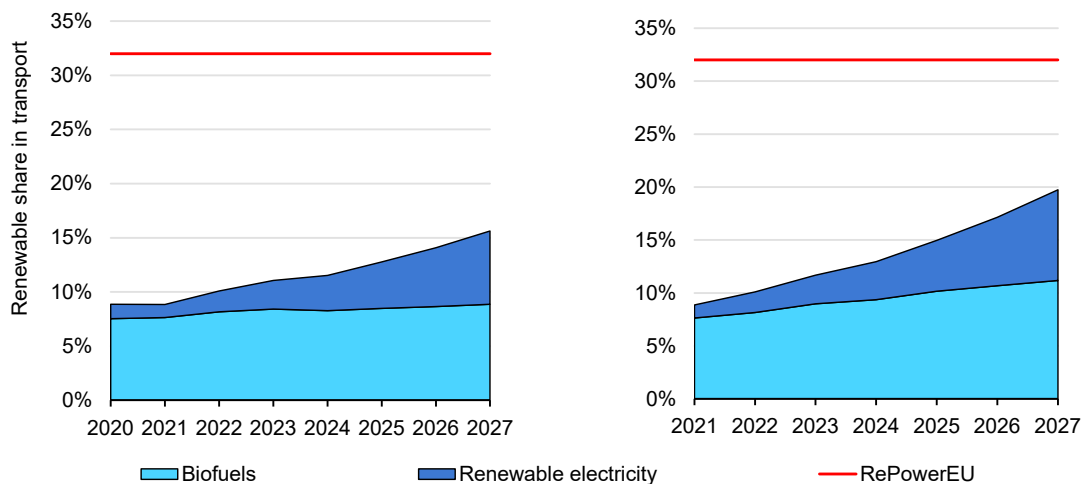
The share of renewable energy consumed in transport in our main case does not meet the level the [European Commission](#) estimates is necessary to achieve the REPowerEU target. While the REPowerEU plan requires a 32%<sup>27</sup> share of renewable energy in transport by 2030, our main case models 16% by 2027, putting the European Union on track for 20% by 2030.

Biofuels make up the largest portion of the renewable energy share in transport, but growing EV sales and renewable capacity expansion mean renewable electricity expands more quickly. To accelerate growth, the European Union would need to adopt more stringent targets, with most member states aligning their domestic policies accordingly. Policies would need to focus on raising biofuel use, boosting EV sales and expanding infrastructure and renewable electricity shares, as well as reducing energy demand through conservation and efficiency measures. Including these actions in the accelerated case puts the European Union on track for a 29% renewable share by 2030, but this still falls short of the REPowerEU requirement.

---

<sup>27</sup> Based on Renewable Energy Directive (Directive 2018/2001/EU) calculation methodology, which includes multipliers for different fuels.

**Figure 4.2 European Union renewable energy share in transport, main case (left) and accelerated case (right), 2020-2030**



IEA. CC BY 4.0.

Notes: Calculations are based on RED II methodology, with multipliers for advanced biofuels (2x), electricity for road transport (5x) and electricity for rail transport (2.5x). Fossil fuel demand include gasoline, diesel and jet fuel based on the IEA Oil Information Database.

In our main case, the renewable share in transport energy consumption expands from 9% in 2020 to 16% in 2027, with biofuel use increasing 1 billion litres during 2022-2027. Member-state policies that require minimum shares of biofuels or renewable fuels (and GHG reductions, in Germany’s case) drive this growth. In most countries, policies are designed to become more stringent over time to meet EU-wide directives, including the revised Renewable Energy Directive (RED II).

The RED II targets 14% renewable energy in transport by 2030, including multipliers, and the share of electric vans and cars on the road rises from [2.3% to 15%](#) across Europe (although every country’s uptake will be different). Electric vehicles are increasingly powered by renewable electricity, as its share in total generation climbs from 37% to almost 55% during 2022-2027. Main-case modelling is based on existing [member state EV policies](#) and EU-level CO<sub>2</sub> emissions standards for new cars and trucks.

Growth is limited in the main case because state- and EU-level policies to meet higher targets are not in place in most cases. To increase the renewable energy share, member states would need to make transport policies more ambitious, expand biofuel production (particularly of advanced biofuels), accelerate electric vehicle deployment and raise renewable electricity shares more quickly. Vehicle efficiency and conservation measures would also reduce gasoline and diesel demand, which could help achieve higher renewable shares in the transport sector.

**Table 4.2 Transport renewable energy shares with and without multipliers, main and accelerated cases**

Year and case	Renewable share with multipliers	Renewable share without multipliers
2020 main case	9%	6%
2027 main case	16%	8%
2027 accelerated case	20%	10%

In the accelerated case, renewable energy in transport climbs to 20% by 2027, putting the European Union on track for a 29% share by 2030. This boost results from policy changes to meet the EU Fit for 55 objective of a 13% decline in GHG emissions intensity in the transport sector by 2030, which the [European Commission](#) estimates would lead to a 28% share of renewable energy in the transport sector. In alignment with this goal, biofuel use expands by an additional 6 billion litres, the electric car and van share of vehicles on the road climbs to 18% and renewable electricity production rises to 59% by 2027. To achieve this growth, member states would need more ambitious transportation programmes. Only Germany, Sweden and Finland have policies in place that exceed the Fit for 55 targets.

Even in the accelerated case, however, the EU transport sector renewable energy share falls short of the REPowerEU estimate. To close this gap, the European Union is considering a 3-percentage-point increase in its requirement for renewable fuels from non-biological sources (such as synthetic fuels made from CO<sub>2</sub> and hydrogen), but it has only one commercial-scale facility under construction so far.

## Renewable heat

In 2020, heating and cooling accounted for over half of the European Union's total final energy consumption, with renewables representing only 23% of it. Decarbonising the heating and cooling sector will thus be crucial for alignment with the overall EU target of at least 55% GHG emissions reductions by 2030. However, our outlook for renewable heat developments in the European Union falls significantly short of REPowerEU requirements.

The 2018 Renewable Energy Directive (RED II) introduced an indicative target for each member country to increase the share of renewables in heating and cooling by 1.1 percentage points annually through 2030, with a similar target for district heating and cooling. The proposed 2021 revision of the RED II strengthens these targets and introduces new ones for integrating renewables in the buildings and industry sectors.

More recently, European Commission modelling of the REPowerEU plan, published in May 2022, suggests a pathway to meet the targeted 45% renewable energy share in overall total final energy consumption. In this scenario, the share of renewables in heating and cooling and in district heating and cooling increases an average of 2.3 percentage points annually to 2030 and by 1.9 percentage points in industry, while the share of renewables in the buildings sector climbs to 60% by 2030.<sup>28</sup>

Nevertheless, in June 2022 the European Council announced its negotiation position, which includes less ambitious minimal binding targets of an 0.8-percentage-point annual increase in the share of renewables in heating and cooling up to 2025, and a 1.1-percentage-point annual increase over 2026-2030. It is also considering the indicative target of a 1.1-percentage-point annual increase for the share of renewables in industry, as well as a 49% indicative target for renewables in buildings sector final energy consumption by 2030.

In September 2022, the European Parliament adopted a series of amendments that define its starting position for the ongoing trilogue negotiations on the RED II revision proposal. They include the indicative target of a 2.3-percentage-point average annual increase in the share of renewables in heating and cooling during the periods 2021-2025 and 2026-2030 (and the same target for district heating and cooling); an indicative average annual increase of 1.9 percentage points in industry during the periods 2024-2027 and 2027-2030; and an indicative target of 49% renewables in buildings by 2030.

**Table 4.3 European Union proposed targets for renewable heating and cooling**

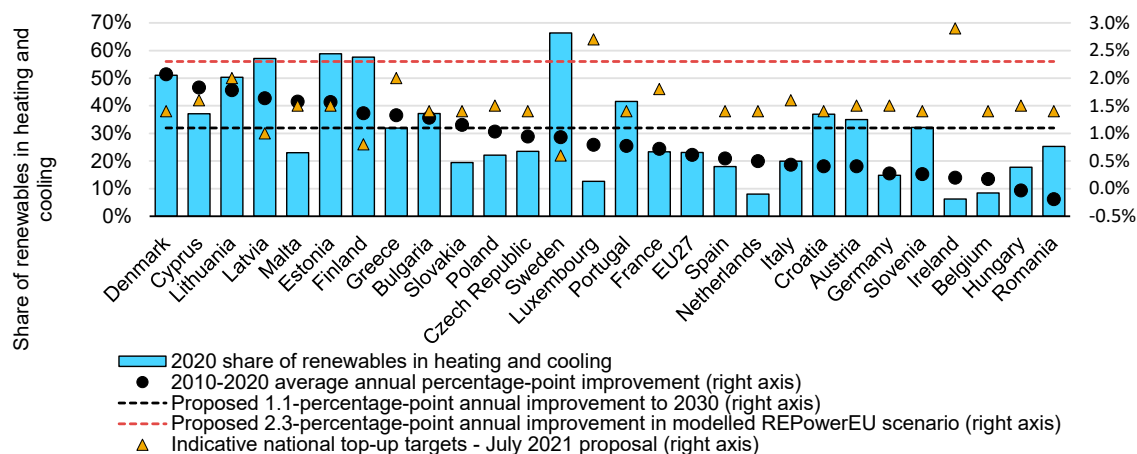
<b>RED II – 2018 (EC 2018/2001)</b>	<p><a href="#">Article 23 – Mainstreaming renewable energy in heating and cooling:</a></p> <ul style="list-style-type: none"> <li>• Indicative target for the share of renewables in heating and cooling: average annual increase of 1.1 percentage points over 2021-2025 and 2026-2030 (1.3 percentage points for states where waste heat and cold are used) <ul style="list-style-type: none"> <li>○ Target reduced by half for countries with share of renewables in heating and cooling between 50% and 60%</li> <li>○ Target does not apply to countries with a renewable share above 60%</li> </ul> </li> <li>• Indicative target for the share of renewables in district heating and cooling: average annual increase of 1 percentage point over 2021-2025 and 2026-2030</li> </ul>
<b>RED II revision proposal – July 2021</b>	<ul style="list-style-type: none"> <li>• Minimal binding target for all member states for the share of renewables in heating and cooling: average annual increase of 1.1 percentage points over 2021-2025 and 2026-2030 (1.5 percentage points for states where waste heat and cold are used) <ul style="list-style-type: none"> <li>○ Target reduced by half for countries with the share of renewables in heating and cooling between 50% and 60%</li> <li>○ Target does not apply to countries with a renewable share above 60%</li> <li>○ Indicative country-specific top-up targets</li> </ul> </li> </ul>

<sup>28</sup> The first figures from the EU Solar Energy Strategy were also announced in May 2022. According to this strategy, the joint contribution of solar thermal and geothermal would need to at least triple by 2030.

	<ul style="list-style-type: none"> <li>• Indicative target for the share of renewables in district heating and cooling: average annual increase of 2.1 percentage point over 2021-2025 and 2026-2030</li> <li>• Indicative target for the share of renewables in industry: annual average increase of 1.1 percentage points over 2021-2025 and 2026-2030</li> <li>• Requirement for each member state to achieve a share of at least 49% renewables in buildings sector final energy consumption by 2030</li> </ul>
<p><b>Commission Staff Working Document Implementing the REPowerEU Action Plan – May 2022</b></p>	<p><a href="#">REPowerEU scenario</a> assessed through modelling (model <i>PRIMES</i>):</p> <ul style="list-style-type: none"> <li>• 2.3-percentage-point average annual increase in the share of renewables in heating and cooling over 2020-2030 at the EU level</li> <li>• 2.3-percentage-point average annual increase in the share of renewables in district heating and cooling over 2020-2030 at the EU level</li> <li>• 1.9-percentage-point average annual increase in the share of renewables in industry over 2020-2030 at the EU level</li> <li>• Share of renewables in buildings: 60% in 2030 at the EU level</li> </ul>
<p><b>European Council revision proposal – June 2022</b></p>	<p>Negotiating positions <a href="#">adopted by the European Council in June 2022</a> :</p> <ul style="list-style-type: none"> <li>• Minimal binding target for each member state for the share of renewables in heating and cooling: 0.8-percentage-point annual increase until 2025; 1.1-percentage-point annual increase over 2026-2030 <ul style="list-style-type: none"> <li>◦ Country-specific indicative top-up targets for the share of renewables in heating and cooling</li> </ul> </li> <li>• Indicative target of 49% renewables in buildings sector final energy consumption by 2030</li> <li>• Indicative target of 1.1-percentage-point annual increase in the share of renewables in industry</li> </ul>
<p><b>European Parliament revision proposal – September 2022</b></p>	<p>Amendments <a href="#">adopted by the European Parliament in September 2022</a>:</p> <ul style="list-style-type: none"> <li>• Indicative target for each member state for the share of renewables in heating and cooling: 2.3-percentage-point average annual increase until 2025 and over 2026-2030 (2.8 percentage points for member states that use waste heat and cold)</li> <li>• Indicative target of 49% renewables in buildings sector final energy consumption by 2030</li> <li>• Indicative target of 1.9-percentage-point annual increase in the share of renewables in industry over the periods 2024-2027 and 2027-2030</li> <li>• Indicative target of 2.3-percentage-point average annual increase in the share of renewables in district heating and cooling over the periods 2021-2025 and 2026-2030</li> </ul>

Over 2010-2020, the EU share of renewables in heating and cooling increased by just 0.6 percentage points annually on average, with the industry sector on its own performing similarly. Only 13 member countries recorded average annual increases of more than 0.8 percentage points, and only 8 exceeded the indicative top-ups proposed in July 2021 for the period to 2030. While this progress was sufficient to meet the EU-wide overall target of 20% renewables in total final energy consumption by 2020, it fell short of REPowerEU targets. Thus, achieving REPowerEU ambitions for 2030 will require considerably faster renewable heat uptake in most member countries.

**Figure 4.3 Share of renewables in heating and cooling, historical average annual progress and proposed targets for EU member states**



IEA. CC BY 4.0.

Source: Eurostat (2020), [SHARES database](#).

Looking forward, the EU share of renewables in heating and cooling – excluding ambient heat – is expected to rise an average of 0.8 percentage points annually over 2022-2025 and by 1.0 percentage point over 2026-2027. Including ambient heat harnessed by heat pumps, the outlook at the regional aggregate level may align with the European Council’s negotiation positions as well as with the minimal heating and cooling targets of the proposed 2021 RED II revision. However, it would still be far behind the much higher development pace required in the European Commission’s modelling assessment of the REPowerEU scenario (i.e. a 2.3-percentage-point annual increase). According to the European Commission, the deployment of renewable heat technologies, especially heat pumps, would need to accelerate tremendously over the next seven years.

Regarding heat pumps, recent European market evolution is encouraging: in 2021, EU sales totalled a [record-high 2.2 million units](#) – a 34% increase year-on-year. In Germany, heat pump installations in the first half of 2022 were [up by one-quarter](#) compared with the same period in 2021, and there were [as many applications for federal funding to install heat pumps in August 2022 as during the whole of 2021](#). In Poland, the share of heat pumps in applications for heat system subsidies under the Clean Air Programme in 2022 [rose from 28% in January to 60% in June](#). This trend is expected to endure in the medium term, sustained by high energy prices and supported by the ambitious REPowerEU target of 10 million hydronic heat pump installations over the next five years. However, such acceleration is already challenging the capabilities of supply chains, which will need to expand rapidly to avoid bottlenecks. The availability of skilled installers is another uncertainty.

Projected developments in the industry sector and district heating are also expected to fall below REPowerEU ambitions, with the share of renewables (excluding ambient heat) in final industrial heat consumption anticipated to rise by less than 0.9 percentage points annually over 2022-2027, and in district heating by only 0.3 percentage points.

Achieving REPowerEU objectives will require strong policy action along two key axes: (i) accelerated deployment of renewable heat technologies in buildings, industry and district heating and cooling; and (ii) energy conservation and demand reductions through energy and material efficiency and from large-scale behavioural changes. Policy strategies may articulate a combination of informational measures, regulatory instruments and incentives. They could, for instance, focus on overcoming the relatively high upfront costs of renewable technologies through specific loan schemes, investment grants or support for the development of innovative business models (e.g. heat-as-a-service). Policies could also focus on making the business case for renewable technologies more attractive by offering specific energy tariffs.

Among the many other policy options to accelerate renewable heat uptake are bans on fossil fuel-based appliances in new buildings; tailored informational support for households and companies (e.g. through audit campaigns); and support for building and heat distribution system retrofits to enhance compatibility with renewable heat options. In addition, industrial policies that include job-training programmes (e.g. for renewable technology installers), as well as strong international co-operation among EU member states and with other regions, will be necessary to enable rapid upscaling of international renewable heat technology supply chains, such as for heat pumps.



## Question 2: Is renewable energy capacity in the European Union making windfall profits from high wholesale prices?

Russia's invasion of Ukraine triggered a global energy crisis, leading to sharp increases in oil, natural gas and coal prices. As a result, electricity prices in Europe have risen drastically because natural gas-fuelled plants remain the price-setter in the wholesale market. Furthermore, high fossil fuel prices have resulted in windfall profits for some energy companies. In fact, the profits of major oil, gas, coal and refinery companies in the first half of 2022 more than doubled from the same period last year, and discussion on windfall profits in the European Union has extended to electricity generators (including renewables-based ones) that can produce electricity at lower marginal costs than natural gas-fuelled power plants.

In October 2022, the European Council passed a [regulation on an emergency intervention to address high energy prices](#). The regulation proposes windfall-profit levies on fossil fuel producers through a temporary solidarity contribution, and on electricity generators (or inframarginal electricity producers) that have lower marginal costs than the price-setting gas units.

The Council also introduced plans to cap the wholesale electricity price at EUR 180/MWh or lower, and expects that member countries would raise [EUR 117 billion](#) annually. This market intervention aims to reduce electricity prices to protect and support vulnerable energy consumers. As the proposal's interpretation and implementation by each member state remains an uncertainty, its implications at the country and EU level are difficult to estimate. In addition, several European countries have already introduced national-level windfall taxes for electricity generation and trading companies.

The direct answer to whether renewable power plant owners are making windfall profits is highly complex. While renewable energy policies can provide insights on whether developers are allowed to receive higher revenues from the market, they can only partially answer the question on windfall profits because data are limited concerning non-policy factors, including long-term bilateral power purchase contracts, developers' hedging strategies and exposure in the wholesale electricity market. To understand these non-policy factors, we examined the balance sheets of the European utilities with large operational renewable and fossil fuel capacities.

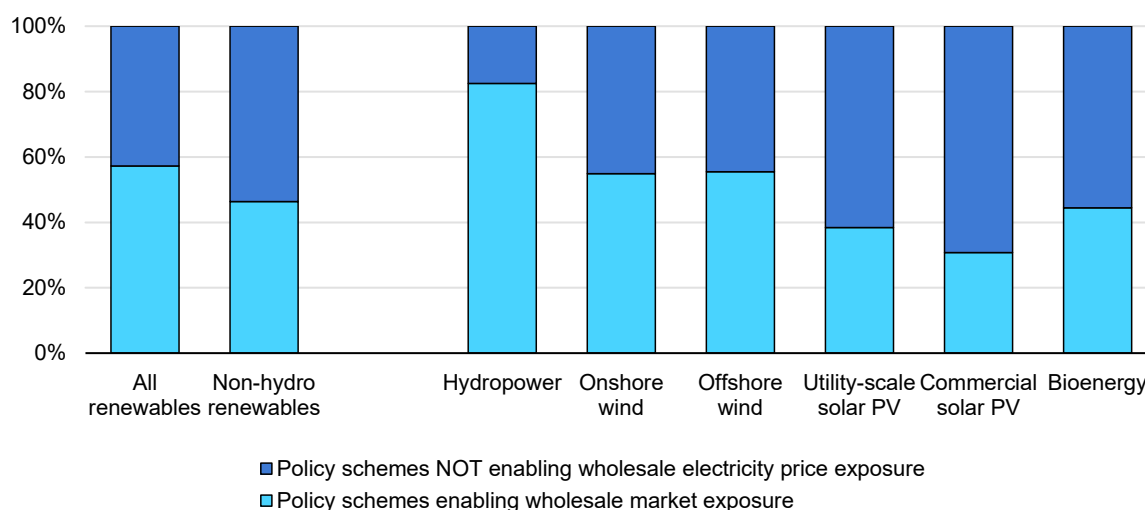
### Policy schemes

In the European Union, policy schemes make more than half of utility- and commercial-scale renewable power capacity (including large-scale hydropower) eligible to receive wholesale energy prices. Excluding hydropower, wholesale market exposure is under 40% for wind, solar PV and bioenergy technologies.

Hydropower plants, which account for one-quarter of EU installed capacity (built mostly during the 1960s and '70s), are usually not covered under any policy scheme unless they are small-scale projects. Thus, a significant majority of these largely amortised hydropower plants could receive high wholesale electricity prices in the absence of long-term fixed-price bilateral contracts. For instance, a [recent financial report](#) of the Norwegian utility Statkraft, which has one of the largest operating hydropower plants in Europe, indicates that only one-third of its generation is hedged in the medium and long term.

Over the last decade, European renewable power incentive schemes have evolved from FITs to competitive auction schemes with FIPs, exposing renewable technologies (especially utility-scale wind and solar PV plants) to market prices. The classical feed-in-tariff policy commonly implemented in most EU member countries until 2015-2017 for utility-scale and commercial projects is based on 20-year fixed-price contracts, and thus does not expose renewable power plants to market prices. We estimate that the significant majority of onshore wind, solar PV and bioenergy projects (totalling around 200 GW commissioned between 2003 and 2013/14) are under classical feed-in-tariff schemes, with the remainder contracted mostly under former green-certificate arrangements exposed to wholesale price revenues.

**Figure 4.4 European Union shares of installed renewable capacity by exposure to wholesale market price, based on member country policy schemes**



IEA. CC BY 4.0.

Note: The significant majority of European hydropower plants are not under a policy scheme.

Since 2012/13, EU countries (led by Germany) have been introducing sliding FIPs with a floor price defined through competitive auctions. The purpose of these schemes is to facilitate market integration of renewables by enabling developers to sell electricity in the spot market while receiving subsidies to top up their

revenues. However, contract prices awarded in feed-in-premium schemes were lower than average wholesale prices over the past decade, enabling projects to receive subsidies. Today, these projects (onshore wind, offshore wind and utility-scale solar PV), located mostly in Germany, the Netherlands and Denmark, could benefit from high spot-market prices. In Spain, the RECORE regime, which caps the returns of most wind and PV plants commissioned before 2019, also enables developers to receive market revenues if projects have already achieved regulated profits.

Recently, more EU countries have introduced CfD auctions. CfDs require developers to pay back additional revenues if wholesale prices exceed the strike price. They provide revenue certainty and enable developers to share risks with off-takers, minimising the impact of wholesale electricity prices on project economics. In the European Union, the majority of onshore and offshore wind capacity operational today could receive market prices through FIPs, while utility-scale solar PV projects are mostly exposed to either classic FITs or CfDs. For commercial solar PV projects, FITs or fixed tariffs for remuneration of excess generation remain the common incentive schemes. Thus, almost 70% of these projects cannot receive wholesale electricity prices.

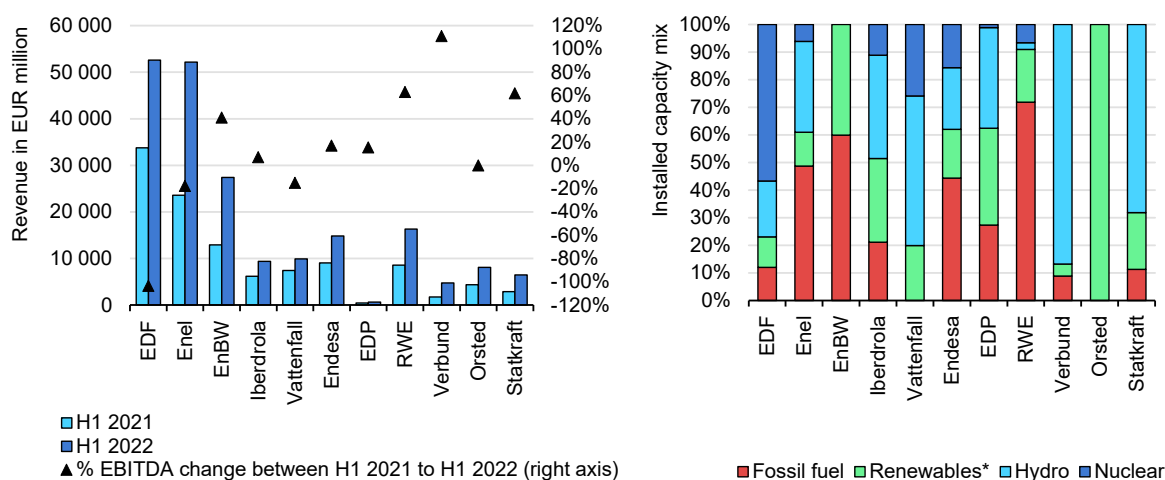
## Financial situation of selected large European utilities

The financial statements of large European utilities indicate higher revenues resulting from steep fossil fuel and electricity prices in the first half of 2022 compared with the same period in 2021. However, unlike for oil and gas majors, higher revenues for European utilities have not always translated into profits in recent months because utility companies have diverse business profiles, allowing them to compensate losses in one business segment with profits from another. Plus, technological and geographical portfolios as well as business strategies have been important determinants for how companies are navigating the global energy crisis.

Our analysis cannot be generalised to cover the entire EU market, as it assesses just ten large utilities, or around one-quarter of total installed EU electricity generation capacity. The majority of installed renewable capacity is owned and operated by private companies that are not obligated to disclose their financial standing.

**All the major utilities reported significantly higher revenues but also higher costs** in H1 2022 than in H1 2021, with hikes ranging from 30% to 170%. Higher average electricity and gas prices since November 2021 have clearly boosted revenues. However, even though all large utilities reported higher revenues in H1 2022, their financial performance and profitability within Europe were quite different due to a myriad of variables, including generation mix diversity; the splitting of earnings before interest, taxes, depreciation and amortisation (EBITDA) into different operations involving regulated networks, contracted renewables and trading activities; and exposure to retail business.

**Figure 4.5 Revenue and EBITDA comparison of major European utilities for the first halves of 2022 and 2021 (left) and their shares in installed generation capacity mix (right)**



IEA. CC BY 4.0.

\* Mainly wind and solar resources. Due to its larger volumes, hydro is shown separately.

Note: Most of these utilities are geographically diversified. For example, utilities such as Iberdrola, EDP and Enel have a strong presence in North America and Latin America, where the markets have different regulations and dynamics. Some European utilities also operate in the United Kingdom and others have a global presence. Most of these utilities are also integrated, giving them cash flows from activities across the value chain.

Sources: [EDF](#); [ENEL](#); [EnBW](#); [Iberdrola](#); [Vattenfall](#); [Endesa](#); [EDP](#); [RWE](#); [Verbund](#); [Orsted](#); [Statkraft](#).

An increase in costly fossil fuel-based generation is compensating for lower hydropower output in Europe. Indeed, extreme drought conditions in Italy, France, Spain and Portugal reduced EU hydropower output by more than 15% in the first half of 2022. Lower hydropower generation reduced the European EBITDA of Enel, Iberdrola and EDP, although higher profits from increased fossil fuel-fired generation and trading activities made up for this loss. In addition, these utilities had to purchase energy from the market at higher prices to meet their retail customer obligations, putting further pressure on their profitability.

EDF's nuclear power generation dropped more than 15% and hydropower production was 23% lower in the first half of 2022 compared with the same period in 2021, requiring the company to purchase electricity from the spot market at high prices and reducing its revenues significantly. In some cases, higher wind and solar PV generation and additional installed capacity have contributed to profitability. For example, EnBW registered an EBITDA rise of 43% related to its renewable energy business, and Orsted, a utility with major investments in renewable generation, increased its EBITDA (excluding new partnerships) by 48% relative to H1 2021.

**Exposure to retail and customer business reduced utilities' profitability.**

Most major European utilities have large retail customer businesses. While electricity generation and purchase costs have risen drastically, retail price increases remain limited in most parts of Europe due to regulated-price contracts

and to additional government interventions to protect consumers in the current extraordinary situation.

For instance, Spain and Portugal capped the wholesale gas price for power plant use at EUR 40/MWh, leading to relatively lower wholesale electricity prices and shielding Iberian electricity consumers. In general, most utilities' retail businesses recorded a lower EBITDA in the first half of 2022 than in 2021. For instance, EDF's EBITDA dropped sharply in France due to the government's regulatory measures to limit sales price increases for consumers in 2022.

**Hedging strategies and long-term contracts are key tools for utilities to navigate the current European energy crisis.** The exposure of European utilities on wholesale markets can vary significantly, impacting their profits. For instance, only [one-third of Statkraft's total generation is hedged](#) through 2030, resulting in higher revenues from the electricity spot market. At the same time, however, [Orsted's low 10% exposure to the wholesale market](#) limits the company's ability to profit from high market prices. For Verbund, the company's hedging strategy has increased its profits, as it was able to obtain an average sale price of EUR 112.5/MWh in H1 2022, boosting its electricity revenue considerably and raising its EBITDA, 111% from the previous year.

Meanwhile, Spain introduced a clawback mechanism for forward electricity contracts of more than EUR 67/MWh, but Iberdrola contracted unregulated renewable generation with its retail business at [EUR 66/MWh in January 2022](#), before Spain had introduced the clawback mechanism. The fixed-price policy partly sheltered the company from volatile wholesale market prices.

### **Policies and regulations on windfall profits**

Several European countries have introduced regulatory measures to tax energy companies' extraordinary profits or revenues, with the aim of limiting inflation increases and protecting society's most vulnerable consumers. For the electricity sector, governments expect to collect additional taxation income on the profits or revenues of generation units that have low marginal costs, including renewable energy producers and energy trading companies that have been selling/trading generation in the wholesale market.

Five European countries (Greece, Hungary, Italy, Spain, and Romania) already began implementing new taxation and fiscal measures in 2022 to claw back windfall profits covering periods of six months to three years, while discussion on this topic is ongoing in nine other EU countries. In addition, Germany has announced that it expects to raise about EUR 10 billion by imposing windfall taxes on electricity generators, and Belgium anticipates EUR 3 billion. While remuneration policies may enable renewable energy generators to tap into the wholesale market to receive higher revenues, hedging mechanisms and long-term bilateral contracts make the actual amount governments could eventually collect less certain.

**Table 4.4 Selected European countries that have introduced or announced a windfall-profit tax**

Country	Tax rate	Status	Period	Announced revenue estimates (EUR billion)
Greece	90%	Implemented	2021 - 2022	<a href="#">0.6</a>
Hungary	40%	Implemented	2022 - 2023	<a href="#">2.1</a>
Italy	25%	Implemented	2021 - 2022	<a href="#">2 (collected)</a> <a href="#">10-11</a>
	50%	Announced/Proposed	2022 - 2023	
Spain	Varying rates	Implemented	2022 - 2024	<a href="#">7</a>
Romania	80%	Implemented	2022 - 2023	Unknown
Germany	90%	Announced/Proposed	Undecided	<a href="#">10</a>
Poland	80%	Announced/Proposed	2022 - 2023	<a href="#">Undecided</a>
Slovakia	50%	Announced/proposed	Unknown	Unknown
Czech Republic	60%	Announced/proposed	2023 - 2025	<a href="#">6</a>
Belgium	38%	Announced/proposed	2022 - 2024	<a href="#">3.1</a>
France	Undecided	Announced/proposed	Unknown	Undecided
Netherlands	Undecided	Announced/proposed	2022 - 2024	<a href="#">2.8</a>
Finland	Undecided	Announced/proposed	2022 - 2023	<a href="#">0.04</a>

## Implications for the energy transition in Europe

Accelerating renewable energy expansion is crucial to reduce EU reliance on imported fossil fuels from Russia. Large utilities and independent power producers continue to be the main investors in renewables in Europe and thus have a pivotal role in increasing the pace of wind and solar PV expansion. Following the European Council's October 2022 regulation of price caps for electricity generators, more EU countries are expected to introduce new regulatory measures.

The current regulation enables member countries to define their own price caps as well as clawback mechanisms for profits or revenues, depending on national circumstances. However, inconsistencies among regulatory regimes could create uncertainty for investors, especially if they make the business case for renewables less appealing. Thus, it is important for regulations to tax profits from energy sales in the wholesale market and not revenues.

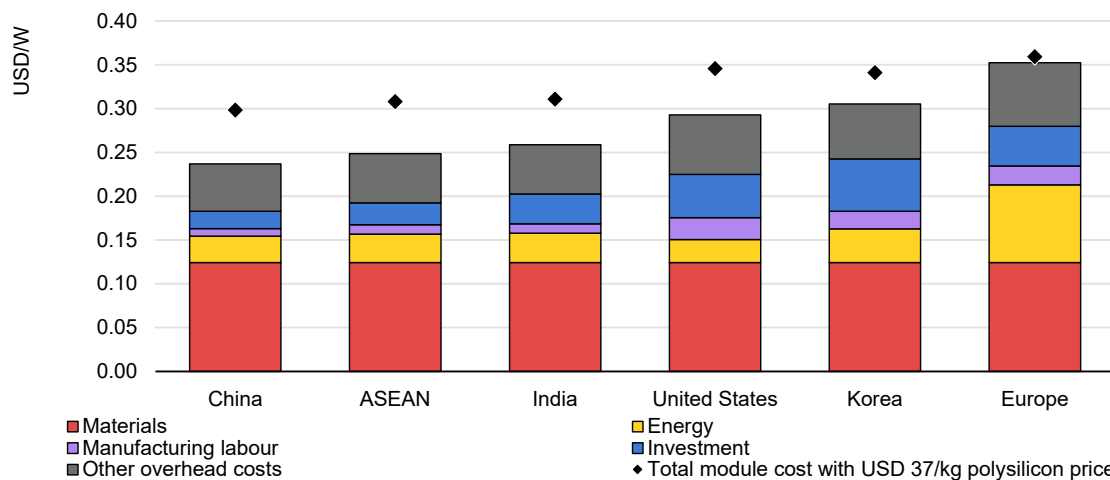
## **Question 3: Will new PV manufacturing policies in the United States, India and the European Union create global PV supply diversification?**

The high level of geographical concentration in the global PV supply chain has led the European Union, India and the United States to introduce policy incentives to support domestic PV production. This could result in an unprecedented expansion of PV manufacturing outside of China in the next five years. However, diversifying manufacturing will be possible only if production costs fall to ensure competitiveness with the lowest-cost producers (e.g. in China and ASEAN countries) in both the short and long term.

### **PV manufacturing cost-competitiveness**

In the past year, rising global commodity prices have led to higher material costs for solar PV manufacturing. Today, China and ASEAN countries (Viet Nam, Thailand and Malaysia) have the lowest solar PV module manufacturing costs for all segments of the supply chain. Economies of scale, supply chain integration, relatively low energy costs and labour productivity make China the most competitive solar module manufacturer worldwide. Higher investment costs in India are the primary reason for the cost differential with China, while higher overhead and labour costs makes US PV manufacturing not as competitive. In Europe, rising energy prices following Russia's invasion of Ukraine widened the cost gap with China. Today, EU industrial energy prices are more than triple those of China, India and the United States.

**Figure 4.6 Total manufacturing costs for mono PERC c-Si solar components by input, 2022**



IEA. CC BY 4.0.

Notes: ASEAN = Association of Southeast Asian Nations. Values exclude subsidies as well as additional costs such as transportation, company profits, taxes and tariffs. Thus, total cost inputs may not match final market sale prices. Polysilicon prices include the processing of metallurgical-grade silicon. Industrial electricity prices used in this analysis: China, USD 88.20/MWh; ASEAN, USD 101.27/MWh; India, USD 123.79/MWh; United States, USD 79.07/MWh; Korea, USD 105.14/MWh; Europe, USD 325/MWh. Commodity prices from October 2021-September 2022 used in this analysis: glass, USD 590/Mt; aluminium, USD 2 779/Mt; polymers, USD 6 000/Mt; silica sand (quartz), USD 100/Mt; copper, USD 9 160/Mt; silver, USD 706/kg; zinc, USD 3 618/Mt; lead, USD 2 203/Mt; tin, USD 35 190/Mt; other, USD 18 700/Mt.

## Manufacturing policies in India and the United States

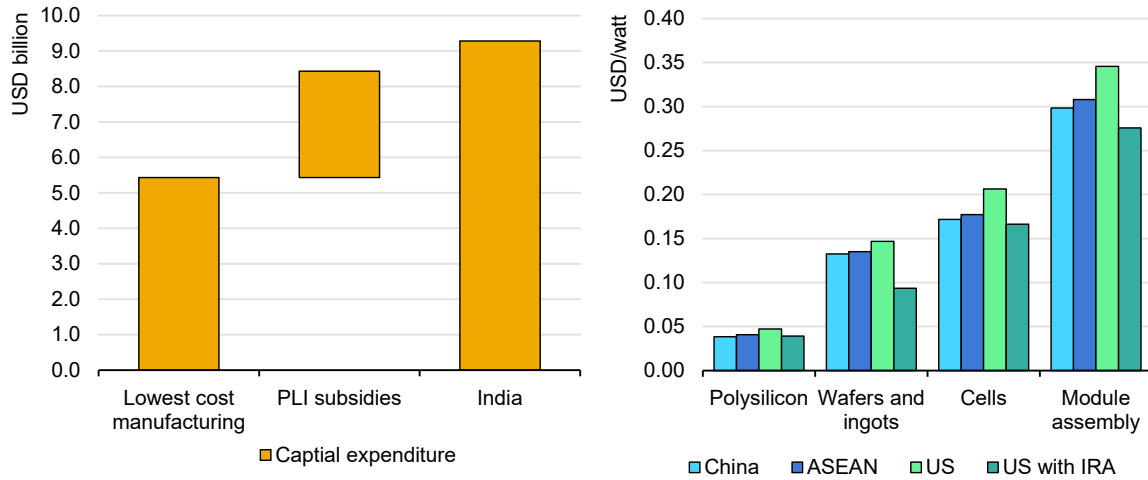
Recent policy actions in India and the United States aim to increase the competitiveness of domestic manufacturing through subsidies and tax rebates, while the European Union is considering similar steps. India’s PLI scheme and the US IRA offer manufacturers support in different ways. While the PLI furnishes a subsidy to reduce plant investment costs through payments linked with achieved production, the IRA provides a PTCs for the manufacturing of certain equipment, including solar PV modules, cells, wafers and polysilicon through 2032.<sup>29</sup>

According to estimates, PLI support closes nearly 80% of the investment cost gap between India and the lowest-cost manufacturers in China. However, the one-time subsidy means that manufacturing efficiencies will need to be achieved through economies of scale to maintain long-term competitiveness. Meanwhile, fully monetising manufacturing tax credits in the United States could bring all the country’s segments of solar PV manufacturing to cost parity with the lowest-cost manufacturers.

<sup>29</sup> The IRA provides tax credits for a range of products, including but not limited to solar PV equipment and inverters and wind turbines.



**Figure 4.7 India PLI subsidies and investment cost difference with lowest cost manufacturing (left) and US c-Si manufacturing costs with and without IRA Manufacturing Production Tax Credit, compared with China and ASEAN (right)**



IEA. CC BY 4.0.

Notes: PLI = Production-Linked Incentive (India). IRA = Inflation Reduction Act (United States). ASEAN = Association of Southeast Asian Nations. PLI costs represent the investment required to produce 18.85 GW of polysilicon, 27.85 GW of wafers/ingots, and 36.85 GW of cells and modules.

Favourable solar PV manufacturing policies in India and the United States have spurred multiple new project announcements. In the first phase of India’s PLI programme, almost 9 GW of integrated manufacturing capacity were contracted, and in the second phase the government is expecting to subsidise another 65 GW. In the United States, expansion already planned includes the manufacturing of roughly 9 GW of integrated crystalline silicon (c-Si) modules and 6 GW of thin-film panels.

**Table 4.5 Planned solar PV component manufacturing expansion in the United States and India in 2022**

Country	Company	Component	New capacity
United States	<a href="#">First Solar</a>	Thin-film modules	3.5 GW
United States	<a href="#">Q Cells</a>	Integrated c-Si modules	9.0 GW
United States	<a href="#">SPI Energy</a>	Wafers/ingots	1.5 GW
United States	<a href="#">REC Silicon</a>	Polysilicon	20 000 MT
United States	<a href="#">Fuyao Group</a>	Glass	-
United States	<a href="#">Toledo Solar</a>	Thin-film modules	2.7 GW

Country	Company	Component	New capacity
United States	<a href="#">Meyer Burger</a>	Modules	1.5 GW
United States	<a href="#">PV Hardware</a>	Trackers	6.0 GW
United States	<a href="#">Endurans Solar</a>	Backsheets	-
United States	<a href="#">Q Cells</a>	Modules	1.4 GW
United States	<a href="#">GameChange Solar</a>	Trackers	6.0 GW
United States	<a href="#">Mission Solar</a>	Modules	700 MW
United States	<a href="#">3Sun (Enel)</a>	Modules/cells	3.0 GW
India	<a href="#">Reliance New Energy</a>	Integrated PV	4.0 GW
India	<a href="#">Adani Infrastructure</a>	Integrated PV	737 MW
India	<a href="#">Shirdi Sai</a>	Integrated PV	4.0 GW

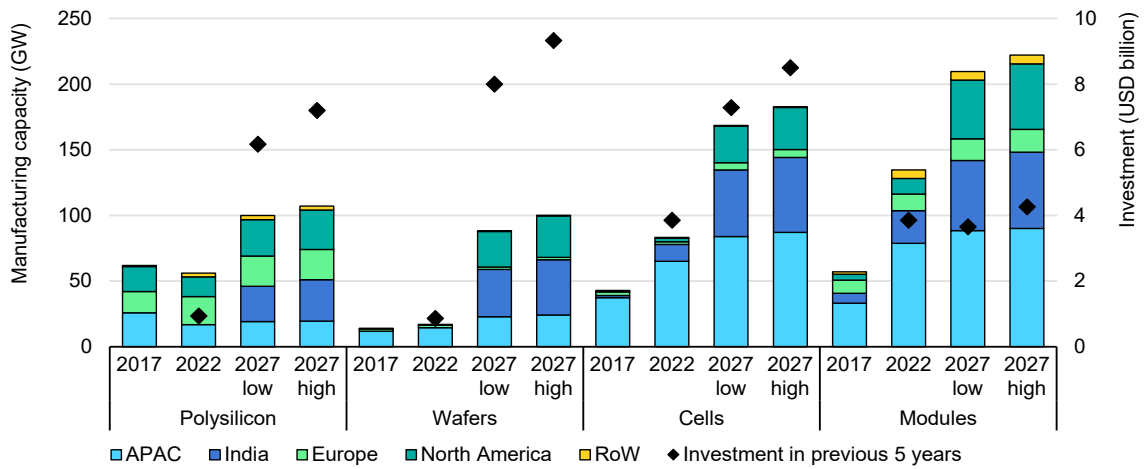
In addition to manufacturing subsidies, tariffs on imported PV equipment and local-content premiums encourage project developers to purchase domestically manufactured products. In India, import duties were increased from 15% to 40% for PV modules and to 25% for cells, making local manufacturers significantly more cost-competitive. In addition, all PV modules used in projects subsidised under national support programmes must be manufactured by companies named in the government-maintained list, which currently has only Indian manufacturers.

In the United States, the IRA offers an additional investment or PTCs bonus for the use of domestically produced content. These types of policies significantly boost local manufacturers' confidence about demand for their products, resulting in more ambitious expansion plans.

## Solar PV manufacturing capacity and production forecast to 2027

Policies and planned PV manufacturing capacity in India, the United States and the ASEAN region will increase production capabilities outside of China, especially for polysilicon, wafer and ingot manufacturing. In fact, wafer manufacturing capacity in these countries is forecast to increase almost fivefold in the next five years, and polysilicon and solar cell manufacturing could double by 2027. However, achieving this level of growth will require almost USD 30 billion of new investment, close to three times more than these countries committed in the previous five years.

**Figure 4.8 Solar PV manufacturing capacity outside China and total investment by 5-year periods, 2017-2027**



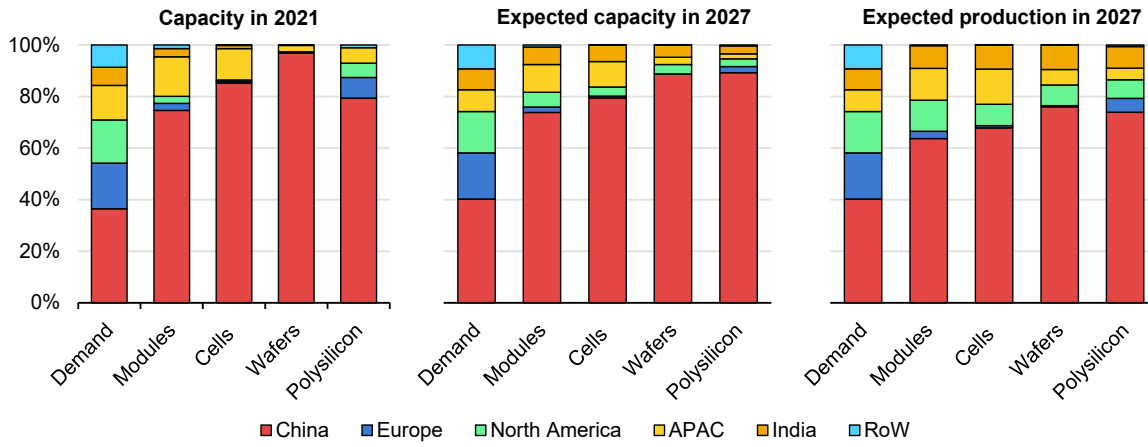
IEA. CC BY 4.0.

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.

As a result, China’s share of manufacturing capacity could decrease slightly, from 80-95% to 75-90% depending on the segment. Furthermore, if countries maintain trade policies that limit imports and favour domestically produced PV products, greater geographical distribution in the global solar PV supply chain could result in China’s share in production shrinking from 75-90% to 60-75% by 2027.

However, China plans to expand manufacturing throughout the entire supply chain much more quickly than India, the United States and other countries do. This is expected to cause a major glut by 2027, with supply significantly exceeding expected global PV demand in most optimistic forecasts. The result would be plant utilisation factors of as low as 25-30% in China for all manufacturing segments, about half of today’s level. This supply glut could also create fierce price competition and cause investors to cancel many announced manufacturing expansion projects both within and outside of China.

**Figure 4.9 Solar PV manufacturing capacity and production by country and region, 2021-2027**



IEA. CC BY 4.0.

Notes: APAC = Asia Pacific region excluding India and China. RoW = Rest of world. Manufacturing capacity and production in 2027 are the values expected based on announced policies and projects.

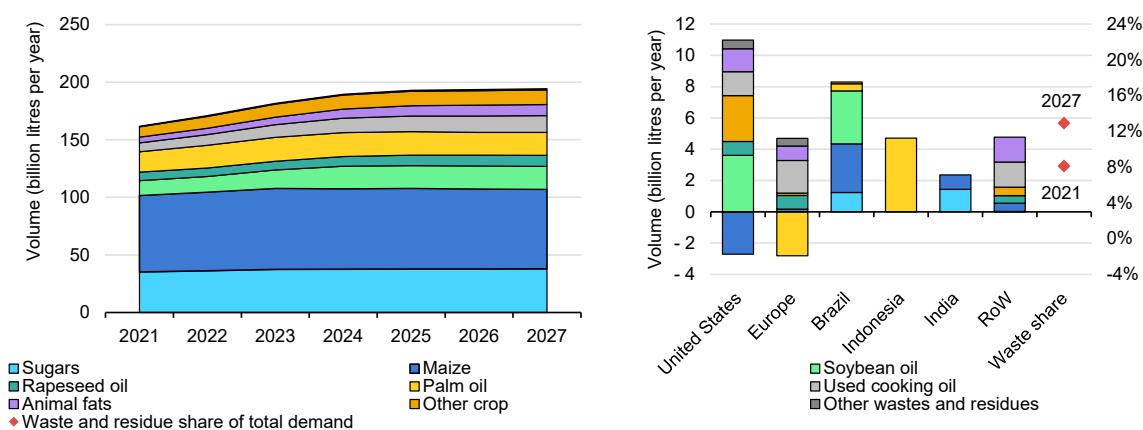
## Question 4: Is the biofuel industry approaching a feedstock crunch?

Biodiesel, renewable diesel and biojet fuel producers are headed for a feedstock supply crunch during 2022-2027 if current trends do not change. In our main case, demand for vegetable oil, waste and residue oils and fats increases 56% to 79 million tonnes over the forecast period. Fuels made from wastes and residues are in particularly high demand because they satisfy GHG and feedstock policy objectives in the United States and Europe. In fact, wastes and residues are expected to be used for 13% of biofuel production in 2027, up from 9% in 2021.

However, demand is approaching the supply limits of the most-used wastes and residues. Nevertheless, markets are dynamic. High prices are a signal to seek out new supplies, which is prompting the development of government programmes and industry innovation to help avoid the crunch.

Compared with wastes and residues, the sugars and starches used to produce ethanol are under less pressure. Although biofuel demand for these feedstocks is growing, sugar cane and maize production expands as well, keep the share dedicated to biofuel production nearly flat over the forecast.<sup>30</sup>

**Figure 4.10 Total biofuel production by feedstock (left) and growth by region (right), main case, 2021-2027**



IEA. CC BY 4.0.

Notes: "Other crop" includes corn oil, wheat, rice, cassava, camelina and plantation wood. "Other wastes and residues" includes municipal solid wastes, wood wastes, tall oil and palm oil mill effluent (POME).

<sup>30</sup> Agricultural growth expectations based on the OECD-FAO *Agricultural Outlook 2022-2031*.

## Four regions are driving demand

The United States, Europe, Brazil and Indonesia are responsible for the majority of biodiesel, renewable diesel and biojet fuel consumption growth. Combined, demand for these fuels increases by 44% or 21 billion litres in our main case over 2022-2027. In the United States, the renewable fuel standard, state-level low-carbon fuel standards and the IRA's tax credits boost demand for renewable diesel and biojet fuel. Most requirements are met with domestic production from a mixture of feedstocks (e.g. soybean oil, rapeseed oil, corn oil, used cooking oil and animal fats).

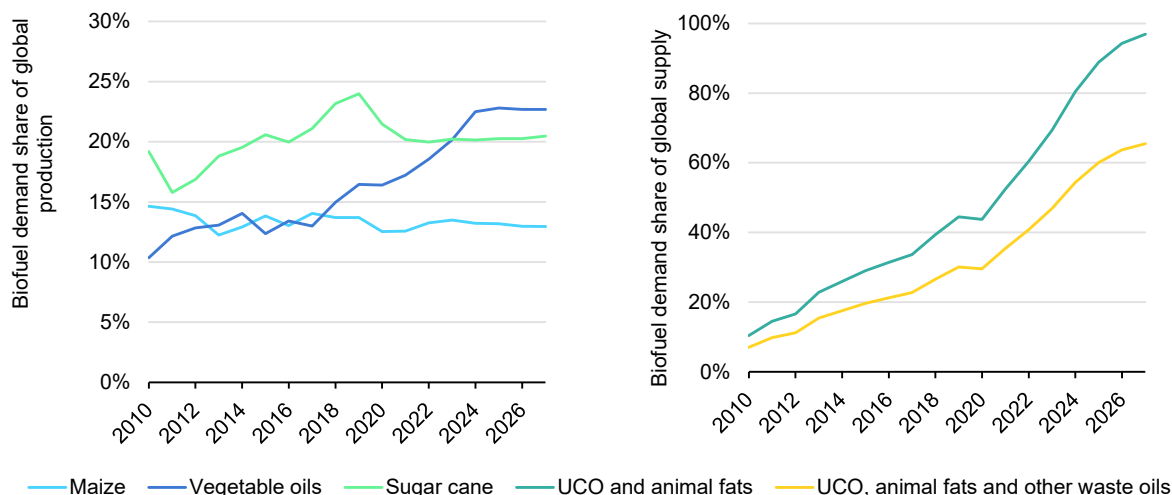
In Europe also, consumption of renewable diesel and biojet fuel increase the most. Total demand growth is relatively small, but the European Union is phasing out the use of palm oil and has placed limits on other feedstocks, which is boosting production from wastes, residues and rapeseed oil. Meanwhile, Brazil and Indonesia both have biodiesel blending mandates that will become more stringent over the forecast period. Indonesian biofuel manufacturers primarily use palm oil to produce biodiesel, and Brazilian ones rely on soybean oil.

## The looming supply crunch...

Consumption of vegetable oil for biofuel production is expected to increase 46% to 54 million tonnes over 2022-2027, raising the share of vegetable oil production directed to meeting growing biofuel demand from 17% to 23%. In the United States, this increase in demand is already reducing [soybean oil export](#) estimates and supporting [higher prices](#).

Used cooking oil and animal fats are unlikely to provide relief, as they are in even higher demand because they offer lower GHG emissions intensity and meet EU feedstock requirements. In fact, the use of used cooking oil and animal fats nearly exhausts 100% of estimated supplies over the forecast period. Even when a broader range of wastes (such as palm oil mill effluent, tall oil and other agribusiness waste oils) is considered, demand still swells to nearly 65% of global supply.

**Figure 4.11 Biofuel demand shares of global crop production (left) and wastes and residues (right), main case, 2010-2027**



IEA. CC BY 4.0.

Notes: UCO = used cooking oil. Biofuel demand by feedstock is calculated based on forecast demand, yield coefficients, project feedstock statements, historical feedstock shares and feedstock policy. Ethanol production using maize produces co-products such as feed, corn oil, CO<sub>2</sub> and electricity. Maize, vegetable oil and sugar cane production is based on the OECD-FAO [Agricultural Outlook 2022-2031](#). Collection potential is based on the [Clean Skies for Tomorrow Coalition](#): used cooking oil, avg. 12 million tonnes; animal fats, 13 million tonnes; and other waste oil, 13 million tonnes.

If this situation remains unchanged throughout the forecast period, the potential for biofuels to contribute to global decarbonisation efforts could be undermined. Bio-based diesel and biokerosene are essential components of net zero pathways because they can be used in marine, aviation and heavy trucking applications, for which few other decarbonisation options exist. However, attaining a [net zero trajectory](#) would require a more than three times production increase in our main case.

## ... and how it may be avoided

Our forecast takes a relatively static view of agricultural and waste oil markets. This doesn't Steep prices will prompt companies and governments to improve feedstock supply chains, seek out new supplies and develop new techniques.

Policies and programmes in the United States, Canada and Europe will be helpful. In the United States, the [Sustainable Aviation Grand Challenge Roadmap](#) aims to improve understanding of the feedstock challenge, boost supply potential and support new technology development. Meanwhile, the European Union as a whole, and individual member states such as Germany, have dedicated targets for fuels made from less-developed wastes and residues. In Canada, a USD 1.1-billion [Clean Fuels Fund](#) supports supply chain development. Policies focused on GHG emissions reductions can also be useful, since they give biofuel

producers an incentive to reduce the GHG intensity of their fuels, not just produce more. This can mean lower feedstock requirements with the same or better GHG emissions benefit.

Biofuel producers and users are also interested in expanding feedstock supplies for commercial biofuel technologies, as additional stocks could support up to another 8.5 EJ of biofuel production (300 billion litres), compared with 4 EJ (160 billion litres) in 2021 (see table below for sources). The industry sector is also investing in new technologies that use more widely available feedstocks, offering up to 50 EJ of sustainable potential. In fact, expanding commercial and new technologies could sustainably [increase bio-based diesel and biokerosene production](#) more than four times by 2030.

Exploiting the potential of conventional crop-based feedstocks that meet sustainability requirements could support a near-[70% increase in biofuel production](#) by 2030 from the 2021 level. Although there are limits to the pace and scale of growth for certain feedstocks such as vegetable oils, crops already support a 20% increase in liquid biofuel production by 2027 in the main-case forecast. However, governments and companies will need to be diligent to detect [fraudulent waste supplies](#) and maintain the integrity of sustainability frameworks, as high costs are also an incentive to circumvent policies.

Biofuel producers are also seeking feedstocks produced on degraded land or from crops planted during what were previously fallow periods to increase acreage without appropriating land that would otherwise be used for food and feed production. In Brazil, for instance, [75% of corn ethanol production](#) comes from second-crop production in existing fields. In Europe, some biofuel producers are sourcing oilseeds grown on degraded terrain to meet RED II sustainability criteria, and bio-based diesel feedstock producers globally are establishing new supply chains for bio-oils such as tall oil and fish oil, and expanding those for animal fats and used cooking oil.

Redirecting some ethanol production to make biojet fuel using alcohol-to-jet or ethanol-to-jet production pathways could also help relieve pressure on vegetable oil demand. As gasoline consumption declines in advanced economies, some ethanol can be redirected towards biojet fuel production. Biogas, which is made mostly from wastes and residues, can also be used to produce biojet fuel.

However, on the path to net zero emissions, these efforts will need to be supplemented with biofuel production from far more abundant resources. The [IEA estimates](#) that nearly 100 EJ of sustainable biomass supplies are available, including from woody residues, organic wastes, forest plantations and short-rotation woody crops planted on marginal land. These resources could support up to 50 EJ of liquid biofuel production, even though biogas and bioenergy producers will compete for the use of these resources. On a net zero trajectory, biofuel



demand reaches 14 EJ in 2040. While gasification and pyrolysis technologies can make use of these more available feedstocks, estimated [production costs](#) remain at least 50% higher than for conventional technologies.

In our accelerated case, we assume that governments and biofuel producers overcome their feedstock challenges, removing one barrier to faster growth and accelerating decarbonisation. Thus, biodiesel, renewable diesel and biojet fuel production are 30% higher in this scenario than in the main case in 2027.

**Table 4.6 Liquid biofuel production pathways, costs and feedstock potential**

Technology	Production cost range (USD/MJ)	Feedstock types	Feedstock demand 2021 / total potential
Conventional ethanol, biodiesel, renewable diesel and biojet fuel	14 – 34*	Conventional biofuel crops such as maize, sugar cane, palm oil, soybean oil and residual or waste oils compatible with FAME and HEFA production. (Production on degraded land, cover crops and intercropping are possible.)	4 EJ / 12.5 EJ
Cellulosic ethanol	34 – 51	Agricultural residues, wood residues, dedicated energy crops and other woody wastes.	
Bio-based Fischer-Tropsch synthesis	25 – 47	Woody biomass, agricultural residues, wastes such as municipal solid waste.	~0 EJ / 50 EJ
Bio-oil co-processing	26 – 46	Woody biomass, agricultural residues, wastes such as municipal solid waste.	

\*This is the market price range for crop-based feedstocks. It does not include production on degraded land, cover crops and intercropping.

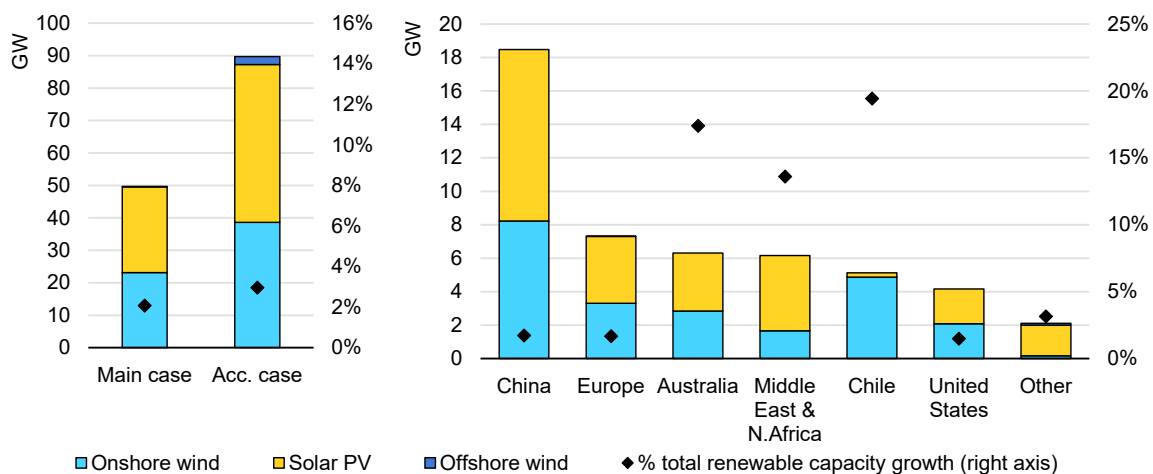
Notes: Production costs and prices are from IEA Bioenergy TCP (2019) [Advanced Biofuels – Potential for Cost Reduction](#). 2021 feedstock demand is based on IEA analysis. Total potential for conventional feedstocks includes current crop demand (IEA analysis), 2030 crop potential (IEA analysis; IEA [2021], *Net Zero by 2050*), global used cooking oil, animal fat, other agrifood oils, potential for vegetable oil production on degraded land and vegetable oil production via cover crops ([Clean Skies for Tomorrow Coalition](#)). Other feedstocks are based on organic wastes, forest and wood residues, short-rotation woody crops and forestry plantations. Biogas and solid bioenergy would compete for these feedstocks (IEA analysis; IEA [2021], *Net Zero by 2050*). Other feedstocks are converted to final liquid biofuel production potential using average conversion efficiency of 50%.

## Question 5: How much will renewable hydrogen production drive demand for new renewable energy capacity by 2027?

Hydrogen production from renewable electricity is expected to play an important role in reaching long-term decarbonisation goals and improving energy security. While less [than 1% of global hydrogen production](#) comes from renewable energy sources today, renewable hydrogen is receiving increasing policy attention. A total of [25 countries, plus the European Commission](#), have announced plans that include hydrogen as a source of clean energy, and several have begun to introduce financial support schemes.

As a result, project pipelines for using electrolyzers to produce hydrogen from renewable electricity have swelled in recent years, with projects at various stages of development. This momentum is expected to increase renewable capacity needs, but the question is: By how much?

**Figure 4.12 Total renewable capacity dedicated to hydrogen production in the main and accelerated case globally (left) and for main case by region (right), 2021-2027**



IEA. CC BY 4.0.

Notes: Acc. case = accelerated case. N. Africa = North Africa.

For 2022-2027, the main case forecasts around 50 GW of renewable capacity to be dedicated to hydrogen production, accounting for 2% of total renewable capacity growth. China leads expansion, followed by Australia, Chile and the United States. Together, these four markets account for roughly two-thirds of dedicated renewable capacity for hydrogen production.

Globally, new capacity is split evenly between PV and onshore wind, although regional shares vary depending on resource availability. For instance, solar PV makes up most of the growth in the MENA, while in Latin America the electrolyser project pipeline is expected to be mostly filled by onshore wind projects in Chile. Given their long lead times, offshore wind projects account for less than 1% of new renewable capacity built for electrolyser plants between 2022 and 2027.

**China** is expected to deploy over 18 GW of dedicated renewable capacity by 2027, prompted by the central government's goals to decarbonise industry and transport as well as an industrial policy on electrolyser manufacturing. While the central government announced renewable hydrogen production targets in its 14th Five-Year Plan, the main catalysts for growth are provincial and local-level policies.

Thus, expansion is expected to be concentrated in provinces with good solar and wind resources and specific targets for renewable hydrogen production, such as Inner Mongolia, which aims to produce 500 000 tonnes/yr of renewable hydrogen – more than twice the national target. Other key drivers are access to affordable financing through state-owned enterprises and to industrial clusters for new project development. Many new electrolyser projects are large demonstration plants located in industrial hubs that can offer economy-of-scale savings, lower unit manufacturing costs and access to local off-takers.

Demand for renewable hydrogen, which is a forecast uncertainty, will determine the pace of dedicated renewable capacity expansion. While many provinces include hydrogen in their industrial development strategies and identify production targets, not all specify that production must be from renewable sources. Furthermore, demand-side policies such as fuel-cell vehicle targets are emissions-agnostic and therefore do not guarantee new demand creation specifically for renewable hydrogen, especially if it costs more than hydrogen made from non-renewable resources.

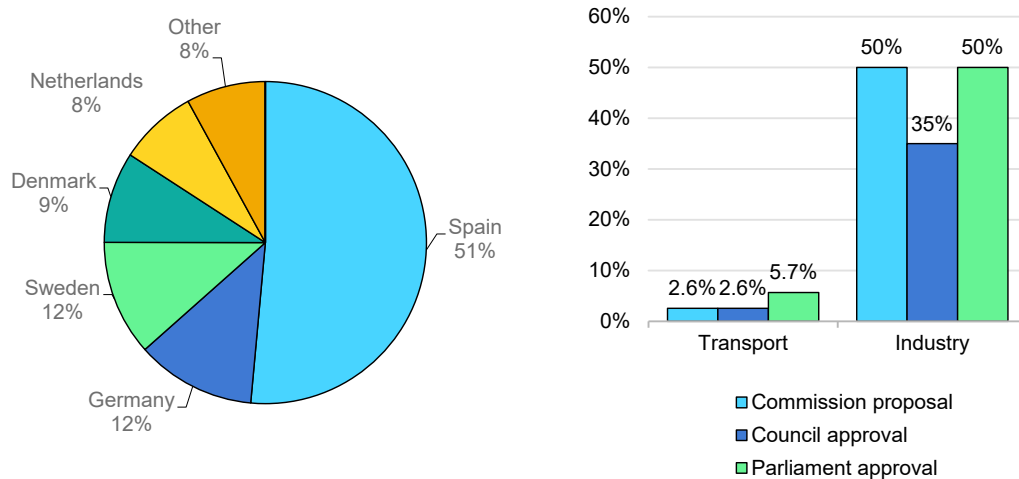
Transport infrastructure limitations may also slow the pace of hydrogen industry development, as provinces rich in renewable resources are located far from new demand centres. Also adding uncertainty to the size of future renewable capacity projects is how much electricity from the grid will be used and whether it can be certified as renewable to meet provincial targets.

Meanwhile, **Europe** is expected to deploy 7 GW of dedicated renewable capacity for hydrogen production during 2022-2027, encouraged by decarbonisation goals and, more recently, the need to strengthen energy security by displacing Russian gas. Spain is in the lead, accounting for half of Europe's growth, followed by Germany, Sweden, Denmark and the Netherlands. The main drivers are ambitious electrolyser goals, supported by financial incentives. While the European Union is

considering setting an electrolyser target of 44 GW by 2030, [REPowerEU modelling scenarios](#) suggest that 65-80 GW would be required to decrease Russian gas imports.

In the meantime, several member states have already formulated their own hydrogen strategies with electrolyser goals for 2030 (e.g. [Germany](#) and [Spain](#)). Projects that are financed are at least partially funded by public support, for instance through the Important Projects of Common European Interest (IPECI) programme, or by other state-specific funds. For example, Spain is providing financial support from funds allocated to Covid-19 crisis recovery in its National Recovery and Resilience Plan.

**Figure 4.13 Europe dedicated renewable capacity in the main case by country, 2021-2027 (left), and proposed EU targets for renewables of non-biological origin in transport and replacing non-renewable with renewable hydrogen use in industry (right)**



IEA. CC BY 4.0.

Notes: “Other” refers to France, the United Kingdom, Italy and Poland. The European Commission’s Fit for 55 and REPowerEU proposals are currently under consideration by the European Council and Parliament.

There are two key uncertainties in the forecast for dedicated renewable capacity expansion in Europe. The first is regulatory, concerning how hydrogen will be defined as renewable and how additionality will be implemented.<sup>31</sup> Developers are awaiting clarity on how electricity from the grid will be monitored to qualify hydrogen production as renewable. This will ultimately affect size and location decisions for dedicated onsite solar and PV wind capacity.

<sup>31</sup> The “additionality” requirement, one of the sustainability criteria proposed to qualify hydrogen as renewable, demands that the renewable electricity used to produce hydrogen come from renewable capacity installed specifically for hydrogen production and not be taken from existing projects generating electricity to meet power demand. Discussions on if it will be implemented and how it will be measured are ongoing.

Second, policy uncertainty over industry and transport mandates makes it challenging to assess renewable hydrogen demand potential and plan new electrolyser investments. The European Union is considering three different proposals for binding targets for renewables in existing hydrogen use in industry (ranging from 35% to 50%) and renewables of non-biological origin in transport (2.6% to 5.7%), but a final decision has yet to be taken. Whether developers will be able to secure off-takers and bring projects to financial close also poses a risk to the forecast.

Producing ammonia for export is the main impetus for dedicated renewable capacity expansion in the **Asia Pacific**, **Latin America** and **MENA** regions. Dedicated renewable capacity is expected to reach a combined 19 GW, led by Australia, Chile, Oman and Saudi Arabia. Large electrolyser project pipelines have emerged in these countries owing to the availability of space, the presence of shipping ports along strategic trade routes, and access to low-cost renewable electricity thanks to ample solar and wind resources.

The share of renewable capacity dedicated to hydrogen in these markets is higher than in other regions, accounting for 14% of total renewable deployment in MENA, 17% in Australia, and 19% in Chile, compared with 2% globally. While most projects are still at the feasibility stage, our forecast assumes that government support will help move projects to financial close, as these countries all aim to obtain market shares of low-carbon fuel exports. In fact, the Australian and Chilean governments have already funded developers, and state-owned enterprises are involved in planned projects in Oman and Saudi Arabia.

For renewable hydrogen exporters, securing off-takers to finance planned projects is a key forecast uncertainty, but policies of importing countries to stimulate demand can help address this challenge. For instance, the European Union proposes to import 10 Mt/yr of renewable hydrogen by 2030. Germany announced funding of [EUR 4 billion](#) will be awarded through competitive tenders through the H2Global initiative to specifically bridge the cost gap between renewable hydrogen imports from non-EU countries and domestic buyers. However, importer countries' decisions on the emissions intensity levels required for hydrogen imports to qualify for targets and support remains an uncertainty for exporting markets. Rules and regulations defining threshold levels will affect project viability and influence decisions on technology choice and oversizing.

Unprecedented federal policy support for low-carbon hydrogen in **the United States** is expected to be responsible for 4 GW of dedicated renewable capacity additions, or 1.5% of total renewable capacity expansion expected over 2022-2027. In 2022, the IRA introduced tax credits based on the emissions intensity of hydrogen production. Renewable hydrogen could be eligible for up to USD 3.0/kg

if labour and wage criteria are met. This incentive, coupled with state-specific support in the form of grants, loans and tax breaks, is expected to drive growth.

However, dedicated renewable capacity expansion will also depend on the business model chosen for new electrolyser projects. Some projects in the pipeline are being developed through long-term contracts with [existing solar PV projects](#) or [operating hydropower plants](#). The main threat to forecast growth is the potential for long project development periods, depending on equipment availability and permitting and regulatory approval wait times.

Project design and business model strongly influence forecasts for renewable capacity dedicated to hydrogen production. Electricity can be supplied from the grid or generated onsite by dedicated renewable plants, or a combination of both. The supply choice will depend mostly on the business model used by the developer, the regulatory requirements for hydrogen to qualify as renewable, and the stability of hydrogen supply needed by the off-taker. When new renewable capacity is built, sizing is highly project-specific and depends on cost optimisation based on multiple factors, including location, the number of full-load hours expected, regulatory requirements to meet renewable thresholds, and whether additional capex needs to be recuperated to provide a stable supply or conversion to other fuels.

Given the considerable number of policy uncertainties, market challenges and project-specific variables affecting dedicated renewable capacity growth, we took a conservative approach in our main-case forecast. Thus, growth could be 80% higher (90 GW) in our accelerated case if certain challenges are addressed. Securing off-takers to bring projects to financial close and obtaining regulatory clarity over definitions of low-emissions hydrogen could be the most important factors to unlock development of the project pipeline.

For example, policy actions to support demand creation for low-emission hydrogen, particularly in the industry and transport sectors (e.g. through mandates, public procurement and auctions) could increase the number of willing buyers; and financial incentives to help reduce production costs could improve the competitiveness of renewable hydrogen with other fuels and raise the likelihood of securing off-takers. Investors would be able to move forward with planned projects once they have regulatory clarity over what qualifies as renewable hydrogen and how electricity is accounted for. Policies that help lower costs associated with transport and reconversion of ammonia and other hydrogen-based fuels would encourage the development of international markets for renewable hydrogen.

## Question 6: Is the energy crisis really making the business case for heat pumps?

As the current energy crisis is reviving energy security concerns, heat pumps have benefited recently from growing policy momentum in a number of countries, particularly the United States and European ones. Heat pumps are expected to be pivotal to reduce fossil fuel dependency and CO<sub>2</sub> emissions in the heating sector by enabling energy savings and supply diversification.

Many heat pump markets are currently experiencing unprecedented growth. While the recent energy price hikes favour the most energy-efficient technologies, thus enhancing the business case for heat pumps, public initiatives to support investment in heat pumps are most often the primary enabling factor for this market acceleration.

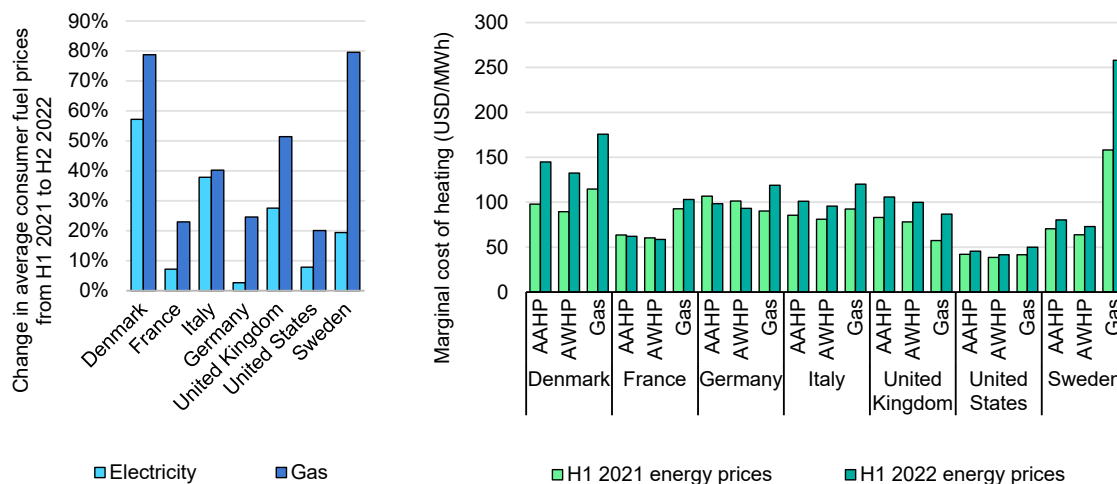
Several obstacles still impede large-scale heat pump deployment. Chief among them is the cost-competitiveness of heat pumps in places where lower-cost fossil fuel alternatives have not yet been banned. Cost-competitiveness is determined by a combination of parameters, including initial investment costs, operating and maintenance costs (including fuel costs), equipment durability and economic incentives. Like most other technologies that exploit renewable energy sources, upfront costs for heat pumps are relatively high, but running costs are generally lower than for fossil fuel-based options.

Soaring energy prices since 2021 have accentuated the running-cost advantage of heat pumps, especially as residential consumer tariffs for natural gas have risen more quickly than for electricity in most major heating markets.<sup>32</sup> This is particularly true for countries such as Denmark and Sweden, where the competitiveness of gas-fired boilers deteriorated substantially when gas prices rose during the first half of 2022. However, in most countries the overall cost-competitiveness of heat pumps with gas boilers is still determined mainly by the significant investment cost difference between the two.

---

<sup>32</sup> Household electricity prices [were higher in all but five EU member states](#) in the first half of 2022 than in the first half of 2021. Many countries [have implemented or are considering implementing differentiated tariff caps](#) for electricity and gas to protect consumers from high market prices.

**Table 4.7 Change in residential consumer prices for electricity and gas between H1 2021 and H1 2022 (left) and marginal cost of heating with residential heat pumps and gas boilers under different energy cost assumptions (right), selected countries**



IEA. CC BY 4.0.

Notes: AAHP = air-to-air heat pump. AWHP = air-to-water heat pump. Gas = condensing gas boiler. The marginal cost of heating estimates the cost of providing an additional 1 MWh of heating with different heating technologies, based on device efficiency and on energy prices. It does not account for capital and fixed operating and maintenance costs. Energy prices used here correspond to average residential consumer prices for electricity and natural gas, including taxes, for the first semesters of 2021 and of 2022.

Sources: IEA (2022), [Energy Prices database](#) (non-EU countries); [Eurostat](#) (EU member states).

Investment costs for residential heat pumps (including installation) are generally higher than for fossil fuel-fired boilers, though the extent of the cost gap varies widely within and across countries, even for the same technology, depending on market maturity. In only a few mature markets (e.g. Denmark, Sweden and Japan) are the upfront costs for lower-cost air-to-air heat pumps comparable with or lower than for gas boilers. Hydronic (air-to-water) heat pumps typically entail higher investment costs than air-to-air heat pumps, while ground-source heat pumps are the most expensive, owing partly to installation of the underground heat exchanger, which can represent more than half of the total system costs.

Plus, switching to a heat pump in an old building can involve additional expense, as the electrical system may need to be upgraded to accommodate a higher power load, or existing radiators may have to be replaced with larger ones or with underfloor heating or a forced-air system to allow more efficient heat pump operation. Such ancillary costs can make up as much as one-third of the total cost of switching to a heat pump. However, some of these upgrades can also improve thermal comfort and reduce heat demand.

High investment costs are a major barrier to heat pump adoption in the residential sector, as financing is a challenge for many households. In the past year, many countries have strengthened investment support for heat pumps or introduced



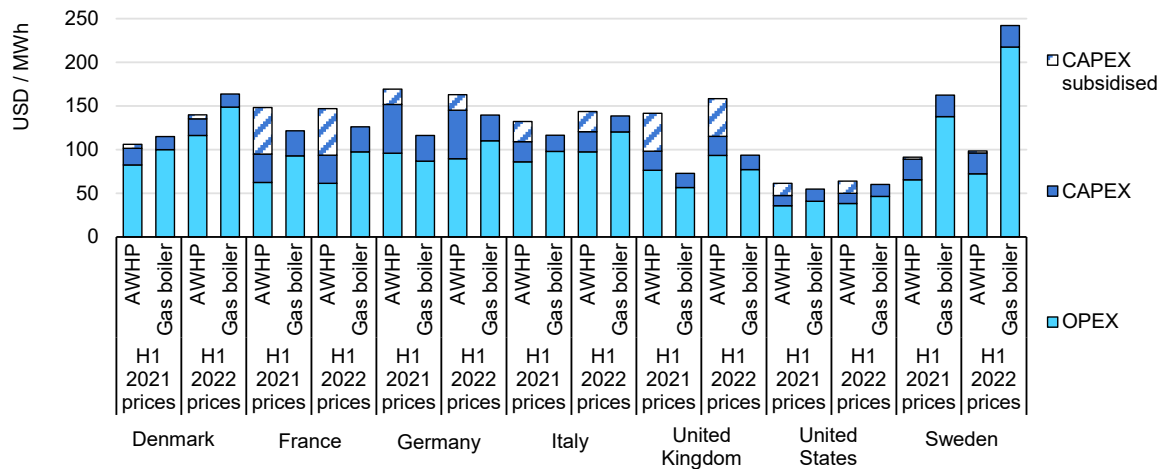
new measures in the form of grants, tax credits, reduced tax rates and specific loan schemes. Some of these measures were taken in response to the energy crisis and, in the European Union, to reduce dependence on Russian gas. Grants are the most common policy tool and are [currently available in at least 30 countries](#) that together represent 70% of global space heating demand. Tax credits are also widely available, but in contrast with direct grants and subsidies, they generally reach consumers only after a delay, sometimes of as much as two years.

**Table 4.8 Prevalent public investment support for heat pumps by policy type, selected countries, 2022**

Policy type	Examples of supporting countries in 2022
Subsidy	Australia, Austria, Belgium, Canada, China, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Romania, Slovakia, Slovenia, Spain, United Kingdom, United States
Tax reduction	Australia, Belgium, Bulgaria, Canada, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, New Zealand, Poland, Portugal, United Kingdom, United States, Slovenia, Sweden
Loan	Australia, Belgium, Bulgaria, Canada, Czech Republic, Denmark, France, Greece, Hungary, Ireland, Japan, Korea, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Poland, Portugal, Slovakia, Slovenia, United Kingdom

The level of support sometimes depends on household revenue (e.g. in France and the United States), and for low-income households it can (in some countries) cover most – if not all – of the purchase and installation costs. In many countries, investment subsidies for heat pumps can substantially reduce or even offset the upfront cost gap with gas boilers, sometimes making heat pumps more economical for consumers than gas boilers over their lifetime.

**Figure 4.14 Levelised cost of heating for air-to-water heat pumps and gas boilers for selected countries, and fuel-price sensitivity**



IEA. CC BY 4.0.

Notes: AWHP = air-to-water heat pump. The levelised cost of heating estimates the average cost of providing 1 MWh of heating over the lifetime of the equipment, considering capital costs, basic installation costs and operating expenditures, which include fuel and regular maintenance costs. Estimates are based on medium market prices for equipment. A lifetime of 17 years is assumed for gas boilers and 18 years for air-water heat pumps. Fuel prices correspond to average residential consumer prices for electricity and natural gas, including taxes, for the first semesters of 2021 and 2022. Calculations use a discount rate of 3% and assume national household average heat demand for Italy and Sweden, and heat demand corresponding to the heating degree days of Paris, Berlin, Edinburgh and Detroit (colder climate than the national average) for France, Germany, the United Kingdom and the United States. Subsidies correspond to minimum available subsidies for a household with median income. They reflect available grants, tax credits and reduced tax rates. In practice, higher subsidies may be available for low-income households or for higher investment costs or high-efficiency heat pumps, depending on the country.

In addition to direct public investment support, alternative business models (e.g. [on-bill financing, leasing, energy performance contracts and heat-as-a-service](#)) can also play a pivotal role in reducing or eliminating investment challenges for households. The two latter options can also help overcome split-incentive barriers.

Investment costs for heat pumps are expected to decline gradually over this decade as markets expand, suppliers benefit from economies of scale, and greater competition puts pressure on prices. Automation and standardisation of parts could further reduce component, installation and repair and maintenance costs, while the development of plug-and-play designs could make installation faster and more affordable. However, clear, stable policy signals are needed for manufacturers to commit to investments in process upgrades. Targeting [serial installations](#) across similar buildings in the same neighbourhood could also help mutualise logistical costs.

Beyond cost-competitiveness challenges, a number of non-cost obstacles must also be addressed to mainstream heat pump adoption. For instance, information campaigns as well as independent and free audits to inform heating system replacement decisions can raise awareness and confidence in the technology's potential benefits, while regulatory changes can make decision making and permitting for collective buildings simpler. Finally, depending on the building,

application specificities, and local energy source availability, other renewable heat options such as solar thermal and bioenergy may sometimes be easier or more economical to implement.

# General annex

## Abbreviations and acronyms

ACPA	American Clean Power Association
AEMO	Australian Energy Market Operator
ANEEL	Agencia Nacional de Energia Electrica
AWEA	American Wind Energy Association
BCD	Basic Customs Duty
CEEW	Council on Energy, Environment and Water
CfD	Contract for difference
CNMC	Comisión Nacional de los Mercados y La Competencia
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSP	Concentrated solar power
DISCOM	Distribution companies
DRHI	Domestic Renewable Heat Incentive
EBRD	European Bank for Reconstruction and Development
EHI	European heating industry
EHPA	European Heat Pump Association
EPA	Environmental Protection Agency
EREF	European Renewable Energy Foundation
ESTIF	European Solar Thermal Industry Federation
FIP	Feed-in premium
FIT	Feed-in tariff
GC	Green Certificate
GE	General Electric
GSE	Gestore dei Servizi Energetici
HEFA	Hydroprocessed esters and fatty acids
HVO	Hydrogenated vegetable oil
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEEJ	Institute of Energy Economics Japan
IHA	International Hydropower Association
IMO	International Maritime Organization
IRENA	International Renewable Energy Agency
ITC	Investment tax credit
MENA	Middle East and North Africa
MODS	Monthly Oil Data Service
NECP	National Energy and Climate Plans
NREL	National Renewable Energy Laboratory
PPA	Power purchase agreements
PSH	Pumped storage hydropower
PTC	Production tax credit
REZ	Renewable Energy Zones
RFS	Renewable Fuel Standard
RIAB	Renewable Industry Advisory Board
RIN	Renewable Identification Number
RPS	Renewable portfolio standard
RRF	Recovery and Resilience Facility
SAF	Sustainable aviation fuel

SMP	System marginal price
TCP	Technology Collaboration Programme
TRNC	Turkish Republic of Northern Cyprus
VAT	Value added tax
VRE	Variable renewable energy
WTPI	Wind Turbine Price Index

## 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 <sub>2</sub>	gigatonne of carbon dioxide
GtCO <sub>2</sub> /yr	gigatons of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
MLPY	million litres per year
MW	megawatt
MWh	megawatt hour

International Energy Agency (IEA).

This work reflects the views of the IEA Secretariat but does not necessarily reflect those of the IEA's individual Member countries or of any particular funder or collaborator. The work does not constitute professional advice on any specific issue or situation. The IEA makes no representation or warranty, express or implied, in respect of the work's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the work.



Subject to the IEA's [Notice for CC-licensed Content](#), this work is licenced under a [Creative Commons Attribution 4.0 International Licence](#).

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

IEA Publications  
International Energy Agency  
Website: [www.iea.org](http://www.iea.org)  
Contact information: [www.iea.org/contact](http://www.iea.org/contact)

Typeset in France by IEA - December 2022  
Cover design: IEA  
Photo credits: © Shutterstock

