# World Energy Outlook 2023

International Energy Agency

iea

# INTERNATIONAL ENERGY AGENCY

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



**IEA member countries:**

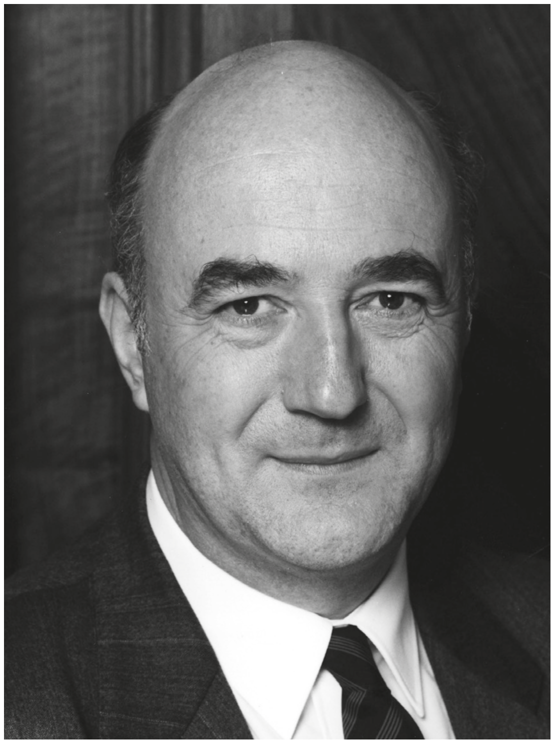
Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea
Lithuania
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Republic of Türkiye
United Kingdom
United States

The European Commission also participates in the work of the IEA

**IEA association countries:**

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

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



# In memory of Robert Priddle

(1938-2023)

Executive Director of the International Energy Agency from 1994 to 2002.

Today, 50 years on from the oil shock that led to the founding of the International Energy Agency (IEA), the world once again faces a moment of high geopolitical tensions and uncertainty for the energy sector. There are parallels between then and now, with oil supplies in focus amid a crisis in the Middle East – but there are also key differences: the global energy system has changed considerably since the early 1970s and further changes are taking place rapidly before our eyes.

One thing that hasn't changed since the 1970s is the IEA's commitment to its core mission of safeguarding energy security. As we have demonstrated throughout the global energy crisis that erupted in February 2022, the IEA is ready to respond quickly and effectively to sudden disruptions in energy markets. At the same time, we continue to dedicate significant efforts to anticipating and addressing the challenges that are evolving and emerging across the entire global energy system. This is an area where the data and analysis of the *World Energy Outlook (WEO)* are so valuable.

With the insights of this new *WEO* in mind, I want to highlight some important differences between where the energy sector was 50 years ago and where it is today. The 1973-74 crisis was all about oil, but today's pressures are coming from multiple areas. Alongside fragile oil markets, the world has seen an acute crisis in natural gas markets caused by Russia's cuts to supply, which had strong knock-on effects on electricity. At the same time, the world is dealing with an acute climate crisis, with increasingly visible effects of climate change caused by the use of fossil fuels, including the record-breaking heatwaves experienced around the world this year.

A crisis with multiple dimensions requires solutions that are similarly all-encompassing. Ultimately, what is required is not just to diversify away from a single energy commodity but to change the energy system itself, and to do so while maintaining the affordable and secure provision of energy services. The growing impacts of global warming make this all the more important, as an increasing amount of energy infrastructure that was built for a cooler, calmer climate is no longer reliable or resilient enough as temperatures rise and weather events become more extreme. In short, we have to transform the energy system both to stave off even more severe climate change and to cope with the climate change that is already with us.

A second difference between the 1970s and today is that we already have the clean energy technologies for the job in hand. The 1973 oil shock was a major catalyst for change, driving a huge push to scale up energy efficiency and nuclear power. But it still took many years to ramp them up while some other key technologies like wind and solar were still emerging. Today, solar, wind, efficiency and electric cars are all well established and readily available – and their advantages are only being reinforced by turbulence among the traditional technologies. We have the lasting solutions to today's energy dilemmas at our disposal.

The third difference is that clean energy transitions have real momentum at the moment. In the 1970s, many countries were going from a standing start as they scrambled to respond to the oil shock. As we show in this *WEO*, clean energy deployment is moving faster than many people realise. And it can and should go faster still for us to meet our shared energy and climate goals. In addition, we have international processes and accords in place today, such as the Paris Agreement, that provide an important framework for stronger action by governments.

And one final difference is, unlike in 1973, we have the IEA. I firmly believe that the Agency has a crucial role to play – by safeguarding against traditional energy security vulnerabilities, by anticipating new ones, and – in the words of our most recent Ministerial mandates – by "leading the global energy sector's fight against climate change".

The world is much better prepared than we were 50 years ago. We know what we need to do and where we need to go. At the same time, the challenges are much broader and more complex – energy security and climate are interwoven, and claiming that we need to focus on just one or the other is a blinkered view. We can still learn from the response to the oil shock of 1973 and from the approach that led to the Paris Agreement of 2015: governments must work together to address our major common challenges because a patchwork of individual efforts will fall short.

We need to co-ordinate and co-operate – those in the lead and with greater resources need to help those further behind who have less. Each country must find its own path, but it still needs some signposts along the way. This *WEO* highlights, once again, the choices that can move the energy system in a safer and more sustainable direction. I encourage decision makers around the world to take this report's findings into account – in the lead-up to the COP28 climate change conference in Dubai later this year and beyond.

I would like to commend my IEA colleagues who worked so hard on this *WEO* – alongside many other key reports, activities and events – for all their efforts, under the outstanding leadership of Laura Cozzi and Tim Gould.

We have chosen to dedicate this edition to a longtime friend of the *WEO* and leading figure in the history of the IEA, our former Executive Director Mr Robert Priddle, who sadly passed away in September. After serving as Executive Director between 1994 and 2002, Mr Priddle continued to make a major contribution for many years as editor of the *WEO*. In this role, his deep understanding of energy and geopolitical matters, as well as his exceptional communication skills, raised our work to a new level. We will miss him greatly.

**Dr Fatih Birol**
**Executive Director**
**International Energy Agency**

This study was prepared by the World Energy Outlook (WEO) team in the Directorate of Sustainability, Technology and Outlooks (STO) in co-operation with other directorates and offices of the International Energy Agency (IEA). The study was designed and directed by **Laura Cozzi**, Director, Sustainability, Technology and Outlooks, and **Tim Gould**, Chief Energy Economist.

The modelling and analytical teams for the *World Energy Outlook-2023* were led by **Stéphanie Bouckaert** (demand), **Christophe McGlade** (lead on Chapter 4, supply), **Thomas Spencer** (climate and environment), **Cecilia Tam** (investment and finance), **Brent Wanner** (power) and **Daniel Wetzel** (sustainable transitions).

Key contributions from across the WEO team were from:

**Oskaras Alšauskas** (transport), **Caleigh Andrews** (employment), **Yasmine Arsalane** (lead on Chapter 5, lead on economic outlook, power), **Blandine Barreau** (government spending), **Simon Bennett** (lead on hydrogen, energy technologies), **Charlène Bisch** (data management), **Eric Buisson** (critical minerals), **Olivia Chen** (lead on buildings, equity), **Yunyou Chen** (power), **Jonathan Coppel** (economic outlook), **Daniel Crow** (lead on climate modelling, behaviour), **Julie Dallard** (power, flexibility), **Davide D'Ambrosio** (lead on data science, power), **Amrita Dasgupta** (critical minerals), **Tanguy De Bienassis** (investment and finance), **Tomás De Oliveira Bredariol** (lead on methane, coal), **Nouhoun Diarra** (access), **Michael Drtil** (power, electricity networks), **Darlain Edeme** (Africa), **Musa Erdogan** (fossil fuel subsidies, data management), **Eric Fabozzi** (power, electricity networks), **Víctor García Tapia** (buildings, data science), **Emma Gordon** (Africa), **Alexandra Hegarty** (methane), **Jérôme Hilaire** (lead on oil and gas supply modelling), **Paul Hugues** (lead on industry), **Bruno Idini** (employment), **Hyeji Kim** (transport), **Tae-Yoon Kim** (lead on critical minerals, energy security), **Martin Kueppers** (industry, decomposition analysis), **Yannick Monschauer** (lead on affordability), **Alessio Pastore** (power, electricity networks), **Diana Perez Sanchez** (industry, affordability), **Apostolos Petropoulos** (lead on transport), **Ryszard Pospiech** (lead on coal supply modelling, data management), **Alana Rawlins Bilbao** (investment and finance), **Arthur Roge** (agriculture, data science), **Gabriel Saive** (climate pledges), **Max Schoenfisch** (power, electricity security), **Siddharth Singh** (lead on Chapter 5, lead on regional analysis), **Leonie Staas** (buildings, behaviour), **Carlo Starace** (Africa), **Matthieu Suire** (demand-side response), **Jun Takashiro** (lead on fossil fuel subsidies), **Ryota Taniguchi** (power), **Gianluca Tonolo** (lead on energy access), **Anthony Vautrin** (buildings, demand-side response), **Peter Zeniewski** (lead on Chapter 3, lead on gas, energy security). Other contributions were from: **Abdullah Al-Abri**, **Emile Belin-Bourgogne**, **France d'Agrain**, **David Fischer**, **Paul Grimal**, **Marco Iarocci**, **Yun Young Kim**, **Alice Latella**, **Carson Maconga**, **Ana Morgado, Rebecca Ruff** and **Natalia Triunfo**.

**Marina Dos Santos**, **Eleni Tsoukala** and **Reka Koczka** provided essential support.

**Edmund Hosker** carried editorial responsibility.

**Debra Justus** was the copy-editor.

Colleagues from the Energy Technology Policy (ETP) Division led by Timur Gül, Chief Energy Technology Officer, co-led on modelling and analysis, with overall guidance from Araceli Fernandez Pales and Uwe Remme. Peter Levi, Tiffany Vass, Alexandre Gouy, Leonardo Collina, Richard Simon, Faidon Papadimoulis contributed to the analysis on industry. Elizabeth Connelly, Jacob Teter, Shane McDonagh, Mathilde Huismans contributed to the analysis on transport. Chiara Delmastro, Rafael Martínez-Gordón contributed to the analysis on buildings. José Miguel Bermúdez Menéndez, Stavroula Evangelopoulou, Francesco Pavan and Amalia Pizarro contributed to the analysis on hydrogen. Praveen Bains contributed to the analysis on biofuels.

Other key contributors from across the IEA were: Heymi Bahar, Carlos Fernández Alvarez and Jeremy Moorhouse.

Valuable comments and feedback were provided by other senior management and numerous other colleagues within the IEA. In particular, Mary Warlick, Dan Dorner, Toril Bosoni, Joel Couse, Paolo Frankl, Dennis Hesseling, Brian Motherway and Hiroyasu Sakaguchi.

Thanks go to the IEA's Communications and Digital Office for their help in producing the report and website materials, particularly to Jethro Mullen, Poeli Bojorquez, Curtis Brainard, Jon Custer, Hortense de Roffignac, Astrid Dumond, Merve Erdil, Grace Gordon, Julia Horowitz, Oliver Joy, Isabelle Nonain-Semelin, Julie Puech, Robert Stone, Sam Tarling, Clara Vallois, Lucile Wall, Therese Walsh and Wonjik Yang. IEA's Office of the Legal Counsel, Office of Management and Administration and Energy Data Centre provided assistance throughout the preparation of the report.

Valuable input to the analysis was provided by David Wilkinson (independent consultant).

Support for the modelling of air pollution and associated health impacts was provided by Peter Rafaj, Gregor Kiesewetter, Laura Warnecke, Katrin Kaltenegger, Jessica Slater, Chris Heyes, Wolfgang Schöpp, Fabian Wagner and Zbigniew Klimont (International Institute for Applied Systems Analysis). Valuable input to the modelling and analysis of greenhouse gas emissions from land use, agriculture and bioenergy production was provided by Nicklas Forsell, Zuelclady Araujo Gutierrez, Andrey Lessa-Derci-Augustynczik, Stefan Frank, Pekka Lauri, Mykola Gusti and Petr Havlík (International Institute for Applied Systems Analysis). Advice related to the modelling of global climate impacts was provided by Jared Lewis, Zebedee Nicholls (Climate Resource) and Malte Meinshausen (Climate Resource and University of Melbourne).

The work could not have been achieved without the support and co-operation provided by many government bodies, organisations and companies worldwide, notably: Enel; Eni; European Commission (Directorate General for Climate and Directorate General for Energy); Hitachi Energy; Iberdrola; Japan (Ministry of Economy, Trade and Industry, and Ministry of Foreign Affairs); The Research Institute of Innovative Technology for the Earth, Japan; and Swiss Federal Office of Energy.

The IEA Clean Energy Transitions Programme, the IEA flagship initiative to transform the world's energy system to achieve a secure and sustainable future for all, supported this analysis.

Thanks also go to the IEA Energy Business Council, the IEA Coal Industry Advisory Board, the IEA Energy Efficiency Industry Advisory Board, the IEA Renewable Industry Advisory Board and the IEA Finance Industry Advisory Board.

### *Peer reviewers*

Many senior government officials and international experts provided input and reviewed preliminary drafts of the report. Their comments and suggestions were of great value. They include:

| | |
|---|---|
| Keigo Akimoto | Research Institute of Innovative Technology for the Earth, Japan |
| Doug Arent | National Renewable Energy Laboratory, United States |
| Papa Samba Ba | Ministère du Pétrole et des Energies, Sénégal |
| Manuel Baritaud | European Investment Bank |
| Marco Baroni | Enel Foundation |
| Harmeet Bawa | Hitachi Energy |
| Christian Besson | Independent consultant |
| Jorge Blazquez | BP |
| Stefan Bouzarovski | University of Manchester |
| Mick Buffier | Glencore |
| Nick Butler | King's College London |
| Rebecca Collyer | European Climate Foundation |
| Russell Conklin | US Department of Energy |
| Anne-Sophie Corbeau | Columbia University |
| Ian Cronshaw | Independent consultant |
| François Dassa | EDF |
| Jonathan Elkind | Columbia University |
| Jason Farr | Oxfam |
| David Fritsch | US Energy Information Administration |
| Hiroyuki Fukui | Toyota |
| Mike Fulwood | Nexant |
| David G. Hawkins | Natural Resources Defense Council |
| Tim Goodson | Independent consultant |
| Francesca Gostinelli | ENEL |
| Yuya Hasegawa | Ministry of Economy, Trade and Industry, Japan |

| | |
|---|---|
| Sara Hastings-Simon | University of Calgary |
| Laury Haytayan | Natural Resource Gouvernance Institute |
| Masazumi Hirono | Tokyo Gas |
| Takashi Hongo | Mitsui Global Strategic Studies Institute, Japan |
| Jan-Hein Jesse | JOSCO Energy Finance and Strategy Consultancy |
| Sohbet Karbuz | Mediterranean Observatory for Energy |
| Rafael Kawecki | Siemens Energy |
| Michael Kelly | World LPG Association |
| Msizi Khoza | Absa Group |
| Ken Koyama | Institute of Energy Economics, Japan |
| Atsuhito Kurozumi | Kyoto University of Foreign Studies, Japan |
| Joyce Lee | Global Wind Energy Council |
| Li Jiangtao | State Grid Energy Research Institute, China |
| Thomas-Olivier Léautier | TotalEnergies |
| Pierre-Laurent Lucille | Engie |
| Ritu Mathur | NITI Aayog, Government of India |
| Felix Chr. Matthes | Öko-Institut – Institute for Applied Ecology, Germany |
| Malte Meinshausen | University of Melbourne, Australia |
| Antonio Merino Garcia | Repsol |
| Tatiana Mitrova | SIPA Center on Global Energy Policy |
| Christopher Moghtader | UK Department for Business, Energy and Industrial Strategy |
| Isabel Murray | Department of Natural Resources, Canada |
| Steve Nadel | American Council for an Energy-Efficient Economy, United States |
| Jan Petter Nore | Norad |
| Thomas Nowak | European Heat Pump Association |
| Pak Yongduk | Korea Energy Economics Institute |
| Demetrios Papathanasiou | World Bank |
| Ignacio Pérez Arriaga | Comillas Pontifical University's Institute for Research in Technology, Spain |
| Andrea Pescatori | International Monetary Fund |
| Glen Peters | CICERO |
| Cédric Philibert | French Institute of International Relations, Centre for Energy & Climate |
| Vicki Pollard | Directorate-General for Climate Action, European Commission |
| Andrew Purvis | World Steel Association |

| | |
|---|---|
| Julia Reinaud | Breakthrough Energy |
| Oliver Reynolds | Global Off-Grid Lighting Association |
| Nick Robins | Grantham Research Institute |
| Jay Rutovitz | University of Technology Sydney |
| Yamina Saheb | OpenEXP, IPCC author |
| Ana Belén Sánchez | Institute for the Just Transition, Spain |
| Hans-Wilhelm Schiffer | World Energy Council |
| Jesse Scott | Deutsches Institut für Wirtschaftsforschung (German Institute for Economic Research) |
| Adnan Shihab-Eldin | Independent consultant |
| Rebekah Shirley | World Resources Institute |
| Maria Sicilia | Enagás |
| Paul Simons | Yale University |
| Gurdeep Singh | National Thermal Power Corporation Limited |
| Jim Skea | Imperial College London, IPCC Co-Chair Working Group III |
| Jonathan Stern | Oxford Institute for Energy Studies, United Kingdom |
| Miguel Gil Tertre | Directorate General for Energy, European Commission |
| Wim Thomas | Independent consultant |
| Rahul Tongia | Centre for Social and Economic Progess, India |
| Nikos Tsafos | General Secretariat of the Prime Minister of the Hellenic Republic |
| Adair Turner | Energy Transitions Commission |
| James Turnure | US Energy Information Administration |
| Fridtjof Fossum Unander | Aker Horizons |
| Noé Van Hulst | International Partnership for Hydrogen and Fuel Cells in the Economy |
| David Victor | University of California, San Diego, United States |
| Andrew Walker | Cheniere Energy |
| Charles Weymuller | EDF |
| Kelvin Wong | DBS Bank |
| Christian Zinglersen | European Union Agency for the Cooperation of Energy Regulators |

**Comments and questions are welcome and should be addressed to:**

Laura Cozzi and Tim Gould

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

E-mail: weo@iea.org

More information about the *World Energy Outlook* is available at www.iea.org/weo.

## Annexes

## The energy world remains fragile but has effective ways to improve energy security and tackle emissions

**Some of the immediate pressures from the global energy crisis have eased, but energy markets, geopolitics, and the global economy are unsettled and the risk of further disruption is ever present.** Fossil fuel prices are down from their 2022 peaks, but markets are tense and volatile. Continued fighting in Ukraine, more than a year after Russia's invasion, is now accompanied by the risk of protracted conflict in the Middle East. The macro-economic mood is downbeat, with stubborn inflation, higher borrowing costs and elevated debt levels. Today, the global average surface temperature is already around 1.2 °C above pre-industrial levels, prompting heatwaves and other extreme weather events, and greenhouse gas emissions have not yet peaked. The energy sector is also the primary cause of the polluted air that more than 90% of the world's population is forced to breathe, linked to more than 6 million premature deaths a year. Positive trends on improving access to electricity and clean cooking have slowed or even reversed in some countries.

**Against this complex backdrop, the emergence of a new clean energy economy, led by solar PV and electric vehicles (EVs), provides hope for the way forward.** Investment in clean energy has risen by 40% since 2020. The push to bring down emissions is a key reason, but not the only one. The economic case for mature clean energy technologies is strong. Energy security is also an important factor, particularly in fuel-importing countries, as are industrial strategies and the desire to create clean energy jobs. Not all clean technologies are thriving and some supply chains, notably for wind, are under pressure, but there are striking examples of an accelerating pace of change. In 2020, one in 25 cars sold was electric; in 2023, this is now one in 5. More than 500 gigawatts (GW) of renewables generation capacity are set to be added in 2023 – a new record. More than USD 1 billion a day is being spent on solar deployment. Manufacturing capacity for key components of a clean energy system, including solar PV modules and EV batteries, is expanding fast. This momentum is why the IEA recently concluded, in its updated *Net Zero Roadmap*, that a pathway to limiting global warming to 1.5 °C is very difficult – but remains open.

**This new *Outlook* provides a strong evidence base to guide the choices that face energy decision makers in pursuit of transitions that are rapid, secure, affordable and inclusive.** The analysis does not present a single view of the future but instead explores different scenarios that reflect current real-world conditions and starting points. The Stated Policies Scenario (STEPS) provides an outlook based on the latest policy settings, including energy, climate and related industrial policies. The Announced Pledges Scenario (APS) assumes all national energy and climate targets made by governments are met in full and on time. Yet, much additional progress is still required to meet the objectives of the Net Zero Emissions by 2050 (NZE) Scenario which limits global warming to 1.5 °C. Alongside our main scenarios, we explore some key uncertainties that could affect future trends, including structural changes in China's economy and the pace of global deployment of solar PV.

## *We are on track to see all fossil fuels peak before 2030*

**A legacy of the global energy crisis may be to usher in the beginning of the end of the fossil fuel era: the momentum behind clean energy transitions is now sufficient for global demand for coal, oil and natural gas to all reach a high point before 2030 in the STEPS**. The share of coal, oil and natural gas in global energy supply – stuck for decades around 80% – starts to edge downwards and reaches 73% in the STEPS by 2030. This is an important shift. However, if demand for these fossil fuels remains at a high level, as has been the case for coal in recent years, and as is the case in the STEPS projections for oil and gas, it is far from enough to reach global climate goals.

**Policies supporting clean energy are delivering as the projected pace of change picks up in key markets around the world.** Thanks largely to the Inflation Reduction Act in the United States, we now project that 50% of new US car registrations will be electric in 2030 in the STEPS. Two years ago, the corresponding figure in the *WEO-2021* was 12%. In the European Union in 2030, heat pump installations in the STEPS reach two-thirds of the level needed in the NZE Scenario, compared with the one-third projected two years ago. In China, projected additions of solar PV and offshore wind to 2030 are now three-times higher than they were in the *WEO-2021*. Prospects for nuclear power have also improved in leading markets, with support for lifetime extensions of existing nuclear reactors in countries including Japan, Korea and the United States, as well as for new builds in several more.

**Although demand for fossil fuels has been strong in recent years, there are signs of a change in direction**. Alongside the deployment of low-emissions alternatives, the rate at which new assets that use fossil fuels are being added to the energy system has slowed. Sales of cars and two/three-wheel vehicles with internal combustion engines are well below where they were before the Covid-19 pandemic. In the electricity sector, worldwide additions of coal- and natural gas-fired power plants have halved, at least, from earlier peaks. Sales of residential gas boilers have been trending downwards and are now outnumbered by sales of heat pumps in many countries in Europe and in the United States.

## *China has changed the energy world, but now China is changing*

**China has an outsized role in shaping global energy trends; this influence is evolving as its economy slows and its structure adjusts, and as clean energy use grows**. Over the past ten years, China accounted for almost two-thirds of the rise in global oil use, nearly one-third of the increase in natural gas, and has been the dominant player in coal markets. But it is widely recognised, including by the country's leadership, that China's economy is reaching an inflection point. After a very rapid building out of the country's physical infrastructure, the scope for further additions is narrowing. The country already has a world-class high-speed rail network; and residential floorspace per capita is now equal to that of Japan, even though GDP per capita is much lower. This saturation points to lower future demand in many energy-intensive sectors like cement and steel. China is also a clean energy powerhouse, accounting for around half of wind and solar additions and well over half of global EV sales in 2022.

**Momentum behind China's economic growth is ebbing and there is greater downside potential for fossil fuel demand if it slows further**. In our scenarios, China's GDP growth averages just under 4% per year to 2030. This results in its total energy demand peaking around the middle of this decade, with robust expansion of clean energy putting overall fossil fuel demand and emissions into decline. If China's near-term growth were to slow by another percentage point, this would reduce 2030 coal demand by an amount almost equal to the volume currently consumed by the whole of Europe. Oil import volumes would decline by 5% and LNG imports by more than 20%, with major implications for global balances.

## *New dynamics for investment are taking shape*

**The end of the growth era for fossil fuels does not mean an end to fossil fuel investment, but it undercuts the rationale for any increase in spending.** Until this year, meeting projected demand in the STEPS implied an increase in oil and gas investment over the course of this decade, but a stronger clean energy outlook and lower projected fossil fuel demand means this is no longer the case. However, investment in oil and gas today is almost double the level required in the NZE Scenario in 2030, signalling a clear risk of protracted fossil fuel use that would put the 1.5 °C goal out of reach.

**Simply cutting spending on oil and gas will not get the world on track for the NZE Scenario; the key to an orderly transition is to scale up investment in all aspects of a clean energy system**. The development of a clean energy system and its effect on emissions can be reinforced by policies that ease the exit of inefficient, polluting assets, such as ageing coal plants, or that restrict the entry of new ones into the system. But the urgent challenge is to increase the pace of new clean energy projects, especially in many emerging and developing economies outside China, where investment in energy transitions needs to rise by more than five times by 2030 to reach the levels required in the NZE Scenario. A renewed effort, including stronger international support, will be vital to tackle obstacles such as high costs of capital, limited fiscal space for government support and challenging business environments.

## *Meeting development needs in a sustainable way is key to moving faster*

**The global peaks in demand for each of the three fossil fuels mask important differences across economies at different stages of development**. The drivers for growth in demand for energy services in most emerging and developing economies remain very strong. Rates of urbanisation, built space per capita, and ownership of air conditioners and vehicles are far lower than in advanced economies. The global population is expected to grow by about 1.7 billion by 2050, almost all of which is added to urban areas in Asia and Africa. India is the world's largest source of energy demand growth in the STEPS, ahead of Southeast Asia and Africa. Finding and financing low-emissions ways to meet rising energy demand in these economies is a vital determinant of the speed at which global fossil fuel use eventually falls.

**Clean electrification, improvements in efficiency and a switch to lower- and zero-carbon fuels are key levers available to emerging and developing economies to reach their national energy and climate targets.** Getting on track to meet these targets, including net zero goals, has broad implications for future pathways. In India, it means every dollar of value added by

India's industry results in 30% less carbon dioxide ($CO_2$) by 2030 than it does today, and each kilometre driven by a passenger car, on average, emits 25% less $CO_2$. Some 60% of two- and three-wheelers sold in 2030 are electric, a share ten times higher than today. In Indonesia, the share of renewables in power generation doubles by 2030 to more than 35%. In Brazil, biofuels meet 40% of road transport fuel demand by the end of the decade, up from 25% today. In sub-Saharan Africa, meeting diverse national energy and climate targets means that 85% of new power generation plants to 2030 are based on renewables. Significant progress is made towards universal access to modern energy, with some 670 million people gaining access to modern cooking fuels, and 500 million to electricity by 2030.

### *Ample global manufacturing capacity offers considerable upside for solar PV*

**Renewables are set to contribute 80% of new power capacity to 2030 in the STEPS, with solar PV alone accounting for more than half.** However, this uses only a fraction of the world's potential. Solar has become a major global industry and is set to transform electricity markets even in the STEPS. But there is significant scope for further growth given manufacturing plans and the technology's competitiveness. By the end of the decade, the world could have manufacturing capacity for more than 1 200 GW of panels per year. But in the STEPS, only 500 GW is deployed globally in 2030. Boosting deployment up from these levels raises some complex questions. It would require measures – notably expanding and strengthening grids and adding storage – to integrate the additional solar PV into electricity systems and maximise its impact. Manufacturing capacity is also highly concentrated: China is already the largest producer and its expansion plans far outstrip those in other countries. Trade, therefore, would continue to be vital to support worldwide deployment of solar.

**Using 70% of anticipated solar PV manufacturing capacity would bring deployment to the levels projected in the NZE Scenario; effectively integrated, this would further cut fossil fuel use – first and foremost coal**. In a sensitivity case, we explore how the STEPS projections would change if the world added over 800 GW of new solar PV per year by 2030. The implications would be particularly strong for China, reducing coal-fired generation by a further 20% by 2030 compared with the STEPS. Without assuming any additional retirements, the average annual capacity factor for coal-fired power plants would fall to around 30% in 2030, from over 50% today. The consequences would spread well beyond China: in this case, more than 70 GW of additional solar PV is deployed on average each year to 2030 across Latin America, Africa, Southeast Asia and the Middle East. Even with modest curtailment, this reduces fossil fuel-fired generation in these regions by about one-quarter in 2030 compared with the STEPS. Solar PV alone cannot get the world on track to meet its climate goals, but – more than any other clean technology – it can light up the way.

### *A wave of new LNG export projects is set to remodel gas markets*

**Starting in 2025, an unprecedented surge in new LNG projects is set to tip the balance of markets and concerns about natural gas supply.** In recent years, gas markets have been dominated by fears about security and price spikes after Russia cut supplies to Europe. Market balances remain precarious in the immediate future but that changes from the middle of the decade. Projects that have started construction or taken final investment decision are set to add 250 billion cubic metres per year of liquefaction capacity by 2030, equal to almost half of today's global LNG supply. Announced timelines suggest a particularly large increase between 2025 and 2027. More than half of the new projects are in the United States and Qatar.

**This additional LNG arrives at an uncertain moment for natural gas demand and creates major difficulties for Russia's diversification strategy towards Asia**. The strong increase in LNG production capacity eases prices and gas supply concerns, but comes to market at a time when global gas demand growth has slowed considerably since its "golden age" of the 2010s. Alongside gas contracted on a longer-term basis to end-users, we estimate that more than one-third of the new gas will be looking to find buyers on the short-term market. However, mature markets – notably in Europe – are moving into stronger structural decline and emerging markets may lack the infrastructure to absorb much larger volumes if gas demand in China slows. The glut of LNG means there are very limited opportunities for Russia to secure additional markets. Russia's share of internationally traded gas, which stood at 30% in 2021, is halved by 2030 in the STEPS.

## *Affordability and resilience are watchwords for the future*

**A tense situation in the Middle East is a reminder of hazards in oil markets a year after Russia cut gas supplies to Europe**. Vigilance on oil and gas security remains essential throughout clean energy transitions, and our projections highlight how the balance of trade and potential vulnerabilities shift over time. In the STEPS, the share of seaborne crude oil trade from the Middle East to Asia rises from some 40% of the total today to 50% by 2050. Asia is also the final destination for almost all of additional Middle East LNG supply.

**The global energy crisis was not a clean energy crisis, but it has focused attention on the importance of ensuring rapid, people-centred and orderly transitions.** Three interlinked issues stand out: risks to affordability, electricity security and the resilience of clean energy supply chains. Sheltering consumers from volatile fuel prices in 2022 cost governments USD 900 billion in emergency support. The way to limit such expenditures in the future is to deploy cost-effective, clean technologies at scale, especially in poorer households, communities and countries that struggle to finance the upfront investments required. As the world moves towards a more electrified, renewables-based system, security of electricity supply is also paramount. Higher investment in robust and digitalised grids needs to be accompanied by a role for batteries and demand response measures for short-term flexibility and lower-emissions technologies for seasonal variations, including hydropower, nuclear, fossil fuels with carbon capture, utilisation and storage, bioenergy, hydrogen and ammonia.

**Diversification and innovation are the best strategies to manage supply chain dependencies for clean energy technologies and critical minerals.** A range of strategies are in place to strengthen the resilience of clean energy supply chains and reduce today's high levels of concentration, but these will take time to bear fruit. Exploration and production investments are rising around the world for critical minerals like lithium, cobalt, nickel and rare earths, but the share of the top three producers in 2022 is either unchanged or has increased from 2019 levels. Our tracking of announced projects suggests concentration levels in 2030 are set to remain high, especially for refining and processing operations. Many midstream projects are being developed in today's major producing regions, with China holding half of planned lithium chemical plants and Indonesia representing nearly 90% of planned nickel refining facilities. Alongside investments in diversified supply, policies encouraging innovation, mineral substitution and recycling can moderate trends on the demand side and ease market pressures. They are vital components of critical minerals security.

## *We need to go much further and faster, but a fragmented world will not rise to meet our climate and energy security challenges*

**Proven policies and technologies are available to align energy security and sustainability goals, speed up the pace of change this decade and keep the door to 1.5 °C open**. The STEPS sees a peak in energy-related $CO_2$ emissions in the mid-2020s but emissions remain high enough to push up global average temperatures to around 2.4 °C in 2100. This outcome has improved over successive editions of the *Outlook* but still points towards very widespread and severe impacts from climate change. The key actions required to bend the emissions curve downwards to 2030 are widely known and in most cases very cost effective. Tripling renewable energy capacity, doubling the pace of energy efficiency improvements to 4% per year, ramping up electrification and slashing methane emissions from fossil fuel operations together provide more than 80% of the emissions reductions needed by 2030 to put the energy sector on a pathway to limit warming to 1.5 °C. In addition, innovative, large-scale financing mechanisms are required to support clean energy investments in emerging and developing economies, as are measures to ensure an orderly decline in the use of fossil fuels, including an end to new approvals of unabated coal-fired power plants. Every country needs to find its own pathway, and it needs to be inclusive and equitable to secure public acceptance, but this package of global measures provides crucial ingredients for any successful outcome from the COP28 climate change conference in Dubai in December.

**No country is an energy island, and no country is insulated from the risks of climate change. The necessity of collaboration has never been higher**. Especially in today's tense times, governments need to find ways to safeguard co-operation on energy and climate, including by embracing a rules-based system of international trade and spurring innovation and technology transfer. Without this, the chance to limit the rise in global temperatures to 1.5 °C will disappear. The outlook for energy security will also look perilous if we lose the benefits of interconnected and well-functioning energy markets to ride out unexpected shocks.

**Fifty years on from the first oil shock, the world has lasting solutions to address energy insecurity that can also help tackle the climate crisis**. The first oil shock 50 years ago brought two crucial policy responses firmly into play: energy efficiency and low-emissions power, led at the time by hydropower and nuclear. Today's energy decision makers are once again facing geopolitical tensions and the risk of energy shocks, but they have a much broader range of highly competitive clean technologies at their disposal, and an accumulated wealth of policy experience on how to accelerate their deployment. The crucial step is to put these readily available solutions to work.

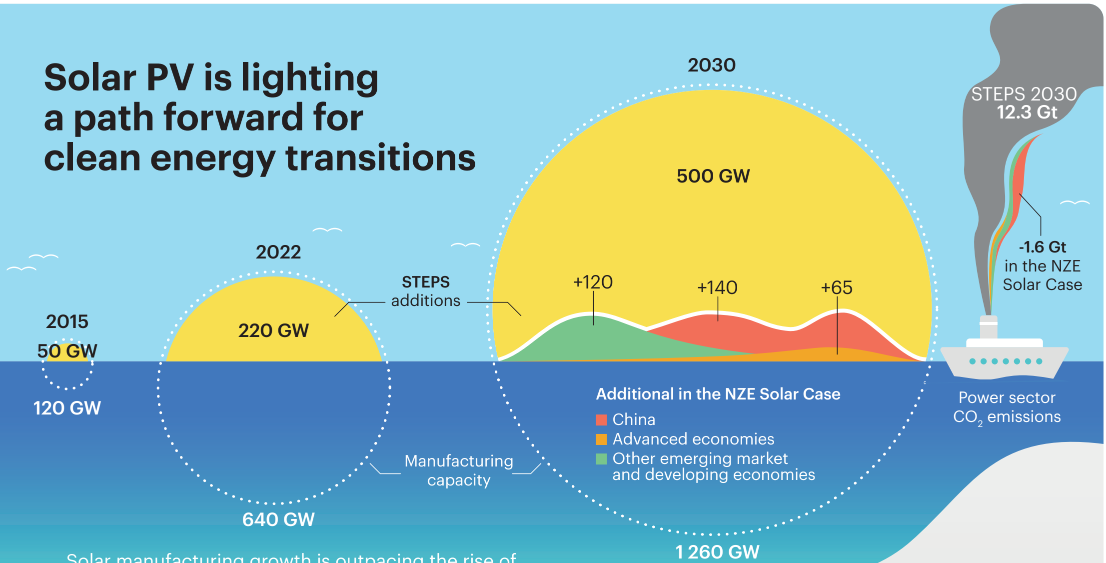
# Overview and key findings

## Transitions are getting competitive

### SUMMARY


- Conflict and uncertainty provide an inauspicious backdrop to the new *World Energy Outlook*. Following Russia's invasion of Ukraine, instability in the Middle East could lead to further disruption to energy markets and prices. This underscores once again the frailties of the fossil fuel age, and the benefits for energy security as well as for emissions of shifting to a more sustainable energy system.
- Clean energy projects are facing headwinds in some markets from cost inflation, supply chain bottlenecks and higher borrowing costs. But clean energy is the most dynamic aspect of global energy investment. How fast it grows in the coming decades in response to policy and market stimuli is key to explain the differences in trajectories and outcomes across our three main scenarios. In all scenarios, the momentum behind the clean energy economy is enough to produce a peak in demand for coal, oil and natural gas this decade, although the rates of post-peak decline vary widely.
- In the Stated Policies Scenario, average annual growth rate of 0.7% in total energy demand to 2030 is around half the rate of energy demand growth of the last decade. Demand continues to increase through to 2050. In the Announced Pledges Scenario, total energy demand flattens, thanks to improved efficiency and the inherent efficiency advantages of technologies powered by electricity – such as electric vehicles and heat pumps – over fossil fuel-based alternatives. In the Net Zero Emissions by 2050 Scenario, electrification and efficiency gains proceed even faster, leading to a decline in primary energy of 1.2% per year to 2030.
- Our analysis explores some key uncertainties, notably regarding the pace of China's economic growth and the possibilities for more rapid solar PV deployment opened by a massive planned expansion in manufacturing capacity (led by China). We highlight the implications of a huge increase in the capacity to export liquefied natural gas starting in the middle of this decade, led by the United States and Qatar. We examine how any deterioration in geopolitical tensions would undermine both the prospects for energy security and for rapid, affordable transitions.
- Extreme volatility in energy markets during the global energy crisis has highlighted the importance of affordable, reliable and resilient supply, especially in price-sensitive developing economies that see the largest increase in demand for energy services. Energy transitions rely on electrification and technologies like wind, solar PV and batteries, and push electricity security and diversified supply for clean technologies and critical minerals up the policy agenda. Emerging market and developing economies account for almost 80% of the global growth in electricity demand in the Stated Policies Scenario, and for over two-thirds in the other scenarios.

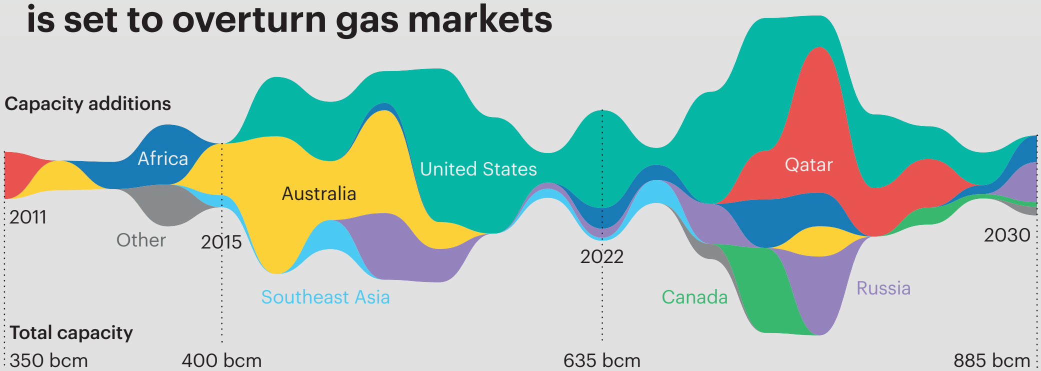
# Solar PV is lighting a path forward for clean energy transitions




Solar manufacturing growth is outpacing the rise of solar PV deployment, creating some risks of imbalances but huge opportunities for the world to accelerate energy transitions.

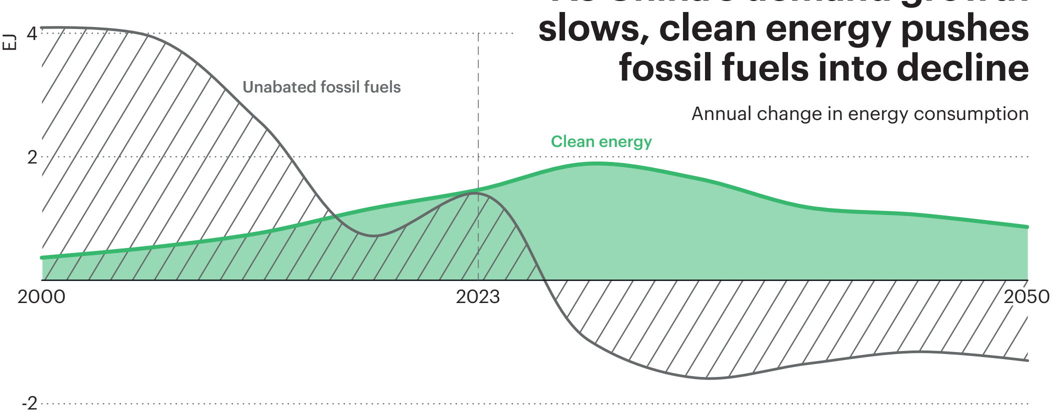
Around 250 bcm of new liquefaction capacity is set to come online by 2030, of which the United States and Qatar account for 60%.

# A wave of new LNG export projects is set to overturn gas markets




# As China's demand growth slows, clean energy pushes fossil fuels into decline

Annual change in energy consumption



## Introduction



Some of the tensions in energy markets receded in 2023 since the extreme volatility of the global energy crisis, but the situation remains fragile. The urgent task of transforming the energy system now takes place in a more challenging macroeconomic and geopolitical context. The frailties of the fossil fuel age and the hazards that it has created for the planet are plain to see, and opportunities in the emerging clean energy economy are growing fast. But many uncertainties remain about the resilience of energy supply chains old and new, about risks to the security and affordability of transitions, and about whether the process of change will be sufficiently rapid to avoid very severe impacts from a changing climate.

Using the latest data for energy markets, policies and technologies, the *World Energy Outlook* (*WEO*) provides insights on all these key issues. It does so by exploring scenarios that reflect different assumptions about the actions taken in the coming years to shape energy systems and reduce energy-related carbon dioxide ($CO_2$) emissions. The projections in the Stated Policies Scenario (STEPS) give a sense of the current direction of travel for the energy economy, based on the actual state of play in different sectors, countries and regions. The Announced Pledges Scenario (APS) shows how that future would be different if all countries were to hit their aspirational targets, including national and regional net zero emissions pledges, on time and in full. The updated Net Zero Emissions by 2050 (NZE) Scenario illustrates what more is required to limit global warming to 1.5 degree Celsius (°C).

This overview chapter provides ten takeaways from the new analysis. Our projections show that for the first time demand for each of the fossil fuels reach a peak in the STEPS before the end of this decade. We examine how uncertainties over the pace of economic growth in The People's Republic of China (hereinafter China) could affect the near-term outlook, as well as the implications of the extraordinary China-led boom in manufacturing capacity for solar photovoltaic (PV) modules. We highlight areas of hope and areas for caution about the prospects of staying within the 1.5 °C limit, and examine the crucial issue of capital flows for clean energy and fossil fuels.

Against a background of macroeconomic uncertainty, we consider the affordability of the transition for households, industry and governments. As the world comes to rely more and more on electricity, we look at risks affecting technologies that have a key part to play in increasing electrification and decarbonising the power supply. We also ask whether the policy and technology choices facing emerging market and developing economies open the possibility of a new lower carbon pathway for development. In addition, we identify the ways in which geopolitical tensions could affect the *Outlook*, and look back to see how and why our projections have changed over time.

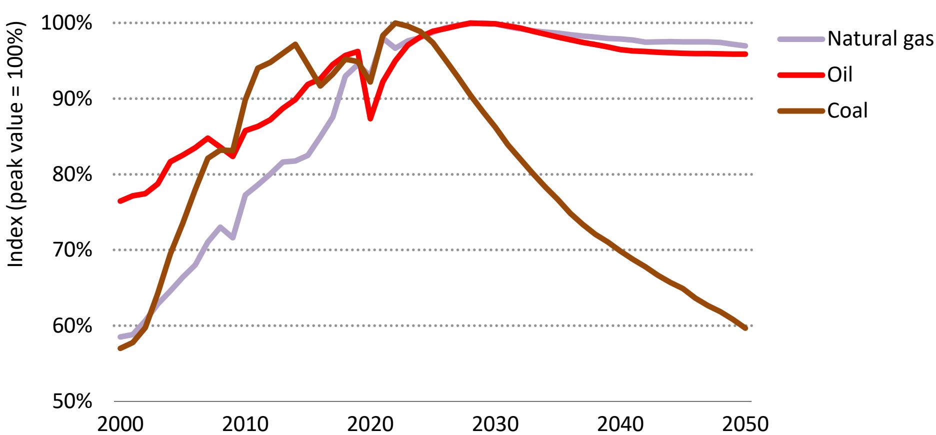
The topics included in this chapter represent key themes of the *World Energy Outlook 2023*. Further information and background on the IEA Net Zero Roadmap is in *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach* published in September 2023. In addition, a range of supply and demand issues for the oil and gas industry and their relation to the *Outlook* are the focus of a forthcoming special report in November 2023.

## 1.1 A peak by 2030 for each of the fossil fuels

In the *WEO-2023*, the Stated Policies Scenario (STEPS) sees lower demand projections for each of the fossil fuels than in the *WEO-2022*. This reflects current policy settings by governments worldwide, a slight downward revision in the economic outlook, and the continued ramifications of the 2022 global energy crisis. It also reflects longer term trends: fossil fuel technologies have been losing market share to clean energy technologies across various sectors in recent years, and in many cases fossil fuel-powered technologies have already seen a peak in sales or additions.

These shifts mean that each of the three fossil fuel categories are now projected to reach a peak by 2030 (Figure 1.1). This has never previously been seen in the STEPS. The changes in our projections highlight how the energy system is changing as low-emissions electricity and fuels meet an increasing share of the world's rising energy needs, and as energy efficiency improvements help to moderate those needs. Total demand for fossil fuels declines from the mid-2020s by an average of 3 exajoules (EJ) per year to 2050 in the STEPS, and the peak in energy-related $CO_2$ emissions in the STEPS is brought forward to the mid-2020s.

**Figure 1.1 ▷ Fossil fuel consumption by fuel in the STEPS, 2000-2050**






***All fossil fuels peak before the end of this decade, with declines in advanced economies and China offsetting increasing demand elsewhere***

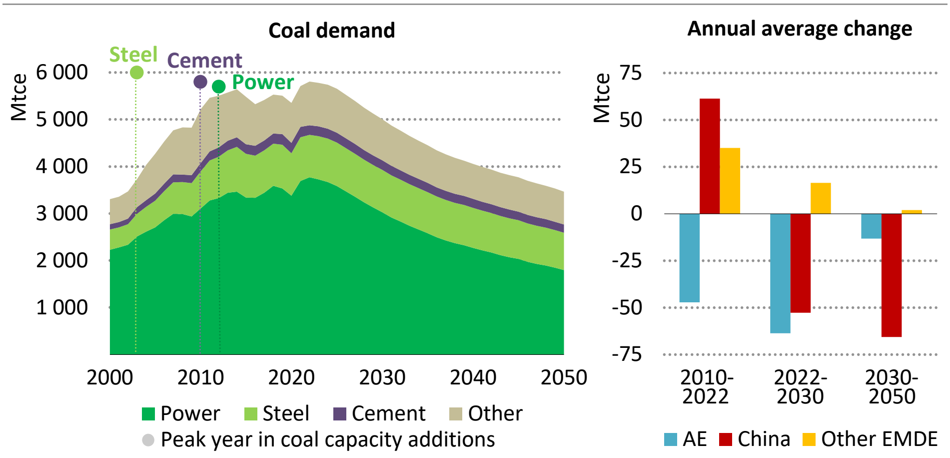
We highlight below some of the key drivers for these changes by fuel, but there are some important issues to bear in mind when considering these trends. First, the projected declines in demand after the peaks are nowhere near steep enough to be consistent with the NZE Scenario – getting on track for this scenario will require much faster clean energy deployment and much more determined policy action by governments (section 1.4). Second, the demand trends for the different fuels vary considerably among regions, with reduced demand in advanced economies partially offset by continued growth in many emerging market and developing economies, particularly for natural gas. Third, while the trajectories in our scenarios reflect underlying structural changes, the demand outlook will not be linear in practice. There will inevitably be spikes, dips and plateaus along the way. For example, heatwaves and droughts could well cause temporary jumps in coal demand by pushing up electricity use at a time when hydropower output may be constrained.

Even as demand for fossil fuels falls, energy security challenges will remain since the process of adjustment to changing demand patterns will not necessarily be easy or smooth. For example, the peaks in demand we see based on today's policies do not remove the need for investment in oil and gas supply, given how steep the natural declines from existing fields often are. At the same time, they underline the economic and financial risks of major new oil and gas projects, on top of their risks for climate change (section 1.5).

### 1.1.1 Coal: Scaling up clean power hastens the decline

After remaining consistently high over the past decade, global coal demand is now set to fall within the next few years in the STEPS (Figure 1.2). This projected trend reflects declines in recent years of capacity additions of both coal-fired power and coal-fired iron and steel production – the two largest consumers of coal today – which account for 65% and 16% respectively of overall coal consumption.

**Figure 1.2 ⊳ Global coal demand by sector and annual average change by region in the STEPS, 2000-2050**






*Peaks in coal capacity additions reached in the power, steel and cement sectors are laying the foundation for global coal demand to peak in the mid-2020s*

Note: Mtce = million tonnes of coal equivalent; AE = advanced economies; EMDE = emerging market and developing economies.

The share of coal-fired power in new worldwide capacity additions hit a high point in 2006 at 45% and has since fallen steadily to 11% in 2022. The size of annual coal capacity additions peaked in 2012 at over 100 gigawatts (GW) before dropping to 50 GW in 2022, with big investments in coal falling away rapidly, and solar PV and wind power increasingly dominating the expansion of electricity systems. The role of coal-fired power plants has started to shift towards providing flexibility and system services rather than bulk power. As a result, the average capacity factor of coal power plants was almost ten percentage points lower over the past decade than during the decade before.

Changes in iron and steel production have also contributed to the decline in coal demand. Capacity additions of coal-based steel production plants[1] peaked in 2003 at over 130 million tonnes (Mt), driven in large part by China's rapid industrialisation. Eleven years later, global coal demand for iron and steel production peaked at over 950 million tonnes of coal equivalent (Mtce) before starting to fall, despite a continuing steady increase in the production of iron and steel. The decline in the global coal intensity of steel production since 2015 is the result of growth in the share of scrap-based production in electric arc furnaces, as well as alternatives to blast furnaces for iron production such as natural gas-based direct reduced iron.

In advanced economies, coal demand peaked in 2007. In China – the world's largest coal consumer – the impressive growth of renewables and nuclear alongside macroeconomic shifts point to a decrease in coal use by the mid-2020s. Coal use continues to increase in other emerging market and developing economies as new power plants and industry capacity come online, but this growth is more than offset by projected declines elsewhere.

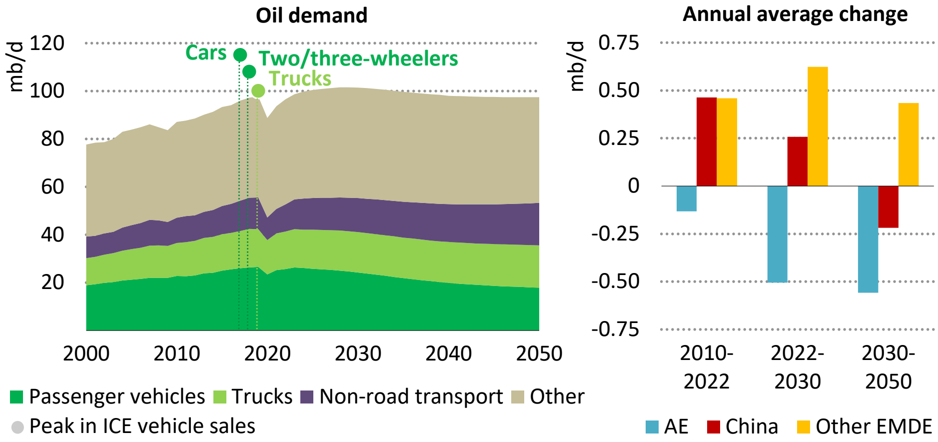
### *1.1.2 Oil: End of the "ICE age" turns prospects around*

In the past two decades, oil demand has surged by 18 million barrels per day (mb/d). Much of the increase has been driven by rising demand in road transport. The global car fleet expanded by more than 600 million cars over the last 20 years, and road freight activity has increased by almost 65%. Road transport now accounts for around 45% of global oil demand, which is far more than any other sector: the petrochemicals sector, second-largest in oil consumption, accounts for 15% of oil demand.

The astounding rise in electric vehicle (EV) sales is now having an impact on demand for oil in road transport. Sales of gasoline and diesel cars, two/three-wheelers and trucks peaked in 2017, 2018 and 2019 respectively (Figure 1.3). In 2020, EVs accounted for 4% of global car sales. They are on track to reach 18% in 2023 with 14 million EV sales, mostly in China and the advanced economies, and are set to continue to increase rapidly in the future. Sales of internal combustion engine (ICE) buses also peak by the mid-2020s in the STEPS, with the uptake of electric buses rising particularly quickly in emerging market and developing economies. By the end of this decade, road transport is no longer a source of oil demand growth.

[1] Includes blast furnaces-basic oxygen furnaces, smelting reduction-basic oxygen furnace, coal-based direct reduced iron-electric arc furnace, coal-based iron in induction or in open hearth furnaces.

**Figure 1.3 ▷ Global oil demand by sector and annual average change by region in the STEPS, 2000-2050**






*Sales of gasoline and diesel passenger vehicles and trucks have already peaked, leading to a peak in oil demand before 2030*

Note: mb/d = million barrels per day; AE = advanced economies; EMDE = emerging market and developing economies.

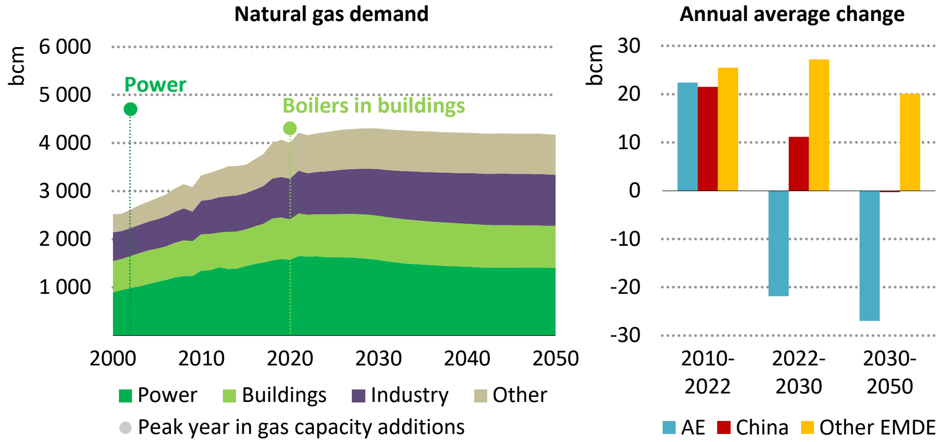
Although oil demand for petrochemicals, aviation and shipping continues to increase through to 2050 in the STEPS, this is not enough to offset reductions in demand from road transport, as well as in the power and buildings sectors. As a result, oil demand peaks before 2030. The decline from the peak however is a slow one in the STEPS all the way through to 2050.

The outlook for oil demand varies across regions. Oil demand in advanced economies peaked in 2005, and its decline becomes more pronounced in the coming decade. China's robust oil demand growth since 2010 weakens in the coming years and declines in the long run. In emerging market and developing economies (other than China), which see growing populations and car ownership, oil demand grows continuously to 2050.

### 1.1.3 Natural gas: Energy crisis marks the end of the "Golden Age"

The "Golden Age of Gas", a term coined by the IEA in 2011, is nearing an end. Global natural gas use has increased by an annual average of almost 2% since 2011, but growth slows in the STEPS to less than 0.4% per year from now until 2030. The power and buildings sectors – today's biggest consumers of natural gas accounting for 39% and 21% respectively of total demand – have already seen peaks in natural gas capacity additions for power plants and space heating boilers, and muted demand in these two sectors reduces natural gas use enough to cause it to peak by 2030 (Figure 1.4).

**Figure 1.4 ▷ Global natural gas demand by sector and annual average change by region in the STEPS, 2000-2050**






*Additions of new gas power plants and gas boilers in buildings are slowing; gas demand peaks before 2030 in the STEPS, though gas use in industry continues to increase*

Note: bcm = billion cubic metres; AE = advanced economies; EMDE = emerging market and developing economies.

The high point for natural gas power capacity additions was in 2002, when they exceeded 100 GW and made up around 65% of total annual capacity additions. Capacity additions fell to less than 30 GW in 2022. Despite this slowing in annual additions, the global installed capacity of natural gas power continues to expand over time. Gas differs in this respect from coal, where installed capacity reduces in the future. Natural gas demand in the power sector nevertheless declines in the STEPS from today until 2050, with a particularly strong dip in the 2030s when co-firing in gas-fired power plants begins to be deployed at scale.

Sales of gas-fired boilers for space heating in buildings have also peaked. At their height, gas boilers accounted for around 40% of total sales of space heating equipment. The subsequent decline in sales over the last few years reflects the rapid rise of heat pumps, especially in advanced economies. Heat pump sales have a strong impact on gas demand in the buildings sector in the STEPS trajectory because space heating is by far the leading end-use in terms of natural gas demand today.

In advanced economies, the rebound in natural gas demand seen in 2021 did not last long, and demand in 2022 was below pre-pandemic levels. This faltering in demand reflects a shift to renewables in electricity generation, the rise of heat pumps, and Europe's accelerated move away from gas following the Russian Federation (hereinafter Russia) invasion of Ukraine. Demand continues to decline in the STEPS, and by 2030 this more than offsets continued demand growth in emerging market and developing economies.

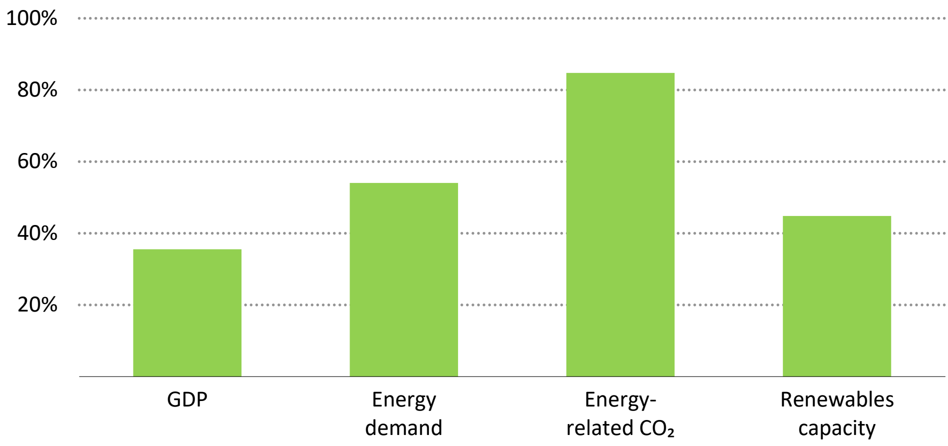
## 1.2 A slowdown in economic growth in China would have huge implications for energy markets



### *1.2.1 China's growth has defined the energy world in recent decades*

China's economic growth has been an epoch-making event over the last several decades. Since 1995, China accounted for two-thirds of the decline in the global population living in extreme poverty. Its GDP per capita increased more than seven-times in the same period, as its economy transformed into a globally integrated, innovative industrial powerhouse.

**Figure 1.5 ▷ China's share in the change of selected global economic and energy sector indicators, 2012-2022**




*China's growth has transformed the global economy, energy sector and environment*

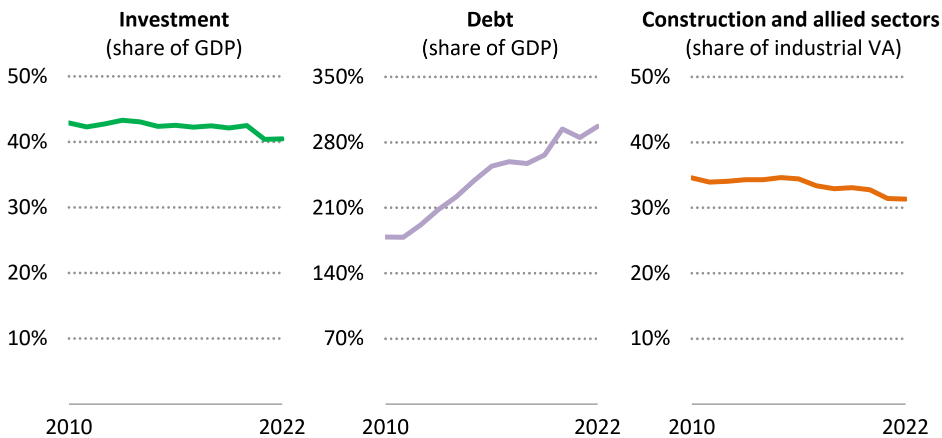
Note: GDP is measured at market exchange rates.

More recently, over the course of the last decade China was responsible for more than one-third of growth in global GDP (Figure 1.5). China's growth has done much to shape energy markets and the global environment: in the last decade, it accounted for more than 50% of global energy demand growth and 85% of the rise in energy sector $CO_2$ emissions. But its economy is changing. China's leaders have long acknowledged that its current phase of massive and resource-intensive investment in urbanisation, infrastructure and factories must end. As far back as 2007, China's then Premier warned that "the biggest problem with China's economy is that growth is unstable, unbalanced, uncoordinated and unsustainable". This rebalancing could have substantial impacts on the outlook for China's energy sector, and given China's size, for the world too.

### 1.2.2 Integrating a slowdown in China's economy into the STEPS

The rebalancing of the Chinese economy still has a long way to go. Savings and investment levels remain very high, the debt-to-GDP ratio has continued to climb, and the construction sector retains an outsized role in GDP (Figure 1.6). This model is pushing against inherent constraints. China already has a world-class infrastructure stock, and after growing almost 30% in the last decade its per capita residential floorspace is already equal to that of Japan, despite China's lower level of GDP per capita. China's working age population peaked around 2015 and is projected to fall by more than 20% by 2050. With this will come a reduced need for investment, such as in new housing and infrastructure (Figure 1.7).

**Figure 1.6 ▷ Selected indicators of structural change in the Chinese economy, 2010-2022**





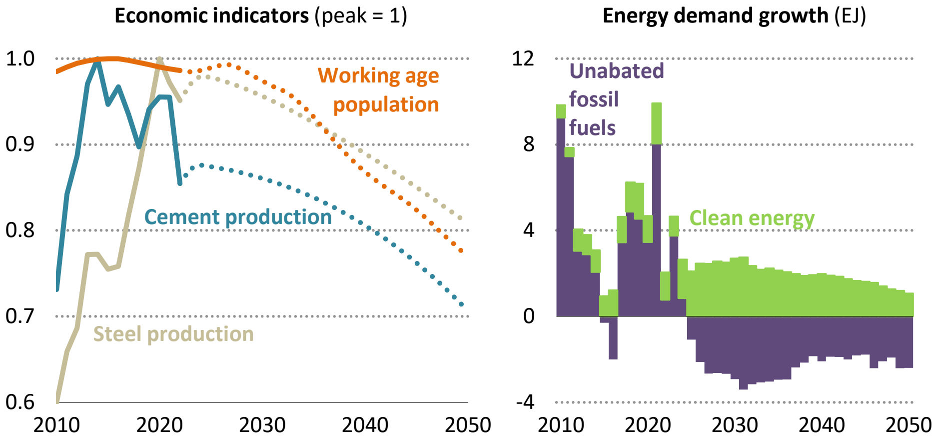

***Rebalancing of China's economy still has a long way to go with investment, debt-to-GDP ratio, and share of the construction sector in GDP remaining high***

Notes: GDP is expressed in market exchange rate terms. VA = value added. Allied sectors are basic chemicals and fertilisers, basic metals, non-metallic minerals, pulp and paper, wood and wood products excluding furniture. Debt refers to total outstanding credit to the non-financial sector from all lending sectors, expressed as a percent of GDP.

Sources: IEA analysis based on data from Oxford Economics (2023) and BIS (2023).

Although the current property crisis in China has attracted much attention, it has not yet significantly impacted the energy sector (Box 1.1). Moreover, the property crisis is a symptom of the broad structural change facing the Chinese economy. How this economic transition plays out is one of the key uncertainties in this *Outlook*. In our scenarios, we have revised downwards the long-term projection of GDP growth in China to just under 4% per year for the period 2022 to 2030, and 2.3% per year for the period 2031 to 2050. This compares to more than 4.5% and more than 2.5% respectively in the *World Energy Outlook-2022* scenarios. As a result, the economy is around 5% smaller in 2030 than projected last year, and slightly less than 15% smaller in 2050. Despite these changes, China remains a critical driver of global growth, accounting for almost one-third of global GDP growth to 2030 in our scenarios. But slower growth results in China's total energy demand peaking around the middle of this decade; with stable and then slowly declining demand, clean energy growth is sufficient to drive a decline in fossil fuel demand and hence emissions.

**Figure 1.7 ▷ Selected economic indicators and annual total energy demand growth in China in the STEPS, 2010 – 2050**





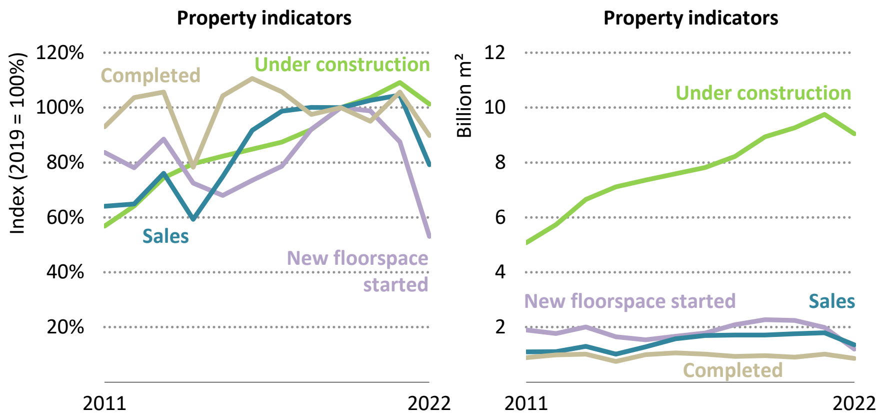

*Cement, steel and working age population each have peaked and are set to decline; as China's economy changes, energy demand growth will slow, peak and decline*

Source: Population projection from the Median Variant of the World Population Prospects (UNDESA, 2022).

**Box 1.1 ▷ The property crisis is everywhere, except in the energy statistics**

Despite the importance of the unfolding property crisis, China's energy demand and its heavy industrial production appear only modestly affected. The total floorspace of new projects started per year fell around 50% from 2019 to 2022; but floorspace under construction, despite falling in 2022, is still 1% higher than in 2019 (Figure 1.8). In other words, the property crisis has impacted new projects, not those already under construction. This explains why material and energy demand has been less impacted than indicators like new project starts or property developer share or bond prices. It also implies that if China's property sector settles into a lower level of activity, over time this will impact the stock of projects under construction and hence energy and material demand underlying construction projects.

**Figure 1.8 ⊳ Selected property sector indicators, China, 2011-2022**




IEA. CC BY 4.0.

*So far, the property crisis has hit the flow of new project starts, but has had limited impact on the stock of projects under construction*

Source: IEA analysis based on data from the National Bureau of Statistics of China (NBSC, 2023).

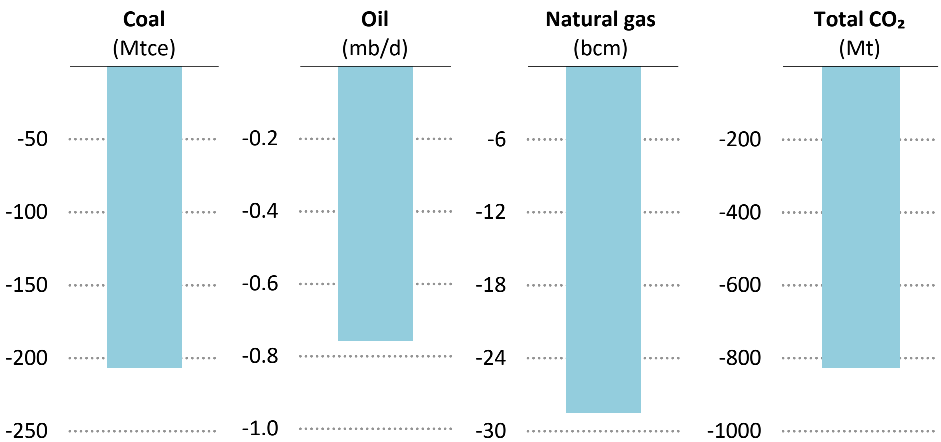
There are several additional reasons, both structural and cyclical, which explain why energy demand has been resilient in the face of the downturn in the property sector in China:

- Rapid electrification has driven strong electricity demand growth. Electricity generation accounted for more than 70% of the increase in energy demand since 2015 in China.
- "New economy" sectors have been growing strongly, including high-tech manufacturing in clean energy areas such as PV and EVs. While the average annual growth of fixed asset investment in property has shrunk by around 5% since January 2022, it has grown by about 15% for automobile manufacturing, for example. To take another example, revenue in the last year for listed solar PV manufacturers and automobile manufacturers amounted to USD 166 billion and USD 135 billion respectively.
- China is massively increasing its domestic petrochemical production. Between 2019 and 2024, China is set to add as much petrochemical capacity as the combined capacity of all OECD countries in Europe and Asia. Feedstock demand for petrochemical production has increased 50% since 2019 and is responsible for around 80% of growth in oil product demand in China over the 2019 to 2023 period.
- Droughts in 2021 and 2022 constrained hydro electricity production (and are continuing to do so in 2023). Without this factor, China's total energy demand growth would have been less in 2022, and its $CO_2$ emissions would have declined rather than risen marginally.

### 1.2.3 *Sensitivities in the Outlook*

But outcomes other than those in the STEPS are possible. To explore possible implications, we have modelled a *Low Case* and a *High Case*. In the Low Case, China's GDP is around 7.5% lower in 2030 than in the STEPS, with a more rapid decline in infrastructure and property investment not fully offset by an increase in consumption and investment in other sectors. Cement production is around 14% lower than in the STEPS, for example. The Low Case assumes slower but ultimately "higher quality" growth.[2] The High Case assumes the reverse, with a delayed rebalancing temporarily increasing GDP growth while at the same time negatively impacting longer term economic sustainability.

**Figure 1.9 ▻ Key energy indicators for China in the Low Case versus the STEPS, 2030**






***Slower but high quality growth in this decade would have large impacts on world energy markets and China's $CO_2$ emissions***

In the Low Case, primary coal demand is around 7% lower than in the STEPS in 2030 due to lower levels of production in heavy industries, less electricity demand, and continued robust expansion of low-emissions sources of electricity generation (Figure 1.9). Oil is less affected than coal, with primary demand around 0.75 mb/d lower than in the STEPS, but the decline in demand nevertheless represents the equivalent of about 5% in projected 2030 oil imports in the STEPS (or about 2% of the global market). Natural gas is also less affected than coal, with demand almost 30 billion cubic metres (bcm) lower in 2030 than in the STEPS, though still over 15% higher than in 2022. This reduction represents the equivalent of more than

[2] Increasingly used in official discourse, the phrase "high quality" growth is taken to mean economic growth based on domestic consumption, external demand and business investment in productive sectors, as opposed to continued growth based on high investment in property and infrastructure with low and diminishing productivity returns.

20% of China's projected liquefied natural gas (LNG) imports in the STEPS in 2030. These various changes result in $CO_2$ emissions that are more than 0.8 gigatonnes (Gt) lower in 2030 than in the STEPS, and nearly 15% lower than in 2022. On the other hand, the High Case sees stronger coal demand and higher $CO_2$ emissions. Emissions still peak before 2030, but in 2030 are about 0.8 Gt higher than in the STEPS, and 1.6 Gt higher than in the Low Case. As in the Low Case, the impact across fuels is not symmetrical, with less of an upside for oil than for coal. In both the High Case and the Low Case, the weight of China in global energy markets means that the changes have significant global implications.

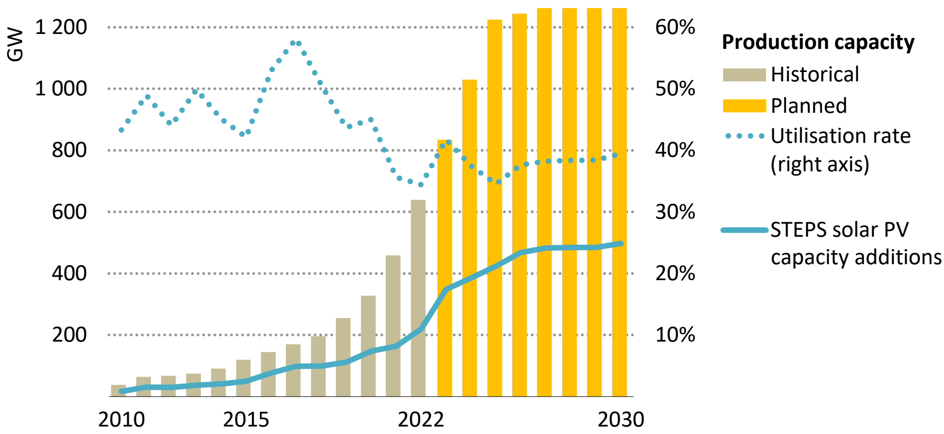
This discussion highlights the importance of paying close attention to China's macroeconomic evolution. The Low Case, predicated on lower but higher quality growth, would have substantial and probably deflationary impacts on global energy commodity and technology markets. At the same time, increased emphasis on export-oriented sectors, including clean energy technology sectors, in order to partially offset the decline of others such as property could have implications for – already strained – trade relations. On the other hand, a prolongation of the current infrastructure and property intensive model might provide a near-term boost to energy and commodity markets, but it would also increase $CO_2$ emissions and could store economic problems for the future.

## 1.3 A boom of solar manufacturing could be a boon for the world

Solar manufacturing has experienced a remarkable expansion over the last decade, increasing ten-fold globally to meet increasing demand for clean energy. This trend is set to continue at an elevated pace, with investments in the pipeline set to raise global solar module manufacturing capacity from about 640 GW in 2022 to over 1 200 GW in the medium term (Figure 1.10). Paired with rapid expansion along the supply chain – from the production of polysilicon to wafers and solar cells – solar PV is poised to accelerate clean energy transitions around the world.

Solar PV has been one of the major successes of the past decade, with annual deployment of electricity generation capacity growing more than sevenfold. Manufacturing capacity expansion has been even faster and the gap has driven down the utilisation rate of solar manufacturing from close to 60% to below 40% in 2022. This is well below the 70% level that would normally be considered healthy for a mature industry. In the STEPS, global solar PV deployment continues to expand from around 220 GW in 2022 to about 500 GW in 2030, but planned manufacturing expansion means that the utilisation rate of solar manufacturing remains below 40% through to 2030. The scope to make fuller use of solar manufacturing capacity represents an enormous opportunity to accelerate the deployment of solar PV around the world and accelerate energy transitions.

**Figure 1.10 ▷ Global solar module manufacturing and solar PV capacity additions in the STEPS, 2010-2030**





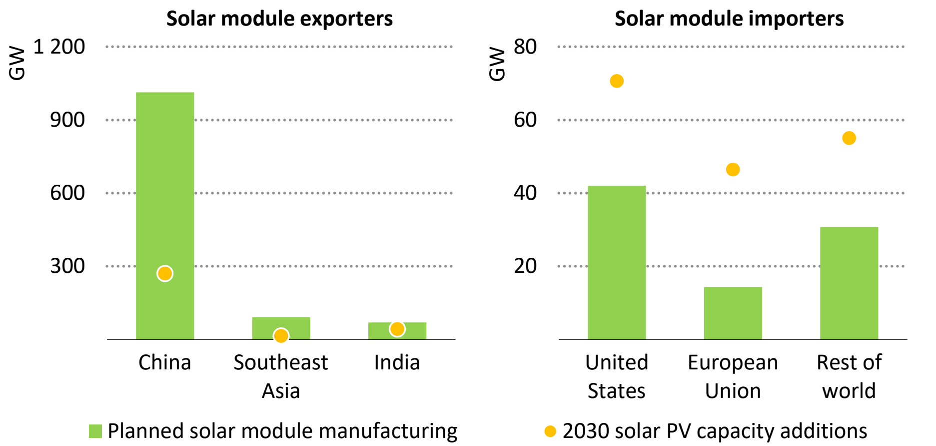

*Planned expansion of solar manufacturing outpaces solar PV capacity additions to 2030; its low utilisation rate presents a huge opportunity to accelerate clean energy transitions*

### 1.3.1 Solar module manufacturing and trade

Solar manufacturing today is highly concentrated – just five countries account for over 90% of global capacity. China is far and away the largest, with the capacity to produce solar modules with an output of over 500 GW every year, equivalent to 80% of world manufacturing capacity. The other four are Viet Nam (5% of the global market), India (3%), Malaysia (3%) and Thailand (2%). The next five leading solar manufacturers – the United States, Korea, Cambodia, Türkiye and Chinese Taipei – each account for around 1% of the global total, as does the European Union.

While fewer than 40 countries have capacity to produce solar modules, over 100 countries completed solar PV projects in 2022, which mostly relied on imported solar panels. China is the primary exporter of solar panels (IEA, 2022a). Its exports, and those of other exporters, facilitate the expansion of renewable energy in markets around the world. Southeast Asia is the second-largest exporter, with many of the panels it exports going to the United States and the European Union. As domestic manufacturing capacity in India has increased in recent years, there is potential to reduce import dependence over the coming years. Today, the European Union and the United States are the largest importers of solar panels. New import tariffs have recently been put in place in the United States on solar modules that originate in China: these are set to change the pattern of imports to the United States, and may have knock-on effects in other markets.

**Figure 1.11 ▷ Planned solar module manufacturing capacity and solar PV capacity additions in the STEPS, 2030**




IEA. CC BY 4.0.

***Solar manufacturing is set to expand in more than a dozen countries: China remains the largest exporter, while the European Union and United States remain the main importers***

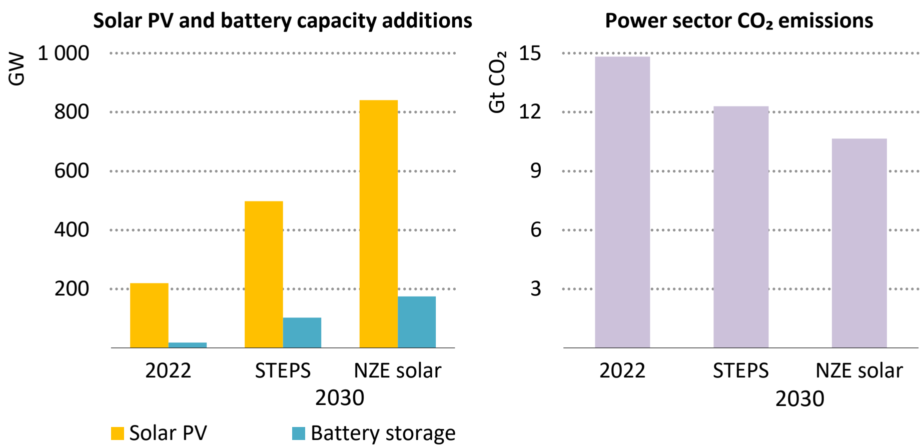
Plans for additional capacity suggest that solar manufacturing will remain highly concentrated, and that trade will continue to be important for many markets (Figure 1.11). China plans to add another 500 GW of solar module manufacturing capacity in the coming years, far outstripping plans for new capacity in other countries. Expansion on this scale means that it is likely to maintain its 80% share of the global total and to remain the primary exporter of solar modules by some distance. India aims to continue expanding its production capacity to meet domestic needs and to export solar modules: projects in the pipeline under the Production Linked Incentives scheme suggest that its manufacturing capacity could exceed 70 GW per year by 2027. Production capacity in Southeast Asia is set to outpace regional needs, allowing it to remain an important exporter. In the United States, planned solar module production capacity investments have been boosted by the Inflation Reduction Act, and are on course to increase sixfold in the medium term. However, without further investment, significant imports will still be needed to meet fast growing solar PV deployment in the STEPS in 2030. Solar manufacturing in the European Union is set to double in the medium term, but here too deployment is increasing rapidly, and about 70% of deployment in 2030 will depend on imported solar modules unless further investments are made in manufacturing in the European Union.

### 1.3.2 Solar PV deployment could scale up faster to accelerate transitions

Planned increases in solar PV manufacturing capacity around the world have the potential to enable over 800 GW of new solar PV to be deployed in 2030, which is in line with the level of deployment reached in the NZE Scenario in 2030 (Figure 1.12). This would raise the average utilisation rate for solar module manufacturing to around 70%, which is roughly what might be expected in a mature industry. We have constructed the *NZE Solar Case* which looks at what would happen if all this potential solar capacity was tapped and compares the outcomes in 2030 with those in the STEPS. The rest of this section highlights this comparison.



**Figure 1.12 ▷ Global solar PV and battery storage capacity additions and power sector $CO_2$ emissions, 2022 and 2030**






***Taking advantage of solar manufacturing capacity could lift solar PV deployment to over 800 GW by 2030, in line with the NZE Scenario, cutting power sector emissions 30% by 2030***

Note: GW = gigawatts; Gt = gigatonnes; NZE solar = NZE Solar Case.

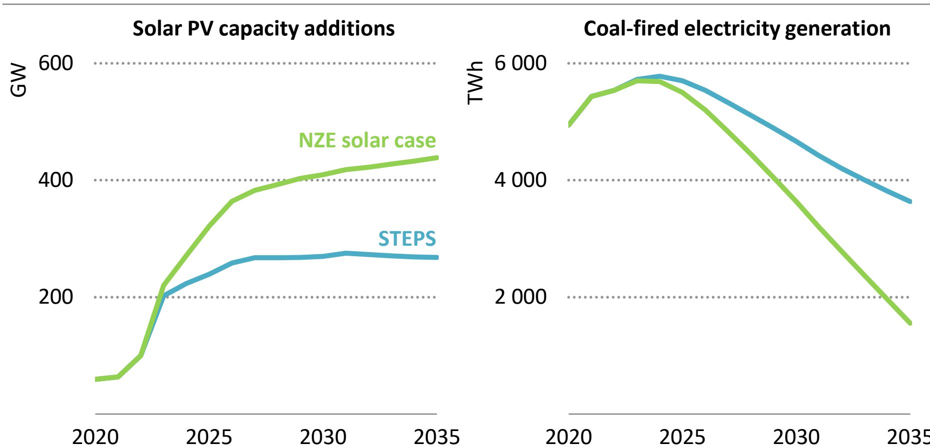
An important initial point is that rapid further deployment of solar PV in the NZE Solar Case would require measures to integrate the additional solar PV into electricity systems and maximise its impact. Scaling up battery storage would be crucial in most cases to improve the alignment of solar PV output with electricity demand patterns and system needs. In the NZE Solar Case, utility-scale battery deployment in 2030 is close to double the level in the STEPS. Measures to modernise and expand networks, facilitate demand response and boost power system flexibility would also be necessary.

Accelerating solar PV deployment to the levels in the NZE Scenario would reduce $CO_2$ emissions in 2030 by displacing some unabated fossil fuels. Global $CO_2$ emissions from the power sector would fall below 11 Gt in 2030, some 15% lower than the level in the STEPS in 2030 and 30% below the level in 2022. Coal-fired electricity generation would be around 15% lower than in the STEPS in 2030: the decline in coal-fired generation would largely take place in emerging market and developing economies and would deliver the bulk of the emissions reductions. Natural gas-fired electricity generation would also be reduced by 15% compared with the STEPS in 2030, with reductions in both advanced economies and emerging market and developing economies.

### *China could accelerate solar PV deployment to shift away from coal faster*

In the STEPS, solar PV capacity additions in China reach over 270 GW per year before flattening. While this means a marked slowing of the rate of growth achieved in recent years, it still puts China five years ahead of schedule to reach 1 200 GW of solar PV and wind capacity, which is one of the targets for 2030 in its Nationally Determined Contribution. Nevertheless, there is scope for China to accelerate its uptake of both distributed solar PV and large-scale projects. In the NZE Solar Case, China's annual solar PV capacity additions exceed 400 GW by 2030 (Figure 1.13). To successfully integrate the additional solar PV and keep curtailment at manageable levels, battery storage and network enhancements would be as important in China as everywhere else. Continued progress on power system reforms, including further moves towards a unified national power market, would help make the best use of the additional solar PV (IEA, 2023a).

**Figure 1.13 ▷ Solar PV capacity additions and coal-fired electricity generation in China in the STEPS and NZE Solar Case, 2020-2035**





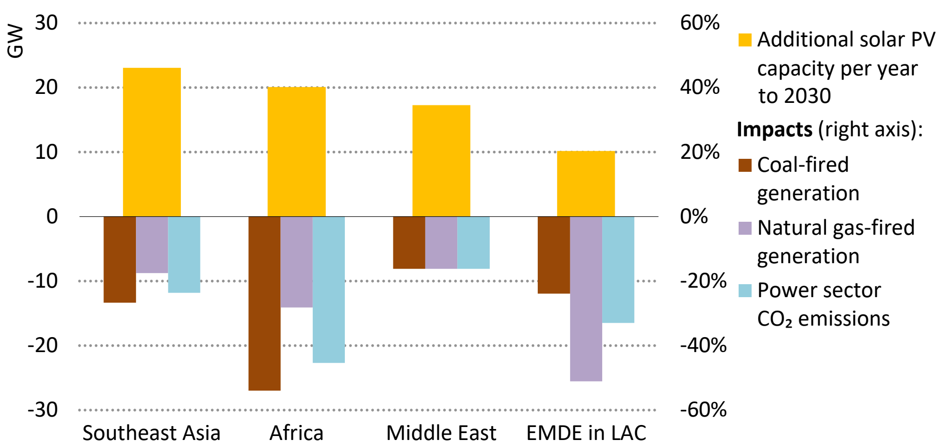

***With targeted integration measures, China could deploy significantly more solar PV and put coal-fired power into a steeper decline***

Effectively integrated, higher solar PV deployment would accelerate the transition away from coal-fired power in China. While coal-fired generation would still peak around 2025, it would decline more steeply afterwards. By 2030, the level of coal-fired generation in the NZE Solar Case would be 20% lower than in the STEPS and 35% lower than in 2022. Without assuming any additional retirements, the average annual capacity factor for coal-fired power plants would fall to about 30% in 2030, compared with about 40% in the STEPS and over 50% in 2022. As a result, power sector $CO_2$ emissions would fall to about 4.2 Gt in 2030, a 30% reduction from the 2022 level.

### *Emerging market and developing economies could also shift away from coal faster*

Spare solar PV manufacturing capacity could also facilitate faster uptake of low cost solar PV in emerging market and developing economies other than China. In the NZE Solar Case, more than 70 GW of additional solar PV is deployed each year to 2030 across Africa, Latin America and the Caribbean (LAC), Middle East and Southeast Asia. Even with modest amounts of curtailment, this would reduce both natural gas-fired and coal-fired power generation by about one-quarter in 2030 compared with the levels in the STEPS, cutting power sector $CO_2$ emissions in 2030 by over 500 Mt, 30% of the total. The Middle East would also have the opportunity to cut both coal and natural gas use in power, while in LAC the additional solar PV would mostly reduce demand for natural gas-fired generation; in Africa and Southeast Asia, its biggest impact would be on coal-fired power (Figure 1.14).

**Figure 1.14 ▷ Additional solar PV capacity additions in the NZE Solar Case and related impacts in selected regions relative to the STEPS, 2030**






***Additional solar PV deployed in emerging market and developing economies could significantly reduce generation from coal and natural gas and cut $CO_2$ emissions***

Note: EMDE = emerging market and developing economies. LAC = Latin America and the Caribbean.

Hydropower resources in LAC and Africa could facilitate the integration of more solar PV, while the Middle East's reliance on natural gas would also help to provide system flexibility. Southeast Asia would face the most serious integration challenges, which could be eased by expanding interconnections and cross-border trade (IEA, 2019). In all emerging market and developing economies, access to finance and the reduced costs of capital would be essential to be able to take advantage of the opportunity to accelerate uptake of solar PV (IEA, 2021a).

## 1.4 The pathway to a 1.5 °C limit on global warming is very tough, but it remains open

*Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach*, the IEA update to the landmark Net Zero by 2050 Roadmap, was published in September 2023 (IEA, 2023b). The updated Net Zero Emissions by 2050 (NZE) Scenario is incorporated in full in this *Outlook*. It reached the conclusion that the pathway to net zero emissions by 2050 has narrowed since the first version published in 2021, but that it remains feasible. In this section, we highlight four reasons why this pathway remains open and look at four areas that require urgent attention if the promise of a 1.5 °C limit on global warming is to be realised.

### *1.4.1 Four reasons for hope*

#### *Clean energy policies are stepping up*

Many countries and an increasing number of businesses are committed to reaching net zero emissions. As of September 2023, net zero emissions pledges cover more than 85% of global energy-related emissions and nearly 90% of global GDP. Ninety-three countries and the European Union have pledged to meet a net zero emissions target. Moreover, governments around the world, especially in advanced economies, have responded to the pandemic and the global energy crisis by putting forward new measures designed to promote the uptake of renewables, electric cars, heat pumps, energy efficiency and other clean energy technologies.

EV targets have driven a major transformation in the industrial strategies of car and truck manufacturers in recent years, together with fuel economy and $CO_2$ emissions standards in the European Union and China, and more recently in the United States. Similarly, electric two/three-wheelers and buses have seen significant uptake in India and other emerging market and developing economies thanks to policy support, increasing economic competitiveness and limited infrastructure needs. The United States, through the Inflation Reduction Act adopted in 2022, has provided unprecedented funding to support deployment and reduce costs for a range of low-emissions technologies, notably carbon capture, utilisation and storage (CCUS) and hydrogen. Successive five-year plans in China have progressively raised ambitions for solar PV and driven down global costs. Offshore wind deployment in Europe has turned into a global industry.

#### *Clean energy deployment is accelerating fast*

Clean energy investment and deployment have increased rapidly in response to the market signals and financial incentives provided by governments, with mass-manufactured technologies such as solar PV, wind turbines and EVs leading the way. Sales of residential heat pumps and stationary battery storage are also rising fast. Since the Paris Agreement was signed in 2015, almost 1 terawatt (TW) of solar PV capacity has been added to the global system – nearly equivalent to the total installed electricity capacity in the European Union.

Around 40% of this deployment was in 2021 and 2022. Well over half of the electric cars on the road worldwide have been sold since 2021.

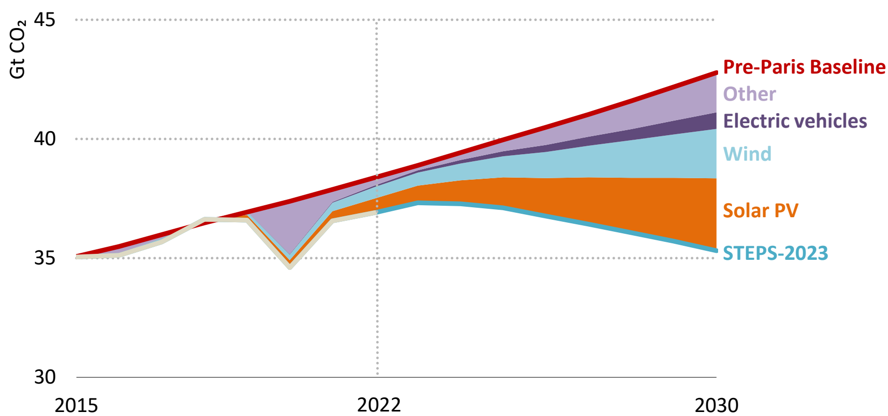


As a result, solar PV capacity additions are currently tracking ahead of the trajectory envisaged in the 2021 version of our NZE Scenario. We now estimate that global manufacturing capacities for solar PV and EV batteries would be sufficient to meet projected demand in 2030 in the updated NZE Scenario, if all announced projects proceed. This progress reflects major cost reductions in recent years: the costs of key clean energy technologies – solar PV, wind, heat pumps and batteries – fell by close to 80% on a deployment weighted average basis between 2010 and 2022.

**Box 1.2 ▹ Clean energy deployment is starting to bend the emissions curve**

Clean energy deployment is starting to bend the emissions curve, thanks largely to solar PV, wind power and EVs. These three technologies contribute the bulk of the emissions reductions in the *WEO-2023* STEPS relative to a pre-Paris Baseline Scenario (Figure 1.15). Solar PV is projected to reduce emissions by around 3 Gt in 2030, roughly equivalent to the emissions from all the cars on the road worldwide today. Wind power is projected to reduce emissions by around a further 2 Gt in 2030, and EVs by around 1 Gt more. This is far from enough to get on track for net zero emissions by 2050; indeed staying on a STEPS trajectory to 2030 would definitely close the door to the 1.5 °C limit. But it is keeping the pathway open.

**Figure 1.15 ▹ Global energy sector $CO_2$ emissions in the pre-Paris Baseline Scenario and the STEPS, 2015-2030**



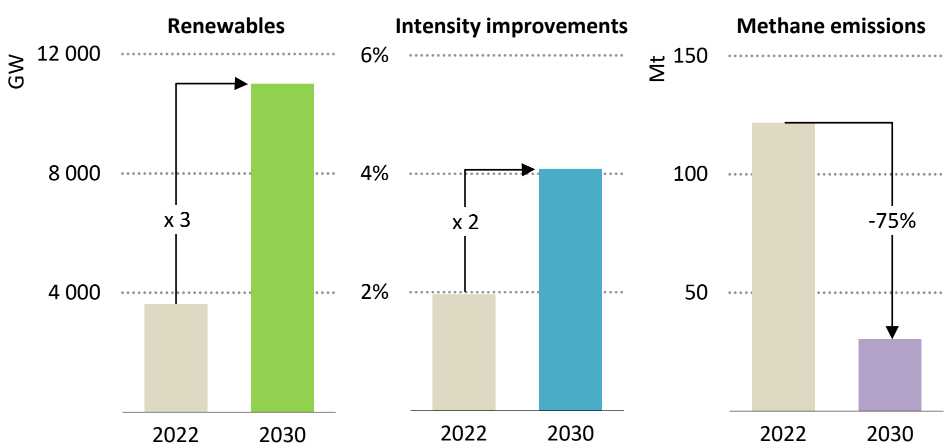



***Solar PV, wind power and EVs reduce emissions by 6 Gt in 2030 in the STEPS relative to the pre-Paris Baseline Scenario***

*We have the tools to go much faster*

The key actions required to bend the emissions curve much more sharply downwards by 2030 are mature, tried and tested, and in most cases very cost effective. More than 80% of the additional emissions reductions needed in 2030 in the NZE Scenario come from well-known sources: ramping up renewables, improving energy efficiency, increasing electrification and cutting methane emissions. In the NZE Scenario, tripling the installed capacity of renewables and doubling the rate of energy intensity improvements are central to the transformation of the energy sector.

**Figure 1.16 ▷ Global renewables power capacity, primary energy intensity improvements, and energy sector methane emissions in the NZE Scenario, 2022 and 2030**






***Renewables, energy efficiency and methane emissions reduction options are available today and crucial to reducing near-term emissions***

Tripling global installed capacity of renewables to 11 000 GW by 2030 provides the largest emissions reductions to 2030 in the NZE Scenario. Current trends are encouraging; repeating the growth rate seen over the last decade would be sufficient, and current policy settings already put advanced economies and China on track to achieve 85% of their contribution to this global goal. The contribution of solar PV has been revised upward from the 2021 version of the NZE Scenario, underpinned by a surge in global manufacturing capacity, but a range of low-emissions technologies is required to ensure balanced and secure decarbonisation of the power sector.

Doubling the annual rate of energy intensity improvement by 2030 in the NZE Scenario not only reduces emissions but also boosts energy security and affordability, saving the energy equivalent of all worldwide oil use in road transport today. Priorities vary by country, but the key improvements at the global level come from upgrading the technical efficiency of equipment such as electric motors and air conditioners, from efficiency gains brought about by electrification and the switch away from solid biomass use in low income countries, and from using energy and materials more efficiently.



Further electrification of end-uses is a priority. EVs and heat pumps are central to this. Sales of EVs are already increasing fast enough to achieve the NZE Scenario milestone of two-out-of-three cars sold in 2030 being electric, and announced production targets from car makers suggest that such an outcome is within reach. Heat pump sales rose 11% globally in 2022, but many markets, notably in the European Union, are already tracking ahead of the roughly 20% annual growth rate needed to 2030 in the NZE Scenario.

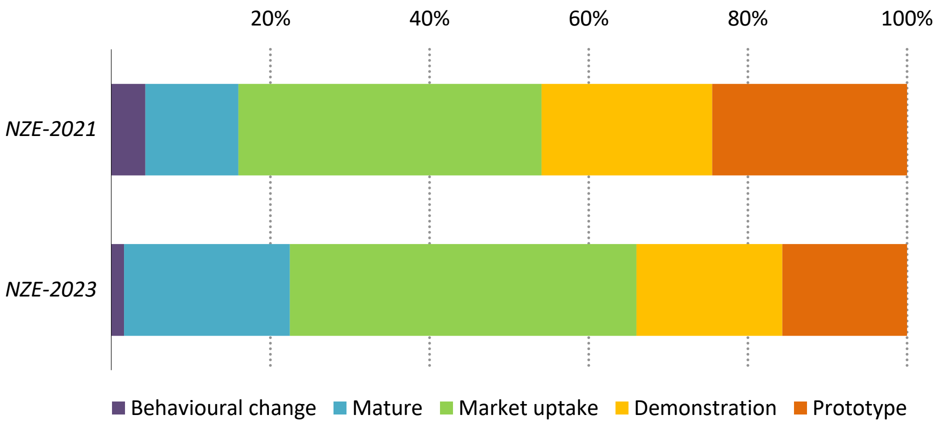
Achieving the rapid growth in renewables, efficiency and electrification envisaged in the NZE Scenario drives down demand for fossil fuels by more than 25% this decade. However, it is also vital to reduce emissions from the fossil fuels that continue to be used. Cutting methane emissions from fossil fuel supply by 75% by 2030 is one of the lowest cost opportunities to limit warming in the near term, and the technical solutions needed are tried and tested. Without action to reduce methane emissions from fossil fuel supply, global energy sector $CO_2$ emissions would need to reach net zero by around 2045 to meet the 1.5 °C limit goal.

### *The world is finding innovative answers*

There is noticeably less reliance on early-stage technologies to reach net zero emissions in the updated NZE Scenario than in our first roadmap report in 2021. At that time, technologies not available on the market, i.e. at prototype or demonstration phase, delivered nearly 50% of the emissions reductions needed in 2050 to reach net zero. Now that number is around 35% (Figure 1.17). Progress has been driven by both public and private efforts to further develop and commercialise new clean energy technologies, spurred by supportive government policies and the growing market prize of the clean energy economy. Energy R&D spending by globally listed companies exceeded USD 130 billion in 2022, an increase of 25% from 2020, and clean energy venture capital flows remain strong, despite the more difficult macroeconomic environment.

Part of this shift is also due to increased confidence in direct electrification as a cost-effective approach. In the road transport sector, for example, cost reductions and standardisation for commercial lithium-ion batteries in particular have strengthened the business case for electromobility over other options for all types of road transport. Overall, the decarbonisation of road transport in the 2023 NZE Scenario relies around ten percentage points less on technologies under development in 2050 than was the case in the 2021 version, in part because of a reduction in the share of hydrogen fuel cell electric heavy-duty vehicles.

**Figure 1.17 ▷ Comparison of $CO_2$ emissions reductions in 2050 relative to base year by technology maturity in the 2021 and 2023 NZE Scenario**






***Emissions reductions by 2050 from technologies in demonstration or prototype stage have been reduced from almost half in the 2021 NZE Scenario to about 35% in 2023 NZE Scenario***

## *1.4.2 Four areas requiring urgent attention*

### *Scale up clean energy investment in emerging market and developing economies*

Clean energy investment needs to rise everywhere, but the steepest increases are needed in emerging market and developing economies other than China (Figure 1.18). From 2015 to 2022, advanced economies and China together accounted for over 95% of global electric car and heat pump sales and nearly 85% of combined wind and solar capacity additions. There are some bright spots elsewhere, notably solar investment in India, but overall clean energy investment outside advanced economies and China has been stagnant in real terms since 2015. It would need to increase by more than six-times over the next ten years to get on track for the NZE Scenario. However, there are significant obstacles to such a scale-up, including tightening financial and fiscal conditions, high levels of government indebtedness, and high cost of capital for clean energy projects. Overcoming these will require stronger domestic policies together with enhanced international support, including much more concessional funding to improve risk adjusted returns and mobilise private capital at scale.

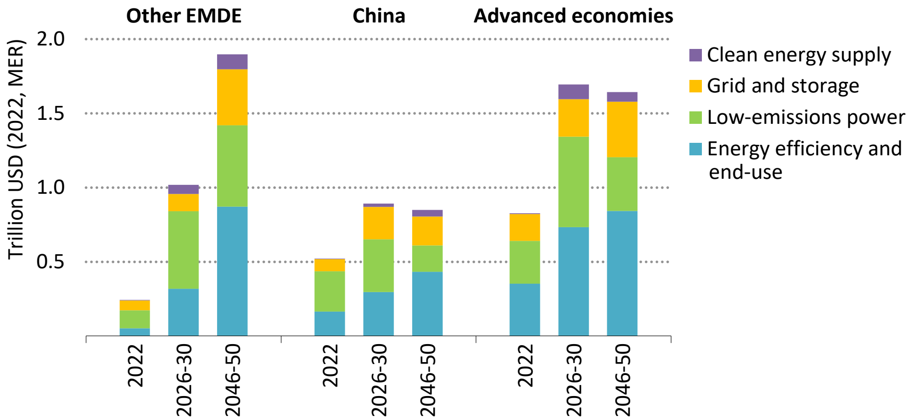
Demand for energy services to 2050 is set to rise fastest in emerging market and developing economies other than China, and it is vital that this increased demand is met in a sustainable way. At the moment, the distribution of clean energy use across countries is even more unequal than for energy consumption as a whole. Among the countries for which IEA has comprehensive energy statistics, the current Gini coefficient[3] of energy inequality is 0.39 for

[3] The Gini coefficient is a measure of inequality typically used to measure income inequality, which has been adopted in this section to evaluate inequality in energy consumption. 1 indicates perfect inequality (where one group or one individual consumes or receives all the resources), while 0 indicates perfect equality.

all sources of energy consumption and 0.46 for clean energy. This underlines the need to find ways to improve investment in emerging market and developing countries other than China, and to raise the level of deployment of clean energy technologies in those countries.



**Figure 1.18 ▷ Average annual clean energy investment needs by region/country in the NZE Scenario, 2022-2050**






***The bulk of increased investment in clean energy is needed in emerging economies other than China; it rises more than sevenfold in the second-half of the 2040s relative to 2022***

Note: MER = market exchange rate; EMDE = emerging market and developing economies.

### *Ensure a balanced mix of investment, especially in infrastructure*

A net zero energy system cannot rely only on solar, wind power and EVs. Rapid growth in the use of these technologies needs to be complemented by larger, smarter and repurposed infrastructure networks, large quantities of low-emissions fuels, and technologies to capture $CO_2$ and store it permanently or transform it into climate neutral fuels. Investments in many of these areas are lagging. Grid infrastructure is a case in point: the time required to obtain grid connections can take several years and appears to be increasing rather than shrinking. This is hindering current projects and risks choking off new ones. In the NZE Scenario, transmission and distribution grids expand by around 2 million kilometres (km) each year to 2030, and around 30 000 to 50 000 km of $CO_2$ pipelines are installed by the same year, together with new hydrogen infrastructure. Investment on this scale depends on expedited planning and permitting processes.

Expanded, modernised and cybersecure transmission and distribution grids are critical to electricity security in a world where the share of solar PV and wind in electricity generation is rising rapidly. Investment is needed to provide adequate system flexibility, without which there is a risk of rising amounts of surplus solar PV and wind power at times when output exceeds demand. Batteries and demand response play a critical role in meeting hourly variability, while dispatchable low-emissions capacity – fossil fuel capacity with CCUS, hydropower, biomass power, nuclear, and hydrogen and ammonia-based plants – play a critical role in smoothing variability across seasons.

### *Make transitions resilient, inclusive and affordable*

Clean energy transitions require significantly fewer extractive resources in aggregate than the current energy system: for every unit of energy delivered in 2050, the energy system in the NZE Scenario consumes two-thirds less in materials, fossil fuels and critical minerals combined, than it does today. But that does not remove concerns about energy and mineral security, indeed some concerns may intensify as the energy sector is transformed across the world.

As demand for oil and gas declines, supply starts to become concentrated in large resource-holders whose economies are most vulnerable to the process of change. There are also potential risks to the supply of critical minerals that are vital to the manufacture of many clean energy technologies. Although capital spending for development of critical minerals saw a 30% increase in 2022 and exploration spending rose by 20%, announced critical mineral mining projects are not sufficient to meet the needs of the NZE Scenario in 2030. Bridging this gap requires a strong focus on investment in mining, processing and refining, as well as on recycling and technology innovation.

Policy makers need to pay close attention to the resilience of clean energy technology supply chains. For the moment, these exhibit a higher degree of geographical concentration than fossil fuels, with China having a notably strong position. This presents an elevated risk of disruption, whether from geopolitical tensions, extreme weather or a simple industrial accident. Many countries are now seeking to promote more diverse patterns of investment and manufacturing in clean energy supply, including for critical minerals. Finding ways to do so while continuing to enjoy the benefits of trade is difficult but crucial.

Governments also need to make sure that the process of change works for everyone, including vulnerable communities and those whose livelihoods are affected by changes in fuels and technologies. This requires an active effort to help poorer households to meet the upfront costs of clean energy technologies and then benefit from their lower operating costs (section 1.6). As an example, a deep building retrofit – an integrated set of energy conservation measures to significantly improve overall building performance – for an average size home can cost four to nine months of income for Chinese or US households in the 25th income percentile, compared with one to two months for households in the 75th percentile.

### *Find ways for governments to work together*

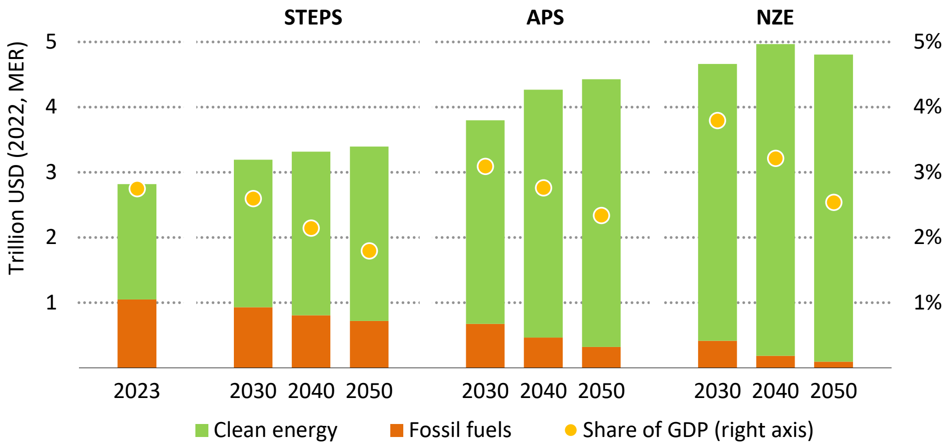
Above all, countries need to find ways to make this a common, unified effort. This is vital to expand financial flows to developing economies, to accelerate clean energy technology development, to ensure equitable and cost-effective clean energy supply, and to ensure that effective safety nets are in place in case of disruptions. The pathway to net zero emissions is much more complex and costly in a low-trust, low-collaboration world (section 1.9).

## 1.5 Capital flows are gaining pace, but not reaching the areas of greatest need

After a period of stagnation in the latter part of the 2010s, energy investment is picking up. The IEA estimates that USD 2.8 trillion is set to be invested in different parts of the energy sector in 2023, up from USD 2.2 trillion five years ago. Almost all of the increase in the last five years has been directed to clean energy and infrastructure, which now accounts for USD 1.8 trillion in spending, compared with around USD 1 trillion on fossil fuels (IEA, 2023c).

All scenarios see a need for increased energy investment from historic levels. Total energy investment rises to USD 3.2 trillion in 2030 in the STEPS, USD 3.8 trillion in the APS and USD 4.7 trillion in the NZE Scenario. Achieving the transformation in the NZE Scenario requires energy investment as a share of GDP to increase by around one percentage point between 2023 and 2030, but the ratio falls back to the current level by 2050 (Figure 1.19).

**Figure 1.19 ▷ Investment trends as share of global GDP by scenario, 2023-2050**




IEA. CC BY 4.0.

*A large increase in clean energy investment is projected in the APS and NZE Scenario, but fossil fuel investment declines and investment requirements as a share of GDP fall after 2030*

An increasing share of investment is directed to clean energy in all scenarios. In the STEPS, the ratio of investment in fossil fuels to investment in clean energy technologies rises from 1:1.8 in 2023 to 1:2.5 in 2030. In the NZE Scenario, it rises to more than 1:10 in 2030. The USD 2.5 trillion increase in clean energy investment in the NZE Scenario to 2030 is far larger than the USD 0.6 trillion reduction in fossil fuel investment over this period.

Today's higher interest rate environment has increased financing costs for energy, and this has had a particularly large impact on relatively capital-intensive clean energy technologies. Emerging market and developing economies in particular are struggling with rising financing costs as higher base rates push up the cost of capital. A combination of policy reforms and de-risking measures, including revenue guarantees, first loss guarantees and currency hedging, is needed to address real and perceived project and country risks.

The large increase in capital investment in the NZE Scenario is partly compensated for by lower operating costs that follow the shift away from fossil fuels towards capital-intensive clean technologies. For fossil fuel importing countries, the shift towards clean energy also improves trade balances and enhances energy security as the share of energy met through domestically sourced renewables starts to rise.

### *1.5.1 Fossil fuels*

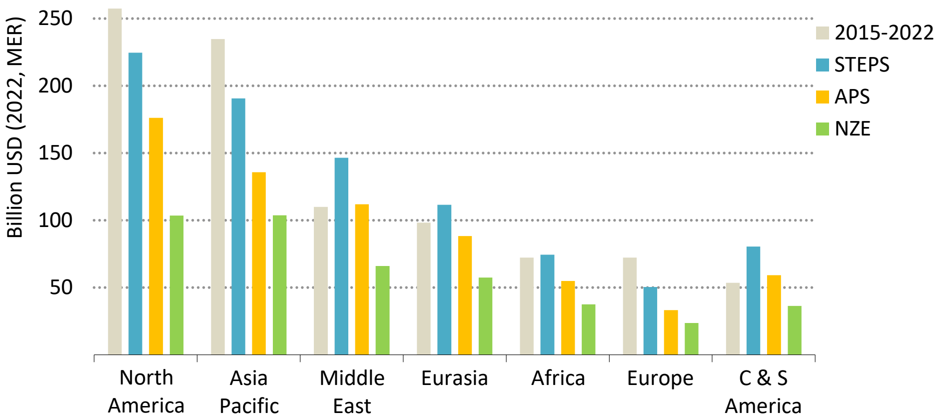
Continued investment in fossil fuels is essential in all of our scenarios. It is needed to meet increases in demand over the period to 2030 in the STEPS and to avoid a precipitous decline in supply that would far outstrip even the rapid declines in demand seen in the NZE Scenario.

In previous editions of the *WEO*, we warned of a risk of underinvestment in a STEPS-like trajectory for demand, noting a gap between the amounts being invested in oil and gas and the future requirements of this scenario. But the situation has evolved and this is no longer the case. Oil and gas investment has risen in recent years, while the benchmark level of investment needed in 2030 has come down with improvements in the capital efficiency of the oil and gas industry and with a decline in the projected level of oil and gas demand. Russia's invasion of Ukraine led to some shortfalls in supply, but immediate issues have now receded because Russian oil production and export has been more resilient than initially anticipated and because a wave of new supply projects, notably for LNG, have received the go-ahead. As a result, the level of investment in oil and gas expected in 2023 is broadly equivalent to the level needed in the STEPS in 2030, and the fears expressed by some large resource-holders and certain oil and gas companies that the world is underinvesting in oil and gas supply are no longer based on the latest technology and market trends.

The risks of overinvestment in fossil fuels have also evolved, but in the opposite direction. Investment in oil and gas today is significantly higher than the amounts needed in the APS and almost double what is needed in the NZE Scenario (Figure 1.20). This creates the clear risk of locking in fossil fuel use and putting the 1.5 °C goal out of reach. Nonetheless, simply cutting spending on oil and gas will not get the world on track for the NZE Scenario: the key is to scale up investment in all aspects of a clean energy system to meet rising demand for energy services in a sustainable way.

Both overinvestment and underinvestment in fossil fuels carry risks for secure and affordable energy transitions. Any assessment of the implications of investment needs to take into account who is investing and the efficiency of the spending, and policy makers need to be mindful in particular of trends that could point to a future concentration in supply or other energy security risks. When it comes to the overall adequacy of spending, however, our analysis suggests that the risks are weighted more towards overinvestment than the opposite.

**Figure 1.20 ⊳ Average annual investment in fossil fuel supply historically and in 2030 by scenario**






*Continued investment in fossil fuels is essential in each scenario, but variations in declining demand mean far less is needed in the APS and NZE Scenario*

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

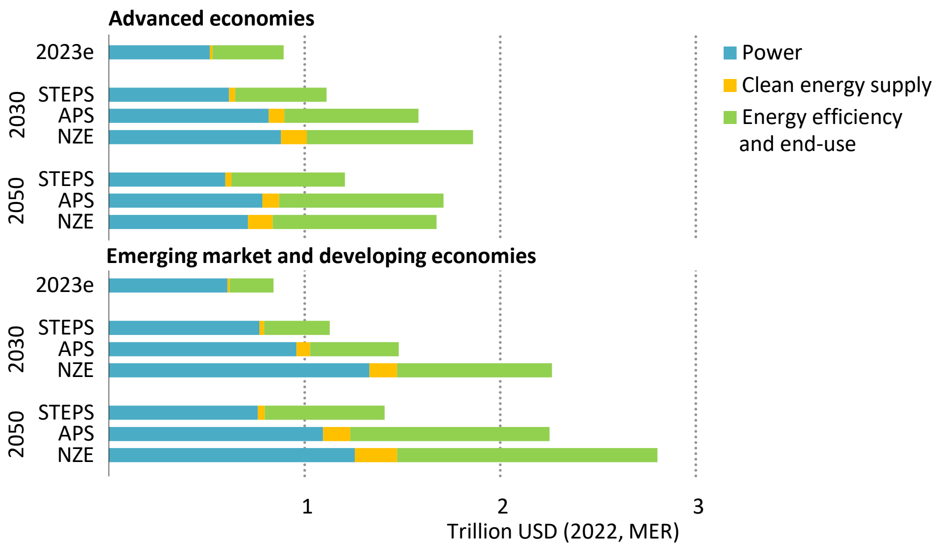
### *1.5.2 Clean energy*

The rise in clean energy spending in recent years has been concentrated in areas linked to clean electrification, in particular solar PV and other forms of renewable power, and end-use electrification, especially EVs and heat pumps (Figure 1.21). If it is maintained, the rate at which clean energy is growing would put aggregate global spending in 2030 on low-emissions power, grids, storage and end-use electrification at levels consistent with the needs of the APS. For some technologies, notably solar PV, it would go beyond the investment required for the NZE Scenario. However, there are significant gaps in spending on other pillars of clean energy transitions. In particular, investment in energy efficiency remains well short of what is needed in the APS and NZE Scenario, despite rising recently. Investment in low-emissions fuels is another area where more is needed: it is increasing, thanks to increased policy support for areas like low-emissions hydrogen and CCUS, but from a very low base.

The increases in spending required to meet climate goals appear challenging but within reach for advanced economies and China. Finance is available for clean energy projects, and many of the main risks, including those related to permitting, now appear to be on the policy and regulatory side. However, other emerging market and developing economies need to triple clean energy spending from 2022 levels by 2030 in the APS and increase them over five-times in the NZE Scenario. Some of the largest gaps are in energy efficiency and end-use decarbonisation. This reflects the fact that many lower income households and businesses are struggling to manage the higher upfront costs of a number of clean energy technologies.

It also reflects the relative weakness of policy frameworks, institutional capacity and enforcement in many countries. The effect of high interest rates on financing costs is another complicating factor.

**Figure 1.21 ▷ Investment in clean energy by scenario, 2030 and 2050**






*Clean energy investment gaps are largest in emerging market and developing economies, especially for energy efficiency and end-use decarbonisation*

Note: 2023e = estimated values for 2023.

Energy efficiency in buildings stands out as a laggard. The urban population is increasing quickly in most developing economies, and ensuring that new buildings meet high performance standards for efficient heating and cooling presents a huge opportunity to limit future strains on energy supply and emissions. However, relatively few emerging market and developing economies have energy efficiency building codes, with India being a notable exception. Higher standards and stronger enforcement of standards for new buildings play a critical role in reducing energy use in buildings in each of the scenarios.

## 1.6 Transitions have to be affordable

The global energy crisis in 2022 catapulted costs and prices of energy to the forefront of the political agenda, and countries are understandably concerned about the costs of the transition. For energy users, a meaningful assessment of transition costs must start with quantifying the additional spending required on clean energy over conventional options: for example, the cost premium to purchase an EV over an internal combustion engine (ICE) vehicle, or to install a heat pump instead of a natural gas boiler.

For some applications and in some parts of the world, clean energy technologies are already cost competitive compared with fossil fuels, meaning net costs are zero or in some cases negative, even without incentives and other support for upfront costs. In other cases, cost gaps remain, and incentives will be crucial to accelerate the adoption of key clean energy measures. These can be narrowed either by reducing the upfront and operating cost of clean options, e.g. through technology and financial innovation or government intervention like clean energy subsidies, or by changing pricing, tax and subsidy frameworks for fossil fuels, e.g. by removing fossil fuel subsidies, or including $CO_2$ costs or other environmental surcharges.



Such policy interventions however must be carefully designed and targeted: political support for the transition can dissipate quickly if households or industries bear too much upfront cost without seeing tangible, near-term benefits. Support may also decrease if insufficient attention is paid to the distributional effects of clean energy support policies or if the fiscal burden on governments is perceived as too high. In this section, insights from the scenarios are used to explore these issues from the perspective of households, industry and governments.

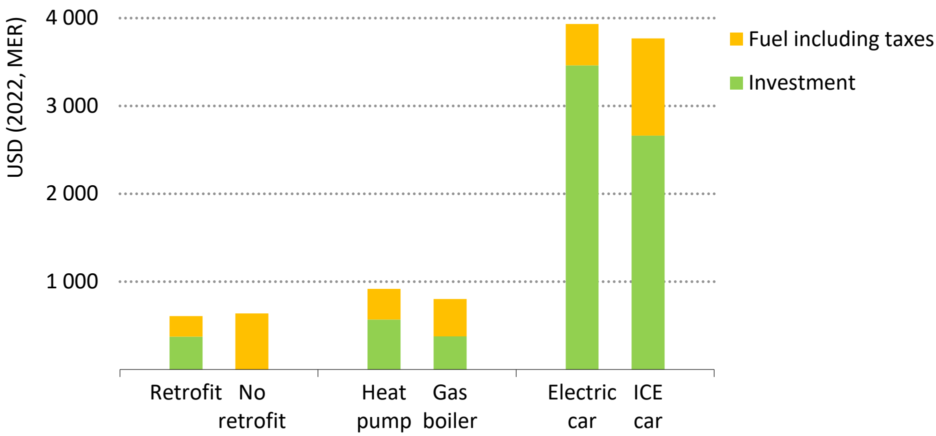
### *1.6.1 Affordability for households*

The energy crisis squeezed budgets as prices soared in 2022. Government interventions moderated the extent to which higher commodity prices fed through to higher household energy bills, nevertheless there were increases in natural gas, petrol and retail electricity prices in various parts of the world. Clean energy technologies such as EVs or heat pumps helped shield consumers that had adopted them from fossil fuel price spikes, and energy efficient buildings and appliances also provided some protection.

Heat pumps, energy efficiency retrofits and EVs – the three most important measures that households can adopt to accelerate clean energy transitions – are already nearly cost competitive over their lifetime in the STEPS in advanced economies, even without incentives (Figure 1.22). Higher upfront costs remain a barrier to accelerated uptake, but in some markets even upfront costs are reaching price parity. Air-to-air heat pumps can be cheaper than natural gas boilers in mature markets, for example, and electric cars sold today in China cost less than their ICE equivalents on average, while more energy efficient air conditioners and refrigerators do not necessarily come with higher upfront costs in markets across Asia, Africa and Latin America and the Caribbean. Even when clean energy technologies have higher upfront costs than their fossil fuel equivalents, they frequently generate energy bill savings over their lifetime because of their lower operating costs. However, the lifetime costs of clean energy alternatives often remain higher in countries where fossil fuel subsidies have still not been phased out.

Finding ways to manage the higher upfront costs of clean energy technologies will play a key role to accelerate their adoption, especially in low income households. Limited disposable income and more constrained access to financing can put higher cost options out of reach for a large share of the population. For example, installing a heat pump can cost up to eight months of income for those with lower incomes (see Chapter 4, section 4.4). Recent interest rate hikes have increased borrowing costs for consumers and are expected to contribute to a slowing of household energy efficiency measures if they persist: a factor that governments will need to take into account in considering how to speed up the adoption of clean energy technologies.

**Figure 1.22 ▷ Annual unsubsidised costs of clean energy versus conventional options for households in advanced economies in the STEPS**




IEA. CC BY 4.0.

***Key clean energy technologies are already roughly cost competitive over their lifetime, though upfront cost barriers remain for most***

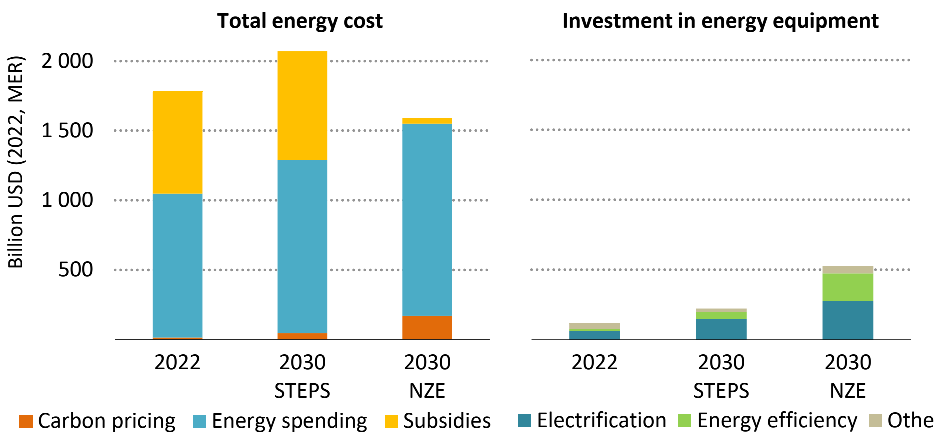
Notes: ICE = internal combustion engine. Assumed lifetimes are 25 years for retrofits, 16 years for heat pumps and natural gas boilers/furnaces, and 12 years for electric and ICE cars. Costs are based on a representative sample of households in Germany, Japan, United Kingdom and United States, with upfront costs financed at an interest rate of 5%, starting in 2024 for five years. Costs do not reflect upfront subsidies.

Energy pricing plays a major role in determining whether clean energy technologies are competitive in terms of costs, and the fossil fuel subsidies that persist in a number of countries are clearly important in this context. In emerging market and developing economies, where the bulk of fossil fuel subsidies exist today, phasing out these subsidies would raise current household energy bills, in aggregate, by 70%. Fossil fuel subsidies distort markets and are often ultimately paid by consumers through higher taxes or consumer prices, especially in importing regions. The effects of subsidy removal on household spending means that the phase-outs have to be planned carefully and accompanied by support for those that need it most.

Reforming energy pricing remains essential though, not only to rectify price signals, but to realise the economy-wide energy cost optimisation. The economy-wide cost of supplying energy used in households and for personal transport in emerging market and developing economies was nearly USD 1.8 trillion in 2022, of which around USD 1 trillion was borne by consumers. The rest represents fossil fuel subsidies borne by other entities, mostly governments and state-owned enterprises, either in the form of reduced prices or forgone revenue. In the NZE Scenario, the economy-wide costs of providing energy decline to USD 1.6 trillion in 2030, 25% lower than in STEPS (Figure 1.23). However, the removal of subsidies and gradual introduction of carbon pricing mean that consumers would pay more per unit of energy, while modern energy consumption increases in absolute terms despite efficiency gains as rising incomes allow for larger residences and more appliances. In addition, households need to shoulder the upfront costs of clean energy technologies.



**Figure 1.23 ▷ Economy-wide cost of household energy in emerging market and developing economies**






*The total cost of supplying energy falls in the NZE Scenario, but vulnerable consumers require support to manage subsidy phase-out and the upfront costs of clean energy*

Notes: Subsidies = fossil fuel consumption subsidies based on the IEA price-gap approach. Energy spending includes transport energy spending.

Targeted support could help reduce the impact of energy price reforms, and would be especially important for low income households. Price reforms should also aim to end rate structures that penalise electrification of end-uses and to incentivise the provision of time-varying electricity tariffs, for example to allow consumers to charge EVs overnight when electricity demand and prices are lower.

### *1.6.2 Affordability for industry*

Industry was more exposed to high commodity prices during the energy crisis than households. Although some larger industries were able to draw on contracting and hedging strategies to guard against commodity price volatility, in aggregate industry paid on average

70% more for natural gas in 2022 than they did in 2021, and around 25% more for electricity. The protection provided for households by governments in many countries means that industry had to cope with much higher price increases than did households.

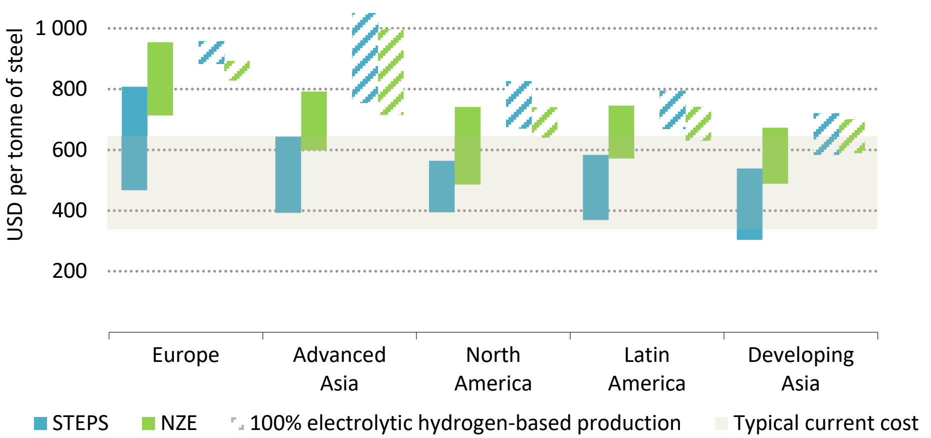
For energy-intensive industries, adopting clean energy technologies while maintaining competitiveness is one of the defining challenges of the energy transition. Many efficiency and clean energy measures in light industry are already cost effective, notably efficient electric motors and heat pumps for low-temperature heat (IEA, 2022b). However, there are fewer cost-competitive clean alternatives for large, energy-intensive industries than for households and light industry, and many of them involve significant upfront capital expenditure. Moreover, many of the clean energy technologies needed by energy-intensive industries are at the demonstration phase.

The position is not straightforward even where new clean technologies are feasible. Many energy-intensive products such as steel or chemicals are traded internationally in competitive markets with margins that are too slim to absorb elevated production costs or to encourage first movers to adopt new technologies. This means that there is an ever present risk of industrial relocation if environmental regulations or energy prices put firms in international markets at a competitive disadvantage. Relocation of businesses in these circumstances to jurisdictions where such regulations are not imposed defeats the purpose for which the regulations were introduced, to say nothing of the damage done to the industrial base in the country that sees the companies depart. This has prompted efforts to implement carbon border adjustment measures and similar pricing schemes to level the playing field and maintain the competitiveness of companies and sectors that adopt decarbonising measures. Revenue from such price rectifying measures can be recycled to help manage the higher material input costs to businesses, which eventually reach the end consumer through higher prices. Industry-led initiatives, such as the First Mover Coalition Steel Commitment, and international agreements on collaboration on industry decarbonisations, like the Glasgow Breakthrough Agenda, can also play a useful role.

In the NZE Scenario, industry spending on energy reaches USD 4.3 trillion in 2030, around 30% more than in the STEPS, even though demand is moderated by material and energy efficiency improvements. The higher costs are due to novel processes in energy-intensive industry, which in many cases have higher input energy costs, and also to increased carbon prices and the phasing out of fossil fuel subsidies.

Pricing emissions from industry remains important to stimulate the switch to clean energy because it helps to improve the cost competitiveness of clean energy technologies and boost their adoption. For instance, carbon pricing and subsidy reform raise the production costs for conventional steel in the NZE Scenario by 2030 and thereby narrow the cost gap with electrolytic hydrogen-based production routes. Nonetheless, electrolytic hydrogen-based steel is still at a premium. In some cases, and especially those where there is easy access to plentiful renewable sources of energy, the gap can be closed by 2030 (Figure 1.24). In other cases, government support is likely to be necessary, not least to help create demand for near zero emissions steel, for example through public procurement. Some important steel making regions (such as Europe, Japan and Korea) might require subsidies for hydrogen to be cost competitive globally.

**Figure 1.24 ▷ Cost of producing steel using conventional methods compared to 100% electrolytic hydrogen by scenario, 2030**






*Carbon pricing and fossil fuel subsidy phase out in the NZE Scenario raise the cost of steel production, bringing it closer to the cost of electrolytic hydrogen steel production.*

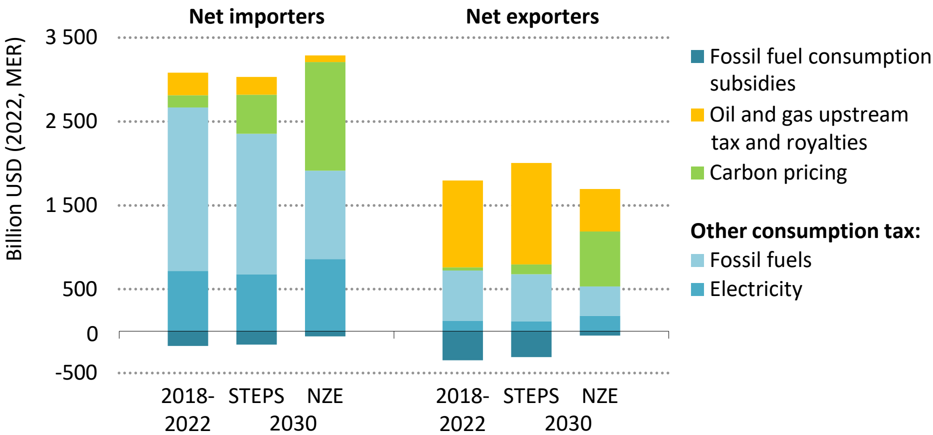
Notes: Cost does not include scrap-based production. See Annex C for regional definitions.

### 1.6.3 Affordability for governments

Governments need to take urgent action to tackle climate change. Yet, many countries, especially emerging market and developing economies, are grappling with increased debt, inflation and uncertain growth prospects. There are multiple demands on public budgets to address development needs, and so governments must design fiscally responsible policies that strike a balance between spending and revenue-based measures (IMF, 2023).

In the NZE Scenario, governments are expected to finance around 30% of the USD 4.2 trillion of clean energy investment spending required in 2030. This includes through low cost loans, grants, direct support to households and industries, and concessional finance. An important question is how governments finance this investment in a scenario where revenues from taxing the production and consumption of oil and gas are falling. In the NZE Scenario, public revenue from taxing $CO_2$ goes some way to offset declining oil and gas revenues, reductions in fossil fuel subsidies provide some direct relief for governments, and taxes on the use of electricity shore up revenue from energy consumption (Figure 1.25). However, governments around the world will make their own decisions about funding based on their specific priorities and national circumstances.

**Figure 1.25 ▷ Government revenue from energy production and consumption for net oil and gas importing and exporting regions by scenario**




IEA. CC BY 4.0.

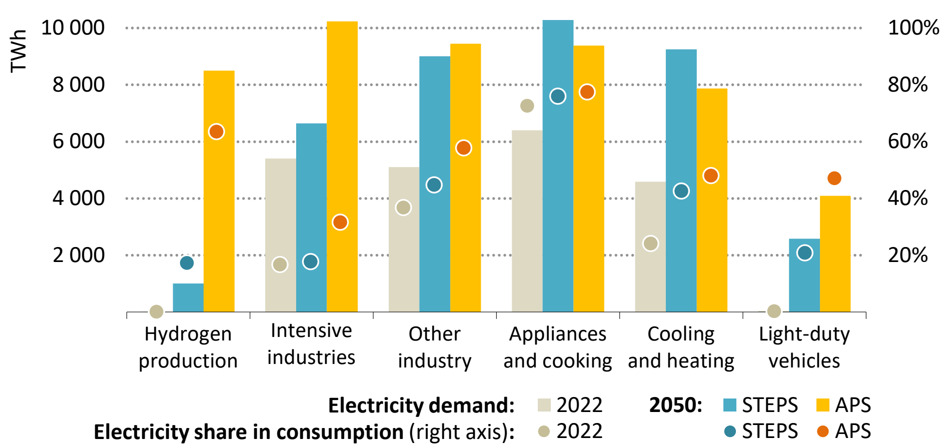
*Carbon pricing revenues and lower subsidy burdens offset lower fossil fuel rents in exporting regions; for net importers, carbon revenue provides funds for clean energy initiatives*

For net oil and gas exporters, economic growth in the NZE Scenario is underpinned by economic diversification rather than continued reliance on fuel exports and royalties. This enlarges the taxable industrial and consumer base, and helps to minimise the transfer of rents from producer to consumer countries that apply $CO_2$ taxation. The lower level of fossil fuel subsidy support in the NZE Scenario and taxes on consumer spending on electricity together offset declining revenues from fossil fuel production, meaning that the net fiscal position in the NZE Scenario in 2030 is comparable to that of STEPS. However, this shift requires citizens and businesses to absorb more of the cost of energy directly through higher upfront investment and higher annual spending on fuels in the near term. To the extent that governments see tangible savings on the public balance sheet from fossil fuel subsidy removal, these can be funnelled into clean energy support mechanisms or otherwise used to help to pay for climate change adaptation or other sustainable public spending initiatives, such as social support schemes to help vulnerable consumers.

## 1.7 Risks on the road to a more electrified future

Electricity demand is projected to increase significantly in sectors ranging from industry and buildings to transport. Yet, this trajectory is not set in stone, and there are a number of risks that could hamper the deployment of key clean electricity technologies. One of the most important risks to projected growth in electrification is the availability of critical minerals for power generation technologies, electricity networks, battery storage and electric vehicles. These trends and risks are discussed in detail in this *Outlook* and summarised in this section.

**Figure 1.26 ▷ Global electricity demand and share of electricity in selected applications, 2022 and 2050**






*Electricity plays an increasingly important role in many end-uses*

Notes: Hydrogen production is the electricity needed for its production and the share of electricity in total energy consumed in the process of producing hydrogen. Intensive industries (energy-intensive industries) include iron and steel, chemicals, non-metallic minerals, non-ferrous metals, and paper, pulp and printing industries. Other industry includes the remaining industrial branches, i.e. construction, mining and textiles. Appliances and cooking includes stoves and ovens, refrigerators, washing and dishwashing machines, clothes dryers, brown appliances (relatively light electronic appliances such as computers or televisions) and other electric appliances (excluding lighting, cooling, cleaning and desalination). Cooling and heating include space and water heating, and space cooling in buildings.

The importance of electricity rises in many applications over the outlook period (Figure 1.26). The biggest consumers of electricity today are the buildings and industry sectors, which together account for over 90% of global electricity consumption. Appliances, cooking, cooling and heating account for most consumption in buildings, and electricity demand increases for all of them in our projections, especially in emerging market and developing economies. Industrial electricity demand continues to rise as industrial output increases, mostly in emerging market and developing economies, and as policies to reduce emissions encourage the electrification of industrial equipment. Transport is also a major contributor to projected electricity demand growth, especially in advanced economies. The number of EVs has increased rapidly in recent years, with electric car sales surpassing 10 million in 2022. In the STEPS, electric cars gain a market share of 38% in new car sales by 2030; in the APS, this rises to nearly 45%.

### 1.7.1 Managing risks for rapid electrification

Technologies essential to clean electricity systems need to scale up rapidly for electrification to proceed at the pace necessary to meet the energy and climate pledges made by governments around the world. However, there are risks that could delay or impede the deployment of some of the key technologies that are needed. It is critical to have sufficient policy support and enabling regulatory frameworks, efficient and timely permitting and certification, while developing robust and resilient supply chains, from raw materials to manufacturing and construction and skilled labour to ensuring access to financing. Reducing the costs of financing and having predictability for revenues or cost savings are also important for rapid electrification. Each technology has its unique risk profile, which may threaten its role in clean electrification (Table 1.1). Progress in one technology may depend on progress in others. The lower these risks are across the board, the better the chance to deliver secure and affordable transitions, calling on governments and industry to take action.

**Table 1.1 ⊳ Primary risks associated with key clean electrification technologies**

| | Wind | Solar PV | Nuclear | Battery storage | Demand response | Grids | Electric vehicles | Heat pumps |
|---|---|---|---|---|---|---|---|---|
| **Regulatory and policy risks** | | | | | | | | |
| Regulatory frameworks | Medium | Low | Medium | Medium | High | Medium | Medium | Medium |
| Policy support | Low | Low | Medium | Low | High | Low | Low | Low |
| Permitting and certification | Medium | Medium | High | Low | Low | High | Medium | Low |
| **Supply chain risks** | | | | | | | | |
| Critical minerals | High | Medium | Low | High | Low | Medium | High | Low |
| Manufacturing | High | Low | Medium | Medium | Low | Low | Low | Medium |
| Skilled labour | Medium | Medium | High | Low | Low | High | Low | Medium |
| **Financial risks** | | | | | | | | |
| Costs of financing | High | Medium | High | Medium | Low | High | Medium | Medium |
| Revenue and savings predictability | Medium | Low | Low | Medium | Medium | Low | Low | Low |
| **Overall risks** | High | Low | Medium | Medium | Medium | High | Low | Medium |

Note: Grids refers to electricity networks, including transmission and distribution.

Regulatory and policy risks include regulatory barriers, inadequate policy support, and slow planning and permitting. Regulatory barriers can inhibit the deployment of technologies, either directly or by closing off potential business cases that developers could pursue in a more supportive or effective regulatory environment. Demand response, a potential key source of power system flexibility in the future is a good example (see Chapter 4). In many markets today, consumers have little incentive to be responsive because short-term price signals from electricity markets are not transmitted to them. A lack of sufficient and continuous policy support increases investor uncertainty, and the sudden withdrawal of policy support can cause nascent markets to crash, as experience has shown with solar PV and wind power in several markets over the past 15 years. Lengthy certification and permitting processes slow deployment and raise costs, as seen in the wind industry (IEA, 2023b), in the construction of new nuclear power plants (IEA, 2022c) and in the expansion of power grids (IEA, 2023d).

There are further potential sources of risk along the supply chain of clean energy technologies. Some relate to the fact that both the supply of critical minerals and the manufacture of solar modules and other key goods are dominated by a small number of countries (section 1.9). Others stem from the danger that demand will outpace the scaling up of mining, processing and manufacturing capacity along the supply chain, pushing up costs and constraining clean energy transitions. In 2021 and 2022, for example, higher input prices for critical minerals, semiconductors and bulk materials resulted in price increases for key clean energy technologies (IEA, 2023c). Another set of risk arises from the need for skilled labour across the various links of clean energy supply chains. Tight labour markets and a shortage of skilled labour have recently contributed to disruptions and project delays in parts of the electricity sector, most notably for offshore wind (IEA, 2022d). Shortages of workers with specific skills are also slowing the expansion of power grids, the construction of new nuclear power plants and the installation of heat pumps (IEA, 2022b). The lack of skilled labour in some sectors underlines the need for collaboration and investment in education and training programmes to develop a skilled workforce capable of supporting the construction, and operation and maintenance of key clean electricity technologies.

Financing risks also need to be addressed, including those that relate to the cost of obtaining finance, to the difficulty of predicting future revenues when new technologies enter the market, and to market instability. Long-term contracting can help to reduce price uncertainty for developers of clean electricity projects, and high quality, high reliability products and components can help to reduce the risk of poor performance. Financing costs for clean energy projects have recently been driven up significantly by rising interest rates in markets around the world, in particular in emerging market and developing economies (IEA, 2023c). Increases in financing costs have the biggest impact on large-scale projects involving capital-intensive technologies such as offshore wind, grids or new nuclear power plants, but rising interest rates also affect consumers that rely on credit to finance an EV or the installation of a heat pump. The progress of electrification will depend on reducing the cost and improving the availability of capital. This is of particular importance for emerging market and developing economies, many of which are currently struggling to raise the capital needed to finance their transitions (IEA, 2021a).

It is important to highlight that these risks are not isolated from one another but are often interdependent. A lack of policy support can, for example, make a project less bankable which raises financing costs. Permitting delays also raise financing costs, while the poorer than expected performance of an asset will depress revenue or raise maintenance costs. Disruptions at one stage of the supply chain can feed through to other technologies, sectors and markets. Poor progress for one technology can also negatively affect others. Delays in extending and reinforcing power grids, for example, can also slow the deployment of renewables, heat pumps and EVs. Lowering risks across the board is vital, whether those risks relate to regulation and policy, clean electricity supply chains, the availability of skilled labour or access to finance. This highlights the need for a holistic approach that ensures every technology is able to play its role in delivering secure and cost-effective electrification.

### *1.7.2 Critical minerals underpin electrification*

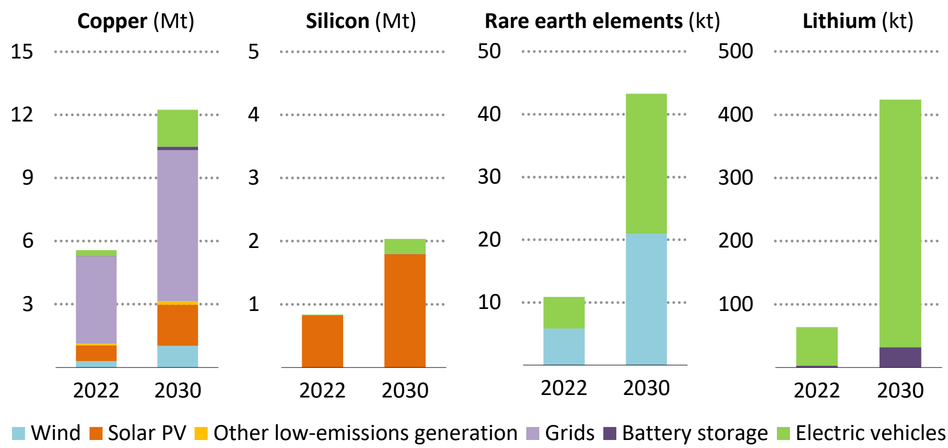
The transformation of the electricity system and increasing electrification leads to rising demand for critical minerals. The size of the market for key critical minerals used in the energy sector has doubled over the past five years and growth is expected to pick up further (IEA, 2023e). As clean energy transitions accelerate, the focus will shift from the supply of traditional fuels to the supply of critical minerals (see Chapter 4). However, the mining and processing of certain critical minerals is heavily concentrated geographically, creating a security of supply risk. Long lead times for mines and the associated infrastructure mean that scaling up supplies takes time, raising the risk of supply bottlenecks. Mitigating these risks requires governments and industry to establish a more diversified network of international producer-consumer relationships, while seeking to ensure that supplies scale up fast enough to meet growing demand.

Copper, rare earth elements, silicon and various battery metals, notably lithium, are critical minerals for electrification. Copper is used extensively in electricity transmission and distribution grids, but its conductive properties also make it an essential component for low-emissions power generation technologies such as solar PV modules, wind turbines and batteries. Rare earth elements (REEs) are used to manufacture the permanent magnets for the motors of direct drive and hybrid wind turbines. Silicon is used to manufacture solar panels. As the deployment of variable renewable technologies increases, the need for storage technologies to complement renewable electricity rises rapidly. Lithium-ion batteries dominate in EVs and are the fastest growing electricity storage technology in the world, making lithium indispensable for electrification (IEA, 2021b).

In terms of absolute volumes, copper dominates total demand for critical minerals in clean energy applications, mostly for use in the electricity sector: current demand of around 6 Mt per year rises to 11 Mt by 2030 in the STEPS and 12 Mt in the APS. However, lithium sees the biggest percentage increase: demand for lithium for battery storage systems and EVs rises more than fivefold from its current level by 2030 in the STEPS and nearly sevenfold by 2030 in the APS. Demand for copper, silicon and REEs nearly doubles to 2030 in the STEPS and rises almost 2.5-fold in the APS (Figure 1.27).



**Figure 1.27 ▹ Demand for critical minerals for selected clean electricity supply and electrification technologies in the APS, 2022 and 2030**






*Electrification raises demand for key critical minerals by two- to seven-times by 2030*

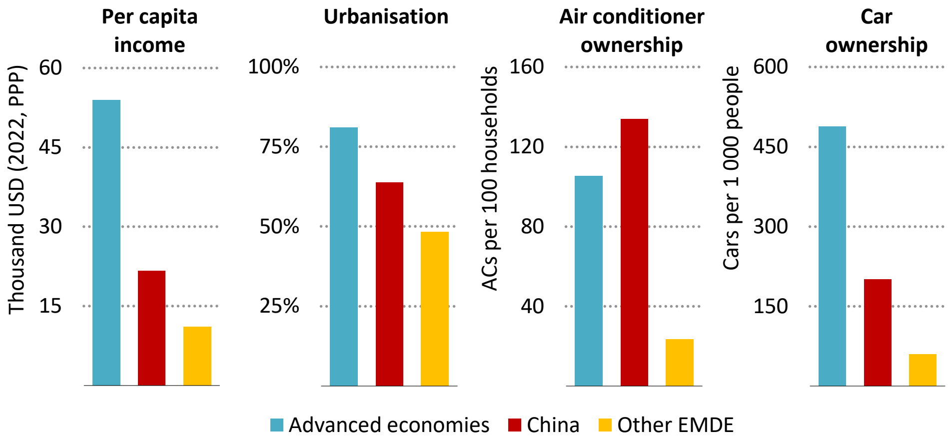
Notes: Mt = million tonnes; kt = kilotonnes. Battery storage is limited to utility-scale systems.

This underlines that scaling up critical minerals supplies while making them more secure is a key challenge. More diverse and resilient critical mineral supply chains are an essential element. These need not just to deliver a reliable supply of critical minerals but also to apply environmental, social and governance standards to their production and processing. Clear policy commitments to scale up clean energy technologies are essential to stimulate the investments that are needed.

## 1.8 A new, lower carbon pathway for emerging market and developing economies is taking shape

Emerging market and developing economies face a diverse set of development challenges that will largely shape their regional energy and emissions pathways, and that therefore have global implications. Some 64% of the world population lives in emerging market and developing economies other than China. These countries have an average per capita income that is around one-fifth of the average in advanced economies, and they lag on various socio-economic and energy indicators (Figure 1.28).

**Figure 1.28 ▷ Selected socioeconomic indicators, 2022**






***Emerging market and developing economies other than China significantly trail advanced economies on key socioeconomic indicators***

Note: PPP= purchasing power parity; ACs = air conditioners; EMDE = emerging market and developing economies.

The emerging market and developing economies other than China include a diverse range of countries. Most face energy-related development challenges that broadly include:

- To provide universal energy access to those who do not have electricity (775 million people in emerging market and developing economies other than China) and those who lack access to clean cooking fuels and equipment (2 billion people in the same group). UN Sustainable Development Goal-7 includes a target for the achievement of universal energy access by 2030, and this is currently off track.
- To facilitate further industrialisation and the modernisation of agriculture, both of which require access to affordable and secure supplies of technologies and energy. The economic output from industry in emerging market and developing economies (excluding China) grows by over 30% by 2030, and more than doubles by 2050. The corresponding energy demand from industry rises by over 20% by 2030 and 65% by 2050 in the STEPS.
- To deliver planned urban growth with efficient modern housing that is well served by public transport. The urbanisation rate, built space per capita, air conditioner ownership and car ownership rates in emerging market and developing economies other than China are far lower than in advanced economies. By 2050, an additional 1.8 billion people will be living in urban areas in emerging market and developing economies (excluding China), contributing to a doubling of residential building space and a sharp rise in urban transport demand.

- To play a bigger part in global energy supply chains, including through domestic clean energy technology manufacturing. Fossil fuel supply, clean energy manufacturing, critical mineral production and refining capacities remain geographically concentrated to varying degrees. Emerging market and developing economies today are particularly vulnerable to supply shocks while wealthier importers are better placed financially to secure their energy and technology needs.
- To reduce environmental pollutants from energy operations. Air pollution from energy use is a major concern, leading to over 5 million premature deaths every year in emerging market and developing economies (excluding China).

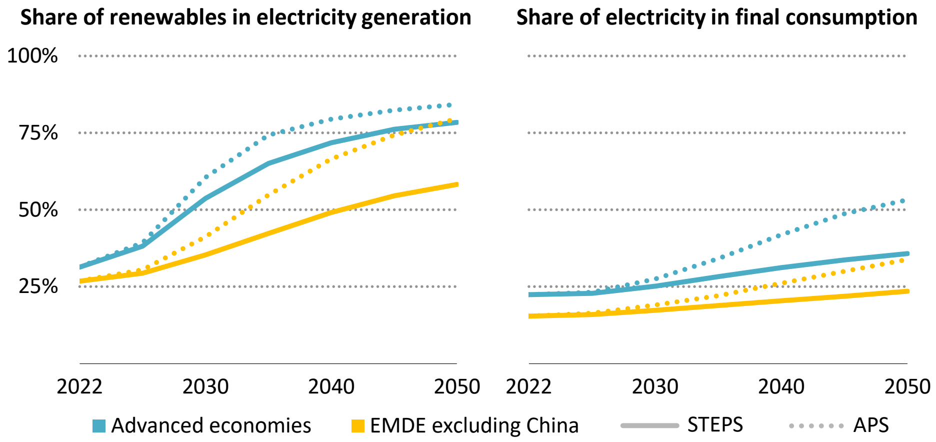
The choices countries make to address these development challenges and their emissions reduction commitments will together shape their future energy policy choices. Historically, economic development has been fuelled by carbon-intensive technologies and sources of energy derived from fossil fuels, but there are several factors that now point to the possibility of a markedly different development pathway for emerging market and developing economies.

First, as discussed in this report, clean energy technology costs have been falling across a broad suite of applications worldwide from clean electricity generation to clean mobility, energy storage and energy efficiency. In some cases, such as electricity generation, clean technologies are now the lowest cost options in most parts of the world. As a result, they now offer promising avenues for energy and industrial development. However, there are barriers that need to be overcome for emerging market and developing economies to make the most of these opportunities. These are often linked to risks that could call into question the bankability of projects in these economies. They include regulatory and policy risks such as inconsistent tariff regimes, off-taker risks such as the financial weakness of power distribution companies, and land acquisition risks such as permitting issues. Risk mitigation through appropriate policy making and regulation has a key role to play in managing these risks, together with financial innovation.

Second, the acceleration of renewable energy deployment is being coupled with increasing electrification of economic activity, even in developing economies. In the past five years, over half of the capacity additions for electricity generation in the emerging market and developing economies other than China are renewables based. This marks a significant acceleration compared to the previous decade, when renewables accounted for around a quarter of capacity additions; further acceleration is likely in the future. In the STEPS, nearly two-thirds of new capacity additions to 2030 are renewables. By 2050, electricity generation from renewables increases fivefold in the STEPS, and over ten-fold in APS by 2050 (Figure 1.29).

Increasing deployment of renewables is being accompanied in emerging market and developing economies by increased electrification, with expanding use of EVs in transport, electric furnaces and electrochemical processes in industry, electric cooking appliances in the buildings sector, and electric farm equipment such as solar pumps in agriculture. In the STEPS, the share of electricity in total final energy consumption among the emerging market and developing economies other than China increases from 15% to nearly 25% by 2050, while in the APS it reaches almost 35% in the same period. Early signs of increased electrification are already apparent. In India, for example, over half of three-wheel vehicle sales are now electric, and in South Africa electricity now meets 80% of residential cooking energy demand. Other countries look set to emulate these examples: for example, the share of energy demand for cooking met by electricity in emerging market and developing economies nearly doubles by 2050 in the APS.

**Figure 1.29 ▷ Share of renewables in power generation and electricity in final energy consumption by region and scenario, 2022-2050**



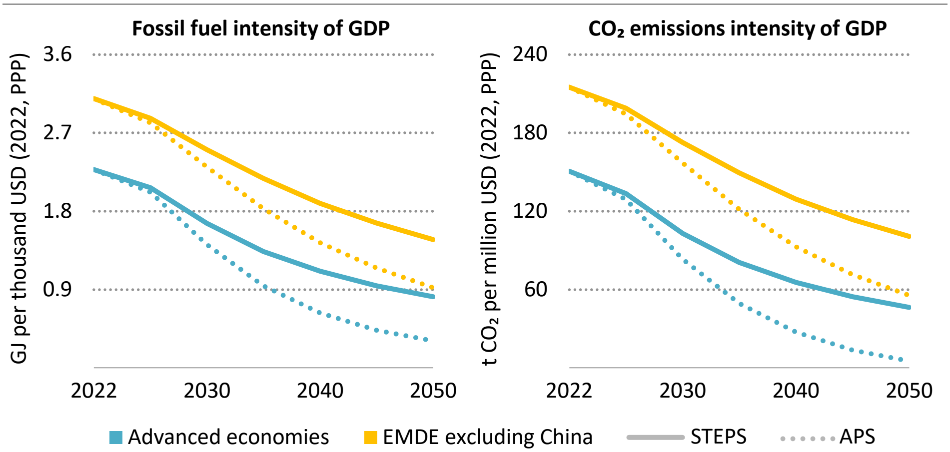

*Share of renewables in power generation and electrification of economies increase in all regions*

Note: EMDE = emerging market and developing economies.

Third, high fossil fuel import dependence, fuel price volatility and large subsidy burdens are concerns shared by many importing countries; clean energy technologies offer scope to reduce them. While the scaling up of clean energy also necessitates imports due to the concentration of supply chains, the use of clean energy reduces risks from price volatility once the necessary infrastructure is in place. All countries are affected by fuel price volatility, but countries with lower incomes suffer acutely more as a result of their limited fiscal room to manoeuvre and less affordability among consumers. Over the past decade, emerging market and developing countries have cumulatively spent USD 3.7 trillion on oil, natural gas, and coal subsidies (USD 3.2 trillion excluding China). Annual subsidies have fluctuated significantly with movements in energy prices, with subsides nearly four-times higher in 2022 than in 2016, and the unpredictable nature of fuel prices has made fiscal planning difficult. In the APS, USD 3.8 trillion is invested in clean energy infrastructure and equipment cumulatively to 2030 to keep emerging market and developing economies (other than China) on the pathway to meet long-term clean energy ambitions, and these investments displace fossil fuel demand, therefore reducing exposure to price volatility and supply shocks.

As well, there is increasing recognition of the potential for clean energy technology manufacturing and critical mineral extraction and refining to act as engines of economic and employment growth. As efforts to create a new global clean energy economy gain momentum, developing countries risk missing out on emerging economic opportunities. Some emerging market and developing countries are already taking initial steps to expand their involvement in the unfolding new clean energy economy. For example, the Indonesia Battery Corporation was established by the government in 2021 to help the country become a leading supplier of EV batteries, with a target to manufacture 140 gigawatt-hour (GWh) battery capacity by 2030. Indonesia is the world's largest producer of nickel, and it aims to move up the value chain of mineral supplies. India implemented the Production Linked Incentives programme to incentivise the production of solar PV modules and batteries. It aims to stimulate greenfield manufacturing capacity and to create new jobs.

**Figure 1.30 ▷ Fossil fuel and $CO_2$ emissions intensity of GDP by region and scenario, 2022-2050**




IEA. CC BY 4.0.

*Fossil fuel and $CO_2$ emissions intensities in emerging market and developing economies other than China fall by half in the STEPS and by over 70% in the APS*

Note: GJ = gigajoule; PPP = purchasing power parity; t $CO_2$ = tonne of carbon dioxide; EMDE = emerging market and developing economies.

As a result of these and other related factors, notably efficiency improvements, all global regions see increasing use of clean energy technologies and reductions in the fossil fuel energy and emissions intensity of GDP across the IEA scenarios. This implies that lower levels of fossil fuel supplies are needed over time to generate the same amount of economic output, and that a given level of economic output is associated with falling emissions over time. There are steep declines in both these metrics across regions (Figure 1.30). Both fossil fuel and $CO_2$ emissions intensities fall by half in the STEPS by 2050, and by over 70% in the APS in emerging market and developing economies (other than China). As a result, even as

GDP nearly triples by 2050 in this group, aggregate annual $CO_2$ emissions rise by only a quarter in the STEPS and fall by 30% in the APS.

Emerging market and developing countries are not bound to track the kind of emissions intensive pathways that have been followed in the past. However, the degree to which such countries are able to chart alternate pathways depends on the amount of investment in clean energy and efficiency technologies that they are able to attract, and on the ability of countries and households to pay upfront clean energy infrastructure costs. Effective policies and regulatory frameworks will be important in this context, as will the development of domestic financial markets and the availability of international finance.

## 1.9 Geopolitical tensions undermine energy security and prospects for rapid, affordable transitions

Geopolitics and energy have been intertwined throughout the fossil fuel era: importers have come to depend on exporters for supplies, and exporters have similarly come to depend on importers for revenue. Political and commercial relationships between producers and consumers have ebbed and flowed as a way to manage these dependencies, but risks have also been mitigated by open international energy markets, initially for oil, more recently also for natural gas. Well-functioning markets, alongside safety nets such as spare capacity held by key producers and the IEA co-ordinated system of oil stocks, have helped countries to manage shifts in supply and demand: they have also provided a buffer against disruptions caused by extreme weather or geopolitical events. Trade provides access to a large balancing area to manage shifts in supply or demand: this insight is also becoming increasingly valuable for electricity security in interconnected and renewables-rich markets.

Russia's invasion of Ukraine provided a stern test of the resilience of today's energy system to geopolitical shocks. The price spikes that followed cuts to gas supply from Russia were certainly very damaging, but the attempt by Russia to use gas supply for political leverage failed. Russia has lost its largest customer, shredded its reputation as a reliable exporter and created incentives for consumers to consider alternatives to natural gas. This is reflected in our projections: the global energy crisis has prompted a significant downward revision to natural gas demand in the STEPS and to Russian gas exports (section 1.10).

The recent crisis has shown how geopolitical events can affect the energy sector. However, the relationship works both ways: changes in energy markets can also shape geopolitics. As energy transitions proceed, they shift demand across fuels and sources of electricity in ways that eventually loosen the grip of fossil fuel resource-holders. The process will be a long one and fossil fuel producers remain influential. Indeed, the share of the Organization of Oil Exporting Countries (OPEC) in global supply rises over time in our NZE Scenario as demand falls. But in exercising this influence they reduce it, because consumers have an increasing range of mature clean energy options that become more attractive as a result.

Energy transitions do not, however, mean an end to geopolitical risks. Traditional risks around fossil fuel supply evolve, but they do not disappear. Transitions could be destabilising for fragile producing states that fail to diversify away from high dependence on hydrocarbon revenues. In the meantime, new geopolitical risks and dependencies arise in clean energy supply chains (Bordoff and O'Sullivan, 2023). And both traditional and new security risks are worsened in a more fragmented international system characterised by rivalries and low co-operation.



The world can ill afford these tensions if it wants to get on track to limit global warming to 1.5 °C. As the acceleration in clean energy deployment in recent years showed, periods of disruption and high fossil fuel prices can give additional momentum to transitions. But this is a very costly way to change the system. The latest numbers from the IEA Government Energy Spending Tracker show that over USD 1.3 trillion has been allocated by governments for clean energy investment support since 2020 (IEA, 2023f). However, since the start of the energy crisis, governments have also allocated some USD 900 billion to short-term consumer affordability measures. In emerging market and developing economies, governments have dedicated more to consumer affordability measures (USD 140 billion) than to clean energy investment support (USD 90 billion). Moving from crisis to crisis is no way to manage the clean energy transition.

There is limited scope to incorporate geopolitical shocks into our long-term *Outlook* scenario structure, given that their effects and duration are by their nature unpredictable. Nonetheless, the baseline expectation is for a future mixture of rivalry and collaboration. Elements of geopolitics come through in the STEPS, especially in relation to the position of Russia in international energy trade, but the hope is that co-operation on clean energy can be ringfenced from broader geopolitical tensions so as to allow rapid progress towards global net zero emissions in line with the NZE Scenario, which depends on co-operation between countries: without this, its objectives fall out of reach.

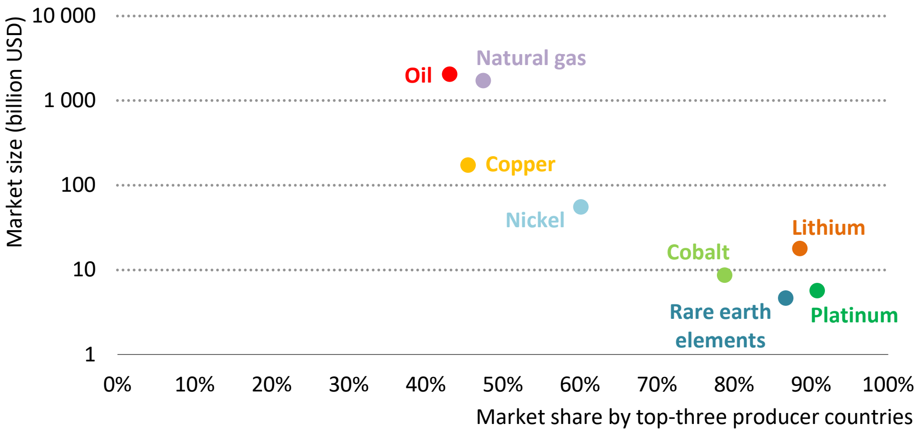
The next section explores how the energy sector might fare in a world that is lower on trust and lower on co-operation than our baseline expectations. It considers in particular how geopolitical tensions might affect the outlook both for clean energy and for fossil fuels.

### *1.9.1 Clean energy in a low-trust world*

Opportunities to produce low-emissions energy cost competitively are far more widely distributed around the world than is the case for fossil fuels. It would therefore be natural to assume that, as a largely domestic source of energy, renewables would fare better in a more fragmented international context, especially in countries that rely on imported fuels. The energy crisis in 2022 provides supporting evidence for this, with deployment of renewable power and improvements in efficiency in the European Union covering nearly 20 bcm or 25% of the supply gap left by Russia's actions. Domestically produced clean energy can clearly be an asset at times of geopolitical stress.

However, while renewable resources are widely distributed, the same is not true for clean energy supply chains, which are heavily concentrated. IEA analysis from the most recent *Energy Technology Perspectives 2023* brings out clearly that the three largest producer countries account for at least 70% of manufacturing capacity for key mass-manufactured technologies – wind, batteries, electrolysers, solar panels and heat pumps – with China dominant in each (IEA, 2023g). For critical minerals, resources are spread quite widely but current mining activities are highly concentrated, much more so than is the case for fossil fuel supply (Figure 1.31). China has invested heavily in midstream refining and processing and has a very strong position in both.

**Figure 1.31 ⊳ Average market size and level of geographical concentration for extraction of selected commodities, 2020-2022**






*Markets for critical minerals are smaller and more concentrated than those for traditional hydrocarbon resources*

Overall, China's investment in clean energy supply chains has helped bring down costs worldwide, with multiple benefits for clean energy transitions. There is also a distinction to be made between energy security hazards in fuel markets (which affect all consumers using the fuel) and those in clean energy supply chains (which affect only the flow of new manufactured products). Nonetheless, one of the clearest lessons from the history of the energy sector still stands: high reliance on single countries, companies or trade routes makes the system vulnerable to unexpected events, be they related to the policy choices of an individual country, natural disasters, technical failures or company decisions. These risks are inevitably heightened at times of geopolitical stress.

A low-trust world could create incentives to rely more on domestically produced clean energy, but these incentives could be undercut in practice by a reluctance to rely heavily on imported technologies, or shaped by a preference for those technologies that require the fewest imported elements, or those where the risks of supply chain disruptions seem lowest. Supply of critical minerals could be a particular pressure point, since now there are relatively few buffers in place to cope with interruptions or disruptions, markets are thinly traded and often opaque, and restrictions on trade have risen in recent years.

Given the high degree of concentration in energy supply chains, there are justifiable reasons for countries to seek to increase the resilience of clean energy supply chains through industrial policies and support for broader supply diversity. The risk in a low-trust world is that this process could tip over into much more widespread barriers to trade as countries prioritise autonomy over managed dependence, and in so doing add costs, complexity and time to the process of change. Barriers to trade of this kind would also limit the scope for cost-effective development of new clean technology markets, which depend heavily on technology learning and collaborations across national borders. Without co-operation, some countries – especially emerging market and developing economies – could struggle to gain a stake in the new clean energy economy, and some of the clean technology markets that are needed for a net zero emissions energy system could take much longer to gain momentum, or fail to take off at all.

### *1.9.2 Fossil fuels in a low-trust world*

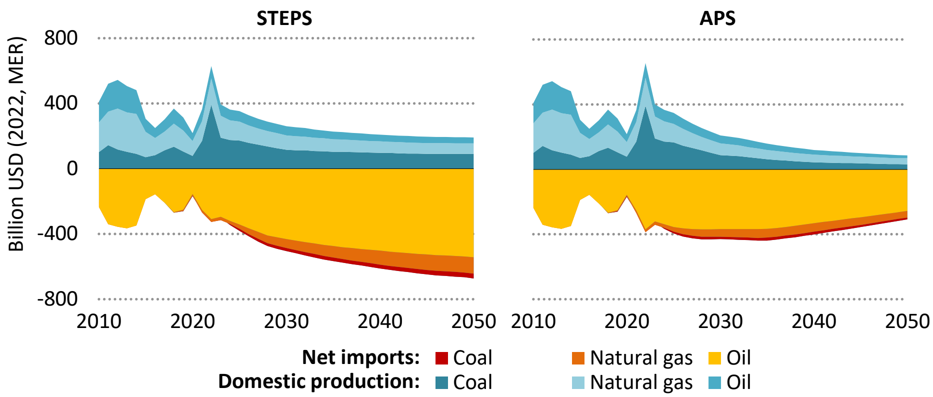
Following Russia's invasion of Ukraine, tensions in the Middle East underscore the potential risks that continue to face oil and gas supply. The STEPS projections highlight that many emerging market and developing economies, notably in Asia, see a significant increase in oil and gas imports both in terms of volume and cost (Figure 1.32). A low-trust world would create incentives to limit these vulnerabilities in favour of resources that are available domestically. As noted, this could create some upside for clean energy, with caveats. But it could also keep coal in the mix for longer as well.

Where resources are available, importing countries could also try to manage vulnerabilities by prioritising domestic production of oil and gas, including by greenlighting new projects. While this might potentially provide some support at the margin, it is unlikely to deliver additional production quickly (with the exception of some short-cycle developments such as shale). Historically it has taken well over ten years on average for a conventional project to move from licensing to first production. Moreover, such an approach would come with a risk of pushing global production beyond the 1.5 °C threshold, and of new projects becoming loss-making if the world gets on track to keep global warming below 1.5 °C.

The outlook for natural gas would face additional uncertainties in a world of high geopolitical tensions. A significant new wave of LNG export facilities is under construction: 250 bcm per year of liquefaction capacity is scheduled to start operation by the end of 2030, which is equivalent to almost half of global LNG supply in 2022. The United States and Qatar account for 60% of the additional LNG, with Asia the intended market: China alone has contracted for an additional 85 bcm of gas since 2022. Gas markets have become increasingly deep and liquid in recent years, a development that has underpinned investor confidence and an enhanced ability to respond to shocks. A reversal of this trend would reduce optionality and security.

Oil markets too could see trade being further determined by political considerations and relationships, as producers attempt to tie in consumers and buyers seek more security. This would come at a cost to efficiency, and could lock in fossil fuel use and related $CO_2$ emissions.

**Figure 1.32 ⊳ Value of domestic production and import bills for fossil fuels in emerging market and developing economies in Asia excluding China by scenario, 2010-2050**




*Increasing fossil fuel import bills in developing Asian economies imply significant vulnerability to global energy price and market volatility*

## *1.9.3 Risks of new dividing lines*

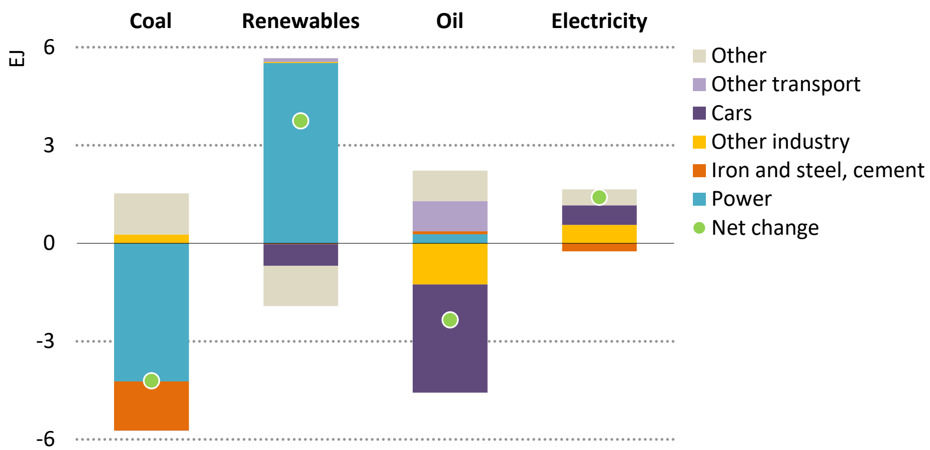
There are major hazards for the energy outlook in a more fragmented and divided world. Such a world could well reduce the ability of countries to tackle climate change, to ensure energy security and to respond to a host of other energy-related challenges. A particular risk is that dividing lines that disadvantage emerging market and developing economies could become entrenched, constraining their ability to access finance and to participate in global supply chains. Competition to secure critical mineral supplies could also mitigate against the push to raise standards, and could result in more tacit acceptance of the kind of poor labour practices and exploitative resource extraction policies that have impoverished countries in the past.

Without international co-operation, the chances of limiting global warming to 1.5 °C recede over the horizon and out of sight. The world needs to embrace a rules-based trading system if energy transitions are to succeed. It will not be possible to expand clean energy in line with the NZE Scenario if countries prioritise self-sufficiency over integration and trade. Nor will it be possible to prevent the road ahead from looking increasingly bumpy and perilous from an energy security perspective if countries start to lose the benefits of interconnected markets as a way of coping with shifts in supply and demand and of riding out unexpected shocks. In these circumstances, a worsening climate could itself pose an increasingly significant threat in the coming decades, widening any fractures in international affairs in the process. This all points to the vital importance of redoubling collaboration and co-operation, not retreating from it.

## 1.10 As the facts change, so do our projections

The STEPS illustrates the direction in which current policy settings are steering the energy sector based on a sector-by-sector assessment of existing policies and announcements. This trajectory is updated on an annual basis in line with changes in policy settings, market conditions and technology developments, and it is instructive to look at how the projections have evolved over time. Any company or policy maker considering our *Outlook* needs to bear in mind the dynamic nature of the scenario: for example, if a company chooses to align its investments with STEPS, it needs to be aware that this is a moving target.

**Figure 1.33 ▷ Differences in global total energy demand by fuel and sector in the *WEO-2023-STEPS* compared to the *WEO-2022-STEPS*, 2030**




IEA. CC BY 4.0.

*In this Outlook, the power sector taps significantly more renewables and uses less coal than in the WEO-2022-STEPS, plus road transport is electrified faster*

Changes in starting conditions since the *World Energy Outlook-2022* (*WEO-2022*) have had a material impact on the outlook for energy (Figure 1.33). As discussed in section 1.1, this 2023 *Outlook* is the first time that a scenario based on existing policy settings sees a peak in demand for each of the fossil fuels before 2030. Some of the key changes in this *Outlook* since the *WEO-2022* are:

- *Faster growth in electric car sales.* In this *Outlook*, the STEPS projections show more than 220 million electric passenger cars on the road in 2030, a 20% increase on the number in the *WEO-2022*. This increase cuts oil demand in 2030 by around 1 mb/d and boosts electricity demand from road transport by 165 TWh.
- *Continued momentum in renewables deployment.* Higher interest rates and near-term supply chain challenges create difficulties for some new projects, but overall our

projections show further acceleration in deployment. Solar PV in particular rises more quickly than in the *WEO-2022*, reflecting strengthened policies in a number of key markets and ample solar PV manufacturing capacity (section 1.3). This results in lower generation from coal and natural gas.

- *Slower economic growth and construction activity in China.* This has an impact on the projections for all fuels, but it has a particular effect on coal demand in China, which is nearly 100 Mtce lower in 2030 than in the *WEO-2022*, with large reductions in power and the steel and cement sectors (section 1.2).

Year-on-year revisions are important, but it is also useful to take a look at how projections have evolved over a longer timeframe. Some of the largest changes in the STEPS over the last five years have been in solar PV and wind generation and, particularly since the global energy crisis, in natural gas demand. These are the focus of the following sections. We also include insights on how the technology mix to reach net zero emissions by 2050 has evolved in the NZE Scenario since it was introduced in 2021 (Box 1.3).

### Box 1.3 ▷ How does the 2023 NZE Scenario differ from the 2021 version?

The updated Net Zero by 2050 Roadmap, released by the IEA in September 2023, achieves the same outcome as the original version from 2021 – limiting the rise in global average temperatures to 1.5 °C – but the trajectory for emissions and the respective roles of different fuels and technologies have changed (IEA, 2023b). This reflects a different starting point for the scenario as well as bigger contributions from technologies that have made good progress in recent years and smaller ones from those that have made more limited progress.

Since 2021, demand for fossil fuels has risen. This partly reflects post-pandemic economic growth and the effects of the global energy crisis, but it is also the result of a collective failure to move more quickly to scale up clean energy investment in efficiency and supply. This means that total energy demand, fossil fuel use and emissions in 2030 are higher than in the 2021 version of the NZE Scenario.

Coal demand declines rapidly, but in 2030 it is nonetheless above the levels in the 2021 NZE Scenario. This reflects an attempt to provide a more manageable and equitable near-term pathway for emerging market and developing economies, which dominate global coal use, but it also stems in part from the energy security concerns around natural gas sparked by Russia's invasion of Ukraine. This change means that the path to achieving net zero emissions by 2050 in the 2023 NZE Scenario is a steeper one than in the 2021 version and requires more to be done after 2030, but the path remains open.

The balance of clean energy technologies used to achieve emissions reduction goals has also shifted. Solar PV takes a more prominent role in the 2023 NZE Scenario, though reductions in projected wind capacity additions mean that the combined 40% share of wind and solar PV in total generation in 2030 is very similar to that projected in 2021.

This reflects the surge in solar PV installations and manufacturing capacity since the 2021 report. The rise in solar PV generation leads to a need for additional stationary battery storage to ensure security of supply.

Electricity and electrification play even more prominent roles in the 2023 NZE Scenario than they did in the 2021 version. This reflects a significant increase in EV sales and progress in scaling up EV manufacturing supply chains. It also reflects accelerated progress in heat pump deployment in buildings and rising market confidence in technologies such as 100% electrolytic hydrogen-based direct reduced iron production.

Near-term deployment is slower for some technologies, notably wind, hydrogen and CCUS. This reflects supply chain constraints, delays in scaling up project pipelines and related infrastructure, and sluggish progress in the development of market frameworks for less mature technologies. For some of these technologies, the downward revision is based on recent investment trends from technology manufacturers compared with investment in other low-emissions alternatives. So, for example, the 2023 Roadmap foresees a reduced role for hydrogen-fuelled trucks.

The outlook for natural gas in the 2023 NZE Scenario has also changed since the first version in 2021. In the 2021 Roadmap, natural gas use fell to 1 750 bcm in 2050; in this *Outlook*, it falls to 920 bcm. Most of this 830 bcm difference in 2050 is because of lower projected hydrogen production from natural gas with CCUS, with a larger role now projected instead for hydrogen production via electrolysis.

### *1.10.1 Solar PV and wind generation*

The STEPS projections for solar PV and wind generation to 2030 have increased substantially in successive editions of the *Outlook* since 2019 (Figure 1.34). Four main factors have been at play:

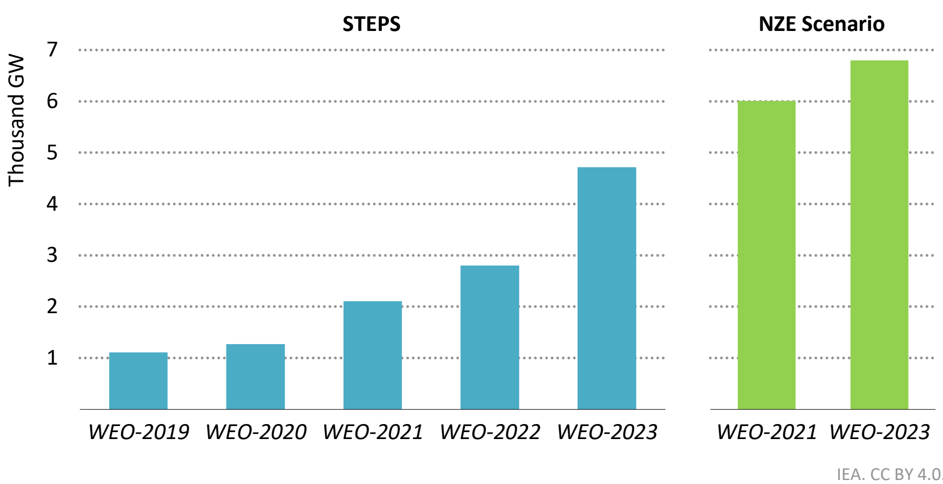
- *Policies*: The number of countries with policies that support expansion of solar PV and wind has steadily risen, and now stands at over 140. At the same time, policy ambitions and related support have been ratcheted up many times in major markets, including in China, European Union, India, Japan and United States.
- *Cost reductions*: Between 2010 and 2022, the levelised cost of electricity fell by about 90% for solar PV, 70% for onshore wind and 60% for offshore wind. Although there has been a rise in costs in recent years (section 1.3) which has created difficulties in particular for wind power in some advanced economies, these cost reductions have largely followed anticipated learning rates linked to the scaling up of deployment and technology innovation. In general, policy support and cost reductions have created a virtuous cycle: increased policy support raised the level of deployment, which led to cost reductions, and those cost reductions have led to additional deployment.

- *Manufacturing capacity and industrial policies*: IEA projections now fully account for developments in clean energy supply chains, which in some cases have far outpaced actual deployment and created an opportunity for further rapid increases, notably for solar PV (section 1.3).

- *Financing conditions*: Cost of capital for solar PV and wind power is especially important because upfront capital costs account for the majority of their lifetime costs. Tried and tested policy and regulatory frameworks have helped reduce financing costs by providing operators with a high degree of revenue certainty, usually through long-term contracts. Against this backdrop, today's higher borrowing costs are a cause for concern as they complicate project economics and could tilt cost calculations back towards (often polluting) technologies that have lower upfront costs but lock in long-term expenditure for fuel.

These factors have been very positive overall for the expansion of wind power and solar PV, and help to explain year-on-year increases in projected deployment. However, the growth in wind and solar PV generation to 2030 in the STEPS is far below the level needed to limit warming to 1.5 °C, highlighting the urgent need for further measures to achieve the goals of the NZE Scenario.

**Figure 1.34 ▷ Increase in solar PV and wind power capacity between 2022 and 2030 in five editions of the *World Energy Outlook***




***Wind and solar PV projections ratcheted up as policy support increased, costs fell and manufacturing expanded, yet more is needed to get on track for net zero emissions***

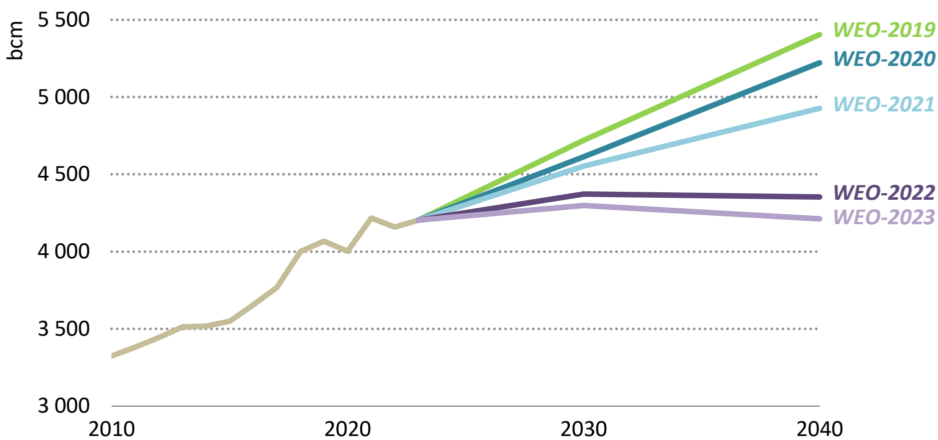
Note: *WEO-2019* data is for the New Policies Scenario, the closest equivalent to the Stated Policies Scenario (STEPS).

### 1.10.2 Natural gas



The STEPS scenarios that were modelled until the *WEO-2021* projected strong continued increases in natural gas consumption (Figure 1.35). Upward revisions to renewables gradually narrowed the space for natural gas to contribute to electricity demand growth, resulting in downward revisions to demand levels, but the long-term picture still supported continued growth to 2040 and beyond.

**Figure 1.35 ▷ Natural gas demand projections in the STEPS to 2040 in five editions of the *World Energy Outlook***




***Upward revisions to renewables have chipped away at long-term natural gas projections, but the sharpest reduction came in 2022 following the global energy crisis***

Note: *WEO-2019* data is for the New Policies Scenario, the closest equivalent to the Stated Policies Scenario (STEPS).

The events of 2022 – especially the Russian invasion of Ukraine – led to a major revision in the outlook for natural gas. There was an immediate cut in exports to Europe, and confidence around the world was shaken in the ability of natural gas to act as a reliable and affordable fuel. As a result, natural gas demand in 2040 was cut by around 570 bcm (12% reduction) in the STEPS published in the *WEO-2022*. Around half of this reduction was due to a faster move away from gas in advanced economies; the other half was the result of much slower projected growth in emerging market and developing economies. Natural gas demand in 2040 has been adjusted down by a further 140 bcm in the STEPS in this *Outlook*. This mainly reflects the upward revision to the outlook for renewables. Advanced economies, led by Europe, account for around three-quarters of the overall downward revision in natural gas demand.

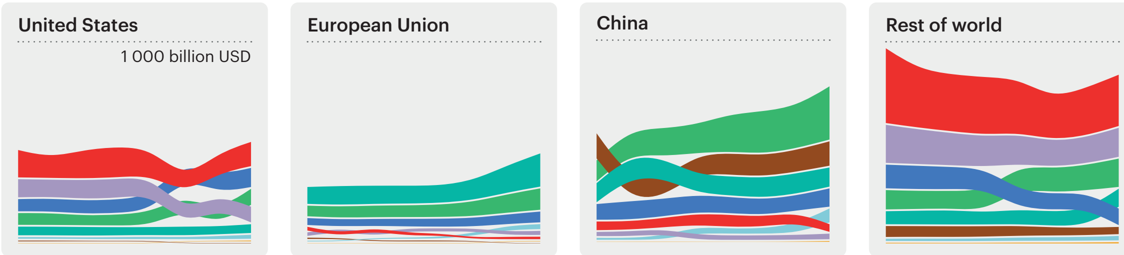
Demand for LNG in 2050 in this *Outlook* is nearly 15% lower than projected in the STEPS of the *WEO-2021*. This is a smaller reduction than the near 20% downward revision in overall natural gas demand between the *WEO-2021* and this *Outlook*. But the large increase in new liquefaction projects approved for development in the intervening years means that planned capacity is now sufficient to meet LNG demand in the STEPS to 2040, which is ten years later than projected in the *WEO-2021*. This opens the prospect of looser market fundamentals, lower prices and an easing of gas supply security concerns from the second-half of 2030s, with potential upside for demand if these developments buttress confidence in gas among price-sensitive emerging market and developing economies. However, it also raises questions about the long-term profitability of projects.

# Setting the scene

## Context and scenario design

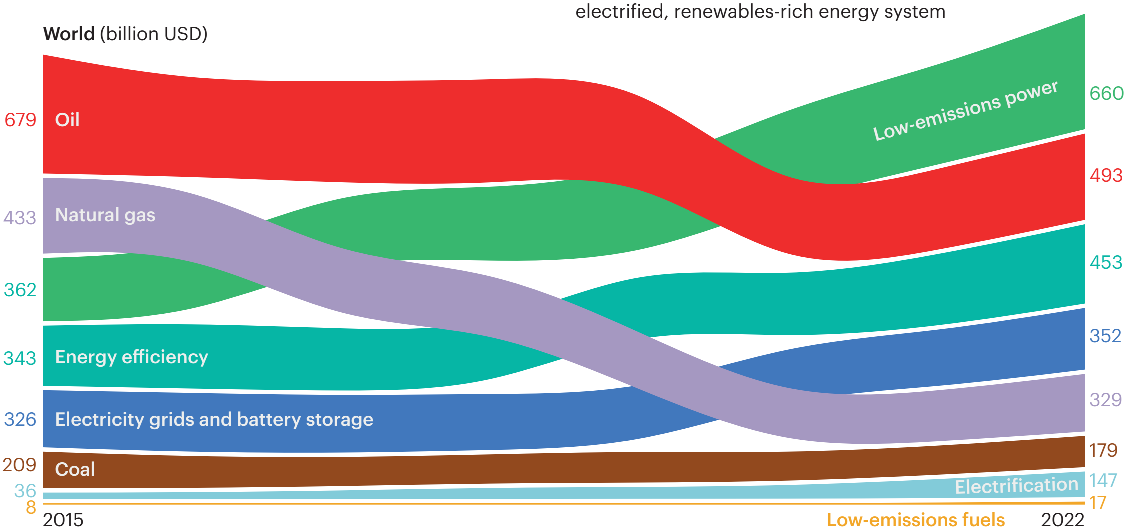

### S U M M A R Y

- There is a new context for this *World Energy Outlook*. A more complex and fragmented geopolitical landscape has energy as one of its dividing lines. Partly as a result, new energy and industrial policy settings are emerging as countries compete for footholds in the new clean energy economy, amid concerns about energy security and resilience. Greenhouse gas emissions remain at record levels and the accumulation of emissions is heightening physical climate risks. And this is all taking place in a difficult macroeconomic context, with the recent crisis pushing up the cost of living and ending a period of low interest rates.
- Some of the tensions in energy markets have receded in 2023 after a period of extended and extreme turbulence since 2020. However, numerous risks remain and the current relative calm may not last. Continued fighting in Ukraine, more than a year after Russia's invasion, is now accompanied by the risk of protracted conflict in the Middle East. Periods of extreme weather are becoming a major hazard for energy security.
- Despite headwinds, there are strong signs of an acceleration in clean energy transitions. The deployment trends for solar PV, electric vehicles, batteries and heat pumps are encouraging and the overall balance of investment is shifting towards clean energy. For every USD 1 spent on fossil fuels, USD 1.8 is now spent on a range of clean energy technologies and related infrastructure: five years ago this ratio was 1:1. The increase in spending is concentrated in advanced economies and China. A much broader flow of clean energy projects – based on stronger national policies and international financial support – is essential to meet the Sustainable Development Goals, including energy access, and global climate and energy security objectives.
- This *Outlook* explores three scenarios – fully updated – that provide a framework for exploring the implications of various policy choices, investment and technology trends. The **Stated Policies Scenario** is based on current policy settings and also considers the implications of industrial policies that support clean energy supply chains as well as measures related to energy and climate. The **Announced Pledges Scenario** gives governments the benefit of the doubt and explores what the full and timely implementation of national energy and climate goals, including net zero emissions targets, would mean for the energy sector. The **Net Zero Emissions by 2050 Scenario** maps out a transition pathway that would limit global warming to 1.5 °C.
- The global economy is assumed to increase at an average of 2.6% per year to 2050 in the three scenarios, while the global population expands from 8 billion today to 9.7 billion in 2050. Energy, carbon and mineral prices find different equilibrium levels across the scenarios, but the potential for volatility remains high.




# Investment flows

The pattern of investments in recent years has started to shift the world towards a more electrified, renewables-rich energy system




Economic and population growth are two key underlying forces for the outlook: the global economy is assumed to increase at an average of 2.6% per year to 2050, while the global population expands from 8 billion today to 9.7 billion in 2050.

# Economic and population drivers

## 2.1 New context for the *World Energy Outlook*

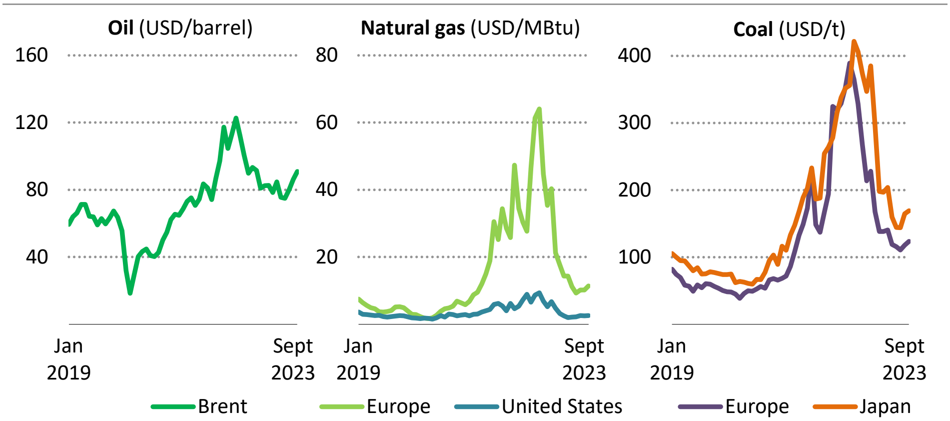
The energy sector has been shaken in recent years, first by the Covid-19 pandemic and then by the global energy crisis sparked by Russia's invasion of Ukraine. Both were hugely disruptive. Both had impacts on energy markets that left many energy producers and consumers feeling bruised by volatile fuel and electricity prices.



These impacts prompted a range of reactions from policy makers to try and lessen the immediate impacts and address future vulnerabilities, including risks to energy security and affordability, while at the same time facing up to the imperative to transition to clean energy technologies. Whether these responses are adequate to the scale of the challenge is the central question of this *Outlook*. When future generations look back, will the extended crisis of 2020-2023 be seen as the moment when the world took decisive steps to address the multiple risks facing the energy sector, or will the reaction to it be seen as another missed opportunity?

Some key trends in 2023 underscore the persistence of the status quo. By mid-year, many indicators of fossil fuel demand were returning to where they had been prior to the pandemic. Natural gas demand rebounded to 2019 levels in 2021, and is now holding steady after a tumultuous 2022. Global demand for all oil products took a little longer to come back, but has also now returned to 2019 levels, with aviation fuels the last to bounce back. And coal demand dipped during the pandemic but then reached a new record level in 2022.

**Figure 2.1 ▷ Prices for oil, natural gas and coal, January 2019 to September 2023**






***Fossil fuel prices spiked in 2022, before moderating back towards pre-crisis levels in recent months***

Notes: MBtu = million British thermal units; USD/t = US dollars per tonne. Europe natural gas price = natural gas TTF index; US natural gas price = natural gas Henry Hub index; Europe coal price = northwest Europe CIF ARA; Japan coal price = Japan CIF marker. Nominal prices.

Sources: US EIA (2023); Argus (2023); McCloskey (2023).

Following a period of extreme volatility, fossil fuel prices moderated in the first half of 2023 although market balances remain fragile (Figure 2.1). Crude oil prices returned above USD 90/barrel in September 2023, as major producers in the Organization of the Petroleum Exporting Countries-plus (OPEC+) grouping enacted cuts to their production. After the extraordinary price spikes of 2022 that saw natural gas regularly trading in Europe at prices above USD 50 per million British thermal units (MBtu) – the equivalent of more than USD 250/barrel of oil – European prices settled back at around USD 10/MBtu, though these prices were still high compared with those seen over the past decade. After record high prices of over USD 400/tonne a year earlier, steam coal prices were back down below USD 150/tonne.

Does this mean that the period of crisis is behind us? And that the energy sector has reverted to the same pathway that it was on before? Neither of these propositions appear to be true. Russia's ongoing war in Ukraine and instability in the Middle East mean a high risk of further disruption and upheaval. And the energy pathway now looks different. There are unmistakeable signs in many parts of the world of a major acceleration in the pace of energy transitions, even if macroeconomic conditions have become more challenging.

These various changes, and the reactions to them, mean that there is a new context for this *World Energy Outlook*:

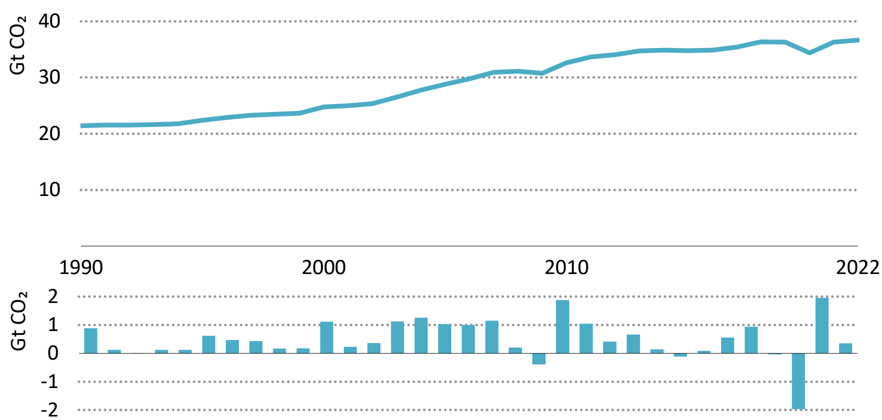
- The future will take shape within a more fragmented **geopolitical and security** context. Russia's invasion of Ukraine has widened fractures in the landscape of international relations, and energy is one of the dividing lines. With flows of Russian energy to Europe now at very low levels, one of the main traditional corridors for international energy trade has been closed, leading to a wholesale realignment in the way that fuels move around the world. In a more fractured geopolitical environment, policy makers tend to view many energy developments through an energy security lens. This does not disadvantage clean technologies; in many cases they provide solutions to energy security concerns. But it puts a premium on orderly and secure change and it has also meant that, as policy makers look beyond the immediate natural gas crisis, attention has focused on dependencies in clean energy supply chains, which exhibit significantly higher levels of concentration in many cases than supplies of oil and natural gas.

- Government responses to the energy crisis are set to have long-term implications for **energy and industrial policy**. In some cases, responses have included efforts to develop fossil fuel resources. But in general the emphasis has been on measures to fast-track the deployment of clean energy, as with the Inflation Reduction Act in the United States, more ambitious near-term targets and support measures in Europe, and strong support for clean energy in China, India and Brazil, among others. A world of more pronounced international rivalries has also produced a renewed focus on industrial strategies. These typically seek to promote investment in domestic production and/or supply from favoured jurisdictions as a way to increase the resilience of supply chains and to benefit from new jobs and economic opportunities. Clean energy has been a major focus for these industrial strategies as countries compete for footholds in the new clean energy economy. These various strategies are integrated into our *World Energy Outlook-2023 (WEO)* scenario design.

- **Emissions** continue to accumulate in the atmosphere with all that this implies for climate-related risks. Between the beginning of 2019 and the end of 2022, the global energy system was responsible for more than 140 gigatonnes of carbon dioxide (Gt $CO_2$) emissions (Figure 2.2). This means that the world is racing through the available budget that is compatible with limiting the rise in global average temperatures to 1.5 degree Celsius (°C). These additional emissions are contributing to more frequent heatwaves, droughts and other extreme weather events that add to the pressure on vulnerable populations and energy systems.

2

**Figure 2.2 ▹ Annual change in global $CO_2$ emissions from energy combustion and industrial processes, 1990-2022**






***Energy-related $CO_2$ emissions rose 1% in 2022, and are expected to rise by a similar amount in 2023***

Note: Gt $CO_2$ = gigatonnes of carbon dioxide.

- The **macroeconomic** background has become more difficult with inflationary pressures in 2022 marking the end of an era of very cheap capital and low interest rates. Many emerging market and developing economies are particularly disadvantaged by higher borrowing costs and rising fiscal pressures. According to the World Bank, incomes per capita in 2024 will remain below 2019 levels in more than one-third of low income countries (World Bank, 2023a). Higher borrowing costs risk putting some clean energy projects at a disadvantage relative to traditional energy investments because the latter have lower upfront costs, even though the clean energy projects may be more cost effective over time since they do not depend on fossil fuel inputs.

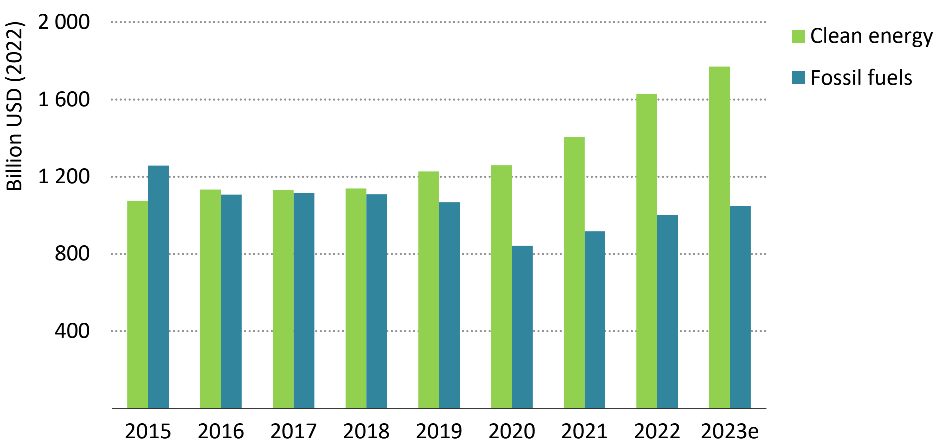
### 2.1.1 *New clean energy economy*

The energy crisis has **brought forward the emergence of a new clean energy economy**. Market turbulence prompted a short-term scramble for alternative fossil fuel supplies, particularly after Russia cut natural gas deliveries to Europe, but it also significantly increased capital flows and associated investments that support structural transformation of the energy system.

Prior to the pandemic, annual investment in energy systems was just over USD 2 trillion, split roughly in equal parts between fossil fuels and clean energy (the latter includes renewables, other low-emissions sources of generation and fuels, and spending on efficiency improvements, end-use electrification, grids and storage). The IEA estimate for 2023 is that around USD 2.8 trillion is set to be invested in the energy sector (IEA, 2023a). Fossil fuel spending has been rising slowly after a sharp drop in 2020 but remains roughly where it was five years ago, so all of the increase has come from clean energy (Figure 2.3). The trends are far from uniform across technologies, but growth in some key clean energy technology areas, notably solar photovoltaics (PV), is now aligned with the near-term requirements of the IEA Net Zero Emissions by 2050 (NZE) Scenario, which limits global warming to 1.5 °C.

The emergence of the new clean energy economy is starting to change the face of the energy system. Our analysis in the *World Energy Outlook-2022* highlighted that the policy and market trends reflected in the Stated Policies Scenario (STEPS), were already strong enough to deliver a peak in global fossil fuel demand by the end of the 2020s. Updated projections in this *World Energy Outlook-2023* underscore this conclusion and bring in new points of reference to support it.

**Figure 2.3 ▷ Global energy investment in clean energy and fossil fuels**






***For every USD 1 spent on fossil fuels, USD 1.8 is now being spent on clean energy; five years ago this ratio was 1:1***

Notes: 2023e = estimated values for 2023. Numbers are in real 2022 US dollars.

The most dynamic areas can be grouped under the heading of **clean electrification**. This is underpinned by investment in low-emissions technologies: annual global renewable electricity capacity additions are set to rise to more than 500 gigawatts (GW) in 2023, the largest absolute increase ever seen. The share of low-emissions generation sources (renewables plus nuclear) in the global mix is set to reach 40% in 2023 – a new high.



Solar is leading the charge: solar PV capacity, including both large utility-scale and small distributed systems, accounts for two-thirds of the 2023 estimated increase in global renewable capacity. The 26% annual growth in solar generation in 2022 was aligned with the near-term rates required in the NZE Scenario, and planned additions provide confidence that high growth can be sustained.

Nuclear capacity additions grew by 40% in 2022, with 8 GW coming online, mostly in China, Finland, Korea and Pakistan. Moreover, many governments are taking a fresh look at how nuclear might contribute to their energy futures, as they did after the oil price shocks of the 1970s.

Electricity is expanding to new end-uses at scale, notably to provide mobility and heat. Global electric vehicle (EV) sales jumped by more than 50% in 2022, reaching a record high of more than 10 million. Deployment of utility-scale and behind-the-meter battery storage grew by 90% in 2022, while heat pumps also saw a record year with sales up 11%, almost double the level of five years ago.

Clean electrification is being complemented by a renewed focus on efficiency. Countries representing more than 70% of global energy consumption have introduced **new or strengthened efficiency policies** since the start of the energy crisis. The European Union agreed on stronger rules in March 2023 which nearly double the rate of annual savings that EU member countries need to deliver between 2024 and 2030; the United States raised the level of support offered to households for efficiency upgrades; China stepped up its push to increase industrial energy efficiency; and India passed new efficiency laws that reinforce building energy codes and appliance standards, while also promoting sustainable choices via its Lifestyle for Environment Initiative domestically and at the Group of 20 (G20).

Progress is advancing most rapidly in areas where technologies are already mature and cost competitive, such as electricity generation and passenger transport. But a full clean energy transition will require progress in all areas, including those where emissions are harder to address. This necessitates policy support for **innovation and early deployment**. New initiatives and programmes are now in place for fuels such as low-emissions hydrogen and technologies such as carbon capture, utilisation and storage (CCUS). Investment in these areas is rising from a low base and only a handful of projects have yet made it over the line: only 4% of announced projects for low-emissions hydrogen have taken a final investment decision. However, policy makers are now looking at ways to provide greater certainty on demand, increase clarity on certification and regulation, and stimulate new infrastructure to allow more projects to progress to the implementation phase.

Analysis prepared by the IEA for the 2023 Group of Seven (G7) Leaders Summit in Hiroshima, Japan, highlighted the impressive growth in **manufacturing capacity announcements** in recent months (IEA, 2023b). If all announced projects were to come to fruition, solar PV manufacturing capacity would comfortably exceed the deployment needs of the NZE Scenario in 2030. Moreover, if they all proceed, announced projects for EV battery manufacturing capacity could cover virtually all of the 2030 global deployment needs identified in the NZE Scenario. The world is still a long way from a trajectory for emissions that is consistent with the Paris Agreement and the 1.5 °C target, but the pace of change in some key areas is impressive.

### *2.1.2 Uneasy balance for oil, natural gas and coal markets*

**Oil markets** faced two major short-term uncertainties at the start of 2023: the strength of the recovery in demand in China as the economy emerged from the Covid-19 lockdowns, and the impact on energy supply from Russia due to the price cap imposed by a G7-led coalition on Russian exports of crude oil and refined products. As of mid-year 2023, the recovery of demand in China has been quite strong. Despite slowing of its economic recovery, China is expected to account for well over half of global oil demand growth in 2023. And Russian production and exports continue to find buyers around the world, although its revenues have been considerably lower than a year earlier. Growth in oil demand is being driven by a handful of segments, notably aviation fuels. Concerns about weaker demand and prices have prompted a series of output cuts from Saudi Arabia and other members of the OPEC+ grouping.

**Natural gas markets** have moved towards a gradual rebalancing after the shocks of recent years. High inventory levels at storage sites in key Asian and European markets provide grounds for cautious optimism ahead of the 2023-2024 winter heating season in the northern hemisphere that markets will be calmer than in recent years, but major uncertainties remain. Relatively mild weather and restrained demand from China lessened the disruptive impact of Russian cuts to its European deliveries in 2021-2022, and it cannot be taken for granted that this will be the case in the coming winter. Markets remain vulnerable to unexpected outages or disruptions, especially for countries dependent on spot markets for supply.

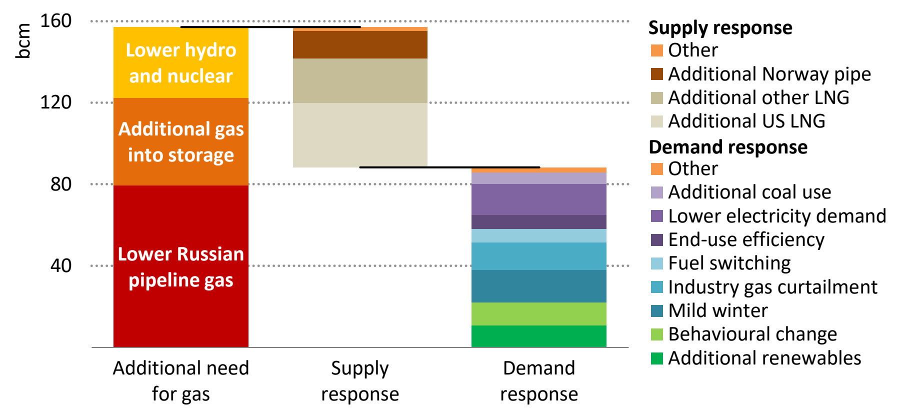
As with oil, patterns of natural gas trade have changed dramatically as a result of the global gas crisis. A striking indicator of a reshaped global gas market is that liquefied natural gas (LNG) has now become a base source of supply for Europe, with its share in total demand in the European Union rising from an average of 12% over the 2010s to close to 35% in 2022, similar to the contribution from piped gas from Russia before its invasion of Ukraine. This has knock-on effects on all aspects of natural gas markets and on how countries collaborate to ensure gas security. A number of new liquefaction projects have received the green light since 2022, adding to the wave of new LNG supply scheduled to start operation in the second half of this decade.

### Box 2.1 ▷ How did the European Union make up for a triple deficit of natural gas in 2022?

Analysis of the global energy crisis tends to focus on the cuts in Russian gas deliveries to the European Union from mid-2022 as the trigger. The 80 billion cubic metre (bcm) drop in pipeline supplies from Russia was indeed a primary cause of market turbulence, both in Europe and further afield. But it was not the only one. Changes in Russian behaviour in gas markets began well before its invasion of Ukraine, and Gazprom was much slower than usual to refill its European gas storage in the third-quarter 2021. The call on the tight gas market was exacerbated even further by a very poor year for both hydropower and nuclear output in Europe in 2022. Overall, this triple deficit meant that there was almost 160 bcm of "missing gas" to replace in 2022 (Figure 2.4).

Alternative sources of supply met over 40% of the deficit, with LNG from the United States making by far the largest contribution. Europe's ability to source supply was greatly facilitated by lower demand in China, but nonetheless caused significant pain for other import-dependent economies that found themselves outcompeted for available supply. However, the main adjustments were made on the demand side. Gas use in industry fell by almost 25%, over half of which was the result of curtailment in energy-intensive industries (with few signs in 2023 of a meaningful recovery). The oft-discussed mild winter accounted for some 10% of the overall deficit, which was around the same as the combined contribution from new renewable capacity and efficiency improvements. Contrary to the perception that coal played a significant role, additional coal consumption filled less than 4% of the gap.

**Figure 2.4 ▷ Factors straining the natural gas balance and accommodating measures in the European Union in 2022**






*Cuts in Russian deliveries put huge strains on the EU gas balance in 2022, but it was not the only factor in play given low storage levels and a poor year for hydro and nuclear*

Notes: bcm = billion cubic metres; LNG = liquefied natural gas.

**Oil and gas investment** has been affected by uncertainties concerning future demand. It is striking that, despite record revenues in 2022, spending on oil and gas production is one of the few investment indicators that remains below pre-crisis levels (coal supply investments, for example, are higher than they were in 2019). In terms of our scenarios, current oil and gas spending is broadly aligned with the levels required in the STEPS in 2030, but well above the levels required to meet much lower demand in the NZE Scenario.

**Coal** demand has been on an elevated plateau and reached a record level in 2022 as higher demand in India, China and Southeast Asia more than offset declines in the United States. In Europe, coal consumption increased by 2% during the energy crisis, with lower industrial consumption balancing out growth in coal use for power generation. Early signs in 2023 suggest continued increases in coal consumption in many parts of Asia, accompanied by significant falls in demand in North America and also in Europe as the latter resumes pre-crisis trends. Increases in coal consumption are being accompanied by increases in coal production in the three largest coal producers – China, India and Indonesia – with both China and India reaching new monthly production highs in March 2023.

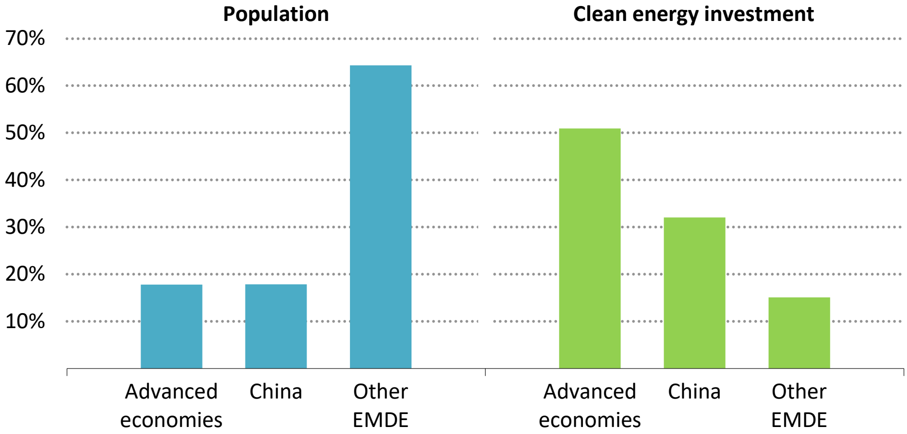
### 2.1.3 Key challenges for secure and just clean energy transitions

Even as clean energy transitions gather pace, IEA analysis has highlighted four key areas that require urgent attention if the world is to see orderly but rapid change. These are recurring themes in this *Outlook.*

First is a crucial concern that a **disproportionately low share of clean energy investment is going to emerging market and developing economies other than China**. With a few exceptions, such as investment in solar PV in India, the level of spending on clean energy in these countries in recent years, at less than USD 250 billion per year, is far out of line with what is required to meet rising energy needs in a sustainable way. As things stand, countries accounting for nearly two-thirds of the world's population account for only 15% of global clean energy investment (Figure 2.5). Bringing down the cost of capital by tackling a host of real and perceived risks associated with these investments and increasing the availability of capital, both domestic and international, is an essential step towards improving the situation.

Expansion of clean energy investment is a precondition not only to achieve universal access to modern energy but also to deliver on other United Nations Sustainable Development Goals in areas as diverse as poverty reduction, health and education. Exposure to volatile energy prices in many developing economies has been accompanied by major concerns about food security caused in part by high fuel and fertiliser prices, and higher debt burdens and fiscal pressures. The drive to provide universal access to modern energy has slowed in recent years and even reversed in some places: 775 million people still lack access to electricity worldwide and 2.2 billion people lack access to clean cooking fuels. This *Outlook* marks the mid-point of the implementation of the UN 2030 Agenda for Sustainable Development, adopted in 2015. In most cases, the world is well short of halfway to reaching its 2030 goals.

**Figure 2.5 ⊳ Share of total population and clean energy investment by region, 2022**






*Most people live in emerging market and developing economies, but only a fraction of clean energy investment is taking place in those countries*

Note: Other EMDE = emerging market and developing economies except China.

Second is the challenge of **uneven progress being made across different areas of technology and infrastructure**. Deployment trends for some technologies are sufficiently fast to be aligned with the IEA NZE Scenario, but the trends for most are not. Of the 50 technologies and cross-cutting areas assessed as part of the IEA *Tracking Clean Energy Progress*, only three were evaluated as fully on track: solar PV, EVs and efficient lighting (IEA, 2023c). Most require additional efforts to get on track: these include wind power, grids and storage, electrolysers, efficiency, innovation and digitalisation. And some are definitively off track, including those needed for long-distance transportation by truck, air and ship and those needed by many large industrial sub-sectors.

Reaching net zero emissions will clearly require progress across the board, and there are multiple commercial, technical, policy and supply chain issues to resolve. The risk with an uneven pace of progress is that slower moving elements may determine the overall pace of change. Grid availability, which is already hindering growth in renewables-based generation in some markets, is a case in point. At least 3 000 GW of renewable power projects, of which 1 500 GW are in advanced stages, are waiting in grid connection queues – equivalent to five times the amount of solar PV and wind capacity added in 2022 (IEA, 2023d).

Maintaining rapid rates of renewables deployment requires broadly matched progress across all the interlinked parts of the energy system, including grids, storage and dispatchable low-emissions sources of generation. Without such progress, the flexible and secure operation of power systems as a whole inevitably will be impaired. Complementary measures can also play an important part to facilitate rapid increases in low-emissions power. For example, improvements in energy efficiency, particularly for rapidly increasing demand areas such as space cooling, can alleviate strains on systems and obviate the need for expensive supply-side investment to meet peak demand levels, while reforms to electricity market structures and pricing can help consumers to benefit from the lower operational costs of renewables.

A third key area is to **mitigate new energy security vulnerabilities** in a rapidly changing energy system. Traditional concerns about fuel security do not disappear in energy transitions, and rapid deployment of clean energy technologies requires resilience along a new set of supply chains. For example, the manufacturing process for EVs depends on steel (which in the future will be required to be near zero emissions steel) and other materials, and ultimately on the minerals and ores needed to produce them, plus anodes and cathodes for battery supply. Each step of the process has different lead times and involves specific challenges.

Clean energy supply chains today are highly concentrated. China has an outsized presence. It has huge shares of global manufacturing capacity for solar PV modules and batteries (75%) as well as a very strong position in the refining and processing of critical minerals. In the last year, major policy announcements indicate developments that will diversify some supply chains, as evidenced by the scale-up in planned battery manufacturing capacity in the United States following the adoption of the Inflation Reduction Act. Yet, levels of supply chain concentration look likely to remain high. This makes the entire system vulnerable to unforeseen changes that could arise due to shifts in national policies, commercial strategies, technical failures or natural hazards.

A fourth key area is the need to ensure **people-centred transitions**. Inclusive approaches are essential to ensure that the benefits of clean energy transitions are felt widely across societies, and to maintain their political acceptability. The turbulent events of recent years clearly point to the risks and costs that arise if the process of change is disorderly or disjointed, or if vulnerable groups within societies are left behind. During the global energy crisis in 2022, governments allocated an extra USD 900 billion to shield consumers from the impact of spiralling energy prices, around a quarter of which was specifically directed to low income households and the hardest hit industries. Further measures will be needed to enable the least well-off to invest in clean and more efficient energy technologies for household use, especially where these technologies entail higher initial capital outlay than fossil fuel equivalents, even though they offer lower operating costs.

## 2.2 *WEO* scenarios

This *Outlook* employs three main scenarios to explore different pathways for the energy sector to 2050. Each scenario is fully updated to include the most recent available energy market and cost data. Each scenario responds in different ways to the fundamental economic and demographic drivers of rising demand for energy services. These differences largely reflect the various policy choices assumed to be made by governments, which, in turn, shape investment decisions and the ways in which households and companies satisfy their energy needs.

The projections are derived from the Global Energy and Climate (GEC) Model, which is a large-scale modelling framework developed at the International Energy Agency (IEA). The model matches energy demand and supply across multiple countries and regions, taking account of a very wide range of fuels and energy technologies, including not only those that are widely available today, but also those that are judged to be approaching commercialisation. The GEC Model is a simulation model that reflects the real-world interplay between policies, costs and investment choices and which provides insights into how changes in one area may affect others.



None of the scenarios included in this *Outlook* should be considered a forecast. The intention is not to guide the reader towards a single view of the future, but rather to promote a deeper understanding of the way that various levers produce diverse outcomes, and the implications of different courses of action for the security and sustainability of the energy system.

An important element of this *Outlook* is that all scenarios now take into account not only energy and climate-related policies but also industrial strategies that affect the rate at which different technologies might enter the mix. This means that the scale and location of manufacturing capacity for various components of the clean energy system have become important variables in scenario construction and design.

The scenarios are:

- **Net Zero Emissions by 2050** (NZE) **Scenario**: This normative scenario portrays a pathway for the energy sector to help limit the global temperature rise to 1.5 °C above pre-industrial levels in 2100 (with at least a 50% probability) with limited overshoot. The NZE Scenario has been fully updated and is the focus of the recently released *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach* (IEA, 2023d). The NZE Scenario also meets the key energy-related UN Sustainable Development Goals (SDGs): universal access to reliable modern energy services is reached by 2030, and major improvements in air quality are secured. Each passing year of high emissions and limited progress towards the SDGs makes achieving the goals of the NZE Scenario more difficult but, based on our analysis, the recent acceleration in clean energy transitions means that there is still a pathway open to achieving its goals.
- **Announced Pledges Scenario** (APS): This scenario assumes that governments will meet, in full and on time, all of the climate-related commitments that they have announced, including longer term net zero emissions targets and pledges in Nationally Determined Contributions (NDCs), as well as commitments in related areas such as energy access. Pledges made by businesses and other stakeholders are also taken into account where they add to the ambition set out by governments. Since most governments are still very far from having policies announced or in place to deliver in full on their commitments and pledges, this scenario could be regarded as giving them the benefit of the doubt,

and very considerable progress would have to be made for it to be achieved. Countries without ambitious long-term pledges are assumed to benefit in this scenario from the accelerated cost reductions that it produces for a range of clean energy technologies. The APS is associated with a temperature rise of 1.7 °C in 2100 (with a 50% probability).

- **Stated Policies Scenario** (STEPS): This scenario is designed to provide a sense of the prevailing direction of energy system progression, based on a detailed review of the current policy landscape. Whereas the APS reflects what governments say they will achieve, the STEPS looks in detail at what they are actually doing to reach their targets and objectives across the energy economy. Outcomes in the STEPS reflect a detailed sector-by-sector review of the policies and measures that are actually in place or that have been announced; aspirational energy or climate targets are not automatically assumed to be met. The STEPS is now associated with a temperature rise of 2.4 °C in 2100 (with a 50% probability).

### 2.2.1 Policies

#### *Energy and climate policies*

A crucial preparatory step for every annual edition of *Outlook* is the review and assessment of new policies, regulatory measures, targets and announcements that might affect the evolution of the energy system. The recent global energy crisis has spurred a wide range of energy and climate policy responses and initiatives that are now incorporated into the scenarios. The US Inflation Reduction Act and other notable new policies that were taken into account in the *WEO-2022* remain important points of reference.

The review covers all types of policies that have a bearing on energy systems, including decisions to proceed with new oil and gas licensing rounds, methane reduction action plans, and initiatives and strategies for energy access. The initial years of the scenario projections are also informed by the detailed databases that the IEA maintains for various types of announced or planned energy projects.

For example, over the last year the European Union stepped up its climate ambition with new targets for renewables and energy efficiency. It reformed the EU Emissions Trading System (ETS) and established a new ETS for the buildings and road transport sectors. Further, it introduced a Carbon Border Adjustment Mechanism (CBAM) that will levy a price on carbon embedded in imported products in selected sectors, and also increased emissions reduction targets for sectors not covered by an ETS. Japan established a roadmap for its Green Transformation (GX) programme that aims to raise the share of renewables and nuclear in power generation and to ensure that all new private cars sold are low-emissions vehicles by 2035. GX will be supported by carbon pricing and sovereign GX transition bonds. Canada, in its 2023 federal budget, allocated significant funding to accelerate the deployment of clean energy technologies and to decarbonise large emitters. Indonesia, Viet Nam and Senegal signed Just Energy Transition Partnerships (JETP), in which they committed to accelerate the decarbonisation of their respective power sectors. South Africa also published its JETP investment plans.

*Industrial policies*

Many countries are putting specific policies in place to encourage clean energy manufacturing. Our scenarios now take account of these policies in association with costs, targets and other variables for modelling and calibrating deployment trends.



China has a very high share of current manufacturing capacity across a range of technologies. Following the adoption of the Inflation Reduction Act (IRA) in 2022, the United States has put in place a range of tax credits and federal support for investment in clean energy manufacturing, with a focus on renewables, low-emissions hydrogen, CCUS, EVs, clean energy manufacturing and critical minerals. Canada has also established funding and tax credit support mechanisms for critical minerals, clean energy technologies and clean energy manufacturing. The European Union adopted a Green Deal Industrial Plan that targets increased public and private investment in clean technology manufacturing, and the European Commission proposed a Critical Raw Materials Act with benchmarks for domestic extraction, processing and recycling. Other countries have moved in a similar direction, with the notable example of India's production-linked incentive scheme to boost battery and solar PV manufacturing capacity.

### 2.2.2 Economic and demographic assumptions

In each of the three scenarios, the global economy is assumed to grow by 2.6% per year on average over the period to 2050. This is broadly in line with trend growth, but varies by country and by region and over time, reflecting investment dynamics, employment rates and changes in terms of trade (Table 2.1).

We hold the assumed rates of economic growth constant across scenarios to allow for a comparison of the effects of different energy and climate choices against a common backdrop. However, we recognise that the pace, design and choice of policy and regulatory mechanisms used to drive change in the energy system will have wider economic impacts – both positive and negative – across countries and regions.

The initial years in the *Outlook* are shaped by countries' exposure and resilience to shocks and by where they are currently positioned in the economic cycle. The reverberations from the pandemic and the global energy crisis are being felt across the broader economy as household purchasing power is eroded by higher inflation and as business investment is restrained by rising borrowing costs (although clean energy appears, in some cases, to be bucking this trend). Notwithstanding, labour market conditions remain relatively buoyant: the unemployment rate is at or near its lowest level in half a century in most countries, and this is helping to support household income and economic activity. Global GDP growth over the period to 2030 is projected to average 3%.

The near-term economic outlooks published by international organisations, such as the International Monetary Fund and the Organisation for Economic Co-operation and Development, emphasise the significant uncertainty and the downside risks that pervade GDP growth and inflation projections. One key risk is that inflation could be more persistent than expected, prompting further hikes in interest rates with uncertain consequences in financial markets, notably in emerging market and developing economies.

**Table 2.1 ⊳ GDP average growth assumptions by region**

| | Compound average annual growth rate | | | |
|---|---|---|---|---|
| | 2010-2022 | 2022-2030 | 2030-2050 | 2022-2050 |
| North America | 2.0% | 1.8% | 2.0% | 1.9% |
| United States | 2.1% | 1.9% | 1.9% | 1.9% |
| Central and South America | 1.2% | 2.3% | 2.4% | 2.4% |
| Brazil | 0.9% | 1.8% | 2.3% | 2.1% |
| Europe | 1.7% | 1.8% | 1.4% | 1.5% |
| European Union | 1.5% | 1.6% | 1.1% | 1.3% |
| Africa | 2.9% | 3.8% | 4.0% | 4.0% |
| South Africa | 1.2% | 1.3% | 2.7% | 2.3% |
| Middle East | 2.5% | 3.0% | 3.1% | 3.0% |
| Eurasia | 1.9% | 1.0% | 1.4% | 1.3% |
| Russia | 1.4% | 0.1% | 0.6% | 0.4% |
| Asia Pacific | 4.8% | 4.1% | 2.9% | 3.3% |
| China | 6.5% | 3.9% | 2.4% | 2.8% |
| India | 5.7% | 6.4% | 4.3% | 4.9% |
| Japan | 0.6% | 0.7% | 0.5% | 0.6% |
| Southeast Asia | 4.3% | 4.6% | 3.3% | 3.7% |
| **World** | **3.0%** | **3.0%** | **2.5%** | **2.6%** |

Note: Calculated based on GDP expressed in year-2022 US dollars in purchasing power parity terms.
Source: IEA analysis based on IMF (2023) and Oxford Economics (2023).

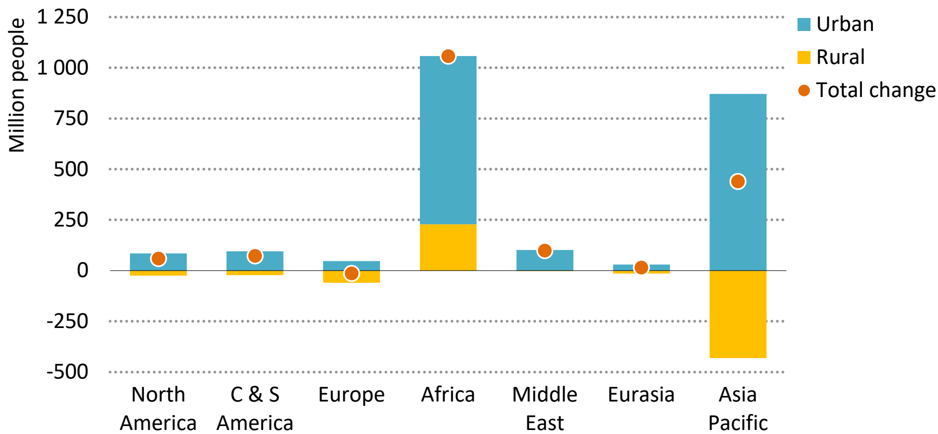
Population is a major determinant of many of the trends in the *Outlook*. We use the medium variant of the United Nations World Population Prospects, where the global population is assumed to rise from 8 billion people in 2022 to 8.5 billion in 2030 and 9.7 billion in 2050. Population growth in the medium variant is not linear, and the rate of growth slows over time.

Demographic trends differ by country and region. Ageing populations and slowing fertility rates mean the size of the population in 2050 is expected to be smaller than today in the European Union, Russia, Japan and China. In contrast, the United Nations projects a billion more people in Africa by 2050, accounting for three-fifths of the global population increase. India’s population has now overtaken that of China and is projected to reach almost 1.7 billion by 2050, some 360 million people more than in China (UN DESA, 2022).

In the past, the development of economies has typically been associated with the migration of rural workers to towns and cities in search of better paying jobs. This pattern of development is assumed to continue over the period to 2050. In fact, in most regions the change in the population is entirely concentrated in urban areas. Only Africa is expected to experience an increase in the size of its rural population by the middle of the century, and even there it is dwarfed by a much larger increase in the urban population (Figure 2.6). In the Asia Pacific region, more than 400 million people move from rural areas to towns and cities by 2050. If the model of urban development remains broadly as it is now, this global increase in the urban population will have major consequences for the energy outlook, not least by increasing demand for construction materials, such as steel and concrete.



**Figure 2.6 ▷ Change in population in urban and rural areas by region to 2050**






*Except in Africa, the increase in population in the coming decades will be entirely concentrated in urban areas*

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

Sources: UN DESA (2022); World Bank (2023b); IEA databases and analysis.

### 2.2.3 Energy, critical mineral and carbon prices

#### *Oil prices*

In each of the three scenarios, oil and natural gas prices act as intermediaries between supply and demand to ensure that sources of supply meet changes in demand and hold the energy system in equilibrium (Table 2.2). This balancing act means prices in our scenarios follow relatively smooth trajectories. We do not try to anticipate the price cycles that characterise commodity markets in practice, but we recognise that the potential for oil and gas price volatility is ever present, especially given the profound changes that are needed to meet the world's climate goals.

In the STEPS, the slight but steady decline in demand from the late 2020s keeps the oil price in check. Falling supply from existing fields, however, means there is not a large overall reduction in price. A number of major resource-holders have pursued active market management strategies in recent years to keep prices higher than they would otherwise be. It is assumed that they will seek to continue to do so, meaning the marginal project is more expensive than implied by the global supply-cost curve alone.

**Table 2.2 ⊳ Fossil fuel prices by scenario**

| | | | STEPS | | APS | | NZE | |
|---|---|---|---|---|---|---|---|---|
| **Real terms** (USD 2022) | 2010 | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **IEA crude oil** (USD/barrel) | 103 | 98 | 85 | 83 | 74 | 60 | 42 | 25 |
| **Natural gas** (USD/MBtu) | | | | | | | | |
| United States | 5.8 | 5.1 | 4.0 | 4.3 | 3.2 | 2.2 | 2.4 | 2.0 |
| European Union | 9.9 | 32.3 | 6.9 | 7.1 | 6.5 | 5.4 | 4.3 | 4.1 |
| China | 8.8 | 13.7 | 8.4 | 7.7 | 7.8 | 6.3 | 5.9 | 5.3 |
| Japan | 14.6 | 15.9 | 9.4 | 7.8 | 8.3 | 6.3 | 5.5 | 5.3 |
| **Steam coal** (USD/tonne) | | | | | | | | |
| United States | 67 | 53 | 46 | 41 | 43 | 26 | 27 | 23 |
| European Union | 122 | 290 | 67 | 69 | 68 | 53 | 57 | 43 |
| Japan | 142 | 336 | 98 | 77 | 80 | 59 | 65 | 47 |
| Coastal China | 153 | 205 | 96 | 80 | 79 | 62 | 64 | 49 |

Notes: MBtu = million British thermal units. The IEA crude oil price is a weighted average import price among IEA member countries. Natural gas prices are weighted averages expressed on a gross calorific-value basis. The US natural gas price reflects the wholesale price prevailing on the domestic market. The European Union and China natural gas prices reflect a balance of pipeline and LNG imports, while the Japan gas price is solely LNG imports. The LNG prices used are those at the customs border, prior to regasification. Steam coal prices are weighted averages adjusted to 6 000 kilocalories per kilogramme. The US steam coal price reflects mine mouth prices plus transport and handling costs. Coastal China steam coal price reflects a balance of imports and domestic sales, while the European Union and Japan steam coal prices are solely for imports.

In the APS, the policy focus on curbing oil and gas demand brings down the prices at which the market finds equilibrium from levels in 2022: the international oil price falls to around USD 60/barrel in 2050. In the NZE Scenario, oil and gas prices quickly fall to the costs of the marginal project required to meet falling demand, which is around USD 40/barrel for oil in 2030, before declining further to USD 25/barrel in 2050. These prices cover the operating expenses to lift oil and gas out of the field of the marginal producer, the capital expenditure and operating cost required in emissions reduction technologies, as well as upstream taxes.

### *Natural gas prices*

In the STEPS, natural gas prices stay somewhat elevated relative to pre-crisis levels until the middle of the decade as global gas markets continue to adjust following the loss of Russian pipeline gas supply to Europe, a loss that is assumed to be permanent. However, a wave of new LNG export capacity from 2025 eases gas market balances, and Asian markets take back the designation of premium market for LNG. As natural gas demand first plateaus and then decreases in the STEPS after 2030, import prices stay around USD 8/MBtu. In the United States, natural gas prices average around USD 4/MBtu due to domestic production of gas.

In the APS, a sharper reduction in European natural gas demand softens prices further. Lower gas demand growth in emerging market and developing economies and fierce competition among LNG suppliers to capture market share means that by 2030, prices for natural gas importers tend towards the range between USD 6.5/MBtu and USD 8/MBtu. In the NZE Scenario, a glut of gas supply forms in the mid-2020s as demand starts to decline rapidly in key markets, and prices in China, Japan and the European Union fall to levels last seen at the height of the Covid-19 pandemic in 2020. This puts a strain on export projects at the margin, especially for the 40% of export projects that have not yet recovered their invested capital.



### *Coal prices*

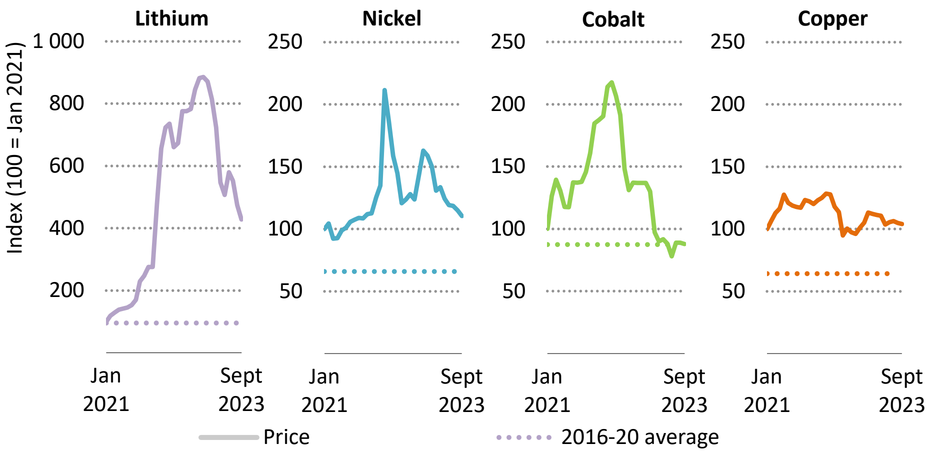
Robust coal supply and lower natural gas prices sent coal prices steeply downward towards the end of 2022, easing an unprecedented period of market tightness. High prices during the energy crisis in the wake of the Russian invasion of Ukraine had previously strengthened the balance sheets of coal mining companies, providing them with an opportunity to invest in maintaining and, in some cases, expanding capacity. However, our scenarios offer a mixed picture, at best, for future demand and prices. The STEPS offers some comfort to coal producers, at least in the near term, but demand falls in all scenarios, and prices decline towards the operating costs of existing mines: the decline is fastest in the NZE Scenario.

### *Critical mineral prices*

Reliable and sustainable supplies of critical minerals and metals such as lithium, nickel, cobalt and copper are fundamental to keep clean energy transitions affordable. Vigorous deployment of clean energy technologies has made the energy sector the main driver of growth in the critical minerals market (IEA, 2023f). After a surge in prices of these critical minerals in 2021 and 2022, prices have started to moderate, but in most cases, they remain significantly above historical averages (Figure 2.7). We do not yet model full long-term supply-demand balances for critical minerals in the same way as for fuels, but we do undertake market monitoring and scenario benchmarking. Based on this analysis, we expect medium-term markets for many energy transition minerals to remain under pressure as the economy recovers and clean energy deployment continues to accelerate.

Delays or cost overruns remain a significant possibility for many announced supply projects, and uncertainty about the future availability of higher specification battery-grade products remains a source of concern. New critical mineral projects generally involve higher production costs: there is a long list of potential plays that require elevated marginal costs to bring volumes on stream ranging from lepidolite-based lithium and to sulfidic-based copper. In addition, supply-side events may induce short-term price pressures: in early 2023 there were mine supply disruptions in Brazil, Chile, Indonesia and Peru (the result of unusually heavy rain in Brazil and Indonesia), plus aluminium production in China was disrupted by hydropower shortages.

**Figure 2.7 ▷ Price developments for selected energy transition minerals and metals, January 2021 to September 2023**






***After surging in 2021 and 2022, many critical mineral prices started to moderate in 2023, but they remain high relative to historical averages***

Notes: Assessment based on the London Metal Exchange (LME) Lithium Carbonate Global Average, LME Nickel Cash, LME Cobalt Cash and LME Copper Grade A Cash prices. Nominal prices.

Source: IEA analysis based on S&P Global (2023).

### *Carbon prices*

Globally, about 23% of energy-related emissions are now covered by a carbon price of some type. Despite the global energy crisis and significant price volatility in energy markets, carbon prices increased in 2022 in about half of the existing carbon pricing schemes, several new instruments were launched, and others extended their scope. The European Union significantly increased the ambition of its ETS and adopted a new emissions trading system for the buildings, road transport and other industry sectors, while also introducing a CBAM which will levy a price on carbon embedded in imported products in selected sectors. China increased the stringency of its national ETS. Indonesia announced the launch of its own ETS for the power sector. India introduced framework legislation to develop a national carbon market. The government in Brazil proposed draft legislation for a national ETS. Revenues generated from emissions trading systems and carbon taxes continue on an upward trend, with almost USD 100 billion generated in 2022 (World Bank, 2023b). Nevertheless, most carbon prices remain below the level that we estimate is needed if the goals of the Paris Agreement are to be met.

In our scenarios, the STEPS incorporates existing and scheduled carbon pricing initiatives, whereas the APS and the NZE Scenario include additional measures of varying stringency and scope. In the NZE Scenario, for example, carbon prices are quickly established in all regions, rising by 2050 to an average of USD 250/tonne $CO_2$ in advanced economies, and USD 200/tonne $CO_2$ in other major economies, e.g. China, Brazil, India and South Africa, with lower price levels elsewhere. As with other policy measures, carbon prices should be introduced only with careful attention to the likely consequences and distributional impacts. The level of carbon prices included in our scenarios should be interpreted with caution: the scenarios include a number of other energy policies and accompanying measures designed to reduce $CO_2$ emissions, and this means that the carbon prices shown are not the marginal costs of abatement (as is often the case in other modelling approaches).



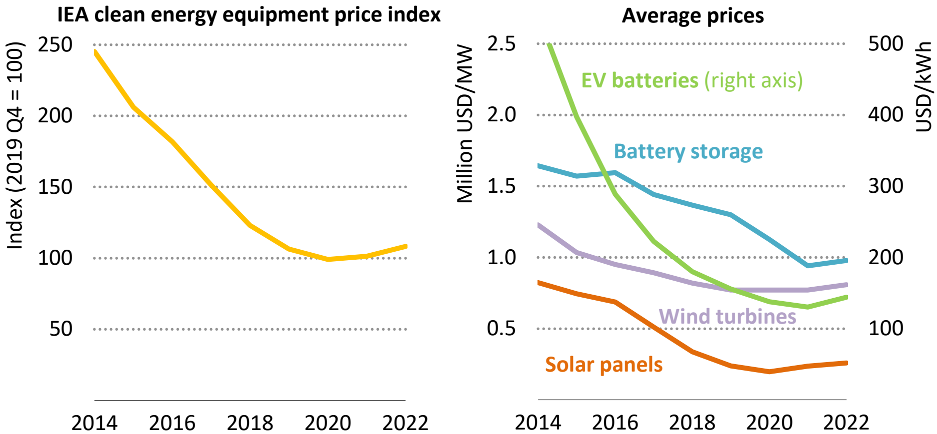
### *2.2.4 Technology costs*

After an unbroken run of cost declines, prices for some key clean energy technologies rose in 2021 and 2022, largely reflecting higher input prices for critical minerals, semiconductors and bulk materials such as steel and cement. This has had negative effects in the short term on the financial performance of some major clean technology suppliers and project developers. Nevertheless, the prices of all clean energy technologies today are significantly lower than a decade ago: they remain competitive with fossil fuel alternatives. Signs are evident in 2023 that some of the cost pressures are easing, although the risk of tight supply chains for key components remains. Overall, we consider that clean energy technology costs will continue to trend downward, and that there is still considerable scope to reduce important cost elements through technology innovation, materials substitution, efficiency improvements and economies of scale.

The GEC Model used to generate our scenario projections includes a very broad representation of energy technologies. The costs of these technologies evolve over time in the scenarios as a result of continued research, improvements in manufacturing and learning-by-doing. These costs are linked in turn to levels of deployment. The link works in both directions: lower costs tend to mean higher levels of deployment, and higher levels of deployment tend to reduce costs. The cost reductions are not linear: a typical curve will be steepest in the earliest phases of innovation and deployment (when overall costs are still high), and much flatter once technologies are mature. Policies play a crucial role in this process, particularly in determining how quickly innovative clean technologies are scaled up in sectors such as shipping, aviation and heavy industry.

Innovation also has an impact on the projected costs of fossil fuel supply, but here the downward pressure from technology learning is offset by the effects of moving to more geologically challenging or remote deposits as cheaper and easier resources are gradually depleted. There are also offsetting pressures in the case of some clean technologies, for example, new sites for onshore wind may be less favourable in terms of wind speeds than those already in operation, and new sites for mining critical minerals for battery manufacturing may involve higher production costs. But overall technology cost trends point in the direction of increasingly stiff competition for fossil fuels from clean energy technologies across a wide range of market segments.

**Figure 2.8 ▹ Recent cost developments for selected clean energy technologies**






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

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

The speed at which new technologies enter the energy system is particularly important in the NZE Scenario, which relies on an extremely rapid pace of innovation in areas such as new battery chemistries, carbon dioxide removal technologies and ammonia to fuel for ships. This requires governments to give a high priority to research, development, demonstration and deployment activities in these areas, especially at a time when capital markets are becoming more expensive to access. There are some positive signs in recent policy announcements that this is happening, although the collaboration that usually plays an important part in accelerating knowledge transfer and supporting rapid diffusion of new technologies cannot be taken for granted, especially in today's fractious international context.

# Pathways for the energy mix

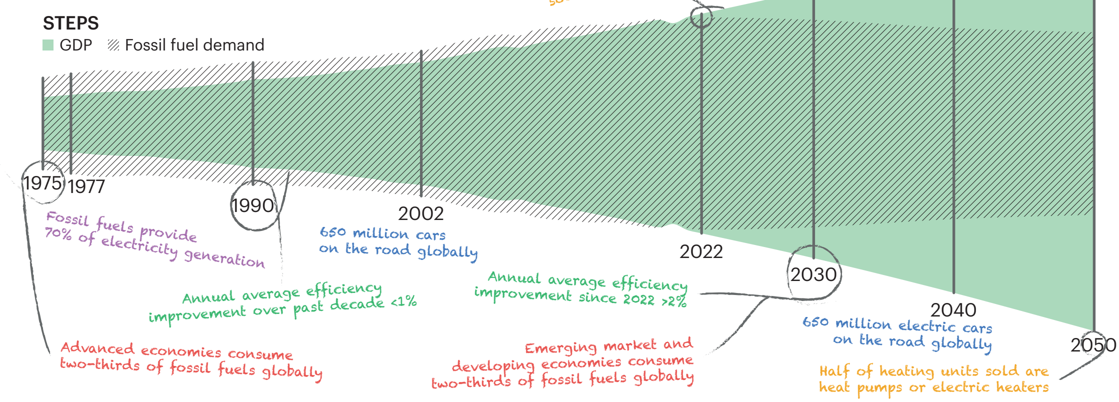
## A view with a peak


S U M M A R Y

- 2022 was a turbulent year for global energy markets, with energy prices – notably for natural gas – skyrocketing in Europe and many other parts of the world. The effects of the price shock on consumers were cushioned to a large extent by government interventions. Global energy demand rose 1.3% in line with its recent average.
- Despite geopolitical friction, volatile commodity prices and uncertainty around costs, transformative changes in parts of the global energy system are coming into view. Electric vehicles (EVs) account for around 15% of car sales today, and are on course to reach a share of 40% by 2030 in the Stated Policies Scenario (STEPS). A record 220 gigawatts (GW) of solar capacity was added in 2022, and deployment levels are projected to more than double, while heat pumps more than double their share of heating equipment sales in the STEPS by 2030. The planned boost in the manufacturing capacity of these clean energy technologies, if fully realised, appears able to meet many of the deployment milestones in the Announced Pledges Scenario (APS) and, in the case of solar and batteries, also to provide what is required in the Net Zero Emissions by 2050 (NZE) Scenario.
- Accelerated scale up of the clean energy transition means there is very little runway left for growth in fossil fuels: for the first time, demand for oil, natural gas and coal each peak in the three *World Energy Outlook-2023* scenarios before 2030. The share of fossil fuels in primary energy demand declines from 80% over the last two decades to 73% in the STEPS by 2030, 69% in the APS and 62% in the NZE Scenario.
- Electricity supply becomes progressively cleaner as low-emissions sources increase faster than demand in each scenario. Solar PV is the clear frontrunner, but wind also scales up despite near-term supply chain challenges, while nuclear power, other renewables and low-emissions fuels all make progress too.
- Electrification of mobility and heat accelerates in each scenario, although not at the same rate as power sector decarbonisation. Energy efficiency plays a key role in all sectors in determining total final consumption. In the STEPS, consumption increases by an annual average of 0.7% through to 2050; in the APS, it peaks in the late 2020s and then slowly starts to decline; in the NZE Scenario, it falls 1% per year from today.
- Hydrogen and carbon capture, utilisation and storage (CCUS) are making much-needed progress. The pipeline of projects shows that more than 400 GW of electrolysis for hydrogen and over 400 million tonnes of $CO_2$ capture capacity are vying to be operational by 2030. This could potentially meet the milestones of the APS if all planned projects go ahead, but cost inflation and supply chain bottlenecks could hamper progress.

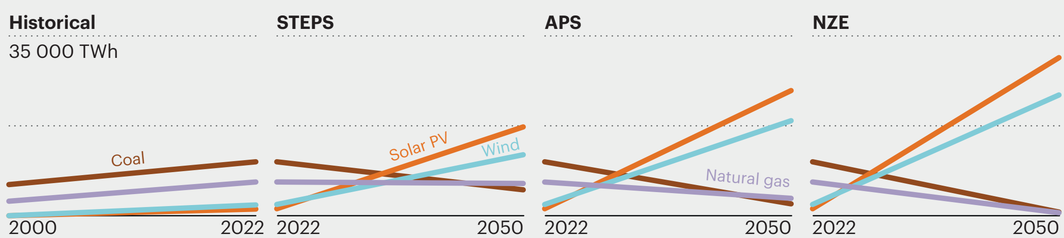
# Transformative changes of the global energy system are coming into view

The close historic relationship between global economic growth and fossil fuel demand is being loosened by the emergence of a new clean energy economy. Based on today's policy settings, each of the three fossil fuels see a peak before 2030.



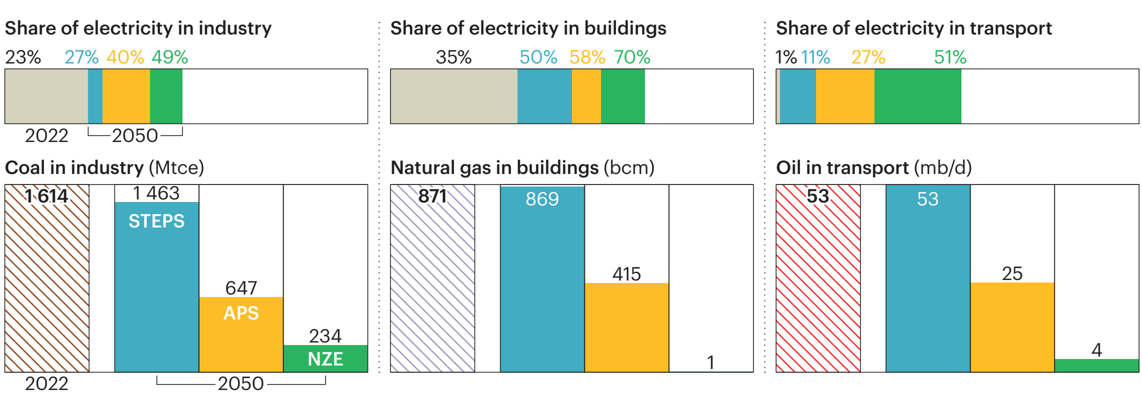

## Solar PV and wind are reshaping electricity supply

Solar PV continues to gain momentum and grows at an astonishing rate in all our scenarios, complemented by robust growth for onshore and offshore wind. Scaling up power system flexibility is critical to integrate more solar PV and wind and accelerate transitions away from coal and natural gas.




## Electrification is gathering pace

The share of electricity in total final consumption goes from 20% today to 41% in the APS and over 50% in the NZE Scenario by 2050. Electrification is a key contributor to reductions in fossil fuel demand, alongside efficiency improvements and greater use of low-emissions fuels.



## 3.1 Introduction

Amid the wild fluctuations in prices and other indicators caused by the global energy crisis, one data point stands out for being unremarkable: global energy demand rose by 1.3% in 2022. That energy demand continued to grow by a more or less average amount amid all the market turbulence hints at the inexorable underlying dynamics of the energy system: the expanding global economy and population simply require more energy services.



This should be the starting point for any conversation about the future of global energy, and indeed this is where our modelling process begins in this *World Energy Outlook (WEO)*. The first step in producing our scenario projections is not to look at emissions, investment or resources, but to look in detail at demand for energy services: how much light, heat or mobility communities, industries and countries around the world will need over the decades to 2050.

Levels of energy services demand evolve at roughly the same rate across each of our scenarios as the global economy grows, with two important nuances. First is that the speed at which the world moves towards universal access to modern energy varies; achievement of this goal invariably leads to higher use of energy services for lighting, cooling, cooking, and appliance and equipment use. Second is that behavioural changes and strategies to improve material efficiency, adopted to varying degrees in each scenario, bring down demand for energy services, for example by substituting short car journeys for walking or cycling.

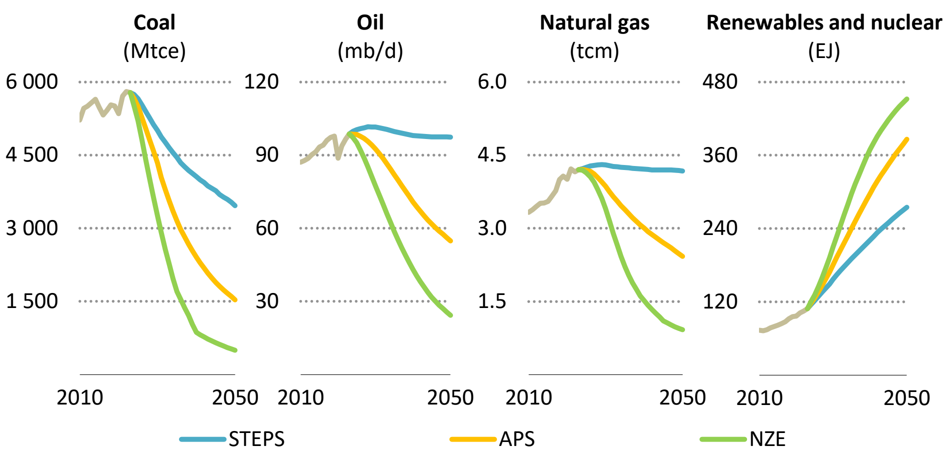
Rising energy services demand is a feature of each scenario, but that does not necessarily translate into rising demand for energy or a higher level of emissions. A wide range of technology mixes can meet needs for heating, cooling or mobility, each with distinctive implications for costs, resource inputs and pollution. We explore different pathways in this chapter, examining how investment in a range of technologies and resources could meet the world's future energy needs, and how policies shape the choices that are made. This chapter starts with an overview of the key changes in the global energy mix across each scenario. This is followed by four sections:

- First is a look at trends in global **energy final consumption** in the industry, transport and buildings sectors and how demand is met in each scenario.
- Second is a detailed consideration of the outlook for **electricity**, including scenario specific mix of generation technologies and at variations in demand stemming from the efficiency of end-use equipment and appliances.
- Third is a look at **fuels**: oil, natural gas, coal and bioenergy. Fossil fuels account for close to 80% of total energy supply today. But the outlook to 2050 varies widely in the scenarios according to the speed at which clean energy technologies enter the system.
- The fourth section considers the evolution of key **clean energy technologies**, focussing on solar photovoltaics (PV) and wind, electric vehicles (EVs), heat pumps, hydrogen and carbon capture, utilisation and storage (CCUS).

## 3.2 Overview

Global total energy demand increases from around 630 exajoules (EJ) in 2022 to 670 EJ by 2030 in the Stated Policies Scenario (STEPS). This corresponds to an average annual growth rate of 0.7%, around half the rate of energy demand growth over the last decade. Demand continues to increase from 2030 through to 2050, with a growth of 16% in emerging market and developing economies more than offsetting a 9% decline in advanced economies. In the Announced Pledges Scenario (APS), total energy demand declines by an average of 0.1% per year until 2030, thanks to faster deployment of renewables, increased energy efficiency and more rapid electrification than in the STEPS. In the Net Zero Emissions by 2050 (NZE) Scenario, electrification proceeds even faster, improving the efficiency of the energy system and leading to a decline in primary energy of 1.2% per year to 2030.

**Figure 3.1 ▷ Global total energy demand by fuel and scenario, 2010-2050**






*Low-emissions sources expand significantly and – for the first time – all fossil fuels peak and start to decline before 2030 in each scenario*

Note: Mtce = million tonnes of coal equivalent; mb/d = million barrels per day; tcm = trillion cubic metres; EJ = exajoules.

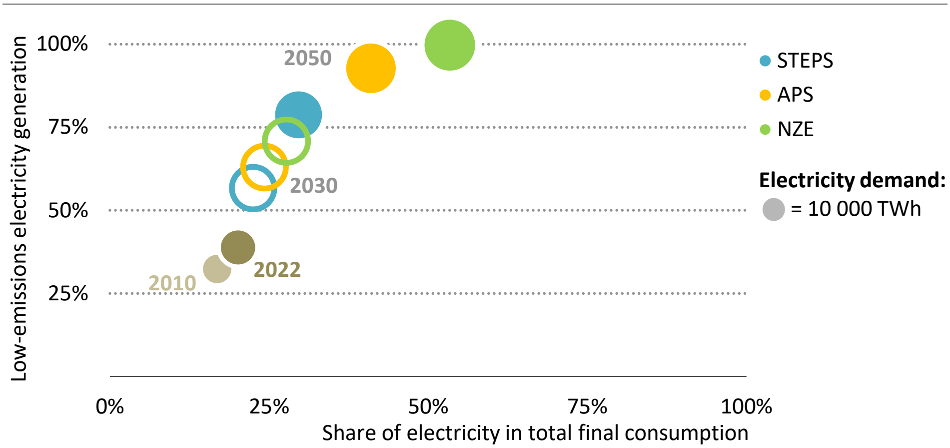
In each of the scenarios in this *World Energy Outlook*, demand for each of the main fossil fuels – coal, oil and natural gas – reaches a peak before 2030 before falling back (Figure 3.1). Coal demand declines furthest and fastest: by 2030, it falls by around 15% in the STEPS, 25% in the APS, and 45% in the NZE Scenario. In the APS, China and India's pledges to reach net zero emissions before 2060 and by 2070 respectively drive a faster decline in coal demand than in the STEPS. In the NZE Scenario, a broader phase out of unabated coal across regions begins during the 2020s, and this leads to demand falling faster than in the APS. Oil peaks towards the end of this decade in the STEPS at around 102 million barrels per day (mb/d). In the APS and the NZE Scenario, rapid and broad-based electrification and fast-growing use of advanced biofuels together hasten the peak in oil demand. Natural gas demand increases until the late 2020s in the STEPS, reaching a high point of around 4 300 billion cubic metres (bcm). In the APS, natural gas demand declines by 7% between 2022 and 2030 as low-emissions power expands rapidly, electrification increases faster than in the STEPS and gains are made in terms of energy and material efficiency in the buildings and industry sectors. In the NZE Scenario, gas demand declines by nearly 20% by 2030 in the face of very large clean energy investments and efficiency gains.



For decades, fossil fuels have met around 80% of total energy demand. Rapid growth in renewables and nuclear begins to erode this dominance in the coming years, lowering the share of unabated fossil fuel demand in 2030 to 73% in the STEPS, 69% in the APS, and 62% in the NZE Scenario. Avoided energy demand helps to enable this shift: without faster efficiency improvements and behavioural changes, more clean energy supply would go toward meeting rising demand, rather than substituting for fossil fuels.

All sources of renewable energy increase over time in each of the scenarios, although their relative weights shift. Today modern bioenergy[1] accounts for over half of renewables energy demand, but solar PV and wind expand extremely fast in the coming years, especially in the power sector. The installed capacity of all renewable power sources more than doubles in the STEPS and the APS by 2030. In the NZE Scenario, the installed capacity of renewables triples by 2030 – a key milestone in the drive to keep the 1.5 °C goal within reach.

**Figure 3.2 ⊳ Electricity in total final consumption and low-emissions sources in electricity generation by scenario, 2010-2050**






*Power sector decarbonisation advances more rapidly than end-use electrification in each scenario, but both are key pillars of the transition to a clean energy economy*

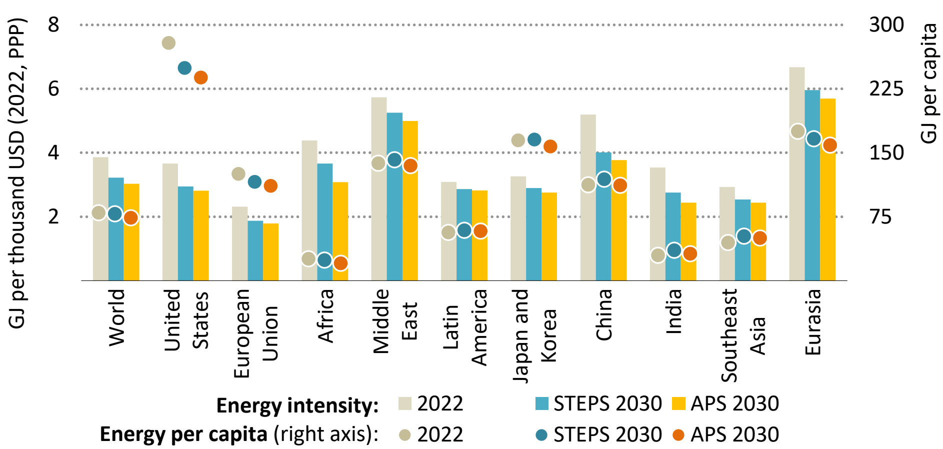
Notes: TWh = terawatt-hours. Bubble size is proportional to total electricity demand.

[1] Modern bioenergy includes biogases, liquid biofuels and solid bioenergy except for the traditional use of biomass.

Today, low-emissions sources of electricity generation mainly include nuclear (9% of electricity generation) and renewables (30%). The share of nuclear power remains broadly stable over time in all scenarios. Low-emissions electricity generation overall increases from 39% of total electricity generation today to 57% by 2030 in the STEPS, 63% in the APS and 71% in the NZE Scenario (Figure 3.2). This constitutes exceptionally rapid growth by historic standards, which reflects the cost effectiveness of solar PV and wind, and their ability to attract investment in manufacturing capacity as well as in deployment.

The share of electricity in final consumption also rises from its current level of 20%, which means that low-emissions sources of electricity generation are increasing their share of a total which is itself increasing. In the STEPS, the electricity share of final consumption rises to 2030 at a rate similar to the past, before accelerating slightly and reaching 30% by 2050. In the APS, it rises faster, in large part due to the more rapid uptake of EVs, reaching 40% by 2050. In the NZE Scenario, it nears 30% in 2030 and exceeds 50% by 2050, propelled in particular by the extremely rapid deployment not only of EVs but also of residential and industrial heat pumps.

**Figure 3.3 ▷ Energy intensity and energy per capita in selected regions in the Stated Policies and Announced Pledges scenarios, 2022 and 2030**






***All regions see energy intensity continue to decline over time in the STEPS and the APS, while energy use per capita increases beyond 2030 in some regions***

Notes: GJ = gigajoules; PPP = purchasing power parity. Energy intensity is defined as the ratio of total energy supply to gross domestic product (GDP) in PPP terms. Energy per capita is defined as the ratio of total energy supply to population.

Energy intensity[2] improves at an average rate of 2.2% per year to 2030 in the STEPS, compared with 3% in the APS and 4.1% in the NZE Scenario. All scenarios improve on the annual average rate of 1.6% over the last decade, thanks to more stringent fuel economy standards, additional building energy codes and retrofit targets, improved industrial energy management systems, and the further electrification of heat and mobility. Advanced economies have lower levels of energy intensity today than emerging market and development economies, but that is in large part a function of them typically having more service-oriented economies.



Global energy demand per capita is around 80 gigajoules (GJ) today, a level that has remained broadly stable over the last decade (Figure 3.3). It remains stable in the STEPS to 2030, but it declines by 7% in the APS and by 15% in the NZE Scenario. In advanced economies, per capita demand declines in all scenarios to 2030. In emerging market and developing economies, it continues to rise in the STEPS as economic growth drives an increase in energy services demand. In each scenario, energy demand per capita in this group of countries remains below advanced economies over the projection period.

## 3.3 Total final energy consumption

Total final energy consumption (TFC) is 442 EJ today and is split between industry (167 EJ), buildings (133 EJ), transport (116 EJ) and other end-uses (27 EJ). In the STEPS, TFC rises by 1.1% per year to 2030 and then continues to rise at a slower rate through to 2050. In the APS, TFC rises until the mid-2020s before starting a gradual decline. In the NZE Scenario, TFC declines by an annual average 0.9% every year from now to 2050.

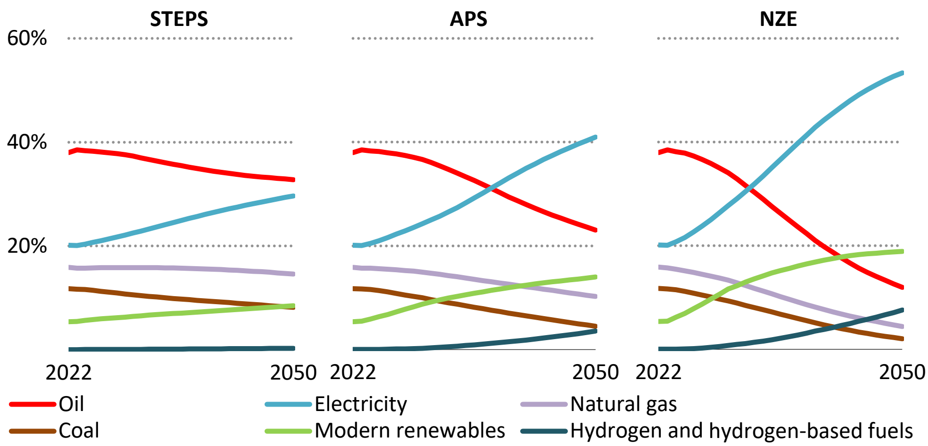
Differences in energy efficiency gains are the primary cause of divergence in total final consumption trajectories. They account for nearly half of the total energy savings in the APS relative to the STEPS by 2030, with the APS reflecting additional retrofit targets and updated building energy codes, more stringent fuel economy standards in transport, and upgrades to industrial processes efficiency. In the NZE Scenario, year-on-year energy intensity improvements double by 2030 (IEA, 2023a).

Differences in the rate of electrification are another important cause of divergence in consumption trajectories. In the APS, electrification provides another 10% of the energy savings relative to the STEPS by 2030. Electric technologies such as heat pumps and EVs provide energy services more efficiently than rival technologies based on the direct combustion of fossil fuels, and use of these electric technologies expands faster in the APS and the NZE Scenario than in the STEPS. The share of electricity in TFC increases from around 20% today by 2 percentage points in the STEPS by 2030, by 4 percentage points in the APS, and by 8 percentage points in the NZE Scenario: it is these differences that deliver the

[2] The energy intensity improvement rate is defined as the annual reduction of energy intensity, or the ratio of energy supply to GDP in purchasing power parity (PPP) terms. In our scenarios, PPP factors are adjusted as developing countries become richer.

additional energy savings in the APS and the NZE Scenario (Figure 3.4). Rail and road transport, iron and steel, aluminium, light industries as well as heating and cooking in buildings see the most substantial increases in electricity share across scenarios.

**Figure 3.4 ▷ Share of global total final consumption by selected fuel and scenario, 2022-2050**






*The contributions of electricity and modern renewables increase while the share of fossil fuels declines in each scenario*

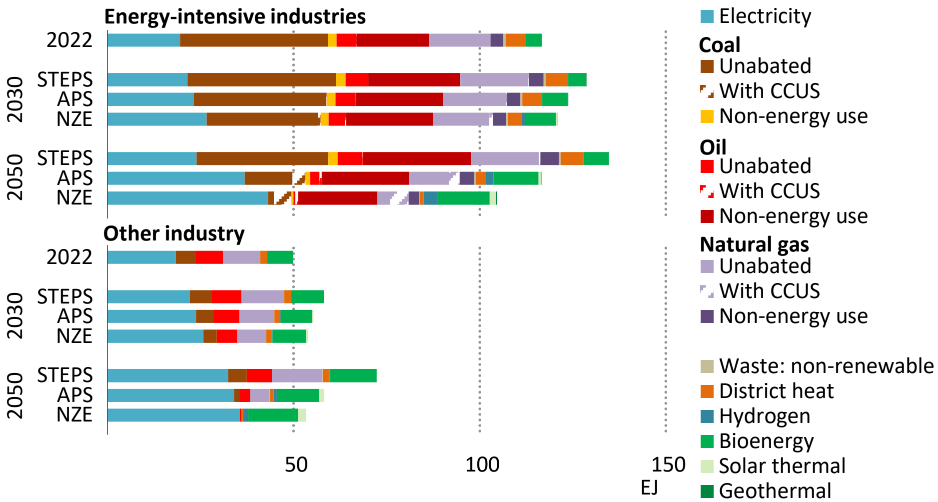
Note: Modern renewables refers to the direct use of renewable energy sources excluding the traditional use of biomass.

The direct use of renewables in total final energy consumption – including modern bioenergy, solar thermal and geothermal – expands significantly in each scenario, by 3% per year in the STEPS, 7% in the APS, and 9% in the NZE Scenario by 2030. Low-emissions hydrogen and hydrogen-based fuels final consumption increases by 200 petajoules (PJ) (of which 1.6 million tonnes [Mt] of hydrogen) in the STEPS by 2030 and 1 000 PJ (of which 6 Mt of hydrogen) in the APS, with growth concentrated in hard-to-abate sectors including aviation and shipping. Renewables and low-emissions fuels contribute 8% of the additional energy savings in the APS compared to the STEPS by 2030.

### 3.3.1 Industry

Industry is the most energy consuming and $CO_2$ emitting end-use sector. It accounts for 38% of TFC and 47% of $CO_2$ emissions (including emissions from electricity and heat). Energy-intensive industries – iron and steel, chemicals, non-metallic minerals, non-ferrous metals and paper sectors – account for almost 90% of demand for coal used in industry, more than 70% for oil used in industry and almost 55% for natural gas (Figure 3.5). Energy-intensive industries have in common high-temperature needs and long-lived assets. Other industry, or non-energy-intensive industries, which includes light industries such as food and textiles, have lower temperature needs and account for the remaining 30% of demand in the industry sector. Its energy mix is mainly electricity (37%), natural gas (20%), oil (15%) and bioenergy (14%).

**Figure 3.5 ▷ Energy demand by fuel for energy-intensive and other industries by scenario**






*Achieving climate ambitions in industry relies on electrification: electric heaters and heat pumps in light industries, and electric processes and onsite hydrogen for steel, ammonia and methanol*

Notes: CCUS = carbon capture, utilisation and storage; EJ = exajoules. Where low-emissions hydrogen is produced and consumed onsite at an industrial facility, the fuel input, such as electricity or natural gas, is reported as final energy consumption, not the hydrogen output.

Industrial production underwent significant disruption in 2022 as a result of Russia's invasion of Ukraine and a slowdown in the construction sector in China. Global cement production was down by 5% and steel production by 4%, though demand for chemicals remained stable, and in the case of methanol it actually rose. These downward pressures on industrial production do not persist: in the STEPS, production of all main industrial materials increases by 2030, including ethylene (27% higher), methanol (17% higher), aluminium (13% higher) and paper (12% higher), and steel and ammonia (each 10% higher) and cement (8% higher). The rise in production mainly occurs in developing Asia.

Progress in developing efficiency and low-emissions policies for industry has been uneven, with patchy adoption of carbon pricing and minimum energy performance standards (MEPS) in emerging market and developing economies (Table 3.1). Some groups of industrial stakeholders have taken the initiative and set targets to produce low-emissions materials. For example, steel purchasers in the First Mover Coalition have pledged that at "at least 10% (by volume) of all our steel purchased per year will be near-zero emissions […] by 2030".

**Table 3.1 ▷ Key energy demand policies for industry by region**

| | Carbon pricing | Minimum energy performance standards for motors | Public procurement of low-emissions materials | Funds for industrial innovation |
|---|---|---|---|---|
| United States | ● | ● | ● | ● |
| Latin America and the Caribbean | ○ | ◔ | ○ | ◔ |
| European Union | ● | ◕ | ◕ | ● |
| Africa | ○ | ○ | ○ | ◔ |
| Middle East | ○ | ◔ | ○ | ○ |
| Eurasia | ○ | ○ | ○ | ◔ |
| China | ● | ● | ● | ● |
| India | ○ | ● | ○ | ○ |
| Japan and Korea | ● | ● | ● | ● |
| Southeast Asia | ○ | ◔ | ○ | ○ |

*Share of countries within each region with policy currently implemented:*

○ <10% ◔ 10-39% ◑ 40-69% ◕ 70-99% ● 100%

In the APS, measures promoting material efficiency, such as lifetime extension of buildings and goods, lightweighting or smart design, help curb global demand for industrial material demand compared with the STEPS. The impact of these measures builds over time. For example, global crude steel demand is 5% lower in the APS than in the STEPS in 2035 and 13% lower by 2050. In the NZE Scenario, more widespread deployment of such measures leads steel, cement and methanol to peak within the next fifteen years.

Coal demand in the industry sector peaks in the mid-2020s in the STEPS, falls below the 2022 level in 2035 and is 10% below this level by 2050, with reductions in demand in China and advanced economies more than offsetting increases in the rest of developing Asia, Africa and Latin America and the Caribbean. The main reason for the overall decline is the rise of secondary steel production, mostly relying on electricity, in lieu of conventional primary steel production using coking coal. In all scenarios, scrap availability limits the deployment of secondary production. In both the STEPS and APS, the share of secondary production doubles compared to today to more than 40% worldwide. In the APS, electrification of light industries, hydrogen-based iron production and higher reliance on bioenergy mean that coal use in industry in 2050 is 55% lower than in the STEPS, and almost 20% of coal use takes place in plants equipped with CCUS.

Oil use in industry, mostly for petrochemical production, increases by 2.8 mb/d to 2030 in the STEPS, with most of the growth taking place in China, Southeast Asia and the Middle East. In the APS, bans on single-use plastics and the widespread collection of plastics help to curb the increase in oil demand to 0.8 mb/d from 2022 to 2030, and to bring it down by 3.6 mb/d by 2050 compared to 2030. The share of non-energy use, i.e. chemical feedstock and anode production, in industry oil demand rises from 60% today to over 65% in 2030 and 80% in 2050.



Natural gas in industry is used in a wide range of applications: a third is consumed in other industry, especially in food and machinery, and more than a fifth goes towards the production of fertiliser. In the STEPS, developing Asia, led by China remains the largest source of growth for natural gas demand in industry until 2030, although its rate of growth is much slower than over the past decade. India becomes the largest source of growth after 2030, while demand in the European Union declines further.

In all scenarios, electricity is the fuel that increases the most in non-energy-intensive industries, and sustainable bioenergy takes second place. Increased electrification plays a significant part in decarbonising energy-intensive industries, whether through direct electrification or through the use of hydrogen produced using electrolysers.

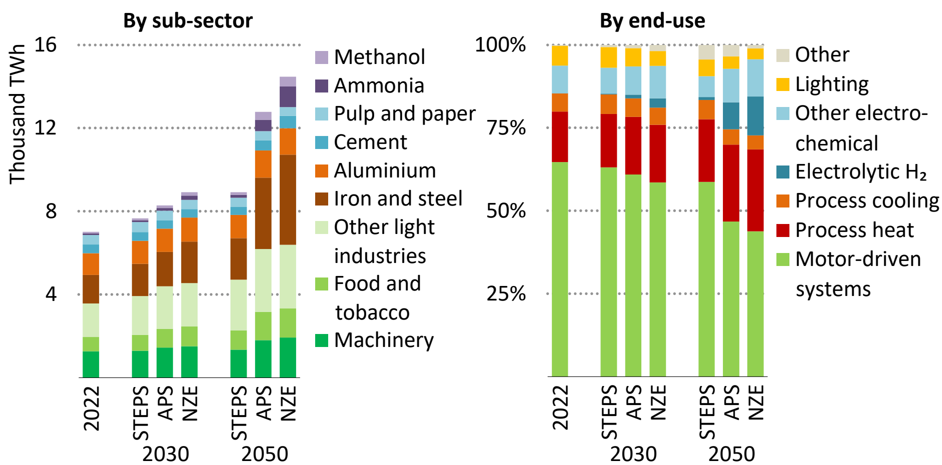
### *How can industrial processes achieve high levels of electrification?*

As of today, most electricity in industry is used for motor-driven systems. Electricity has the potential to provide heating across a wide range of temperature levels for heating, including through heat pumps for low-temperature applications and electric arc furnaces for high temperature (as it already does for secondary steel making). It also has the potential to provide power for a range of industrial processes including alumina electrolysis, which produces aluminium and electrowinning, which produces copper and nickel. Electrification reduces energy demand because it is generally more efficient that the fossil fuel processes that it replaces. To the extent that it draws on low-emissions sources of power, electrification also drives down $CO_2$ emissions from the industry sector.

Around 65% of electricity use today in industry is for motor-driven systems. Motors are used to drive pumps, fans, compressed air systems, material handling, processing systems and more. Over the last decade, motor-driven systems accounted for almost 60% (630 terawatt-hours [TWh]) of growth in electricity demand in light industries, and they are set to be the largest source of electricity demand in the industry sector in the years ahead. There is some potential to improve energy efficiency not only by upgrading the motors themselves but also by making other improvements to the system, for example by downsizing electric capacity to match the service required. Sixty-two countries have implemented MEPS for industrial electric motors, covering more than half of the global industrial motor fleet in 2022: more widespread adoption of MEPS would bring further energy efficiency gains.

Electrification of process heat increases in all scenarios, though at various speeds (Figure 3.6). In the light industry category, over 700 TWh or one-fifth of electricity is currently used for heating purposes, and this rises to over 800 TWh in 2030 and 1 000 TWh in 2050 in the STEPS. In the APS, the electrification of process heat happens much faster: the 1 000 TWh mark is passed by 2030, and demand reaches 1 800 TWh by 2050. The APS also sees innovative progress towards the direct electrification of energy-intensive processes such as alumina refining, secondary aluminium production, kilns and steam crackers.

**Figure 3.6 ▷ Electricity demand by selected industry sub-sector, end-use and scenario, 2022-2050**






***All industry sub-sectors depend on electricity and demand rises notably for process heat and hydrogen in the APS and NZE Scenario***

Notes: TWh = terawatt-hours; $H_2$ = hydrogen. Machinery sub-sector refers to the production of machines and their components. Other electro-chemical includes primary aluminium production, chlor-alkali industry and some organic synthesis.

The use of electricity in steel, ammonia and methanol production is likely to depend on the onsite production and use of electrolytic hydrogen. There is scope, for example, for hydrogen to be used in ancillary processes in various heavy industries, including semi-finishing for steel and aluminium. These important near-zero-carbon options are mostly deployed in the APS and the NZE Scenario. In 2050, global onsite electrolytic hydrogen demand in industry reaches 36 Mt in the APS, consuming 1 600 TWh of electricity: the hydrogen is used to produce around a quarter of iron, ammonia and methanol.

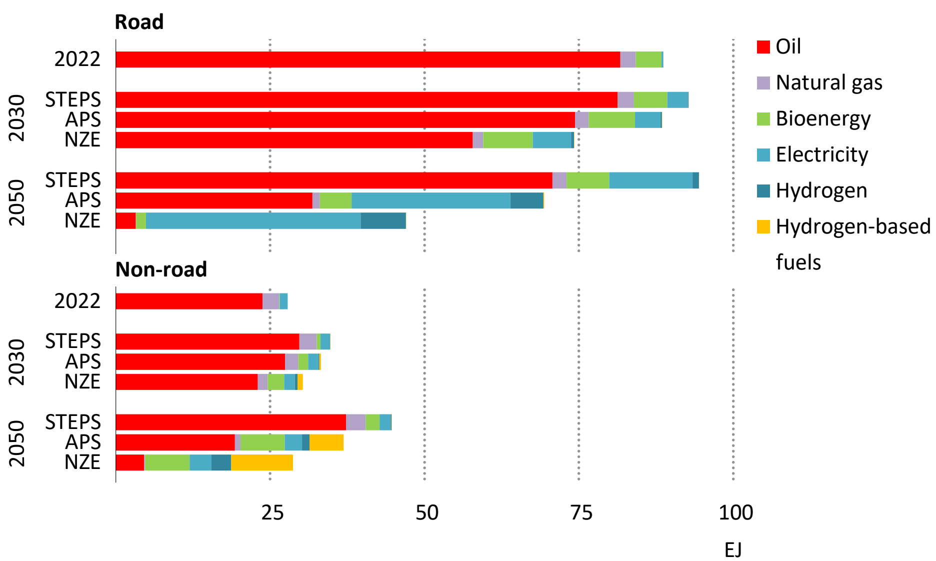
Electricity is also used in other electro-chemical processes mostly for primary aluminium production. Electricity use for primary aluminium production increases in the APS until 2040, rising to 700 TWh, then declines as expanding scrap availability leads to rising levels of secondary production.

### 3.3.2 Transport

Energy demand in transport rose by 4% in 2022 as it continued to rebound towards pre-Covid levels, with oil accounting for 90% of this growth. This was mainly driven by the aviation sector, which saw 20% year-on-year growth: despite this, aviation energy demand remains a quarter below its 2019 level. Electricity demand from road transport was nearly 60% higher in 2022 than in 2019, and the market share of electric cars[3] in new registrations reached 14%.

In the STEPS, the global car fleet increases by over 15% by 2030, and a similar increase is projected for buses. The fleet of two/three-wheelers[4] increases by over 20% and the number of trucks by over 10% over the same period. Aviation activity doubles from today's level, rail passenger-kilometres increase by 36%, and shipping tonne-kilometres increase by almost 20% in 2030. In the APS, modal shifts away from private transportation lessen the growth of the car fleet and lead to rail passenger-kilometres being over 5% higher in 2030 than in the STEPS. In the NZE Scenario, stronger measures to minimise emissions reduce the activity in aviation by 20% and the car stock by 15% compared to the STEPS in 2050: these measures include behaviour changes and the expansion of high-speed rail.

**Figure 3.7 ▷ Energy demand in transport by fuel and scenario, 2022-2050**




IEA. CC BY 4.0.

*Electricity is key to decarbonising road transport and meets nearly 40% of demand in the APS by 2050; low-emissions fuels make inroads mainly in aviation and navigation*

Notes: Non-road transport includes aviation, shipping, rail, pipeline and non-specified transportation. Hydrogen and hydrogen-based fuels are produced via low-emissions pathways.

[3] Electric cars include both battery electric and plug-in hybrids.

[4] Two/three-wheelers include electric and non-electric scooters but not bicycles.

By 2030, the share of oil in road transport energy demand drops from 92% today to 88% in the STEPS, 84% in the APS, and 78% in the NZE Scenario (Figure 3.7). A tectonic shift towards electromobility and the increased use of biofuels drive this drop. Electricity demand for road transport rises by more than 12-times by 2030 in the STEPS and over 15-times in the APS. Supported by phase-out dates for internal combustion engine (ICE) vehicles and incentives for electromobility, EVs account for nearly 20% of total road vehicle-kilometres in the APS in 2030. However, since they are three- to four-times more efficient than ICE vehicles, they only account for 5% of road transport energy demand.

**Table 3.2 ▷ Key energy demand policies for transport by region**

| | Fuel economy | | ZEV incentives | | ICE phase out | | Support for SAF |
|---|---|---|---|---|---|---|---|
| | Cars | Trucks | Cars | Trucks | Cars | Trucks | |
| United States | 100% | 100% | 100% | 100% | 10-39% | 10-39% | 100% |
| Latin America and the Caribbean | 10-39% | <10% | 40-69% | <10% | <10% | <10% | <10% |
| European Union | 100% | 100% | 100% | 100% | 100% | <10% | 100% |
| Africa | <10% | <10% | <10% | <10% | <10% | <10% | <10% |
| Middle East | <10% | <10% | 10-39% | <10% | <10% | <10% | <10% |
| Eurasia | <10% | <10% | 10-39% | <10% | <10% | <10% | <10% |
| China | 100% | 100% | 100% | 100% | <10% | <10% | <10% |
| India | 100% | 100% | 100% | <10% | <10% | <10% | <10% |
| Japan and Korea | 100% | 40-69% | 100% | 40-69% | <10% | <10% | 40-69% |
| Southeast Asia | 10-39% | <10% | 40-69% | <10% | <10% | <10% | 10-39% |

*Share of countries or jurisdictions within each region with policy currently implemented:*

<10%   10-39%   40-69%   70-99%   100%

Notes: ZEV = zero emissions vehicles including EVs and fuel cell vehicles with zero emissions at the tailpipe. ICE = internal combustion engine. E-fuels-powered vehicles = conventional vehicles which run on electro fuels. SAF = sustainable aviation fuels. In regions with only one country, unless there is a national policy in place, shares are shown for subnational jurisdictions. In the European Union, the ICE vehicle phase-out policy exempts e-fuels-powered vehicles.

Electrification of trucks so far has made slower progress than the electrification of cars, in part because it has attracted less policy support (Table 3.2). Battery electric trucks have nevertheless seen notable advancements, particularly as medium-duty trucks and other vehicles with relatively short, fixed routes. In the STEPS, the market share of electric trucks rises from 3% of global truck sales today to nearly 20% by 2030 in the STEPS and to 25% in the APS.

The electrification of two/three-wheelers proceeds much more rapidly, in part because of their limited power needs and the relatively modest upfront cost increase compared to conventional powertrains. The electric two/three-wheelers fleet in 2030 is more than four-times larger than today.

In non-road transport energy demand, the share of oil remains nearly at today's level (85%) in both the STEPS and APS by 2030; it drops to around 75% in the NZE Scenario. Rail is the most electrified transport mode today, and the share of oil in energy demand in rail falls from 53% today to 46% and 40% in the STEPS and APS due to increased rail electrification. In the NZE Scenario, the speed and breadth of further electrification reduces the share of oil in total rail demand to around 30% by 2030. Oil continues to account for most of the energy demand in aviation to 2030 in both the STEPS and APS. The same is broadly true for shipping, although the share of oil in energy demand in shipping starts to decline slightly by 2030 as natural gas and bioenergy begin to make inroads into its energy mix. In the STEPS, together they account for 4% of energy demand in shipping by 2030. In the APS, they account for 6% of demand, while ammonia, hydrogen, electricity and synthetic methanol reduce the share of oil by another 4 percentage points. In the NZE Scenario, the share of oil in energy demand in shipping falls to 80% by 2030. The European Union decision to include maritime emissions in the EU Emissions Trading System (EU ETS) and the International Maritime Organization revision of its greenhouse gas strategy both boost efforts to decarbonise shipping. The FuelEU Maritime initiative and the US Clean Shipping Act support efforts to do the same by incentivising the use of cleaner fuels.



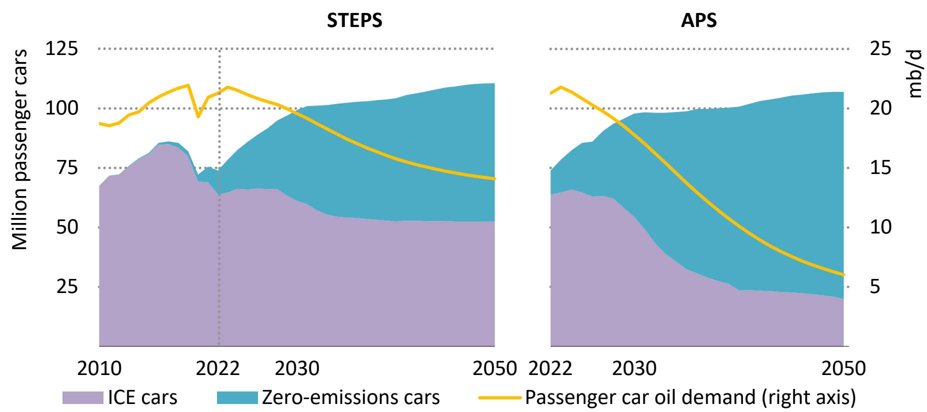
### *Are we heading towards the end of the ICE age?*

Oil use for road transport is responsible for nearly 45% of global oil demand. It currently totals around 41 mb/d, with cars accounting for 21 mb/d and trucks for 16 mb/d.

ICE car sales grew by an annual average of 3.4% from 2010 to 2017, peaking at 85 million vehicle registrations in 2017. The Covid-19 pandemic caused sales to dip by 13% in 2020. Since then, sales of ICE cars have recovered only marginally while sales of electric cars shot up from 3 million in 2020 to over 10 million in 2022. In the years ahead, total car sales are set to increase by over 30% to reach nearly 100 million by 2030. Around two-thirds of this comes from emerging market and developing economies, in particular China, India and Indonesia. But the rise of EVs means that sales of ICE cars does not revert to the 2017 peak level (Figure 3.8). In the STEPS and APS, widespread policy support helps sales of electric cars worldwide to continue their impressive expansion. More than 50 countries, home to around 60% of the world population, have policies in place to incentivise the uptake of EVs. Around 30 countries have set target dates to phase out ICE vehicles, and several others are considering similar action. In addition, automobile manufacturers have plans to release over 150 new electric car models in the coming years, and some have made their own net zero emissions commitments. Efforts are being made to establish local EV manufacturing hubs in a number of countries including India, Indonesia and Thailand, providing a further boost for their switch from ICE vehicles to EVs.

These measures mean that sales of electric cars continue their impressive growth. By 2030, sales of ICE cars decline to around 60 million in the STEPS and 55 million in the APS. With this structural decline of ICE vehicles in road vehicles, oil demand does not recover to its pre-pandemic levels: it stands at around 41 mb/d by 2030 in the STEPS and around 38 mb/d in the APS. Electric cars currently displace 0.4 mb/d of oil demand, and this rises to nearly 4 mb/d by the end of this decade, bringing energy security benefits to oil importing countries and reducing the number of consumers exposed to volatile oil prices.

**Figure 3.8 ▷ New passenger car registrations by type and passenger car oil demand in the Stated Policies and Announced Pledges scenarios, 2010-2050**




IEA. CC BY 4.0.

***Registrations of new conventional cars peaked in 2017; policies supporting electromobility deliver a sharp decline in oil demand from road transport***

In China, sales of electric cars accounted for 29% of the market in 2022; they are set to reach over 35% in 2023 and 65% by 2030 in the STEPS with the support of tax exemptions. Sales of electric cars in the European Union made up over 20% of the market in 2022, and the latest $CO_2$ standards adopted for passenger cars look set to help increase that market share to over 60% by 2030. In the United States, electric car sales saw a more than 55% year-on-year increase in 2022 and now represent around 8% of the market. The sales share increases to 50% by 2030 as the Inflation Reduction Act and Bipartisan Infrastructure Law help to boost affordability and support the roll-out of charging infrastructure.

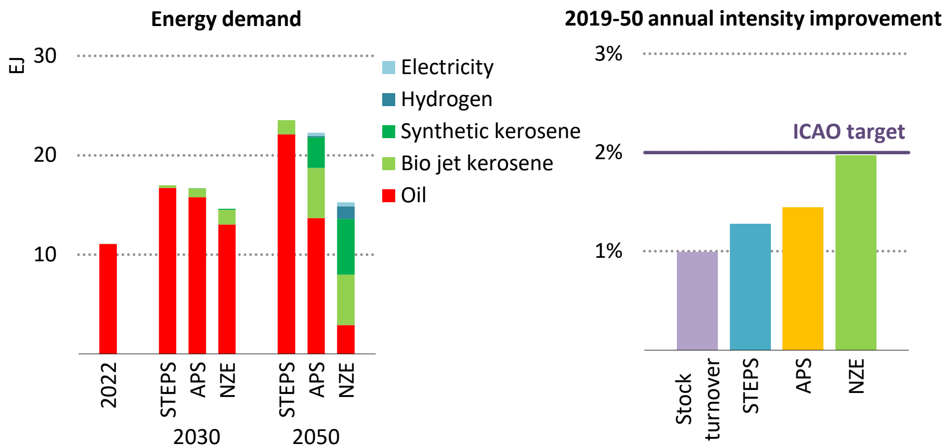
Strong policy support, particularly in China, helped EVs to become increasingly competitive in the market and to become central to the challenge to reduce emissions. Action is now needed to ensure rapid deployment of EV charging facilities and to enhance electricity networks so that inadequate infrastructure does not hold back their expansion. Action is also needed to continue the rapid deployment of renewables in electricity generation: the emissions benefits of the shift to EVs depend upon the availability of low-emissions electricity.

*How can emissions from aviation be reduced?*

Aviation accounts for over 2% of energy-related emissions and is currently dominated by oil. A variety of parallel strategies are needed to decarbonise aviation. Improvements in aerodynamics and lightweighting materials have led modern airplanes to be nearly 20% more efficient than those built around a decade ago. There will be further improvements to come, but technology, material and design changes in aeronautics are characterised by long implementation times. Sustainable aviation fuels (SAF) offer scope to replace oil and reduce emissions, but they are still very expensive and today represent less than 0.01% of energy demand in aviation. In the NZE Scenario, behaviour changes are another key lever, without them, total aviation activity would be 10% higher by 2030 and over 20% higher by 2050.



**Figure 3.9 ▷ Energy demand in aviation by fuel and scenario, 2022-2050, and annual fuel intensity improvement rate, 2019-2050**






***Accelerating the use of sustainable aviation fuels and reducing in-flight energy demand through efficiency measures are key to curbing oil demand growth***

Note: The International Civil Aviation Organization (ICAO) set an aspirational goal in 2010 to improve fuel intensity (measured per revenue tonne-kilometre) by 2% per year to 2050.

Each year, the fuel intensity of the global aircraft fleet improves by around 1% due to stock turnover as older models are retired. In the STEPS, the widespread use of cost-effective operational efficiency measures such as single engine taxiing and optimised flight trajectories increases this efficiency rate to 1.3% each year through to 2050. The APS sees this rise to over 1.4% as a result of further improvements including electric taxiing and formation flying. The NZE Scenario reaches the International Civil Aviation Organization (ICAO) goal of a 2% annual reduction each year until 2050: this assumes vital additional support for research and development for revolutionary airframes and hybrid electric aircrafts (Figure 3.9).

Efficiency improvements have a very important part to play, but they offer only a partial answer to the problem of aviation emissions. They cannot even entirely counterbalance growth in demand for aviation, which is expected to lead to an increase of around 4% in flight activity each year until 2050. This points to an urgent need for the development and deployment of lower carbon fuels. SAF look to be the most promising option: whether in the form of biojet kerosene or synthetic kerosene, they are drop-in fuels that can be blended with conventional oil products at rates of up to 50%. They also have the potential to be used on their own: manufacturers and airlines are currently testing flights that run solely on SAF.

Although SAF off-take agreements more than doubled in volume between 2021 and 2022, signalling growing demand, high costs remain a barrier to widespread adoption, and the announced project pipeline covers only 1-2% of global aviation demand by 2027 (IEA, 2022a). Bio-kerosene production currently costs twice as much as conventional kerosene, and synthetic kerosene four-times more. Expanding supply will help reduce costs, but the average price of SAF is still expected to be around two times higher than that of conventional kerosene in 2030.

In the STEPS, biojet kerosene makes up 2% of total energy demand in aviation in 2030 and 6% in 2050, compared with over 5% and 37% respectively in the APS, and 11% and 70% respectively in the NZE Scenario. Synthetic kerosene demand in 2050 in the NZE Scenario is nearly double the levels in the APS. The higher levels of demand in the APS and the NZE Scenario assume higher levels of support for SAF from governments and increased industry investments in the context of broader policy frameworks that give a high priority to reducing emissions.

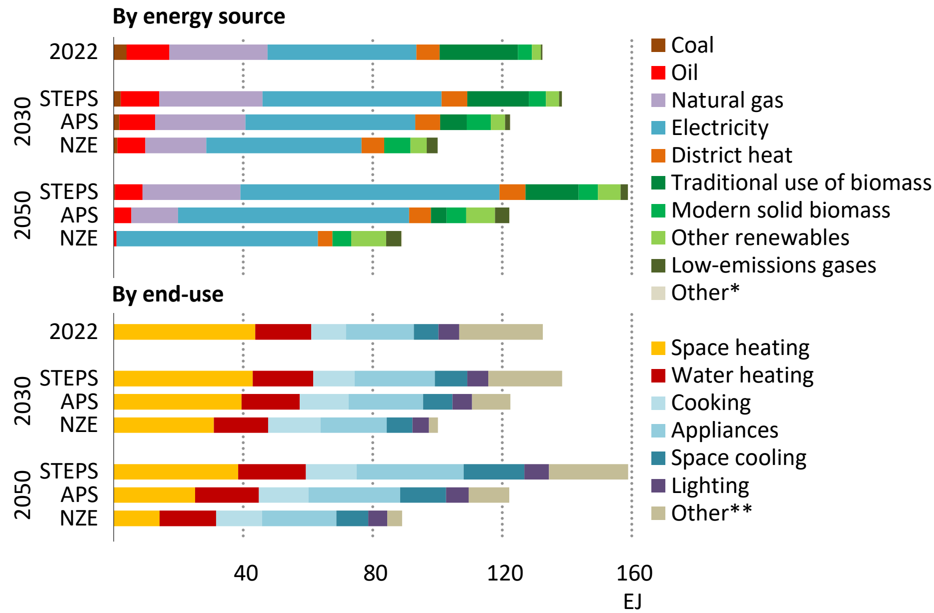
There are some grounds for optimism on this score, since there are already a number of policies focussed on SAF, though the detail has still to be worked through in many cases. The US Inflation Reduction Act provides tax credits for SAF, and this support could enable production to reach 3 billion gallons (0.2 mb/d) in 2030 and 35 billion gallons (2.3 mb/d) by 2050, which would be enough to fuel all US flights by 2050. SAF are also supported by EU Innovation Fund grants, Japan's planned mandate for SAF to provide 10% of aviation fuel use by 2030, the UK Jet Zero pledge to decarbonise aviation by 2050, and ReFuelEU Aviation's mandate for the share of SAF in aviation fuel to reach 70% by 2050.

However, there is a limited supply of the resources used today to produce sustainable biofuels, including cooking oil and waste animal fats, and a feedstock crunch could hamper growth in the short term. To meet additional biofuel demand over time, alternative production pathways using materials such as municipal solid waste and agricultural and forestry residues need to be commercialised. Government support and private investments are also needed for the development and commercialisation of SAF technologies that have low technology readiness and high costs today, notably synthetic kerosene.

### 3.3.3 Buildings

Total energy consumption in the buildings sector increased on average by 1% per year over the last decade and reached 133 EJ in 2022 (Figure 3.10). Natural gas demand declined in 2022 following Russia's invasion of Ukraine and a mild winter, with the decline most noted in Europe, but natural gas still met 23% of energy demand in buildings worldwide. Electricity now accounts for over one-third of energy demand in the buildings sector: its share has steadily increased with expanding ownership of appliances and air conditioners, and electrification of heating and cooking. Modern bioenergy meets 4% of energy demand in buildings, and other direct uses of renewables, in the form of solar thermal and geothermal heating, more than doubled over the last decade to now account for 2% of demand.

**Figure 3.10 ▷ Buildings sector energy demand by source and end-use by scenario, 2022-2050**






*Energy consumption in the buildings sector increases steadily to 2050 in the STEPS but declines in the APS and NZE Scenario; electricity expands its share in each scenario*

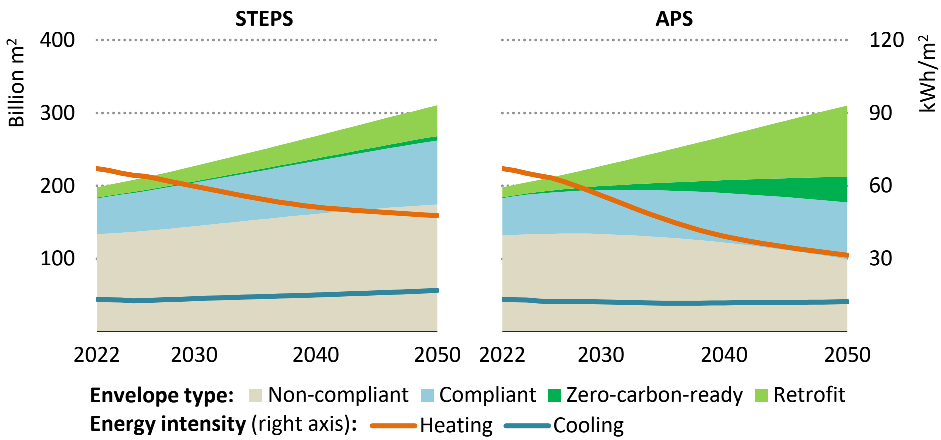
Notes: Low-emissions gases include hydrogen and biogases. Other renewables include solar thermal and geothermal. Other* includes bioliquids and non-renewable waste. Other** includes the traditional use of biomass and desalination. Space heating and cooling projections reflect expected changes in climate.

In the STEPS, global buildings energy demand increases to almost 140 EJ in 2030 and 160 EJ in 2050, primarily because the number of households increases from around 2.2 billion today to 3 billion by 2050, with the largest increases in Africa and the Asia Pacific. Global floor area of residential buildings expands from around 200 billion square metres today to 310 billion in 2050. In the APS, energy demand declines over time despite these upward pressures on energy demand, thanks to improved efficiency in building envelopes and technologies. By 2030, energy demand in buildings is 12% lower in the APS than in the STEPS.

The share of electricity in buildings sector energy demand increases substantially in each scenario, rising from 35% today to 40% in the STEPS, 43% in the APS, and 48% in the

NZE Scenario by 2030. In the STEPS, power sector decarbonisation and the use of electricity and renewables in place of coal and oil leads to a decline in buildings sector emissions (including indirect emissions[5]) of 1.4 gigatonnes of carbon dioxide (Gt $CO_2$) by 2030 despite rising energy demand, notably for space cooling. The APS reflects additional pledges to provide access to clean cooking (see Chapter 4, section 4.4.1), with modern bioenergy meeting most of this additional consumption. Buildings sector emissions decline more than twice as fast as in the STEPS by 2030.

**Figure 3.11 ▷ Residential floor area by envelope type and energy intensity of heated and cooled floor area by scenario, 2022-2050**






*Implementation of proposals to improve building envelopes lowers heating and cooling intensities by 30% in the APS relative to the STEPS by 2050*

Notes: $m^2$ = square metre; kWh/ $m^2$ = kilowatt-hour per square metre. Zero-carbon-ready envelopes enable a building to be zero-carbon emissions without further renovation once the power and natural gas grids that it relies on are fully decarbonised. Heated and cooled floorspace evolves over time with changes in climate and in the ownership of heating and cooling technologies.

A key difference between the scenarios is the level of ambition for improving building designs (Figure 3.11). In the STEPS, around 45% of the building stock is constructed or retrofitted in compliance with building energy codes or zero-carbon-ready standards by 2050. In the APS, this share exceeds 65%, accounting for increased policy ambition including the proposed update to the EU Energy Performance of Buildings Directive, proposed new standards for federal buildings in the United States, and China's Carbon Peaking and Neutrality Blueprint for Urbanisation and Rural Development. While the energy savings gained from compliance with building energy codes vary depending on the stringency of the codes, zero-carbon-ready standards more than halve heating and cooling demand compared with the average stock today. Policy incentives counterbalance barriers to improving building envelopes, including

[5] Indirect emissions are from the electricity and heat generation needed to meet demand in buildings.

the cost of materials and the split incentives faced by property owners and tenants (IEA, 2023a). Compared to buildings constructed over the last decade, those constructed in the 2030s are on average 15% more efficient in the STEPS and 36% more efficient in the APS. In the NZE Scenario, they are 66% more efficient, with all new buildings from 2030 onwards being zero-carbon-ready and a larger share of existing buildings undergoing retrofits.

**Table 3.3 ▷ Key energy demand policies for buildings by region**

| | Mandatory building energy codes | Incentives | | Minimum energy performance standards | |
|---|---|---|---|---|---|
| | | Retrofits | Heat pumps | Cooling | Appliances |
| United States | 70-99% | 100% | 100% | 100% | 100% |
| Latin America and the Caribbean | 10-39% | 10-39% | <10% | 70-99% | 70-99% |
| European Union | 100% | 100% | 70-99% | 100% | 100% |
| Africa | 10-39% | <10% | <10% | 10-39% | 10-39% |
| Middle East | 40-69% | 40-69% | 40-69% | 40-69% | 70-99% |
| Eurasia | 40-69% | 10-39% | <10% | 10-39% | 100% |
| China | 100% | 40-69% | 40-69% | 100% | 100% |
| India | 70-99% | <10% | <10% | <10% | 100% |
| Japan and Korea | 100% | 100% | 100% | 100% | 100% |
| Southeast Asia | 40-69% | 10-39% | <10% | 40-69% | 40-69% |

*Share of countries or jurisdictions within each region with policy currently implemented:*

<10% | 10-39% | 40-69% | 70-99% | 100%

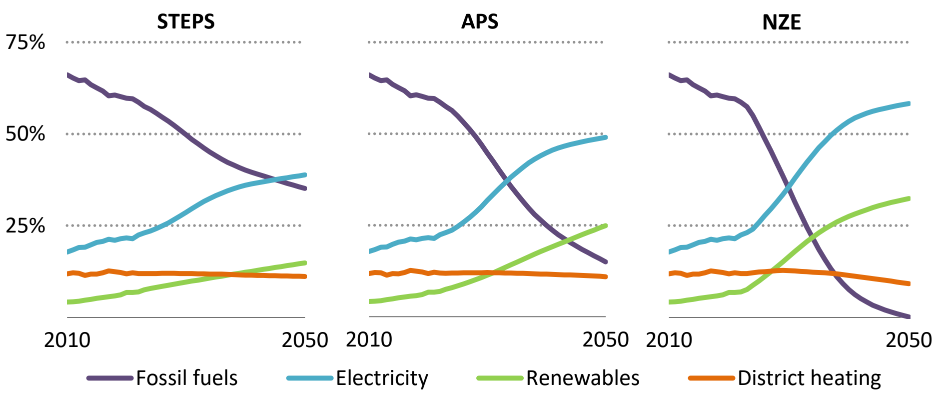
Notes: In regions with one country, unless there is a national policy in place, shares are shown for subnational jurisdictions. Some policy types are not equally relevant for all regions given variations in heating and cooling needs and the age of the building stock.

Deploying more energy-efficient technologies is another key factor differentiating energy demand and emissions in the buildings sector in our scenarios. Installed capacity of heat pumps in buildings is around 15% higher in the APS than in the STEPS by 2030, while unit electricity consumption of appliances decreases by over 10% over the same period compared with around 5% in the STEPS, partly because of more effective MEPS. They are a primary policy tool for improving technology efficiency and are implemented relatively consistently across regions compared to other types of policies related to the buildings sector (Table 3.3). Nevertheless, there is scope for them to be more widely adopted, and for more stringent standards and enforcement. Second-hand markets for appliances pose a particular barrier to further efficiency gains, especially with rapid growth in the ownership of appliances and air conditioners in developing economies. In the NZE Scenario, light-emitting diodes (LEDs) make up 100% of lighting sales by 2030 and best available technologies make up the majority of appliance and cooling equipment sales by 2035.

*What will it take to decarbonise heating in buildings?*

Heating – space and water heating – accounts for around 45% of energy demand and 80% of direct $CO_2$ emissions from buildings. In the STEPS, the share of energy service demand for heating met by fossil fuels is 50% by 2030 and 35% by 2050, and heating still releases emissions of 1.5 Gt $CO_2$ each year by 2050 (Figure 3.12). In the NZE Scenario, by contrast, heating is entirely decarbonised through a switch to electricity, renewables and district heat and through efficiency gains via envelope and technology improvements. Electrification in the NZE Scenario relies strongly on the uptake of heat pumps, which have seen rapid expansion in recent years (section 3.6).

**Figure 3.12 ⊳ Share of global energy service demand for heating in buildings by fuel and scenario, 2010-2050**






***Fuel switching is critical to decarbonise heating, including through the phase-out of fossil fuel boilers and the uptake of heat pumps and other low-emissions options***

Policies that support the decarbonisation of heating include building energy codes, heating intensity standards, carbon pricing, incentives to adopt heat pumps and clean technologies and bans on the sale of new fossil fuel equipment. To date, 13 European countries have implemented or announced national bans or other national policies to limit the installation of oil-fired boilers, of which nine have done the same for gas-fired boilers. Sub-national jurisdictions within Australia, Canada, China and United States, among other countries, have announced similar measures. In the APS, the implementation of bans on fossil fuel boilers or furnaces that have been announced to date reduces heating direct emissions by 420 million tonnes of carbon dioxide (Mt $CO_2$) by 2050. While bans on fossil fuel boilers are only one example of many policy solutions that can decarbonise energy use for heating in buildings, they can be useful to provide clear market signals to stakeholders and to align incentives for property owners and renters. In the NZE Scenario, bans on fossil fuel boilers are applied in every region from 2025 onwards, resulting in cumulative emissions savings of 19 Gt $CO_2$ from today to 2050.

Although high upfront costs present a deterrent to many households, switching to non-fossil fuel options can reduce household spending on heating over time (IEA, 2022b). While fossil fuel boilers and furnaces have lower upfront costs in most markets, heat pumps typically have lower operating costs due to their high efficiency. IEA analysis of life cycle costs by heating technology (based on average non-subsidised technology prices and relying on end-user fuel price projections consistent with the STEPS) finds oil-fired boilers to often be the most expensive option. Heat pump and gas-fired boiler life cycle costs are more comparable, with cost differences depending chiefly on fuel and $CO_2$ prices and on gas and electricity network costs. In densely populated areas, where the installation of heat pumps can prove difficult in some buildings, district heating can provide a viable low-emissions alternative.

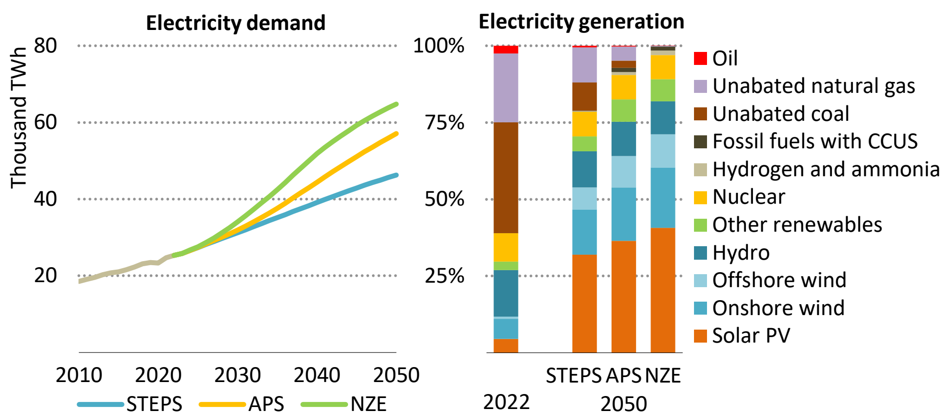


## 3.4 Electricity

### *Overview*

Global electricity demand is set to increase rapidly in all scenarios as a result of population and income growth and the electrification of increasing numbers of end-uses. By 2050, demand for electricity rises from its current level by over 80% in the STEPS, 120% in the APS and 150% in the NZE Scenario (Figure 3.13). The additional demand is met mainly by low-emissions sources of electricity – renewables, nuclear power, fossil fuels equipped with carbon capture, hydrogen and ammonia – raising their share of electricity supply in each scenario. The share of unabated fossil fuels declines sharply, with their combined output falling by over one-third from 2022 to 2050 in the STEPS, three-quarters in the APS and nearly 100% in the NZE Scenario.

**Figure 3.13 ▷ Global electricity demand, 2010-2050, and generation mix by scenario, 2022 and 2050**






***Electricity demand rises over 80% to more than 150% by 2050 across scenarios and is met increasingly by low-emissions sources at the expense of unabated coal and natural gas***

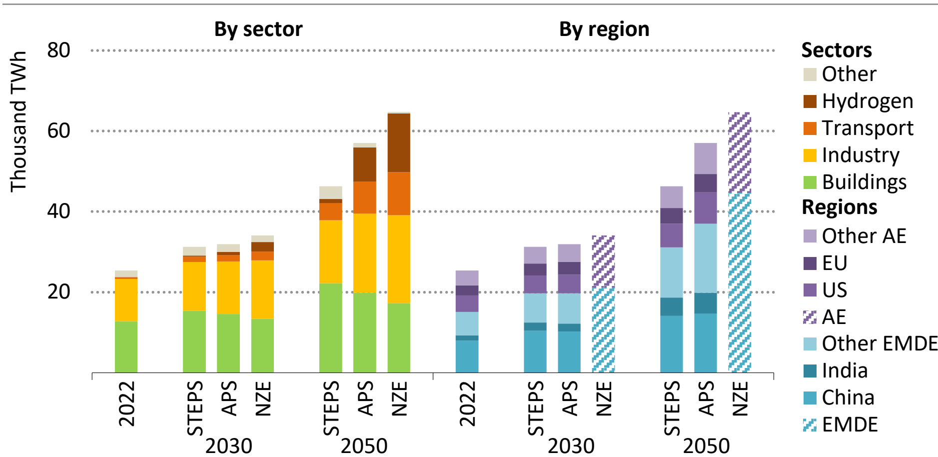
Notes: TWh = terawatt-hours. Other renewables include bioenergy and renewable waste, geothermal, concentrating solar power and marine power.

### *Electricity demand*

Global electricity demand growth to 2050 is driven by emerging market and developing economies, which together account for about three-quarters of the global total in the STEPS, APS and NZE Scenario. Today, China is the largest electricity consumer and demand growth of over 2% on average per year to 2050 in all scenarios means that it uses twice or more as much electricity as any other country by 2050. Annual electricity demand growth of around 5% puts India behind only China and the United States in terms of electricity consumption by 2050 in all scenarios. Other emerging market and developing economies also see robust electricity demand growth stemming from increasing populations, economic development and rising incomes. In advanced economies as a group, electricity demand growth is lower, ranging between 1.4% per year in the STEPS to 2.4% in the NZE Scenario.

Global electricity demand rises in all sectors and in all scenarios. The buildings sector remains the largest in terms of consumption through to 2050 in the STEPS and APS as demand continues to rise for appliances, space cooling and heating and water heating, though enhanced energy efficiency tempers growth in the NZE Scenario (Figure 3.14). The industry sector continues to be the second-largest user of electricity in the STEPS and APS, with electric motors accounting for much of its demand, but becomes the largest in the NZE Scenario. EVs account for about 15% of total electricity demand growth to 2050 in the STEPS, and a higher percentage in the APS and NZE Scenario, where EV sales rise faster and become a key driver of electricity demand growth. The production of hydrogen via electrolysis remains limited in the STEPS but adds significantly to electricity demand growth in the APS and even more so in the NZE Scenario.

**Figure 3.14 ▷ Electricity demand by sector and region, and by scenario**




IEA. CC BY 4.0.

***Emerging economies see robust electricity demand growth reflecting population growth and rising incomes; EVs and hydrogen production add to electricity demand growth***

Note: EMDE = emerging market and developing economies; AE = advanced economies; US = United States; EU = European Union.

## *Electricity supply*



Responses to the current energy crisis have emphasised addressing security challenges while accelerating clean energy transitions, particularly in the electricity sector. Recent policy developments have boosted the prospects for renewables in major markets, including China, European Union, India, Japan and United States (Table 3.4). Prospects for nuclear power have also improved in leading markets, with support for lifetime extension of existing nuclear reactors in a number of countries including Japan, Korea and United States, and support for new reactors in Canada, China, United Kingdom, United States, and several EU member states (IEA, 2023b). Recent policy developments have been mixed for natural gas use in the power sector: European Union, Korea and Japan are taking efforts to reduce demand and reliance on imports, while China sees a continued role for natural gas. While the current global energy crisis has led to a temporary uptick in coal-fired power generation, countries with plans to phase out unabated coal remain committed.

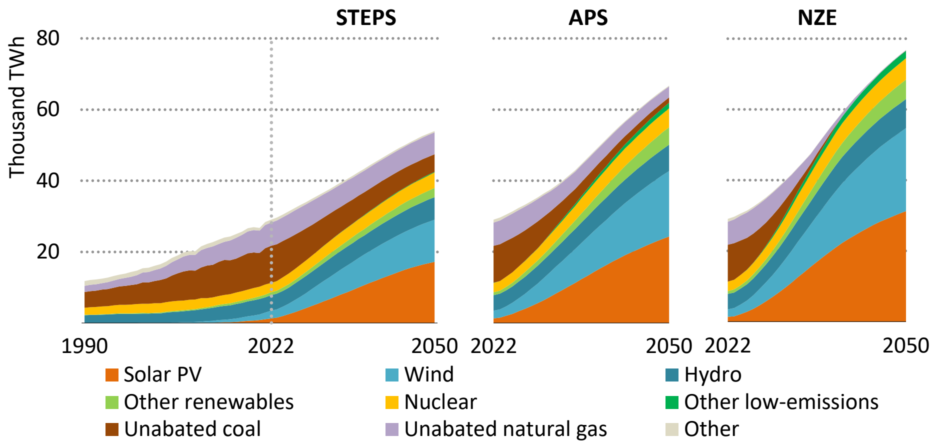
**Table 3.4 ▷ Recent major developments in electricity supply policies and their combined impact on the outlook for selected regions**

| Region | Major policy | Combined impact on outlook for: | | | |
|---|---|---|---|---|---|
| | | Renewables | Nuclear | Unabated natural gas | Unabated coal |
| China | 14th Five-year Plan and updated Nationally Determined Contribution | Favourable | Favourable | Neutral | Unfavourable |
| India | Revised Nationally Determined Contribution aiming for 50% non-fossil power generation capacity by 2030 | Favourable | Neutral | Neutral | Neutral |
| European Union | Renewable Energy Directive III (42.5% of gross final consumption in 2030), including nuclear-based hydrogen | Favourable | Favourable | Unfavourable | Unfavourable |
| United States | Inflation Reduction Act with USD 370 billion for clean energy technologies | Favourable | Favourable | Neutral | Unfavourable |
| Canada | Investment Tax Credits for electricity, hydrogen, CCUS and manufacturing | Favourable | Favourable | Neutral | Unfavourable |
| Korea | 10th Basic Plan for Long-term Electricity Supply and Demand | Neutral | Favourable | Unfavourable | Unfavourable |
| Japan | 6th Strategic Energy Plan and Green Transformation (GX) policy initiative | Favourable | Favourable | Unfavourable | Unfavourable |

Favourable   Unfavourable   Neutral

The growth of electricity generation from low-emissions sources accelerates in all three scenarios, with their combined output quadrupling from 2022 to 2050 in the STEPS, growing to 5.5-times its current level in the APS, and increasing sevenfold in the NZE Scenario (Figure 3.15). As a result, the global share of electricity generation from low-emissions sources from 39% in 2022 rises by 2050 to about 80% in the STEPS, over 90% in the APS, and nearly 100% in the NZE Scenario. This enables advanced economies and emerging market and developing economies alike to reduce their reliance on fossil fuels.

**Figure 3.15 ▷ Global electricity generation by source and scenario, 1990-2050**





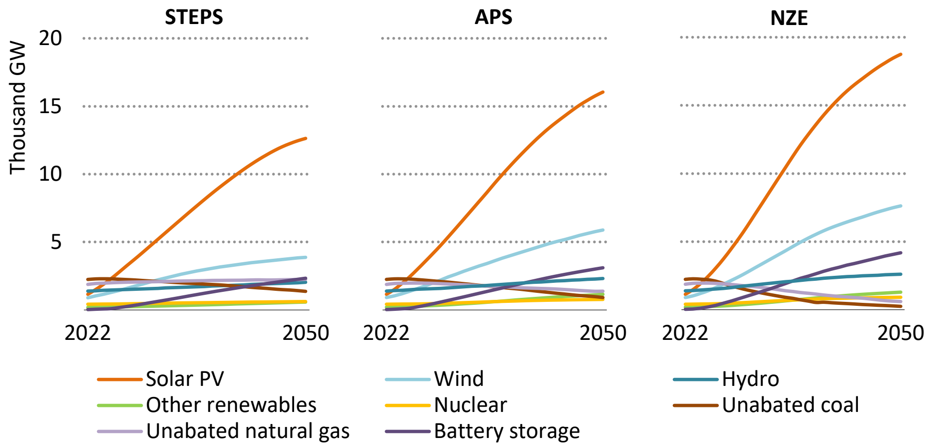

***Renewables outpace electricity demand growth to 2030 in the STEPS, leading to a peak in coal-fired power in the near term though announced pledges call for faster declines***

Notes: TWh = terawatt-hours. Other low-emissions include fossil fuels with CCUS, hydrogen and ammonia.

Renewables provided 30% of electricity generated worldwide in 2022, and this rises to nearly 50% by 2030 in the STEPS. Hydropower is the largest low-emissions source of electricity today, accounting for 15% of generation, but its annual output can vary widely, and high upfront capital costs and limitations on development of favourable sites constrain further growth prospects. Other renewables – bioenergy, geothermal, concentrating solar and marine power – have a part to play too, but solar PV and wind are the central technologies in the roll-out of renewables to decarbonise energy supply faster. Renewables capacity expands 2.4-fold in the STEPS by 2030, 2.7-fold in the APS and triples in the NZE Scenario, and almost 95% of this growth is in the form of solar PV and wind (Figure 3.16). The share of wind and solar PV in total generation is set to rise from 12% to about 30% by 2030, putting power system flexibility at the heart of electricity security (see Chapter 4) and underlining the need to speed up permitting and grid expansion (IEA, 2023a).

Nuclear power is the second-largest source of low-emissions power worldwide today, behind hydropower but far larger than wind or solar PV. In advanced economies, nuclear power is the largest source of low-emissions electricity. After a decade of slow deployment in the wake of the accident at the Fukushima Daiichi Nuclear Power Station in Japan, a changing policy landscape is creating opportunities for a nuclear comeback (IEA, 2022c). Nuclear power capacity increases from 417 GW in 2022 to 620 GW in 2050 in the STEPS, with growth mainly in China and other emerging market and developing economies, while advanced economies carry out widespread lifetime extensions and look to build new projects to offset retirements. Large-scale reactors remain the dominant form of nuclear power in all scenarios, including advanced reactor designs, but the development of and growing interest in small modular reactors increases the potential for nuclear power in the long run (NEA, 2022). More lifetime extensions and new construction in countries open to nuclear power boost global capacity in the APS to 770 GW in 2050, and to well over 900 GW in the NZE Scenario, where nuclear construction reaches new heights (IEA, 2023a).

**Figure 3.16 ▷ Global installed power capacity by selected technology and scenario, 2022-2050**






*Solar PV capacity takes off in all scenarios, with only wind power at the same scale in the long term; their variable nature leads to increased deployment of battery storage*

Coal is the largest source of electricity in the world today, accounting for 36% of the total, but is overtaken by renewables by 2025 in all three scenarios. By 2030, with new construction slowing and efforts to transition away from coal underway in many countries (IEA, 2022d), the share of unabated coal in electricity generation falls below 25% in the STEPS, 20% in the APS and 15% in the NZE Scenario. In STEPS, unabated coal-fired power peaks in China around 2025 and shortly after 2030 in India. Beyond 2030, the use of unabated coal in power continues to diminish as the largest users – China, India, Indonesia and other emerging market and developing economies – increasingly look to alternatives.

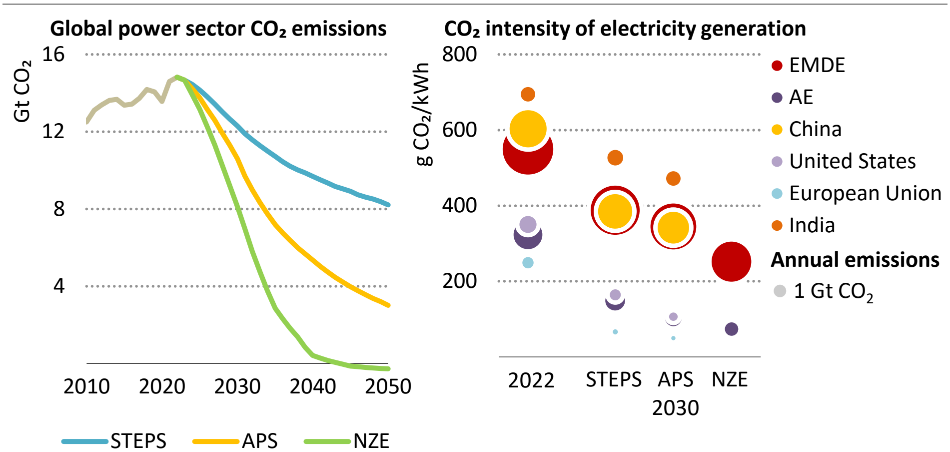
The role of natural gas in power systems is evolving and varies widely by scenario. Today, natural gas provides 22% of global electricity as well as flexibility and reliability services, but gas-fired generation peaks before 2030 in all three scenarios. Its share in total electricity generation falls to under 20% in 2030 and close to 10% by 2050 in the STEPS, with markets in advanced economies increasingly looking to gas-fired power plants for flexibility rather than bulk output as they integrate rising shares of solar PV and wind. While gas-fired power rises in absolute terms in China and other emerging market and developing economies beyond 2030, its share gradually declines. In the APS, transitions happen more quickly, leading to unabated natural gas-fired generation falling by half from 2022 to 2050, and to a near complete phase out in the NZE Scenario by 2050.

Coal- and gas-fired power plants equipped with CCUS and those co-firing with hydrogen and ammonia contribute to low-emissions power mainly after 2030. Limited progress is made in the STEPS, but the pace picks up in the APS and the NZE Scenario. They provide over 1 500 TWh of electricity generation by 2050 in the APS, rising to more than 2 100 TWh in the NZE Scenario, which is equivalent to all global wind generation today. Along with repurposing to focus on flexibility and retiring plants early, retrofitting existing coal plants to co-fire ammonia offers significant opportunities to cut emissions while continuing operations (IEA, 2022d).

### *Power sector $CO_2$ emissions*

Global power sector $CO_2$ emissions were close to 15 gigatonnes (Gt) in 2022 (including both electricity and heat production), accounting for almost 40% of all energy-related $CO_2$ emissions. Power sector emissions are set to peak in the near term and then start declining in all scenarios. Weather conditions in major markets will influence the precise timing, for example droughts could lower hydropower output and temporarily raise the use of fossil fuels. By 2030, global power sector emissions are down about 15% in the STEPS, 30% in the APS and 45% in the NZE Scenario, which sees electricity sector emissions subsequently fall to net zero by 2035 in advanced economies in aggregate, 2040 in China and just before 2045 globally (Figure 3.17). This makes the power sector the first to reach net zero emissions.

**Figure 3.17 ▷ Global power sector emissions, 2010-2050, and $CO_2$ intensity of electricity generation by region and scenario, 2022 and 2030**






***Global power sector emissions peak in the near term and then decline by about 15% in the STEPS and 30% in the APS by 2030; they fall faster in all regions in the NZE Scenario***

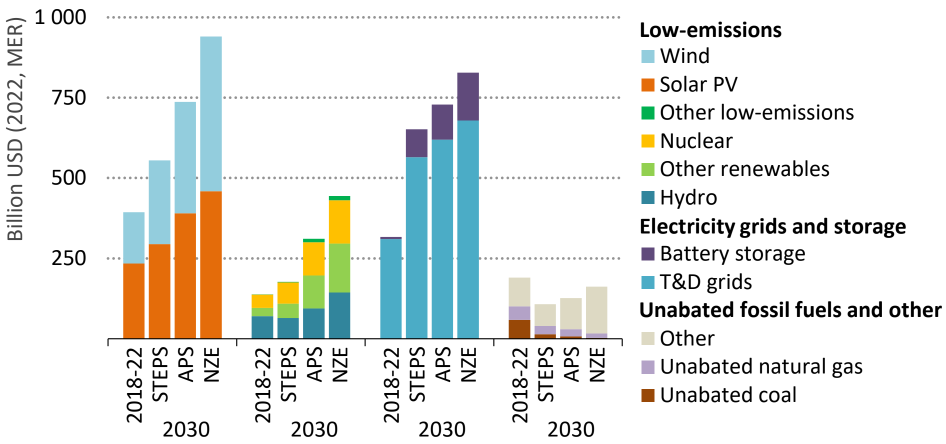
Notes: Gt $CO_2$ = gigatonnes of carbon dioxide; g $CO_2$/kWh = grammes of carbon dioxide per kilowatt-hour; EMDE = emerging market and developing economies; AE = advanced economies. In the NZE Scenario, emissions from fossil fuel combustion are counterbalanced by carbon dioxide removal through bioenergy with carbon capture and storage.

### *Power sector investment*

Total power sector investment increases in all scenarios to meet electricity demand growth, support clean energy transitions and maintain electricity security. Solar PV and wind currently account for more investment than electricity grids, but projected cost reductions for solar PV and wind moderate future investment needs at the same time as grid investment needs rise (Figure 3.18). Grid investment is key to connect millions of new customers and new renewable sources, reinforce transmission and distribution, and modernise and digitalise systems (IEA, 2023c). Battery storage attracts increasing investment to provide hour-to-hour flexibility and grid stability, while investment in unabated fossil fuel power plants, already low in recent years, drops to a minimal level and is mostly focussed on natural gas-fired power for the provision of flexibility services. In the STEPS, global power sector investment rises from USD 1.0 trillion on average over 2018-2022 to USD 1.4 trillion by 2030 and maintains that level through to 2050. In the APS, power sector investment rises to USD 1.8 trillion by 2030; in the NZE Scenario, it increases further to USD 2.2 trillion.



**Figure 3.18 ▷ Average annual global investment in the power sector by type and scenario, 2018-2022 and 2030**






***Power sector investment rises by 50% to 2030 in the STEPS, 90% in the APS, mainly due to higher spending on solar PV, wind, grids and storage, but the NZE Scenario calls for more***

Notes: MER = market exchange rate; T&D = transmission and distribution. Other low-emissions include fossil fuels with CCUS, hydrogen and ammonia.

## 3.5 Fuels

### *3.5.1 Oil*

**Table 3.5 ⊳ Global liquids demand and supply by scenario** (mb/d)

| | | | STEPS | | APS | | NZE | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Road transport | 36.5 | 41.3 | 41.1 | 35.5 | 37.6 | 15.9 | 29.1 | 1.6 |
| Aviation and shipping | 9.9 | 10.6 | 13.5 | 17.2 | 12.5 | 9.0 | 10.5 | 2.1 |
| Industry | 17.2 | 20.6 | 23.3 | 25.5 | 21.4 | 17.8 | 20.3 | 14.3 |
| Buildings and power | 12.4 | 11.4 | 9.5 | 6.7 | 8.6 | 4.1 | 6.1 | 0.5 |
| Other sectors | 11.1 | 12.6 | 14.0 | 12.5 | 12.4 | 7.9 | 11.4 | 5.7 |
| **World oil demand** | **87.1** | **96.5** | **101.5** | **97.4** | **92.5** | **54.8** | **77.5** | **24.3** |
| Liquid biofuels | 1.2 | 2.2 | 3.0 | 4.5 | 4.8 | 6.9 | 5.6 | 5.3 |
| Low-emissions hydrogen-based fuels | - | - | 0.0 | 0.2 | 0.2 | 3.6 | 0.7 | 6.0 |
| **World liquids demand** | **88.4** | **98.7** | **104.5** | **102.1** | **97.5** | **65.3** | **83.7** | **35.5** |
| Conventional crude oil | 67.4 | 62.8 | 61.3 | 58.2 | 54.9 | 29.8 | 48.0 | 15.8 |
| Tight oil | 0.7 | 8.3 | 11.1 | 10.2 | 10.3 | 6.9 | 7.6 | 1.8 |
| Natural gas liquids | 12.7 | 19.0 | 21.2 | 19.4 | 20.1 | 13.6 | 16.2 | 4.4 |
| Extra-heavy oil and bitumen | 2.0 | 3.7 | 4.4 | 5.5 | 3.9 | 2.5 | 3.0 | 1.5 |
| Other production | 0.5 | 0.9 | 1.0 | 1.2 | 0.9 | 0.3 | 0.3 | 0.0 |
| **World oil production** | **83.1** | **94.8** | **99.1** | **94.5** | **90.2** | **53.1** | **75.1** | **23.5** |
| *OPEC share* | 40% | 36% | 35% | 43% | 35% | 45% | 37% | 53% |
| World processing gains | 2.2 | 2.3 | 2.4 | 2.9 | 2.4 | 1.6 | 2.3 | 0.7 |
| **World oil supply** | **85.3** | **97.1** | **101.5** | **97.4** | **92.5** | **54.8** | **77.5** | **24.3** |
| **IEA crude oil price** (USD [2022]/barrel) | **103** | **98** | **85** | **83** | **74** | **60** | **42** | **25** |

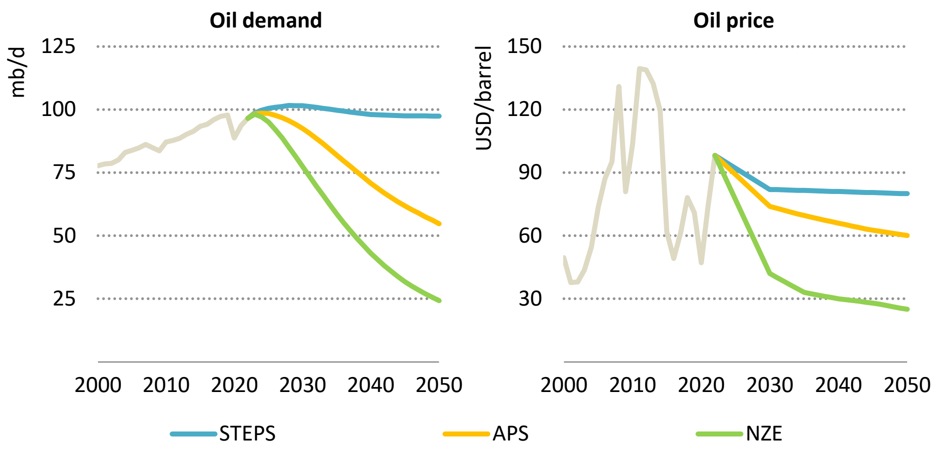
Notes: mb/d = million barrels per day; OPEC = Organization of the Petroleum Exporting Countries. Other production includes coal-to-liquids, gas-to-liquids, additives and kerogen oil. Historical supply and demand volumes differ due to changes in stocks. Liquid biofuels and low-emissions hydrogen-based liquid fuels are expressed in energy equivalent volumes of gasoline and diesel, reported in million barrels of oil equivalent per day. See Annex C for definitions.

Global oil markets have been reshaped by the turbulence caused by the Covid-19 pandemic and Russia's invasion of Ukraine. Overall oil demand in 2022 remained slightly below 2019 levels: oil use as a petrochemical feedstock in 2022 was around 1 mb/d higher, but this was more than offset by lower levels of use in road transport (1 mb/d lower) and aviation (2 mb/d lower). Demand continued to increase in 2023 and reached a new monthly record in June. On the supply side, cuts in production by the OPEC+ grouping, which includes Russia and other exporters, in the first-half of 2023 were largely offset by higher output elsewhere. Non-OPEC+ increases in supply are expected to be limited during the rest of 2023 despite further cuts by OPEC+ in July and August.

There are a number of changes in demand and supply trends from the *WEO-2022.* Oil demand reaches its maximum level in this *Outlook*'s STEPS around five years earlier than in the *WEO-2022* and total demand in 2050 is around 5 mb/d lower. This stems mainly from faster projected increase in EV sales in this *Outlook* in the light of additional policy support as well as plans to establish EV manufacturing hubs in a number of emerging market and developing economies. On the supply side, the fall in production from Russia is less immediate than projected in the *WEO-2022*, but the long-term decline remains similar. Production by members of OPEC and by countries in Latin America and the Caribbean in 2050 is around 2 mb/d lower in each than projected in the *WEO-2022,* and production in North America is around 1 mb/d lower. In this *Outlook*, oil prices remain flat in the STEPS at around USD 80/barrel, whereas they gradually fall to USD 60/barrel by 2050 in the APS (Figure 3.19). In the NZE Scenario, the price gradually falls to the marginal cost of oil production, dropping to USD 40/barrel in 2030 and trending lower thereafter.



**Figure 3.19 ▷ Global oil demand and crude oil price by scenario, 2000-2050**






*Oil demand and prices peak in the late-2020s in the STEPS; there are much sharper declines in both the APS and NZE Scenario*

### *Demand*

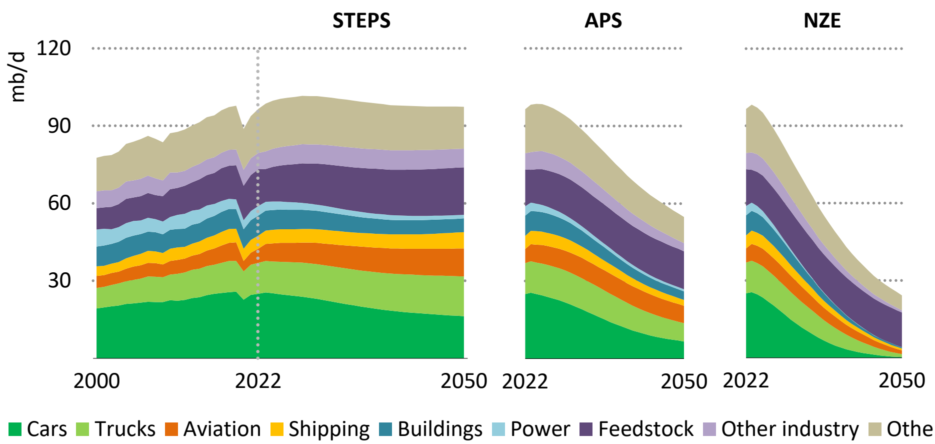
In the STEPS, oil demand reaches its maximum level of 102 mb/d in the late 2020s before declining slightly to 97 mb/d in 2050, with reduced demand in road transport as a result of the rise of EVs offset by increased oil use in petrochemicals and in aviation. In practice, this would probably mean an undulating plateau lasting for many years with demand moving slightly above and below a long-term average from year to year.

In the APS, there is a much more pronounced decline in demand, which falls to 93 mb/d in 2030 and to 55 mb/d in 2050. Oil demand in road transport modes falls more sharply, with EVs accounting for more than 75% of passenger car and truck sales in 2050. Only in petrochemicals and aviation is more oil used in 2050 than in 2022. There are plans to restrict or ban the production and utilisation of single-use plastics and to scale up plastics recycling, but these do not prevent an overall increase in global demand for plastics. The use of sustainable aviation fuels increases, but oil use for aviation nevertheless grows to the mid-2030s and then only declines slowly. Maritime oil use falls by 55% between 2022 and 2050, however, and half of the fuels used in ships in 2050 are low-emissions fuels.[6]

In the NZE Scenario, oil demand falls to 77 mb/d in 2030. The electrification of cars and trucks makes a bigger contribution than anything else to reduce oil use, but efficiency improvements and low-emissions fuels also play an important role, especially in aviation and shipping. Oil demand falls to just under 25 mb/d in 2050: around 70% of this is accounted for by the use of oil as a petrochemical feedstock and in products such as paraffin waxes, asphalt and bitumen where the oil is not combusted.

Across the three scenarios, there is a much wider variation in the demand outlook in emerging market and developing economies than in advanced economies. Oil demand in advanced economies declines by between 35-85% through to 2050; in emerging market and developing economies, it ranges from a 20% increase to a 70% decrease over this period.

**Figure 3.20 ▷ Global oil demand by sector and scenario, 2000-2050**






*Demand in the STEPS peaks by 2030; increases in aviation and petrochemicals mostly offset declines elsewhere through to 2050; demand declines rapidly in the APS and NZE Scenario*

### *Production*

In the STEPS, US tight oil production in 2022 stood at just over 7.5 mb/d and it increases by around 2 mb/d to 2030; production peaks soon thereafter and falls back to around 8.5 mb/d in 2050. There are also major contributions to the supply mix from Brazil and Guyana, with Guyana increasing production to a maximum level of around 2 mb/d in the mid-2030s before it declines slightly. Production in Russia declines by 3.5 mb/d between 2022 and 2050 as it struggles to maintain output from existing fields or to develop large new ones. Total

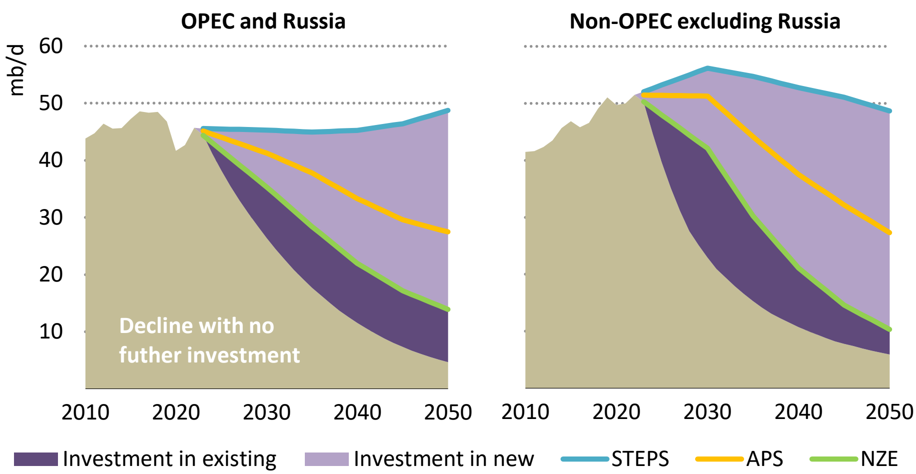
[6] In July 2023, the International Maritime Organization adopted a version of its greenhouse gas emissions strategy that looks to achieve net zero emissions from international shipping by 2050, however, enforcement mechanisms have yet to be decided. This strategy is not included in the APS.

production by members of OPEC increases by a modest 1 mb/d to 2030, given around 1.5 mb/d of declines from OPEC producers in Africa. OPEC and Russia's combined share of global oil supply remains between 45-48% to 2030 but it rises above 50% by 2050 as Saudi Arabia increases production. We also assume that by then there is a gradual normalisation of the international situation in countries subject to sanctions, notably Iran and Venezuela, and production from these countries rises.

In the APS, oil demand declines by 0.5% each year to 2030, but existing sources of supply fall at a faster rate, which means that new conventional crude oil projects are needed (Figure 3.21). Guyana is one of the few countries to see an increase in production of more than 1 mb/d to 2030. There is continued drilling for tight oil in the United States, but production peaks before 2030 and is around 1.5 mb/d lower in 2050 than 2022 levels.

3

**Figure 3.21 ▷ Oil production by OPEC and Russia and other non-OPEC producers by scenario, 2010-2050**




IEA. CC BY 4.0.

*New oil projects are needed in the STEPS and APS, but not in the NZE Scenario; OPEC and Russia take a larger share of the market in the NZE Scenario*

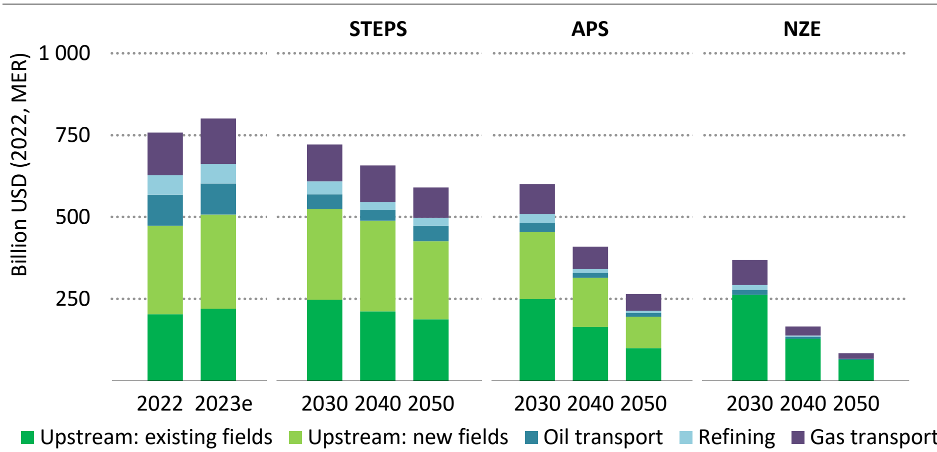
In the NZE Scenario, oil demand declines by 2.5% each year on average to 2030 and can be met without any new conventional long lead time oil projects. Production falls across all regions to 2030. After 2030, oil demand falls by more than 5.5% each year: this is sufficiently rapid to cause the closure of a number of higher cost projects before they have reached the end of their technical lifetimes.

### *Refining, trade and investment*

The refining industry enjoyed bumper profits in recent years as a recovery in demand after the Covid-19 pandemic, particularly for middle distillates such as diesel and kerosene, coincided with the first net reduction in capacity in 30 years. The industry is now set to add more than 6 mb/d of refining capacity, mostly in developing economies in Asia and the Middle East: however, this wave of capacity additions is likely to be the last, with limited capacity growth after 2030 projected in all scenarios. Transport fuels have historically been the main cause of demand growth in refining over the past few decades but this is set to end: in 2050, the share of gasoline in total demand drops from 25% today to 17% in the STEPS, to 14% in the APS, and to close to zero in the NZE Scenario.

Emerging market and developing economies in Asia currently account for just over 40% of global crude oil imports. More robust demand and limited domestic production potential cause this share to rise to 45-60% in 2050 in all scenarios. The Middle East remains the largest crude oil exporter in all scenarios, but crude oil exports from North America and Latin America and the Caribbean rise from a 23% share of the total today to 30% in the STEPS in 2050 and 40% in the APS. Russia's share meanwhile continues to decline. In the NZE Scenario, the Middle East plays an outsized role in serving global crude oil markets as a low cost producer, with its share in total exports reaching 65% by 2050. Most of the new refining facilities currently under development are in product exporting regions, which means the availability of oil products on the market is set to rise: the decline in product trade is much more muted than the overall decline in demand in the APS and the NZE Scenario.

**Figure 3.22 ⊳ Global oil and natural gas investment by scenario, 2022-2050**






***Oil and gas investment is expected to increase in 2023 and to be similar to 2030 levels in the STEPS; it is much higher than the levels needed in the APS and NZE Scenario***

Notes: 2023e = estimated values for 2023. New field investment in the NZE Scenario in 2030 is for projects that are currently under construction or those that are approved before the end of 2023.

At around USD 800 billion, expected oil and natural gas investment levels in 2023 are broadly aligned with the level needed in the STEPS in 2030, which suggests that the oil and gas industry today does not yet see a significant near-term reduction in demand as likely (Figure 3.22). In the APS, investment in new and existing fields is required to avoid supply falling faster than demand, but the overall level of investment in 2030 falls to around USD 630 billion. In the NZE Scenario, investment in existing fields is needed to ensure that supply does not decline faster than demand, but no new conventional long lead time oil and gas projects are developed after 2023 and investment is much lower than today.

Reductions in fossil fuel investment need to be sequenced carefully with the scaling up of investment in clean energy. Investing more than is needed when clean energy investment is ramping up and efficiency measures are reducing demand would lead to lower prices and could also risk lock-in of fossil fuel use. Conversely, reducing fossil fuel investment in advance of action and investment to reduce demand would lead to much higher and more volatile prices during energy transitions.



### 3.5.2 Natural gas

**Table 3.6 ▷ Global gas demand, production and trade by scenario**

| | | | STEPS | | APS | | NZE | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **Natural gas demand** (bcm) | **3 326** | **4 159** | **4 299** | **4 173** | **3 861** | **2 422** | **3 403** | **919** |
| Power | 1 346 | 1 638 | 1 570 | 1 409 | 1 436 | 776 | 1 435 | 112 |
| Industry | 692 | 861 | 970 | 1 061 | 868 | 654 | 788 | 325 |
| Buildings | 761 | 871 | 917 | 869 | 803 | 415 | 540 | 1 |
| Transport | 109 | 150 | 157 | 158 | 125 | 60 | 94 | 6 |
| Low-emissions hydrogen inputs | - | 1 | 8 | 27 | 36 | 212 | 71 | 327 |
| Other | 418 | 638 | 678 | 655 | 597 | 301 | 482 | 179 |
| *of which abated with CCUS* | 7 | 15 | 32 | 79 | 93 | 359 | 162 | 512 |
| **Natural gas production** (bcm) | **3 274** | **4 138** | **4 299** | **4 173** | **3 861** | **2 422** | **3 403** | **919** |
| Conventional gas | 2 769 | 2 871 | 2 894 | 3 016 | 2 742 | 1 940 | 2 363 | 627 |
| Unconventional gas | 504 | 1 266 | 1 405 | 1 157 | 1 119 | 482 | 1 040 | 293 |
| **Natural gas net trade** (bcm) | **640** | **810** | **919** | **921** | **827** | **370** | **719** | **187** |
| LNG | 276 | 479 | 611 | 656 | 588 | 242 | 507 | 121 |
| Pipeline | 364 | 331 | 309 | 265 | 246 | 125 | 220 | 47 |
| **Natural gas price** (USD/MBtu) | | | | | | | | |
| United States | 5.8 | 5.1 | 4.0 | 4.3 | 3.2 | 2.2 | 2.4 | 2.0 |
| European Union | 9.9 | 32.3 | 6.9 | 7.1 | 6.5 | 5.4 | 4.3 | 4.1 |
| Japan | 8.8 | 13.7 | 8.4 | 7.7 | 7.8 | 6.3 | 5.9 | 5.3 |
| China | 14.6 | 15.9 | 9.4 | 7.8 | 8.3 | 6.3 | 5.5 | 5.3 |
| **Low-emissions gases** (bcme) | **23** | **39** | **89** | **324** | **197** | **1 161** | **414** | **1 797** |
| Low-emissions hydrogen | 0 | 2 | 23 | 99 | 80 | 809 | 232 | 1 385 |
| Biogas | 23 | 28 | 42 | 89 | 51 | 117 | 56 | 129 |
| Biomethane | 1 | 9 | 24 | 136 | 66 | 235 | 126 | 283 |

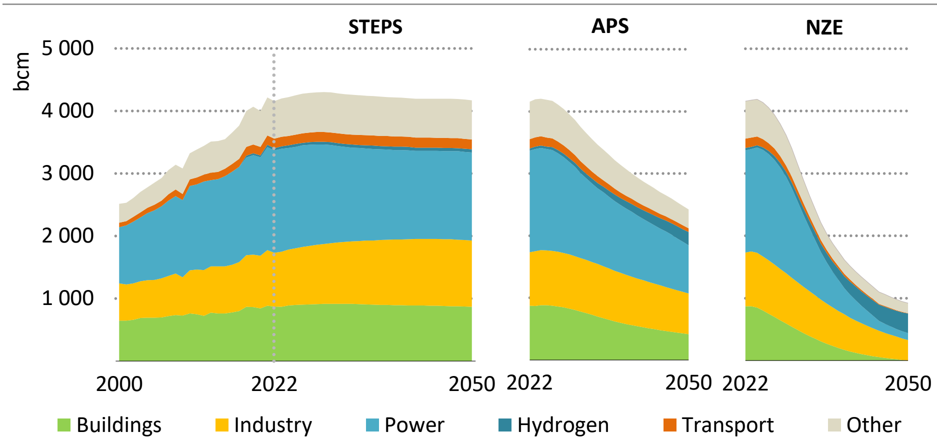
Notes: bcm = billion cubic metres; CCUS = carbon capture, utilisation and storage; LNG = liquefied natural gas; MBtu = million British thermal units; bcme = billion cubic metres equivalent (1 bcme of hydrogen = 0.3 million tonnes). Net trade reflects volumes traded between regions modelled in the IEA Global Energy and Climate Model and excludes intra-regional trade. Other includes other non-energy use, agriculture and other energy sector. The difference between production and demand is due to stock changes.

Natural gas markets have been upended by Russia's invasion of Ukraine. The sharp reduction in pipeline supply to Europe tightened global gas markets, resulting in record high prices and a drop in global demand by around 1% in 2022. Demand fell by a record 13% in Europe, but there were also ripple effects in emerging markets and developing economies in Asia, where demand in aggregate fell for the first time ever. Major gas producing regions showed resilience, with output increasing in the Middle East by 3% and in the United States by 4%. Global demand remained muted in the first half of 2023; China's recovery has been uneven, while a retreat from record natural gas prices in Europe so far has not reinvigorated gas consumption in the industry or power sectors.

The crisis prompted a scramble by gas importing countries around the world to secure supplies. This has boosted near-term prospects for additional investment, especially for liquefied natural gas (LNG) export projects. But responses to the crisis have also laid the groundwork for a more rapid shift away from natural gas in Europe and the United States, while more upbeat projections for renewables imply weaker natural gas demand growth, especially in emerging markets in Asia.

### *Demand*

**Figure 3.23 ▷ Global natural gas demand by scenario, 2000-2050**




IEA. CC BY 4.0.

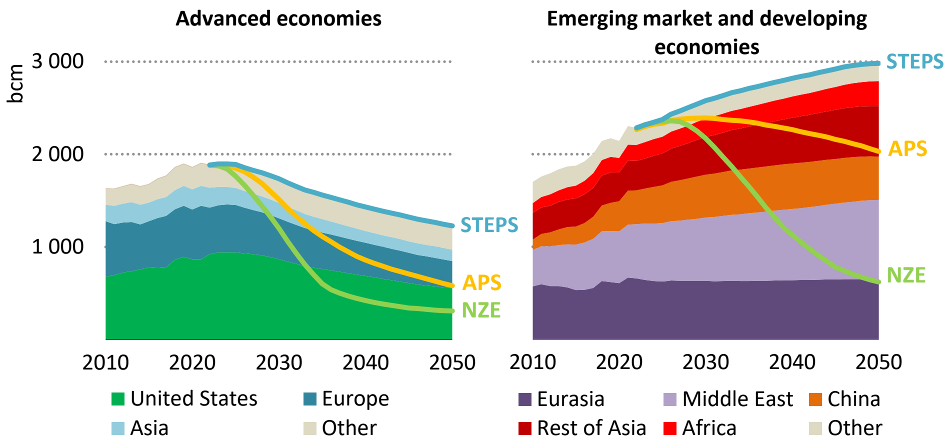
***Each scenario projects an end to growth for gas; future prospects depend largely on the pace and scale of growth in clean power, electrification and efficiency improvements.***

In the STEPS, natural gas demand growth between 2022 and 2030 is much lower than the 2.2% average rate of growth seen between 2010 and 2021 (Figure 3.23). It reaches a peak by 2030, maintaining a long plateau before gradually declining by around 100 bcm by 2050. In the APS, demand peaks even sooner, and is 7% lower by 2030 than 2022 levels. In the NZE Scenario, demand falls by more than 2% per year from 2022 to 2030, and by nearly 8% per year between 2030 and 2040. Decline rates are moderated after 2040 by the growing use of natural gas with CCUS for the production of low-emissions hydrogen.

Natural gas demand declines in advanced economies in all scenarios. Robust support for clean energy reduces the share of natural gas in energy supply by 2030 in the power sector and then increasingly in buildings and industry. There is a continued need for natural gas to back up variable renewables, and this is often highlighted as a reason for its enduring role in transitions, but this standby role requires much less consumption of natural gas than operating plants as baseload supply; moreover, the role of gas in ensuring flexibility over time is complemented by other options such as batteries and demand response. By 2050, gas demand in advanced economies falls to 1 200 bcm in the STEPS, 40% below the current level. More rapid electrification of heat demand and efficiency gains bring gas down to 480 bcm by 2050 in the APS and to 300 bcm in the NZE Scenario. There is a wider range of possible outcomes for natural gas demand in emerging market and developing economies (Figure 3.24). Major differences emerge by 2030, at a time when ample new LNG supplies are anticipated, keeping gas prices low and potentially stimulating robust demand growth. In the APS and NZE Scenario, this possibility is precluded by rapid growth of renewables in the power sector, which starts to reduce the market share of natural gas after 2030.



**Figure 3.24 ⊳ Natural gas demand by region and scenario, 2010-2050**






***Natural gas demand declines in advanced economies in each scenario; in emerging market and developing economies the difference between scenario outcomes is larger***

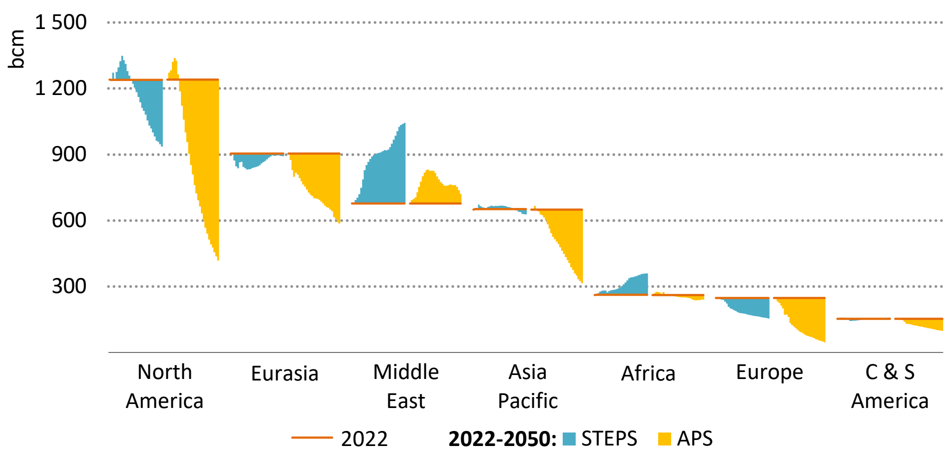
### *Production*

Russia's invasion of Ukraine has prompted major gas producers to bring new supplies to the market. In 2022, upstream spending outside Russia shot up by more than 15%, with around half of planned new supply linked to export projects.

In the STEPS, the Middle East emerges as the main source of incremental global supply; its global share of total production of natural gas rises from 15% in 2022 to 25% by 2050. In the APS, Middle East production remains resilient as the sole region producing more gas in 2050 than in 2022 (Figure 3.25). The rate of decline in other regions is determined by the pipeline of projects under development in the near term, the ability of major producers to find export outlets in a world where natural gas trade is shrinking, and the cost of developing new supplies in the long run. Among exporting regions, the United States records impressive supply growth to 2030 in the STEPS with an increase of 90 bcm in shale and tight gas production. Over the longer term US production falls, contributing to an overall decline in production in North America of nearly 400 bcm between 2030 and 2050 – primarily due to declining domestic demand. The loss of Russian gas supply to Europe and stagnant demand leads to a 300 bcm drop in Eurasian production by 2050.

In the NZE Scenario, global gas production falls sharply in all regions at a rate that implies that some projects have to close before reaching the end of their technical lifetimes, though growing gas use for hydrogen production slows the decline after 2040 in areas where hydrogen is exported, notably the Middle East and Australia.

**Figure 3.25 ▷ Natural gas production by region in the Stated Policies and Announced Pledges scenarios, 2022-2050**




IEA. CC BY 4.0.

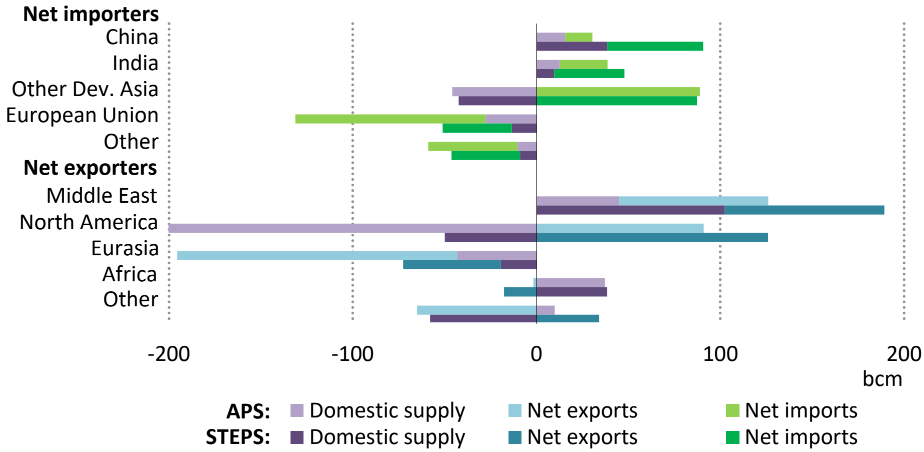
***A global peak in gas demand in the STEPS leaves only a handful of regions producing more than they did in 2022; production in the APS falls across the board, led by North America***

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

### *Trade and investment*

Global natural gas trade in the STEPS increases nearly 15% between 2022 and 2030, which is half the rate of growth during the previous decade, but more than four-times higher than growth in overall natural gas demand to 2030 (Figure 3.26). Two-thirds of globally traded natural gas is delivered as LNG in the STEPS by 2030, up from a level of around 50% in 2021. Trade is also relatively resilient in the APS and NZE Scenario to 2030: total exports in 2030 are 20 bcm above their 2022 level in the APS and 90 bcm below it in the NZE Scenario.

**Figure 3.26 ▷ Change in natural gas supply balance by region in the Stated Policies and Announced Pledges scenarios, 2022-2030**






*Global gas trade shows resilience in both scenarios for the rest of this decade*

Note: Other Dev. Asia = Other countries in developing Asia.

The United States, which accounts for over 90% of LNG export projects approved since the start of 2022, solidifies its position as the world's largest gas exporter through to 2030 in all scenarios. Although exports also rise in the Middle East, notably from Qatar, most additional production in the region to 2030 is needed to meet domestic demand. Russia fails to regain its pre-2022 volumes of total gas exports in any of our scenarios. They fall another 20% by 2030 in the STEPS, as rising deliveries to China through the Power of Siberia pipeline and modest growth in LNG exports are offset by further declines in pipeline exports to Europe. In the APS, lower gas demand growth in China and a global surplus of LNG leaves Russia with few options to diversify into non-European markets: despite modest incremental growth in exports to Türkiye and Central Asia, total exports fall 25% by 2030. Mozambique emerges as a large exporter by 2030, but Africa's overall gas trade balance falls by 2030 in the STEPS as LNG exports from West Africa decline and a higher share of North African gas production goes towards meeting domestic demand. In the APS, a dearth of buyers willing to sign up for new, long lead time export projects means African exports fall one-third below 2022 levels by 2050.

Since natural gas demand peaks in all *WEO* scenarios by 2030, there is little headroom remaining for either pipeline or LNG trade to grow beyond then. With around 650 bcm of annual liquefaction capacity in operation and a further 250 bcm under construction, global LNG markets look amply supplied in the STEPS until at least 2040. In the APS, LNG demand peaks by 2030 and projects under construction today are sufficient to meet demand. In the NZE Scenario, a global supply glut forms in the mid-2020s and under construction projects are no longer necessary.

In the STEPS, around USD 190 billion is invested each year to develop upstream gas between 2022 and 2030, and a further USD 40 billion is spent each year on LNG infrastructure. In the APS, total investment spending falls to 80% of STEPS levels by 2030. In the NZE Scenario, upstream investment in natural gas is limited to maintaining supply at existing projects and minimising the emissions intensity of production.

While the sponsors of all LNG projects currently under construction can expect to fully recover their initial capital investment in the STEPS, around two-thirds of these projects are at risk of not doing so in the APS, and up to 75% could fail to do so in the NZE Scenario. In both the APS and NZE Scenario, a good deal of gas would probably end up being sold in an over-supplied market at close to short-run marginal costs, although the degree of exposure to volume and price risk between suppliers and off-takers would depend on contractual arrangements. Some operators, notably in the case of pipelines, can take comfort from projected spending of USD 100 billion each year on hydrogen transport infrastructure in the NZE Scenario by 2050: this could provide a route for them to diversify into low-emissions gases.

### 3.5.3 Coal

**Table 3.7 ⊳ Global coal demand, production and trade by scenario** (Mtce)

| | | | STEPS | | APS | | NZE | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **World coal demand** | **5 218** | **5 807** | **5 007** | **3 465** | **4 377** | **1 530** | **3 257** | **499** |
| Power | 3 108 | 3 769 | 3 030 | 1 799 | 2 578 | 843 | 1852 | 240 |
| Industry | 1 688 | 1 614 | 1 642 | 1 463 | 1 457 | 647 | 1 239 | 234 |
| Other sectors | 422 | 424 | 335 | 203 | 302 | 41 | 167 | 26 |
| *of which abated with CCUS* | *0%* | *0%* | *0%* | *1%* | *0%* | *25%* | *3%* | *81%* |
| Advanced economies | 1 585 | 1 018 | 509 | 245 | 367 | 95 | 266 | 63 |
| Emerging market and developing economies | 3 633 | 4 789 | 4 498 | 3 221 | 3 970 | 1 435 | 2 991 | 436 |
| **World coal production** | **5 235** | **6 122** | **5 007** | **3 465** | **4 337** | **1 530** | **3 257** | **499** |
| Steam coal | 4 069 | 4 888 | 3 974 | 2 669 | 3 388 | 1 135 | 2 457 | 397 |
| Coking coal | 866 | 988 | 886 | 691 | 830 | 350 | 739 | 100 |
| Peat and lignite | 300 | 246 | 146 | 105 | 120 | 45 | 60 | 2 |
| Advanced economies | 1 512 | 1 075 | 650 | 468 | 500 | 199 | 381 | 95 |
| Emerging market and developing economies | 3 723 | 5 047 | 4 357 | 2 998 | 3 837 | 1 331 | 2 876 | 404 |
| **World coal trade** | **948** | **1 164** | **920** | **831** | **803** | **417** | **635** | **129** |
| *Trade as share of production* | *18%* | *19%* | *18%* | *24%* | *19%* | *27%* | *19%* | *26%* |
| **Coastal China steam coal price** | **153** | **196** | **87** | **72** | **71** | **56** | **58** | **45** |

Notes: Mtce = million tonnes of coal equivalent. Coastal China steam coal price reported in USD (2022)/tonne adjusted to 6 000 kcal/kg. See Annex C for definitions.

The aftermath of Russia's invasion of Ukraine led to coal demand reaching an all-time high in 2022, and that led to soaring prices and the disruption of traditional trade flows. Record high coal prices and energy security concerns led to renewed coal investment in China and India, where domestic production was ramped up to reduce reliance on imports, and in Indonesia, a major supplier of these two economies. Elsewhere, countries did not use much additional coal, or not for very long: the increase in demand for coal in the European Union due to the energy crisis in 2022 was equivalent to less than one day of coal demand in China. Many governments, banks, investors – as well as mining companies – continue to show a lack of appetite for investment in coal, particularly steam coal (which is mainly used in the power sector).

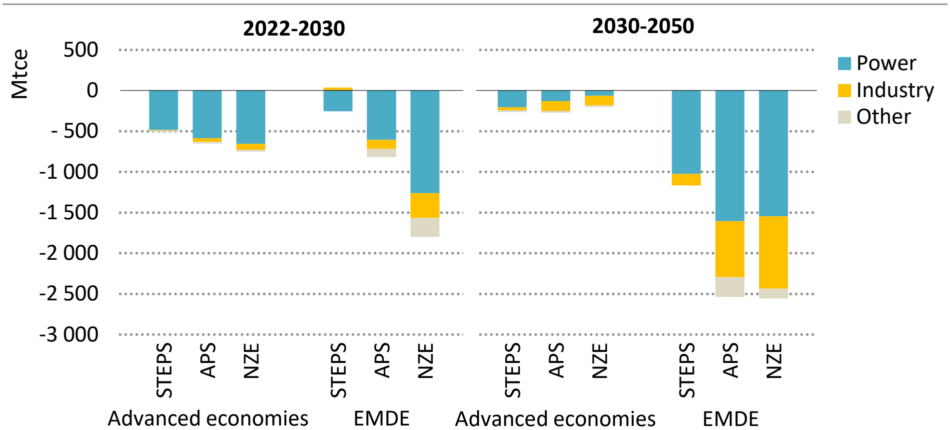


Unabated coal is proving to be a difficult fuel to dislodge from the global energy mix. In advanced economies, there are signs that its share is being structurally eroded by the rapid rise of renewables, but the overall outlook for coal depends to a large extent on developments in emerging market and developing economies. China is especially important in this context, since it accounts for at least half of all coal demand throughout the *Outlook* period across all scenarios. In the power sector, coal transitions are complicated by the relatively young age of coal plants across much of the Asia Pacific region: plants in developing economies in Asia are on average less than 15 years old.

### *Demand*

The outlook for coal is heavily dependent on the strength of the world's resolve to address climate change (Figure 3.27). In the STEPS, coal demand declines gradually. In the APS, it drops 25% below current levels by 2030, and 75% by 2050; coal demand peaks in China in the mid-2020s and in India in the late 2020s. In the NZE Scenario, global demand falls by around 45% by 2030 and 90% by 2050.

**Figure 3.27 ⊳ Change in coal demand by region, sector and scenario, 2022-50**






***Coal demand drops sharply in the NZE Scenario from 2022 and in the APS from 2030, mostly due to pledges from China and India to achieve net zero emissions after 2050***

Notes: Mtce = million tonnes of coal equivalent; EMDE = emerging market and developing economies. Other includes buildings, agriculture and other energy sector.

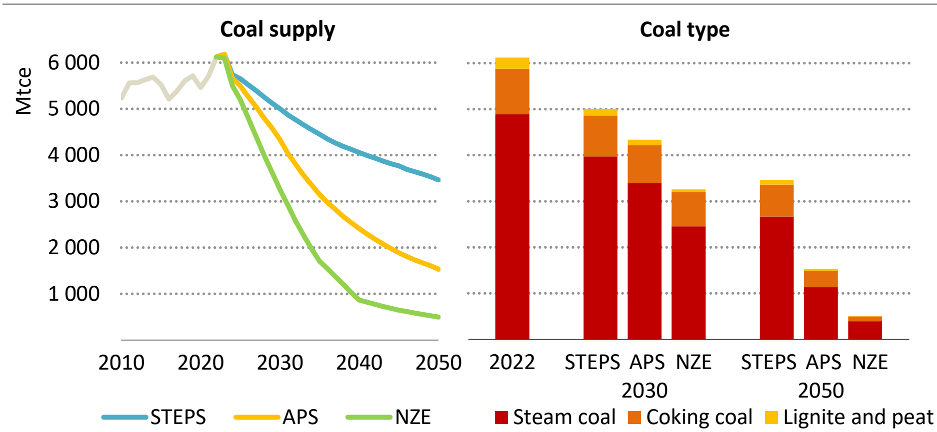
In advanced economies, coal-fired power plants are rapidly replaced by renewables and other low-emissions alternatives in the power sector in all scenarios, and there is a continued focus on replacing coal in the industry sector, where new technologies and efficiency gains help to reduce coal demand in steel production and other industries. In China, coal use also falls in all scenarios, with progress speeding up in the APS from 2030 and in the NZE Scenario from now onwards. In India and other emerging market and developing economies, the outlook for coal varies markedly between scenarios. In the STEPS, coal demand increases to the mid-2030s and then mostly plateaus, with reductions in the power sector being offset by higher demand from the industry sector. In the APS and NZE Scenario, patterns of coal demand are similar to those seen in China.

There is very limited use of CCUS with coal in the STEPS. Around 400 million tonnes of coal equivalent (Mtce) of coal demand in 2050 is equipped with CCUS in both the APS and NZE Scenario: this equates to around 25% of demand in the APS and more than 80% in the NZE Scenario. Unabated coal use drops by over 98% between 2021 and 2050 in the NZE Scenario.

### *Production*

Global coal production rose above 6 billion tonnes of coal equivalent in 2022, its highest level ever. Energy prices and energy security concerns led China, India, Indonesia and other major coal producers to expand domestic supply, but this increase in supply may be short lived (Figure 3.28). New mine developments, especially those which would produce steam coal, are facing concerns about future demand, difficulties accessing finance and scrutiny on environmental, social and governance issues.

**Figure 3.28 ▷ Global coal supply and type by scenario**






***Coal production falls by nearly 45% between 2022 and 2050 in the STEPS, 75% in the APS and over 90% in the NZE Scenario; coking coal supply declines much less than steam coal***

Note: Mtce = million tonnes of coal equivalent.

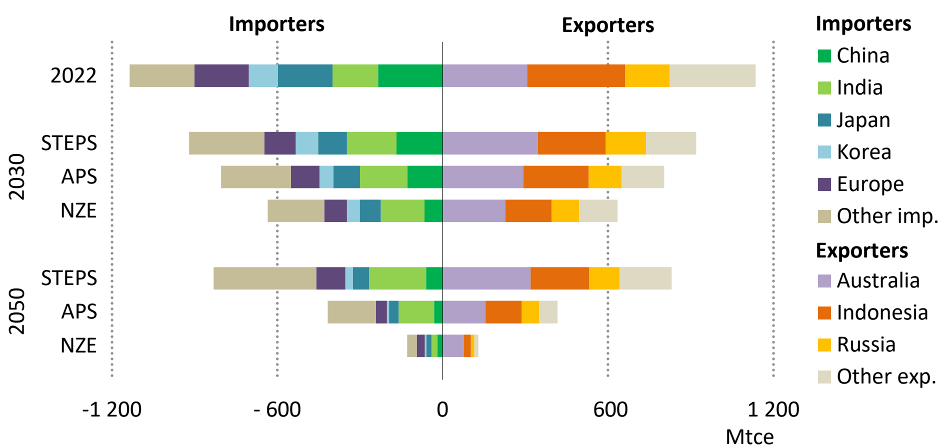
In the STEPS, global coal supply falls gradually to 2030, with increases in India offset by reductions in advanced economies, and then drops by about 30% from 2030 to 2050. In the APS, supply declines by 30% to 2030 and by 75% to 2050, compared to 2022 levels. Steam coal falls by over 3 750 Mtce by 2050 (75% reduction), while coking coal falls by less than 650 Mtce (65% reduction). Production in China falls by 2 680 Mtce (80% reduction), accounting for close to 60% of the global decline in supply. Production in India falls by 260 Mtce (60% reduction). The leading exporters, Australia and Indonesia, see production fall by around 85% and 65% respectively between 2022 and 2050. In the NZE Scenario, global coal production declines by 45% to 2030 and a further 85% between 2030 and 2050. Remaining production in 2050 is around 400 Mtce of steam coal and 100 Mtce of coking coal.



### *Trade*

The Asia Pacific region is the main driver of international coal trade, accounting for around three-quarters of global coal imports in 2022 (Figure 3.29). China was the largest importer (around 230 Mtce), while Australia and Indonesia were the two main coal exporters, together accounting for 60% of coal exports in 2022. Australia alone provided half of all coking coal exports.

**Figure 3.29 ▷ Top coal importers and exporters by scenario, 2022, 2030 and 2050**






*Coal trade diminishes in volume but increases as a share of production to 2050 in all scenarios*

Note: Other imp. = other importers; Other exp. = other exporters; Mtce = million tonnes of coal equivalent.

In the STEPS, India becomes the world's largest coal importer in the late 2020s: its imports rise by almost 10% to 2030 while China's decrease by nearly 30%. In 2050, India imports 25% more coal than in 2022, most of which is coking coal. This changes the dynamics of exporting economies: Australian exports, which are around 50% coking coal, increase by 5% to 2050, while Indonesia, mainly a steam coal exporter, sees exports fall by 40%.

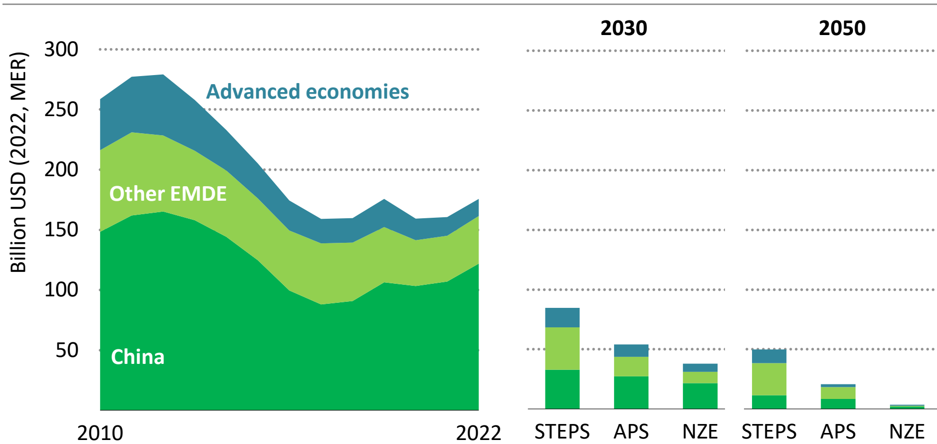
In the APS, global coal trade falls by 30% to 2030 and by 65% to 2050 compared to 2022. Around 420 Mtce of coal is imported in 2050, mainly by countries with large distances between domestic production and consumption hubs and where differences in coal quality require domestic production to be supplemented with imports. Imports of coking coal in India increase by more than 55% to 2030 as it expands steel production. Indonesian exports drop by nearly 35% to 2030 as the market for steam coal shrinks. Australia produces a higher proportion of coking coal than Indonesia and initially fares better, with coal exports falling by 5% to 2030, although its exports subsequently fall by over 45% between 2030 and 2050.

In the NZE Scenario, global coal trade declines by 90% between 2022 and 2050 as clean energy technologies progressively and speedily displace coal across the energy system. In 2050, advanced economies import small quantities of coal that is mostly used with CCUS to produce steel or supply power during demand peaks.

### *Investment*

Despite renewed interest in 2022, investment in coal supply and coal-fired power worldwide has fallen around 15% since 2015. Most new projects in recent years have been in China and India, which together accounted for around 80% of global investment in coal-fired power plants and supply in 2022 (Figure 3.30).

**Figure 3.30 ▷ Average annual investment in coal supply and coal-fired power generation by region and scenario, 2010-2050**




IEA. CC BY 4.0.

***Investment in coal falls in each scenario this decade: investment in 2030 is about 50% lower than recent years in the STEPS, 70% lower in the APS and 80% lower in the NZE Scenario***

Notes: EMDE = emerging market and developing economies. Includes demand from coal-fired power plants equipped with carbon capture.

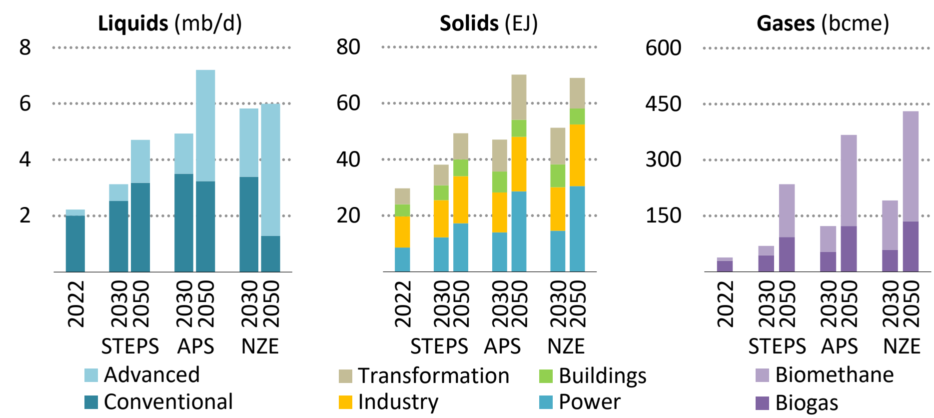
### 3.5.4 Modern bioenergy

Modern bioenergy comes in solid, liquid and gaseous forms. Together these fuels make up more than half of global renewables supply today. Overall production increased 5% in 2022 to reach 40 EJ.

Solid bioenergy currently accounts for the vast majority of production. It is mostly derived from organic waste sources, such as forestry residues or municipal solid waste, and often pelletised for use in power generation or industry, with a small but important share used in the buildings sector. In the STEPS, modern solid bioenergy reaches 44 EJ in 2030 and 57 EJ in 2050. In the APS and the NZE Scenario, production rises to more than 70 EJ by 2050. This provides dispatchable renewable power, a cost-competitive source of clean heat for industry and an alternative to the traditional use of solid biomass in emerging market and developing economies.

3

**Figure 3.31 ▹ Global bioenergy supply by type and scenario, 2022-2050**





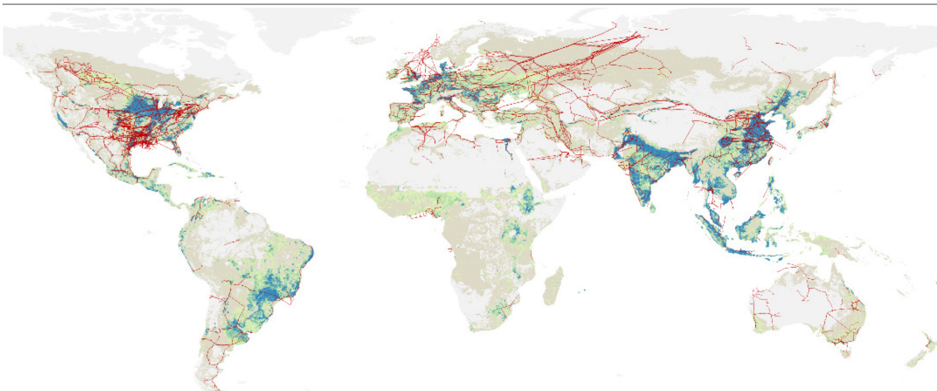

***Full sustainable potential of bioenergy of around 100 EJ is fully exploited in the APS and NZE Scenario, with its different forms used across the clean energy economy***

Note: mb/d = million barrels per day; EJ = exajoules; bcme = billion cubic metre equivalent.

Liquid biofuels production increased by nearly 5% in 2022 to 2.1 mb/d. In the STEPS, production increases at around 4% annually, reaching 3 mb/d in 2030 and 4 mb/d in 2050. In the APS, it rises faster as liquid biofuels are increasingly used to help meet Nationally Determined Contribution and net zero emissions targets. In the NZE Scenario, liquid biofuels use expands more rapidly to 2030 than in the APS but then decreases below the level in the APS by 2050. The reduced demand for liquid biofuels in the NZE Scenario in 2050 compared with the APS is driven by several factors, including faster uptake of EVs, more rapid efficiency improvements in road vehicles, shipping vessels and airplanes, and reduced demand for aviation due to behaviour change.

Biogas and biomethane are the smallest part of the bioenergy supply chain, but there is growing interest in biomethane in particular as a source of low-emissions domestic gas supply, especially in Europe. Worldwide around 300 bcm of potential production from agricultural wastes and residues lies within 20 kilometres of major gas pipeline infrastructure, providing a good match with possible large-scale production and injection into gas networks (Figure 3.32). In the STEPS, combined biogas and biomethane production nearly doubles by 2030 to reach 80 billion cubic metres equivalent (bcme). In all scenarios, the share of biomethane in total biogas demand increases, driven in large part by the value attached to its use as a dispatchable source of energy and drop-in substitute for natural gas. In the APS, total biomethane production reaches 240 bcme by 2050; in the NZE Scenario, this rises to nearly 300 bcme.

**Figure 3.32 ▷ Assessed yearly biomethane potential from agricultural wastes and residues, and location of natural gas transmission pipelines**




*Around 300 bcm of biomethane could be produced from agricultural wastes, upgraded to meet pipeline quality standards and subsequently injected into nearby gas pipelines*

Source: IEA analysis based on Global Energy Monitor (2022); UN FAO (2023).

Total modern bioenergy supply is around 65 EJ in the APS by 2030 and over 70 EJ in the NZE Scenario (Figure 3.31). By 2050, the total sustainable potential assessed by the IEA of around 100 EJ is fully exploited in both the APS and the NZE Scenario, with large increases in the use of organic wastes and short rotation woody crops more than offsetting a decline in the use of conventional bioenergy crops and the traditional use of solid biomass. Around 10% of total bioenergy use in the NZE Scenario is equipped with bioenergy carbon capture and storage (BECCS) by 2050, and this plays a critical role in offsetting residual emissions. The share of advanced liquid biofuels in total production rises from more than 10% today to 55% in 2050 in the APS and around 75% in the NZE Scenario. In all scenarios, maximising the use of advanced biofuels helps to expand biofuel production in a way that has minimal impact on land use, food and feed prices.[7]

[7] Advanced biofuels are produced from non-food crop feedstocks, which can deliver significant life cycle greenhouse gas emissions savings compared with fossil fuel alternatives and do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts.

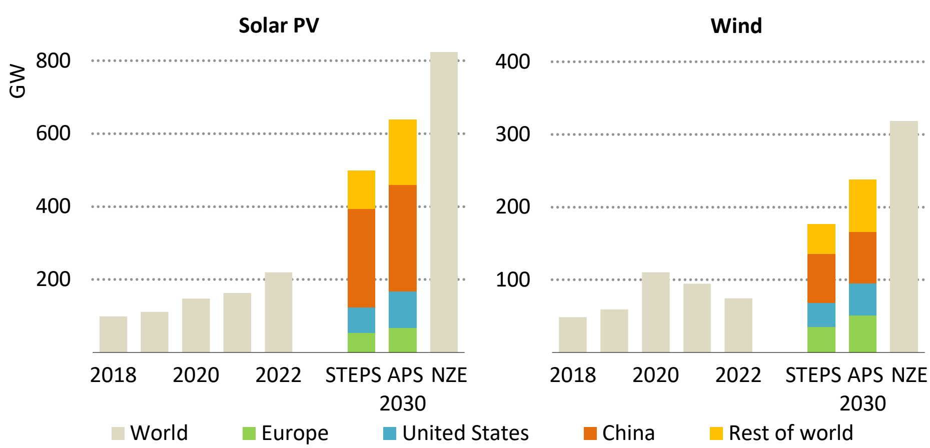
## 3.6 Key clean energy technology trends

### *Solar PV and wind*

Solar PV and wind are set to dominate power capacity additions. Globally, they account for over 70% of total capacity additions between now and 2050 in all *WEO* scenarios. They do so because they are now the cheapest new sources of electricity in most markets, widely available and enjoy policy support in over 140 countries.

Global solar PV capacity additions, including both rooftop solar and utility-scale projects, reached a record high of 220 GW in 2022, twice the level in 2019 and more than seven-times the level ten years earlier. In the STEPS, capacity additions rise to 500 GW in 2030 and 580 GW in 2050: this includes replacements of solar panels that typically last 20-30 years (Figure 3.33). In the APS, capacity additions rise faster, reaching 640 GW in 2030 and 770 GW in 2050. In the NZE Scenario, capacity additions reach 820 GW by 2030 and the same level is achieved in 2050. Solar PV on buildings, including rooftops, represents about half of total solar PV capacity additions today, and this more than doubles to 2030 in all three scenarios. Off-grid solar home systems play a vital role in closing electricity access gaps in sub-Saharan Africa, and their use increases too (see Chapter 4, section 4.4). However, utility-scale projects make up the majority of new solar capacity in all scenarios, in large part because of their significantly lower levelised costs of electricity.

**Figure 3.33 ▷ Solar PV and wind capacity additions by scenario, 2018-2030**






***Solar PV and wind capacity additions double by 2030 in the STEPS and expand nearly fourfold in the NZE Scenario***

China is the largest solar PV market, accounting for 45% of all capacity additions in 2022. It maintains its leading role in all scenarios, accounting for about half of global cumulative additions from 2023 to 2050 in the STEPS and about 40% in the APS. Its rapid growth in deployment is supported by huge domestic solar manufacturing capacity (see Chapter 1). In 2022, the next largest markets for solar PV were the European Union (17% of global additions), United States (9%) and India (8%). These remain leading markets in all scenarios, complemented by increasing deployment in Southeast Asia, Africa and the Middle East.

Global wind capacity additions dropped to 75 GW in 2022. While this level is nearly a third below the peak in 2020, it remains above deployment levels before 2020. By the end of this decade, global wind capacity additions rise to 175 GW per year in the STEPS as technology continues to improve and costs to fall, though additional manufacturing capacity is required to meet this level of demand. By 2050, annual deployment levels reach 195 GW, taking into account replacements of ageing wind turbines. In the APS, 240 GW of wind capacity are added in 2030, increasing to 310 GW in 2050. In the NZE Scenario, these figures rise to 320 GW in 2030 and 350 GW in 2050. Offshore installations account for just 15% of wind capacity additions today, but their share roughly doubles by 2030 across all scenarios.

China is the largest market for wind power, as it is for solar PV. It accounted for half of global capacity additions in 2022 and is responsible for around 40% of global cumulative wind capacity additions from 2023 to 2050 in the STEPS and around 28% in the APS. The European Union (18% of global additions), United States (11%) and Brazil (4%) were other leading markets in 2022 and continue to be so across all scenarios.

Scaling up and maintaining much higher levels of solar PV and wind power generation requires action to address a number of barriers, including those related to:

- *Permitting and licensing of new projects*. Work to complete the necessary regulatory steps for new projects, including environmental assessments where applicable, can delay individual projects by years and slow market growth. Standardising and streamlining these processes, while ensuring that they involve local communities, will be critical to clean energy transitions (IEA, 2023a).
- *Grid development and connections*. Modernising, digitalising and reinforcing existing electricity networks can take years, and the same is true for the addition of new grid connections. Streamlining permitting and licensing processes would help with this, but timely grid development also calls for improved long-term planning and the scaling up of investment to support the rapid deployment of wind and solar PV (IEA, 2023c).
- *Expanding wind manufacturing capacity and improving the financial health of wind supply chains*. Despite low levelised costs of electricity and recent market growth, the manufacture of turbines and other equipment needed for wind power involves thin profit margins as a result of uncertainty about commodity prices and the way that auction schemes are operated. Measures to mitigate these risks, including through contract terms, are needed to ensure that they do not endanger the wind industry and impede clean energy transitions.
- *Enhancing power system flexibility to integrate rising shares of solar PV and wind*. Action to enhance power system flexibility is essential to make the best use of solar PV and wind. Battery storage and demand response have a major part to play in meeting short-

term flexibility needs, while hydropower and thermal sources will play a central part in the provision of seasonal flexibility (see Chapter 4). Reliable supplies of critical minerals will also be essential.

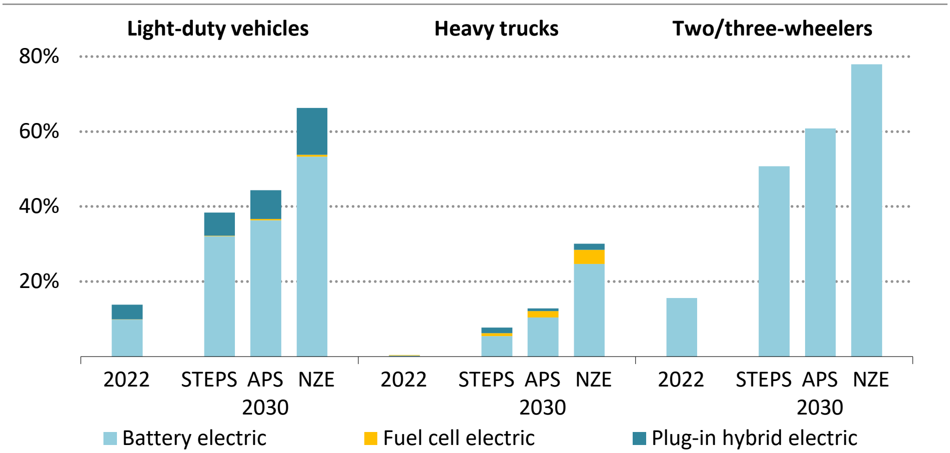
### *Electric vehicles*

The share of EVs cars in global car sales more than tripled to 14% in the last two years. Further record sale levels are expected in 2023, particularly in the United States. China is the most important market for electric cars: more than half of all the electric cars on the road today are in China, which has already exceeded its 2025 target for new energy vehicle sales.



In the STEPS, nearly 40 million electric cars are purchased in 2030, accounting for nearly 40% of all vehicle sales. This is well above the 25% projection for 2030 in the *WEO-2022* and not far behind the level of purchases in the APS (Figure 3.34). This more optimistic outlook is due to new voluntary EV targets by major automakers as well as new vehicle standards, mandates and subsidies in China, European Union and United States. In the NZE Scenario, the share of electric cars account for two-thirds of total sales by 2030. If they all come to fruition, plans that have been announced for battery manufacturing capacity would be sufficient to meet demand for EV batteries in the NZE Scenario in 2030.

**Figure 3.34 ▷ Global share of electric vehicle sales by type and scenario, 2022 and 2030**





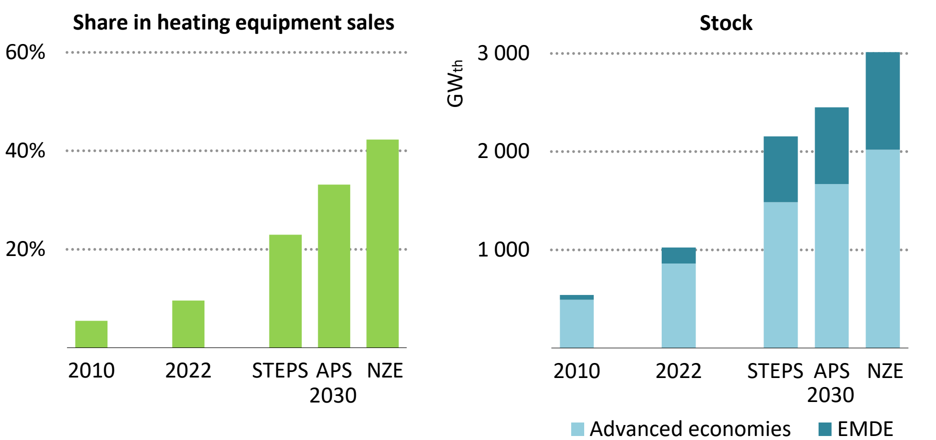

***Electric car sales shares nearly triple in the STEPS, around 40% below NZE Scenario levels, though electric truck sales in the STEPS are nearly four-times lower than in the NZE Scenario***

Two/three-wheelers already have the highest electrification shares today of any road transport mode, in particular in emerging market and developing economies, and that looks set to continue as infrastructure requirements and cost premiums are limited. However, less than 1% of heavy trucks sold today are electric, and limited progress is made in the STEPS, where sales in 2030 are nearly four-times lower than in the NZE Scenario. More widespread deployment of charging infrastructure is needed to increase the rate of heavy trucks electrification, especially in emerging market and developing economies. Deployment levels are higher for electric buses, which are already cost competitive on a lifetime basis and are often subsidised by local municipalities.

### *Heat pumps*

Global sales of heat pumps in the buildings sector increased by 11% in 2022, marking the second year of double-digit growth for this central technology in the world's transition to secure and sustainable heating. Heat pumps overtook sales of fossil fuel-based heating systems in key markets such as France and the United States, while sales doubled in various European countries where financial incentives and bans on fossil fuel boilers have helped to build momentum (section 3.3.3). Manufacturing capacity is expanding rapidly, and further announcements from key manufacturers are expected, driven by new deployment targets, direct industry support and incentives for consumers.

**Figure 3.35 ▷ Global heat pump sales and stock by scenario, 2010-2030**






***Share of heat pumps in heating equipment sales doubles by 2030 in the STEPS and increases fourfold in the NZE Scenario, tripling global heat pump capacity***

Note: EMDE = emerging market and developing economies; $GW_{th}$ = gigawatts thermal.

Today, heat pumps account for around 10% of sales of residential heating equipment worldwide. Sales growth is particularly strong for air-to-water heat pumps in Europe where they typically replace gas-fired boilers. By 2030, the share of heat pumps in heating equipment sales is set to more than double in the STEPS and to reach around a third in the APS (Figure 3.35). The global installed capacity of heat pumps more than doubles by 2030 in the STEPS from around 1 000 gigawatts thermal ($GW_{th}$) in 2022, while APS deployment levels are close to 2 500 $GW_{th}$ by 2030. Between 2022 and 2030, global heat pump deployment saves more than 5 EJ of fossil fuels in the APS. However, upfront costs often remain high, particularly for low income households, while the design of electricity tariffs and energy taxation still put heat pumps at a disadvantage relative to fossil fuel boilers in some countries. Meeting existing targets also requires more installers and faster progress in colder climates, multi-family apartment buildings and homes with retrofit requirements. Efforts are ramped up further to tackle these obstacles in the NZE Scenario, where the global heat pump stock expands to nearly 3 000 $GW_{th}$ by 2030: more than two-thirds of which is installed in advanced economies.



### *Hydrogen*

Progress in scaling up low-emissions hydrogen continues apace, with investment in projects reaching USD 1 billion in 2022 and a raft of new policies around the world boosting confidence.[8] In May 2023, a new record was set for the world's largest operational electrolyser plant – a 260 megawatt facility in China that will replace hydrogen from natural gas in an oil refinery – and a 2 GW project in Saudi Arabia reached a final investment decision after the company, Air Products, agreed to shoulder the off-take risk for its ammonia trade. Increasingly, such projects are linked to dedicated renewable electricity supplies rather than relying mostly on the electricity grid. If all announced projects come to fruition, more than 400 GW of electrolysis could be operational by 2030. Two projects in Canada and the United States have started construction to produce hydrogen from natural gas with a target of 95% $CO_2$ capture, which would result in a combined hydrogen capacity equivalent to 1.4 GW of electrolysis (at a 90% capacity factor) (IEA, 2023d).

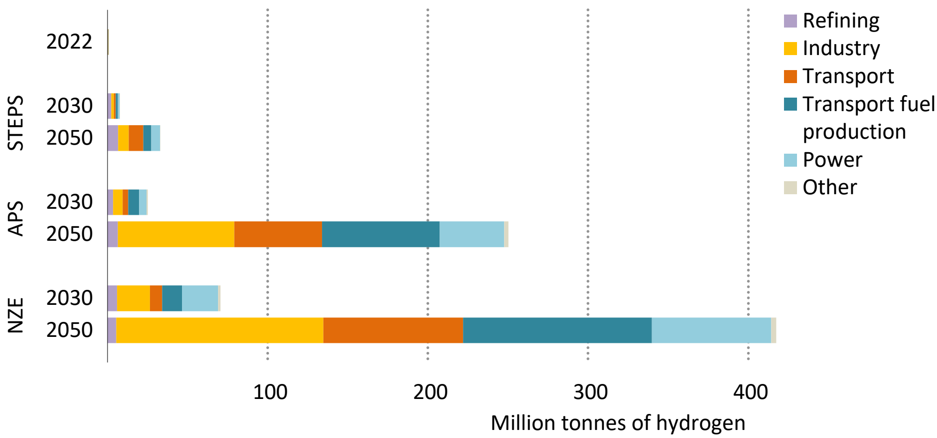
The near-term outlook is clouded by cost inflation, uncertainty around policy details and supply chain bottlenecks. In the STEPS, 7 Mt of low-emissions hydrogen is produced in 2030, most of which replaces existing supplies of hydrogen for ammonia plants and refineries (Figure 3.36). In the APS, low-emissions hydrogen demand reaches 25 Mt in 2030, and this rises in the NZE Scenario to 69 Mt. These trajectories depend on much stronger policies than those in the STEPS to bolster demand, finance demonstration projects and support infrastructure expansion.

Dilemmas facing electrolyser manufacturers illustrate some of the value chain challenges for low-emissions hydrogen. Taken together, the available manufacturing capacities announced by electrolyser manufacturers total 14 GW, half of which is in China, where the domestic market is increasing rapidly. However, output to date has been much lower, estimated at just above 1 GW in 2022, and many of the plants in development are progressing slowly because hydrogen producers are reluctant to commit to electrolyser purchase contracts at current prices, which have risen due to inflation. Meanwhile, a fall in natural gas prices and a corresponding increase in relative costs for electrolysis hydrogen have spurred competition to maintain profit margins among players along the value chain. Without the opportunity to get large-scale systems installed quickly and used commercially, manufacturers cannot

[8] Low-emissions hydrogen includes: those produced from water using electricity generated by renewables or nuclear, bioenergy, other fuels equipped to avoid greenhouse gas emissions, e.g. via CCUS with a high capture rate and low upstream methane emissions; other sources with an equivalent $CO_2$ intensity (IEA, 2023e). Demand for low-emissions hydrogen includes its use to produce hydrogen-based fuels.

accumulate sufficient operating hours to provide industry standard performance guarantees, exacerbating risks and inflating costs for the most efficient designs. The scale-up of production in all scenarios is predicated on a break in this cycle and better co-ordination of manufacturing investments, low-emissions hydrogen production projects and demand creation.

**Figure 3.36 ⊳ Global hydrogen demand by sector and scenario, 2022-2050**






***Demand for low-emissions hydrogen increases 60% per year to 2030 in the APS, but despite continued strong growth, by 2050 it is at only 60% of the level required in the NZE Scenario***

Notes: Other includes the buildings and agriculture sectors. Transport fuel production includes inputs to hydrogen-based fuels and liquid biofuel upgrading. Ammonia for power generation is included in power in units of hydrogen input to ammonia plants.

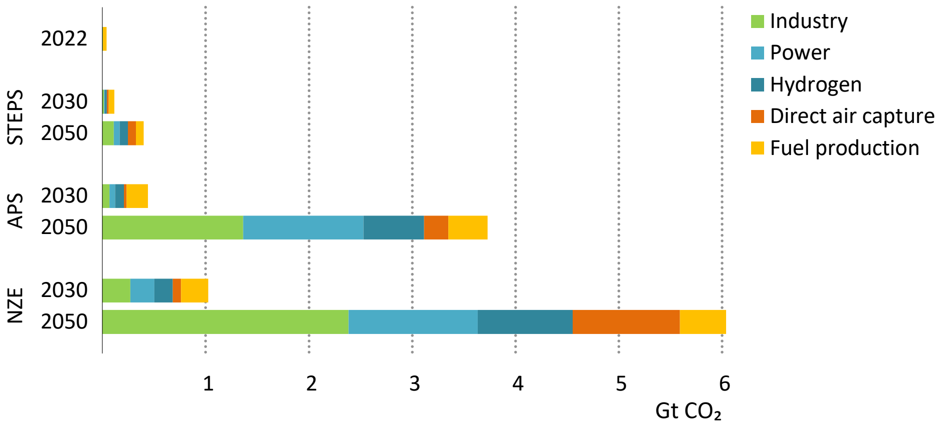
### *Carbon capture, utilisation and storage*

For the first time in a decade, multiple CCUS projects are in construction around the world. Total investment in projects reached a record USD 3 billion in 2022. The outlook for CCUS is for continued growth. Momentum is fuelled by activity in North America, where more generous tax credits and new grant funding programmes are the driving forces behind announcements of over 100 projects across the CCUS value chain since January 2022. The global project pipeline now represents over 400 Mt $CO_2$ capture capacity vying to be online by 2030. In the United States, where a fixed amount of funding is available per tonne of $CO_2$ safely stored, many of the projects focus on capturing $CO_2$ from bioethanol and hydrogen production, since these are among the cheapest options. Notable progress also is being made elsewhere, with investment in large-scale projects in Canada and China, and key regulatory advances in Canada, Denmark, Indonesia, Japan and Malaysia.

Current policies, however, are wholly insufficient to support the outcomes that match government net zero emissions pledges. In the STEPS, CCUS deployment grows nearly threefold from the 40 Mt $CO_2$ captured in 2022 to 115 Mt $CO_2$ in 2030 (Figure 3.37), three-quarters of which is in North America and Asia Pacific. This increase is dwarfed by the projections in the APS, which sees CCUS increase more than tenfold in the period to 2030.The APS also projects more regional diversity, with the share of captured $CO_2$ in Europe rising to above 15% of the global total, over half of it in the European Union. The requirements of the NZE Scenario are even more ambitious, as more countries and sectors adopt best available technologies to mitigate emissions from industrial plants and to meet global demand for low-emissions hydrogen. In the NZE Scenario, around 1 Gt $CO_2$ is captured in 2030, including 265 Mt $CO_2$ from bioenergy and direct air capture, almost 90% of which is geologically stored.



**Figure 3.37 ⊳ Global $CO_2$ captured by source and scenario, 2022-2050**






*More CCUS projects become competitive as climate ambitions rise and sectors need to fully mitigate emissions; NZE Scenario projects 6 Gt $CO_2$/year captured and stored by 2050*

Reaching the levels of CCUS projected in the APS and NZE Scenario requires strong policy support, including measures to facilitate strategic investment in infrastructure. For example, the total length of existing $CO_2$ pipelines is 9 500 kilometres (km), which needs to increase to between 100 000 and 600 000 km in order to facilitate the storage of 5.5 Gt $CO_2$ and utilisation of a further 0.6 Gt $CO_2$ in the NZE Scenario by 2050 (IEA, 2023f). The high end of this range is a similar order of magnitude to the more than 1 million km of natural gas transmission pipelines that have come online over the past century. Enabling such a huge scale-up, and a parallel investment in seaborne $CO_2$ transport, requires new businesses that offer commercial $CO_2$ transport and storage services. There are signs that these are emerging in some regions, exemplified by the development of the Northern Lights $CO_2$ storage resource in Norway, where there are now agreements that could lead to $CO_2$ being transported to the site from facilities in Denmark, Netherlands, Norway and United Kingdom. The European Commission has proposed that oil and gas producers take legal responsibility for ensuring the development of European $CO_2$ storage resources, initially targeting 50 Mt $CO_2$/year of capacity by 2030. Policy developments of this type have the potential to accelerate progress.

# Secure and people-centred energy transitions

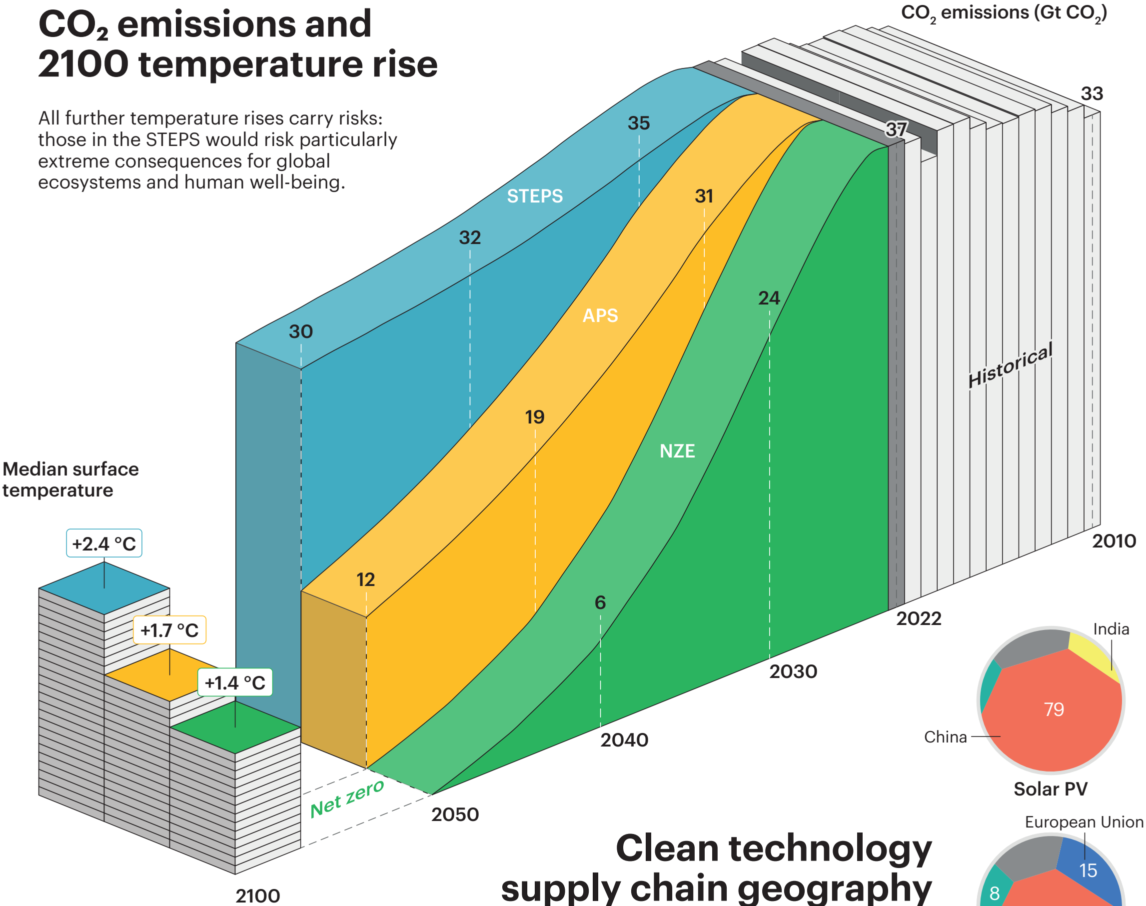
## Critical ingredients for success


### SUMMARY

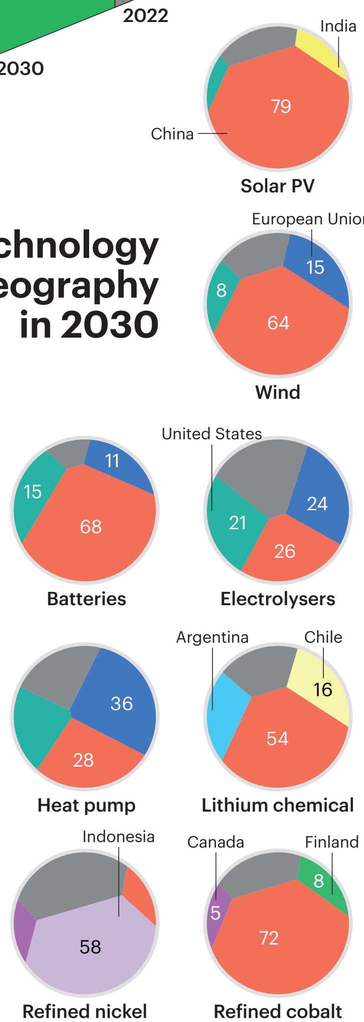
- Secure energy transitions depend on keeping the global average surface temperature rise below 1.5 °C. The temperature today is around 1.2 °C above pre-industrial levels, and global emissions have not yet peaked. In the Stated Policies Scenario (STEPS), the temperature rises to 1.9 °C in 2050 and 2.4 °C in 2100. This is 0.1 °C lower than projected in the STEPS from the *World Energy Outlook-2022*, but far above the levels of the Paris Agreement. In the Announced Pledges Scenario (APS), the temperature rise in 2100 is 1.7 °C; in the Net Zero Emissions by 2050 (NZE) Scenario, the temperature peaks in mid-century and falls to around 1.4 °C in 2100.
- Energy transitions do not bring an end to traditional risks to energy security. Global oil and gas trade becomes increasingly focussed on flows between the Middle East and Asia, exposing importers to a variety of risks. Electricity faces rising short-term flexibility needs which can be met through demand response and storage, and rising seasonal flexibility needs which can be met by hydropower and thermal sources, all enabled by expanding and modernising grids.
- Energy transitions also bring new risks to energy security. One set of risks relate to supply chains for clean energy technologies and for critical minerals. Supply chains for both are highly geographically concentrated. Diversified investment to meet growing demand can help, but international partnerships will also be necessary.
- Another set of risks relate to the people-centred aspects of energy transitions, including what they mean for access, affordability and employment. The number of people without access to clean cooking (2.3 billion) and electricity (760 million) today fall by around 15% to 2030 in the STEPS, by two-thirds in the APS, and to zero in the NZE Scenario in response to measures to improve access. Household energy bills in advanced economies fall by nearly 20% in the STEPS to 2030, as fossil fuel use drops and energy efficiency gains accrue. In emerging market and developing economies, fossil fuel subsidies need to be phased out carefully to limit impacts on household budgets. Estimates of new jobs created range from 7 million in the STEPS to 30 million in the NZE Scenario: these increases outweigh losses in fossil fuel and related industries but will often be in new locations and require new skills.
- Prospects for secure and people-centred energy transitions depend on securing high levels of investment. Energy investment levels show encouraging trends for renewables and electric vehicles, but there are large energy investment gaps in emerging market and developing economies other than China, and investment in most end-use areas is lagging in all regions. The expected level of oil and gas investment in 2023 is similar to the amounts required in the STEPS in 2030 and far above the levels needed in the APS and NZE Scenario, implying that the oil and gas industry does not expect there to be any significant near-term reduction in demand.

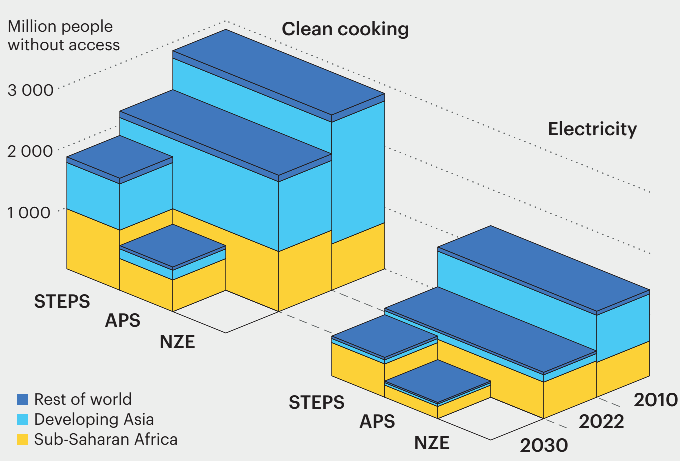
# $CO_2$ emissions and 2100 temperature rise

All further temperature rises carry risks: those in the STEPS would risk particularly extreme consequences for global ecosystems and human well-being.




# Clean technology supply chain geography in 2030




# Access to modern energy

Transitions depend on placing people at the centre of discussions. Particular help is needed for those that currently lack access to modern energy services.

## 4.1 Introduction

Russia's invasion of Ukraine turned strains in energy supply related to the Covid-19 pandemic into a full-blown energy crisis. Consumers around the world were exposed to higher energy bills and supply shortages, providing a stark reminder of the importance of secure, affordable and people-centred energy transitions, and of the risks that could undermine such transitions. Traditional risks to energy security do not disappear in energy transitions, and there are potential new vulnerabilities in a more electrified and renewables-rich system. New risks arise in addition from the impact that our changing climate is producing on weather patterns. Successful transitions also depend on placing people at the centre of discussions about the future of energy: they cannot be achieved without sustained support and participation from citizens, and particular help is needed for those that currently lack access to modern energy services.



This chapter examines several key aspects of people-centred and secure energy transitions. It is divided into four sections:

- First, it highlights the nature and scale of the risks posed in our projections by a range of energy-related environmental hazards, including carbon dioxide and methane emissions, and examines their implications for the global temperature rise and air pollution.
- Second, it reviews how traditional and new energy security hazards play out in the scenario projections. Traditional fuel security risks persist against a backdrop of more fragmented international energy markets, while new risks arise for electricity security as both power supply and demand become more variable. In addition, there are major uncertainties about the resilience of clean energy supply chains, including for critical minerals.
- The third section further develops the people-centred aspects of energy transitions, starting with the provision of access to electricity and to clean cooking fuels. It examines the implications of the scenario projections for the affordability of energy supply and energy employment, as well as the behavioural changes needed to achieve rapid energy transitions.
- Ultimately, the prospects for affordable, sustainable and secure energy supply boil down to questions about investment. The fourth section discusses capital flows to the energy sector and looks at what faster energy transitions mean for investment in fossil fuels.

## 4.2 Environment and climate

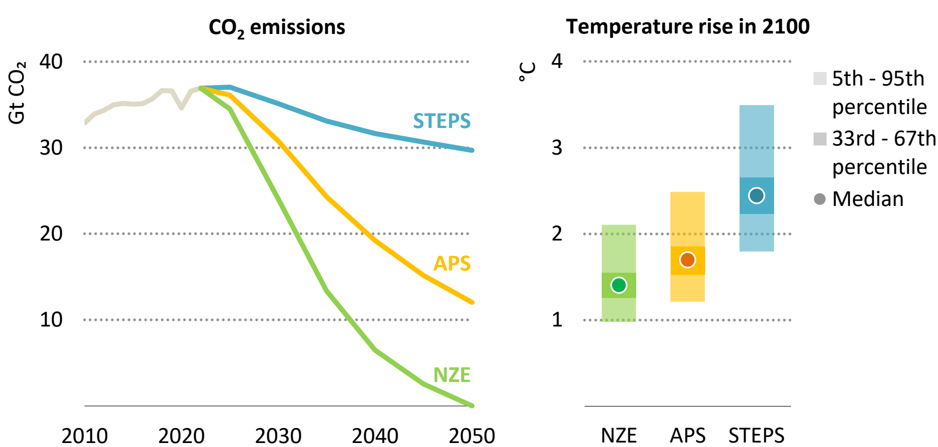
### 4.2.1 Emissions trajectory and temperature outcomes

#### *Emissions and temperature outcomes by scenario*

The global average surface temperature rise now stands at around 1.2 degrees Celsius (°C) above pre-industrial levels. This year has seen a number of extreme weather events, including heat waves and droughts in many parts of the world. These have had major impacts on those affected by them. They have also put significant strain on power systems by curtailing supply from sources like hydro and thermal power, and dramatically increasing demand for space cooling.

Global energy-related $CO_2$ emissions rose to an all-time high of 37 gigatonnes of carbon dioxide (Gt $CO_2$) in 2022. In the Stated Policies Scenario (STEPS), emissions remain largely flat until the late 2020s and then decline slowly to 30 Gt $CO_2$ in 2050. In the Announced Pledges Scenario (APS), emissions fall by just over 2% per year to 31 Gt $CO_2$ in 2030 and then fall further to 12 Gt $CO_2$ in 2050. In the Net Zero Emissions by 2050 (NZE) Scenario, emissions drop by more than 5% per year to 24 Gt $CO_2$ in 2030 and then fall to net zero in 2050 (Figure 4.1). The NZE Scenario also assumes rapid reductions in $CO_2$ emissions from land use, which reach net zero just after 2030, and in emissions of all non-$CO_2$ greenhouse gases.

**Figure 4.1 ⊳ Global energy-related and industrial process $CO_2$ emissions by scenario and temperature rise above pre-industrial levels in 2100**






***Temperature rise in 2100 is 2.4 °C in the STEPS and 1.7 °C in the APS: it peaks at just under 1.6 °C around 2040 in the NZE Scenario and then declines to about 1.4 °C by 2100***

Note: Gt $CO_2$ = gigatonnes of carbon dioxide; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.

Source: IEA analysis based on outputs of MAGICC 7.5.3.

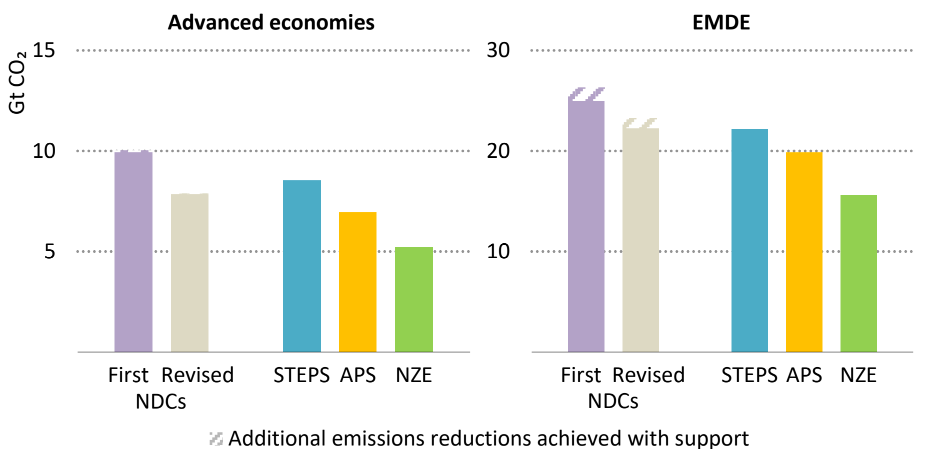
In the STEPS, the global average surface temperature increases to 1.9 °C above pre-industrial levels around 2050 and is on track for 2.4 °C in 2100 and still higher temperatures thereafter.[1] Inherent uncertainties in the earth's response to future emissions mean that there is a one-third probability of the temperature rise exceeding 2.6 °C in the STEPS in 2100, and a one-in-twenty chance of it exceeding 3.5 °C. In the APS, the temperature rises more slowly, especially after 2030, and reaches around 1.7 °C in 2100. In the NZE Scenario, the temperature rise peaks just below 1.6 °C around 2040 before falling back to around 1.4 °C in 2100. All further temperature rises carry risks: those in the STEPS would risk particularly extreme consequences for global ecosystems and human well-being.

4

### *How big are the implementation and ambition gaps?*

The Paris Agreement requires all countries to develop, submit and implement Nationally Determined Contributions (NDCs) and to set a schedule for updating them to increase ambition. As of September 2023, 168 NDCs had been submitted, covering 195 Parties to the United Nations Framework Convention on Climate Change (UNFCCC), and nearly 90% had been updated since the first NDC round.

**Figure 4.2 ▷ Projected $CO_2$ emissions from fuel combustion under first and revised NDCs and by scenario in 2030**






***Achieving targets in the revised NDCs would reduce emissions by 5 Gt $CO_2$ from the level in the first round, nevertheless substantial implementation and ambition gaps remain***

Notes: EMDE = emerging market and developing economies. Additional emissions reductions achieved with support refers to the difference between unconditional and conditional NDCs.

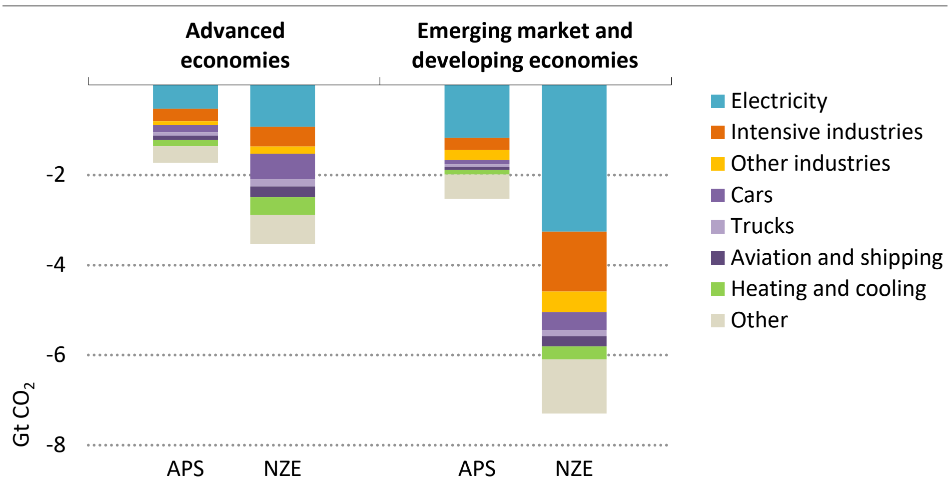
[1] Temperature rise estimates quoted in this section refer to the median temperature rise calculated using the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC 7.5.3). All changes in temperatures are relative to 1850-1900 and match the IPCC 6th Assessment Report definition of warming of 0.85 °C between 1995-2014 (IPCC, 2021).

The most recent submissions have lowered projected emissions in 2030 by around 5 Gt $CO_2$ from the NDCs first submitted in 2016, if all targets conditional on international support are reached (Figure 4.2). For advanced economies, achieving the revised NDCs would lower emissions in 2030 by around 2.1 Gt $CO_2$ compared with the first submissions. In emerging market and developing economies, emissions in 2030 under the revised NDCs would be around 2.8 Gt $CO_2$ lower than in the first round of submissions.

In advanced economies, there is a 0.7 Gt $CO_2$ gap between emissions projected for 2030 in the revised NDCs and the STEPS, which indicates that countries have not yet introduced all the specific policies needed to achieve their NDCs. In emerging market and developing economies, the situation is reversed, with emissions in the STEPS projections 1 Gt $CO_2$ lower in 2030 than under their revised unconditional NDCs. This indicates that their current policies provide scope for their NDCs to be made more ambitious.

In both advanced economies and emerging market and developing economies, there is a large implementation gap between the STEPS and the APS and a large ambition gap between the APS and the NZE Scenario. In advanced economies, there is an implementation gap of 1.7 Gt $CO_2$ in 2030 and an ambition gap of 1.8 Gt $CO_2$. In emerging market and developing economies, there is an implementation gap of 2.5 Gt $CO_2$ in 2030 and an ambition gap of close to 5 Gt $CO_2$. This suggests that more ambition on net zero emissions pledges is required by countries around the world, and that countries need to do much more to back up their pledges with firm policy commitments and measures to ensure their realisation..

**Figure 4.3 ▷ Reductions in energy-related $CO_2$ emissions by region and scenario, 2022-2030**






*In both scenarios, about 40% of total emissions reductions in emerging market and developing economies come from renewables replacing coal power*

The largest single contribution to closing the ambition and the implementation gaps in both the APS and the NZE Scenario comes from replacing coal-fired power generation with renewable energy sources. In emerging market and developing economies, the switch to clean sources of electricity makes up 40% of total emissions reductions between today and 2030 in both scenarios (Figure 4.3).

In the APS, most of the remaining emissions reductions compared with the STEPS come from more rapid energy efficiency improvements and the electrification of end-uses. Heavy industry contributes the largest share of reductions, reflecting more stringent efficiency standards than in the STEPS and wider deployment of large-scale near zero emissions plants in energy-intensive industries.



In the NZE Scenario, there are large additional emissions reductions from cars and trucks, particularly in advanced economies, reflecting a faster roll out of electric vehicles (EVs) and supporting infrastructure. In hard-to-abate sectors, such as aviation and shipping, the risks associated with being a first mover deter some firms from adopting innovative low-emissions technologies during this decade in the APS, but measures taken in the NZE Scenario counter these risks and contribute emissions reductions of 0.5 Gt $CO_2$ globally.

### 4.2.2 Methane abatement

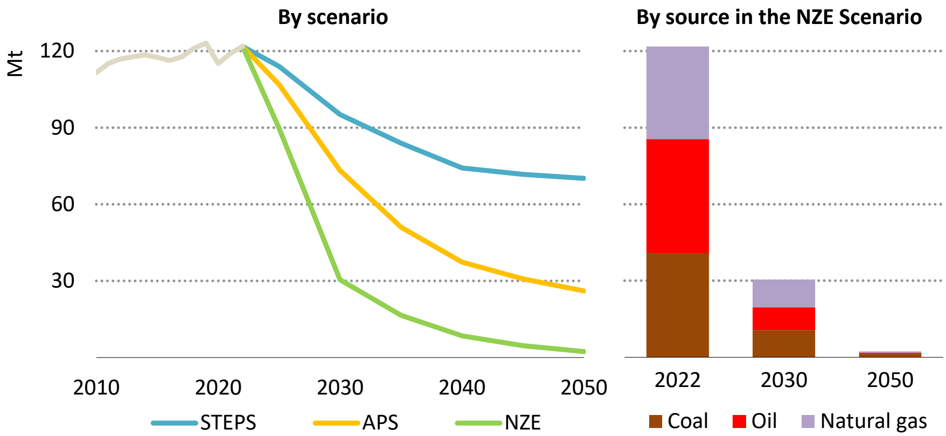
*What is the outlook for methane emissions from fossil fuels?*

Methane is responsible for around 30% of the rise in global temperatures since the Industrial Revolution; rapid and sustained reductions in methane emissions are key to limiting near-term global warming (IPCC, 2021). The energy sector accounts for nearly 40% of methane emissions from human activity. Methane emissions from fossil fuel operations account for the vast majority of energy sector emissions, and indeed for nearly 10% of total greenhouse gas (GHG) emissions from the energy sector. We estimate that the fossil fuel industry could avoid more than 70% of its current methane emissions with existing technology, much of it at little or no net cost.

Methane emissions from fossil fuel operations fall in all scenarios from 2023 to 2030: in the STEPS by around 20%; in the APS by 40%; and in the NZE Scenario by 75% (Figure 4.4). Around one-third of the reductions in the NZE Scenario are due to reduced demand for oil, gas and coal and two-thirds are from the rapid deployment of emissions reduction measures and technologies. Some of the key measures include a stop to all non-emergency flaring and venting, and universal adoption of regular leak detection and repair programmes. By 2030, all fossil fuel producers reduce their methane emission intensities to levels similar to the world's best operators today.

China and Russia are the two largest emitters of methane from fossil fuels. Together they accounted for around one-third of methane emissions from fossil fuel operations in 2022. Neither has committed to absolute methane reductions before 2030. However, many countries that have net zero emissions goals also are not currently doing enough to address methane emissions.

**Figure 4.4 ▷ Methane emissions from fossil fuel operations**






***If countries make good on their pledges, methane emissions will fall by around 50 Mt to 2030; they fall an additional 45 Mt in the NZE Scenario***

Note: Mt = million tonnes.

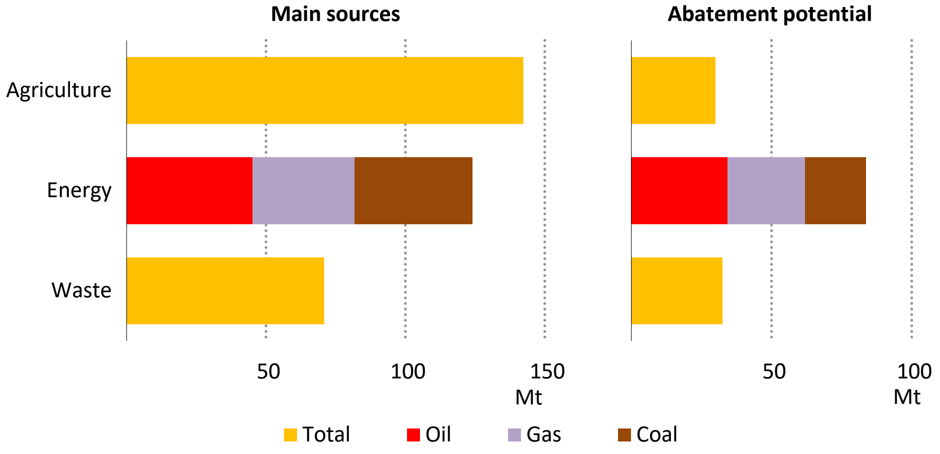
### *How can cutting methane from fossil fuels contribute to the Global Methane Pledge?*

The Global Methane Pledge was launched at COP26 in November 2021 to catalyse action to reduce methane emissions. Led by the United States and the European Union, 150 countries are now participants and together are responsible for more than half of global methane emissions from human activity. By joining the Pledge, countries commit to work together to collectively reduce methane emissions by at least 30% below 2020 levels by 2030.

Achieving the 75% cut in methane emissions from fossil fuel operations in the NZE Scenario would lower total human-caused methane emissions by more than 25% (Figure 4.5). Generally, many of these reductions can be achieved at very low cost or while generating overall savings. Based on average natural gas prices from 2017 to 2021, around 40% of emissions from oil and gas operations could be avoided at no net cost because the outlays for the abatement measures are less than the market value of the additional gas that is captured.

Emissions could be reduced very quickly if countries and companies were to adopt a set of tried and tested measures and policy tools related to leak detection and repair requirements, technology standards, and a ban on non-emergency flaring and venting. In the oil and gas sector, these measures would cut methane emissions from operations by half. If adopted worldwide in the coal sector, around half of methane emissions could be cut by making the most of the potential to use coal mine methane in mining operations, or by making use of flaring or oxidation technologies. Advances in technology, such as improved satellite coverage for leak monitoring, are making it easier to pinpoint sources of emissions and to facilitate abatement in both sectors, but action so far has been slow.

**Figure 4.5 ▹ Main sources of methane emissions from human activities and abatement potential based on available technologies**




*The energy sector has more near-term potential for methane abatement than other sectors*

Notes: Abatement potential for agriculture and waste is based on the Global Methane Assessment (UNEP, 2021). Emissions from biofuel and biomass burning are not shown.

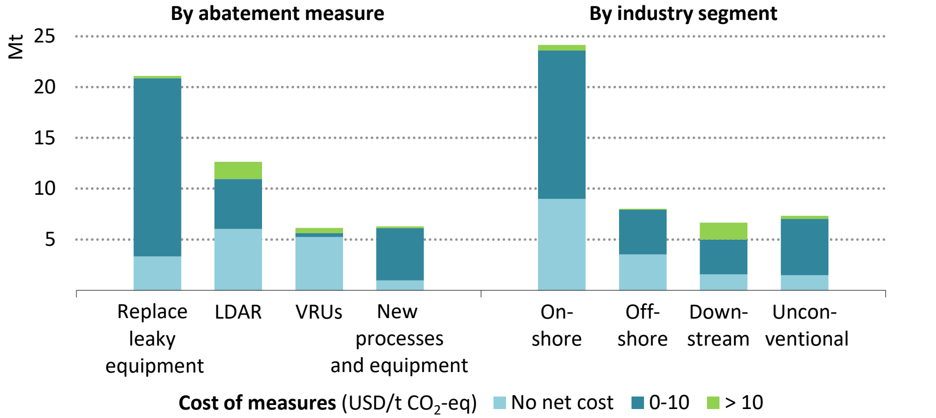
### *What is needed to increase action on methane?*

Methane abatement in the energy sector is one of the best options available to reduce GHG emissions (Figure 4.6). Just over USD 75 billion in cumulative spending is required to 2030 to cut methane emissions from oil and gas operations by 75% in the NZE Scenario, which is less than 2% of the net income received by this industry in 2022 (IEA, 2023a).

There are a variety of reasons why methane emissions from fossil fuel operations have remained stubbornly high in recent years, including information gaps, inadequate infrastructure or underdeveloped local markets that make it difficult to find a productive use for abated gas, and misaligned investment incentives that, for example, rule out any spending that does not provide a quick payback.

There are various ways to speed up progress. There is a role for governments in implementing and enforcing policies and regulations to incentivise or require early company action, but oil, gas and coal companies carry primary responsibility for methane abatement and should move quickly towards a zero tolerance approach to methane emissions without waiting until legislation compels them to do so. Banks, investors and insurers have an opportunity to add to the pressure for more rapid action by incorporating methane abatement into their engagement with the hydrocarbon industries with the aim of promoting strict performance standards, verifiable methane reductions, and transparent and comparable disclosures on measured emissions. There is also scope for consumers to work with suppliers to create a market for certified low-emissions fuels and to provide economic incentives for methane abatement.

**Figure 4.6 ⊳ Oil and gas methane emissions savings and net costs by measure and industry segment in the NZE Scenario, 2030**






*Nearly 95% of abatement has a net cost below USD 10 per tonne $CO_2$-eq*

Notes: USD/t $CO_2$-eq = US dollars per tonne of carbon-dioxide equivalent; LDAR = leak detection and repair; VRUs = vapour recovery units. One tonne of methane is considered to be equivalent to 30 tonnes of $CO_2$ based on the 100-year global warming potential (IPCC, 2021).

Of the total USD 75 billion required spending on methane abatement to 2030 in the NZE Scenario, we estimate that about USD 15-20 billion will be hard to finance through traditional channels (IEA, 2023a). This includes spending required in low and middle income countries, at facilities owned and operated by national oil companies and smaller independent companies, and for measures that generate a small return over their lifetime. A new international effort is needed from the industry, governments and other stakeholders to fill this financing gap.

## 4.2.3 Air quality

### Overview and scenario outcomes

Air pollution is one of the world's most significant environmental risks to human health, with one-in-nine deaths linked to poor air quality. Over 90% of people are exposed to polluted air,[2] leading to more than 6 million premature deaths a year – more than twice the number of deaths during 2020 from Covid-19. Air pollution also compounds multiple chronic health conditions, such as asthma, and leads to serious diseases, such as lung cancer.

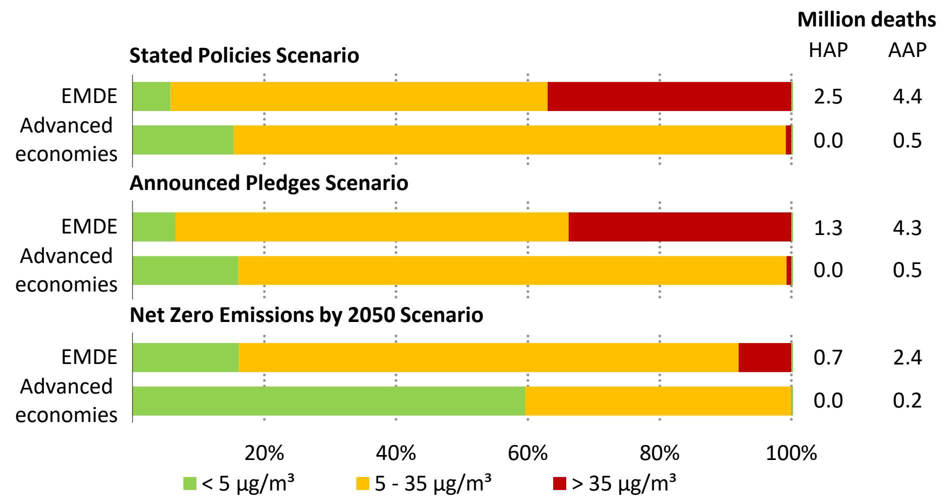
Today, about 4.4 million premature deaths a year are caused by breathing polluted air from outdoor sources (ambient air pollution), and around 3.2 million are the result of breathing polluted air from indoor sources (household air pollution) due mainly to the traditional use

[2] Polluted air is defined here as having a $PM_{2.5}$ concentration higher than 5 µg/m$^3$.

of biomass for heating and cooking. The majority of premature deaths from ambient air pollution and almost all of those from household air pollution are in emerging market and developing economies, where air pollution also comes with a significant economic cost. It is estimated to reduce global gross domestic product (GDP) by around 6%, and the GDP of some emerging market and developing economies by more than 10% per year (World Bank, 2022).

In the STEPS, premature deaths attributable to ambient air pollution increase to 4.9 million in 2030, while premature deaths due to household air pollution fall to around 2.5 million (Figure 4.7). These worldwide results mask strong regional differences. Around 1% of people in advanced economies have long-term exposure today to fine particulate matter ($PM_{2.5}$) concentrations exceeding 35 microgrammes per cubic metre (µg/m³), the least stringent interim target of the World Health Organization (WHO, 2021), which remains largely unchanged to 2030 in the STEPS. In contrast, 40% of people in emerging market and developing economies breathe air with concentrations of $PM_{2.5}$ above the least stringent WHO target today. In the STEPS this reduces only marginally to 37% in 2030 as reductions in $PM_{2.5}$ emissions are offset by increases in the urban population.

**Figure 4.7 ▷ Share of people exposed to various $PM_{2.5}$ concentrations and deaths from household and ambient air pollution, 2030**






*By 2030, the number of people breathing the most heavily polluted air is 80% lower in the NZE Scenario than in the STEPS, resulting in over 3 million fewer premature deaths*

Note: µg/m³ = microgrammes per cubic metre; HAP = household air pollution; AAP = ambient air pollution; EMDE = emerging market and developing economies.

Source: IEA analysis based on IIASA modelling.

In the APS, reductions in the use of traditional biomass to heat buildings and cuts in pollutant emissions in industry bring down the number of people exposed to concentrations of $PM_{2.5}$

above the least stringent WHO target from 2022 levels by 230 million (or 3% of the global population) in 2030. Premature deaths from household air pollution in the APS are around 1.3 million lower than in the STEPS in 2030, and deaths associated with ambient air pollution are about 200 000 lower than in the STEPS.

In the NZE Scenario, the next decade brings dramatic reductions in premature deaths both from ambient and indoor air pollution. By 2030 there are 2.5 million fewer premature deaths from household air pollution per year than in 2022, and around 1.7 million fewer premature deaths from ambient air pollution. The benefits are largest in emerging market and developing economies, where the share of the population exposed to $PM_{2.5}$ concentrations above the least stringent WHO target falls by four-fifths to 7% in 2030.

Rapid reductions in air pollution in the NZE Scenario are achieved with feasible energy and air quality policies and proven technologies. Access to clean cooking for all is essential to reduce the use of inefficient biomass cookstoves and associated $PM_{2.5}$ emissions, and there is a lot of experience in devising successful clean cooking programmes (section 4.4.1). Since the majority of transport emissions take place at street level, and often within densely populated areas, strictly enforced emissions standards in road transport are central to reduce nitrogen oxides ($NO_X$) emissions, particularly in cities. Achieving reductions in sulphur dioxide ($SO_2$) emissions depends to a large extent on fuel switching in the power sector and on increasing energy efficiency in industry. The value of the resultant benefits is typically many times higher than the costs of bringing about cleaner air.

## 4.3 Secure energy transitions

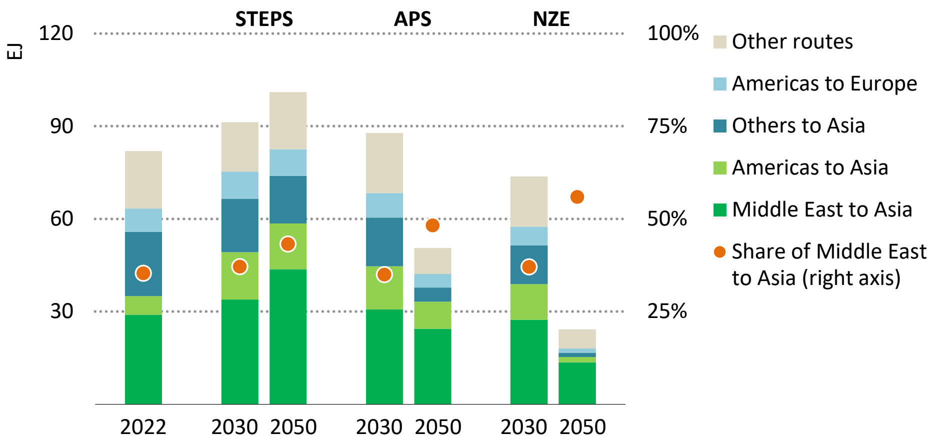
### *4.3.1 Fuel security and trade*

At the height of the energy crisis in 2022, record high natural gas prices were translating into a daily flow of USD 500 million from the European Union to Russia. Over a year on from the start of Russia's invasion of Ukraine, energy flows from Russia to Europe have slowed to a trickle and the contours of a new global oil and gas trade balance are coming into view. Russia is redirecting its oil and, to a lesser extent its natural gas, to Asia and other non-European markets. However, its role in global oil and gas trade is set to diminish as a result of the long-term effects of sanctions, further reductions in exports to Europe, and difficulties in fully offsetting the lost volume by redirecting exports to Asia.

Global oil and gas trade is set to become increasingly concentrated on flows between the Middle East and Asia. In the STEPS, seaborne crude oil trade from the Middle East to Asia rises from around 40% of total global trade today to around 50% by 2050. Asia is also the final destination for three-quarters of incremental Middle East liquefied natural gas (LNG) supply between 2022 and 2030 (Figure 4.8). In the APS, developing economies in Asia continue to draw in oil and gas imports as they build their clean energy systems. The Middle East-Asia trade route accounts for some 40% of all global oil and gas trade in 2030 and 45% in 2050, up from 35% today. In the NZE Scenario, the share of this route increases further to

55% by 2050 even as the total volume of trade declines dramatically. The changing fuel trade patterns in the APS and NZE Scenario have important implications for exporters and importers alike and raise questions about how countries can work together to avoid supply disruptions while achieving rapid transitions.

**Figure 4.8 ▻ Seaborne crude oil and LNG trade by route and scenario**






*Global crude oil and LNG trade flows are increasingly concentrated on the routes between the Middle East and Asia in all scenarios*

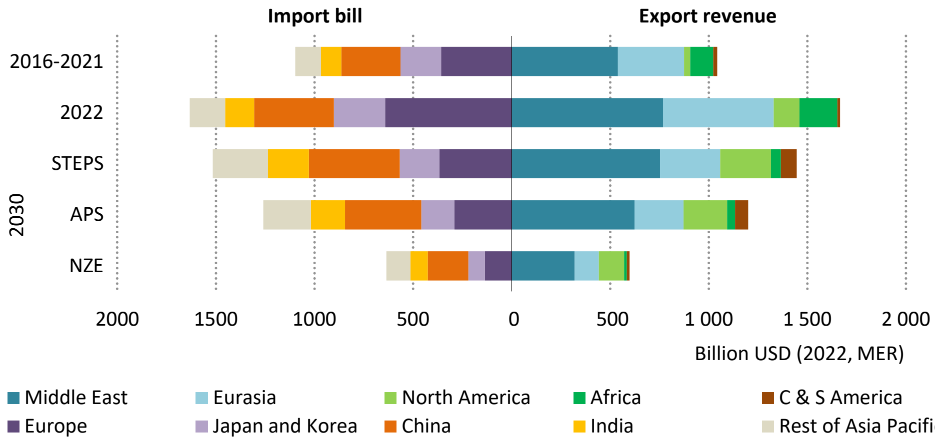
Note: EJ = exajoule.

### *How does oil and natural gas trade change in the APS and NZE Scenario?*

Oil and gas trade is relatively resilient in the APS and NZE Scenario to 2030: while oil and natural gas demand fall by around 6% in the APS and 20% in the NZE Scenario by 2030, trade expands by 2% in the APS and falls by only 12% in the NZE Scenario. In both scenarios, sharply declining domestic demand in North America opens a large production surplus which drives exports to 2030. Demand in emerging market and developing economies in Asia remains relatively robust to 2030, meaning imports continue to rise, with falling domestic production contributing to import demand in some countries. The value of trade nonetheless declines sharply in the NZE Scenario as oil and natural gas prices drop (Figure 4.9).

There are many uncertainties about how global oil and gas trade might evolve under the pressure of climate policy. In the APS, trade flows are determined by existing contractual commitments, the pipeline of projects under development in the near term, the ability of major producers to find export outlets in a world where oil and gas trade is shrinking, and the cost of developing new supplies in the long run. In the NZE Scenario, trade flows are dictated more by short-run costs and the production surpluses that form as falling domestic demand frees up additional volumes for export.

**Figure 4.9 ▷ Average annual value of oil and natural gas trade**





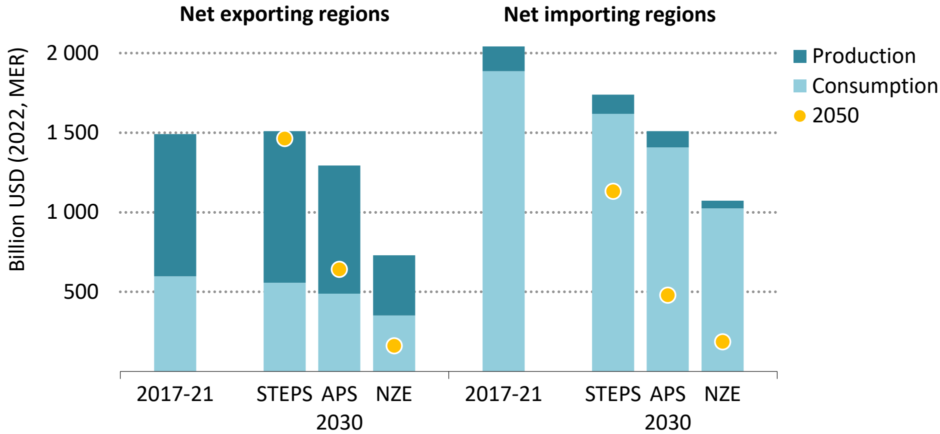

***The value of global oil and gas trade holds steady in the STEPS and to a lesser extent in the APS; trade volumes are lower in the NZE Scenario, and less profitable too***

Note: MER = market exchange rate; C & S America = Central and South America.

A number of exporters have set out why they think that they will continue to thrive even during rapid transitions. Some say that their low production costs will allow them to out-compete rival producers; others point to lower emissions intensities than those of rival producers, or claim that they are a better option in terms of energy security. However, there is no getting away from the point that any new resource developments in the NZE Scenario would need to be matched by faster declines elsewhere to avoid oversupply or fossil fuel lock-in, and that some producers could face large potential losses. The supply-side assumptions in the NZE Scenario look to chart a middle ground between the various trade-offs that exist, but other variants are possible.

In the APS and the NZE Scenario, the reduction in oil and gas production results in a large drop in government revenue for producer economies that in many cases rely on income from state-owned oil and gas companies to fund fiscal spending. In the NZE Scenario, governments in net exporting regions collect around USD 375 billion from the production of oil and gas in 2030, around 50% below the average take between 2017-2021. By 2050, this value falls to around USD 90 billion (Figure 4.10). This reduction in state income underscores the importance of developing economic diversification strategies, including by making full use of the potential for clean energy.

**Figure 4.10 ▷ Average annual government revenue from oil and natural gas production and consumption taxes**






*Reductions in government revenue from oil and gas taxes affect exporters and importers*

On the other side of the ledger, governments also earn revenue from oil and gas consumption, for example in the form of excise taxes on gasoline at the pump. Globally, these taxes exceed upstream taxes and royalties by a factor of two, suggesting that the shift away from oil and gas might also pose major fiscal challenges for some net importers. In the NZE Scenario, consumption-related taxes collected by net importing regions fall by USD 750 billion between 2022 and 2030. The reduced tax take is, however, smaller as a share of GDP in net importing regions than in producer economies heavily reliant on income from hydrocarbon production and export. Moreover, the drop in oil and gas import bills in the APS and NZE Scenario improves the overall trade balance for importing countries. In India, for example, the oil import bill falls by USD 60 billion (40%) in the NZE Scenario in 2030 compared with 2022. Fiscal balances can also be shored up by increasing tax revenue in other parts of the energy sector, or by using levies collected from $CO_2$ prices in place of the revenues derived from the taxation of oil and gas consumption.

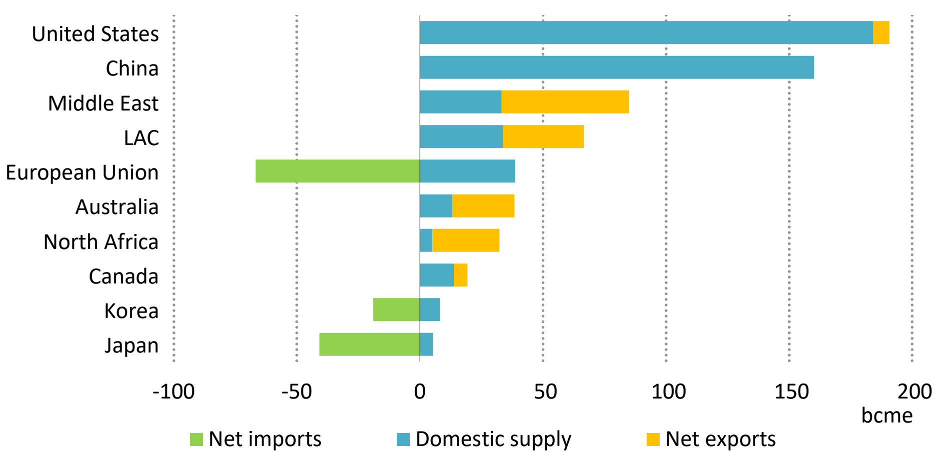
### *How can countries and companies work together to navigate secure transitions?*

Fragmented approaches by oil and gas producers and consumers could heighten energy security risks and geopolitical tensions during net zero transitions. Any mismatch in the pace of demand and supply reductions could cause very high or low prices, leading to turbulent and volatile markets. Uncoordinated policy implementation could lead to overinvestment in new oil and gas capacity or the premature retirement of existing infrastructure, and either of these could undermine efforts to bring about secure energy transitions. A lack of co-operation could also hamper the development and smooth functioning of the complex values chains that are needed for large-scale trade in low-emissions fuels.

Avoiding these pitfalls will require countries and companies to work together. There are several ways for them to do this. Clear long-term plans on the part of major consuming countries and sectors would help producers to make informed infrastructure and capital investment decisions. If these consumers signal that they intend to place economic value on products with lower emissions, producers will be incentivised to make capital investments to lower the emissions intensity of their resources. Consumers and producers could in addition explore joint investments to link clean energy supply with demand. Many producer economies hold abundant renewable resources, as well as subsurface data and expertise for potential $CO_2$ storage: there is scope for countries to work together to boost investment in renewables and to support technology demonstration and joint R&D projects to unlock $CO_2$ storage potential. Regular bilateral and multilateral dialogues could further improve mutual understanding of policy goals, help avoid potential disruptions and reduce the risks of stranded capital.

The challenges of scaling up low-emissions fuels offer a clear example of the need for enhanced co-operation across borders. Hydrogen trade is expected to involve almost all regions (Figure 4.11). Long-term contracts, mutually agreed standards and certification schemes are crucial to underpin the capital-intensive projects that will be needed. Governments around the world have an important part to play in facilitating co-ordinated and timely investments, and this means in particular setting clear policy frameworks that are compatible across borders.

**Figure 4.11 ▷ Low-emissions hydrogen demand and production in selected regions in the APS, 2050**





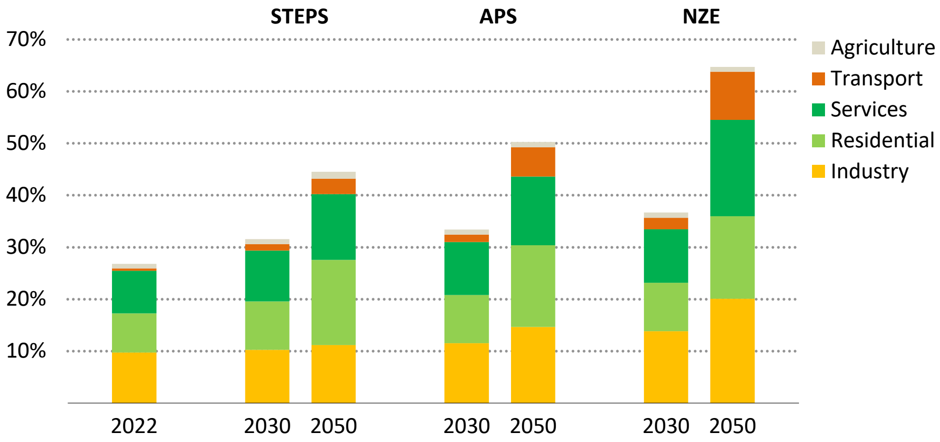

*Close producer-consumer co-operation is key to developing a new hydrogen industry*

Notes: bcme = billion cubic metres of natural gas equivalent (equivalent to 36 petajoules). Includes trade of hydrogen and hydrogen-based fuels. Final use may not be in the form of gaseous hydrogen. LAC = Latin America and the Caribbean.

### 4.3.2 Electricity security

Electricity is central to modern economies, accounting for around 20% of total final energy consumption today. This increases in all scenarios, reaching 30% in the STEPS in 2050, 40% in the APS and more than 50% in the NZE Scenario. Due to the higher efficiency of many electrical processes, its share of useful energy provided is even larger, rising from 27% today to about 45% in the STEPS in 2050, 50% in the APS and 65% in the NZE Scenario (Figure 4.12).

**Figure 4.12 ▷ Share of electricity in useful energy demand by sector and scenario**






*The share of electricity in useful energy demand increases significantly in all scenarios, most of all in the NZE Scenario*

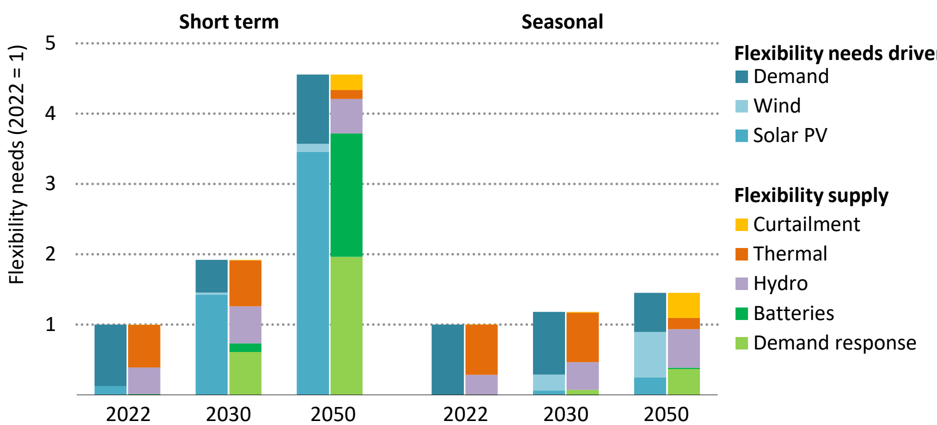
Electricity security means having a reliable and stable supply of electricity that can meet demand at all times at an affordable price. Electricity supply has always needed to meet demand continuously, down to the scale of seconds or less, to maintain system stability. However, power systems are becoming more complex, and power system flexibility needs are set to increase sharply in the future as a result of the rising share of variable wind and solar photovoltaics (PV) and rising electricity demand.

In the light of these changes, maintaining electricity security in future power systems calls for new tools and approaches. Power generators will need to be more agile, consumers will need to be more connected and responsive, and grid infrastructure will need to be strengthened and digitalised to support more dynamic flows of electricity and information. Sufficient flexible capacity will have to be available to deal with variability across all timescales, from the very short term to the very long term, across seasons and years. Power systems will also need to adapt to both changing climate and weather patterns as well as changing consumer behaviour (Box 4.1).

*How are increasing power system flexibility needs met in the future?*

Most of the flexibility required across all timescales today is provided by dispatchable thermal power plants and hydropower (including pumped storage).[3] In our three scenarios, much of the additional short-term flexibility that is needed is provided by batteries and demand response, especially after 2030. Thermal power plants and hydropower continue to provide most seasonal flexibility, with demand response and curtailment of surplus generation playing an increasingly important role towards the end of the outlook period.

**Figure 4.13 ▷ Global power system flexibility needs and supply in the APS**






***Short-term needs increase significantly, mainly due to solar PV, with batteries and demand response emerging as crucial suppliers of flexibility; seasonal needs rise less sharply***

Notes: Flexibility needs are computed for 2030 and 2050 taking into account changes in electricity supply and demand and weather variability over 30 historical years. Demand response includes the flexible operation of electrolysers.

In the STEPS, short-term power system flexibility needs more than triple globally by 2050 relative to today. In the APS, they double by 2030 and rise 4.5-fold by 2050 (Figure 4.13). Global needs for seasonal flexibility increase less sharply: they rise by nearly 20% to 2030 and 45% to 2050 in the APS. The fast-rising share of solar PV emerges as the key factor increasing short-term flexibility needs: wind is less variable in the short term but can vary significantly across weeks or seasons, and it becomes an important driver of seasonal flexibility needs as its share increases in power systems across the world. Patterns of wind and solar output can be complementary to variations in electricity demand, but their rising share tends to increase overall system flexibility needs.

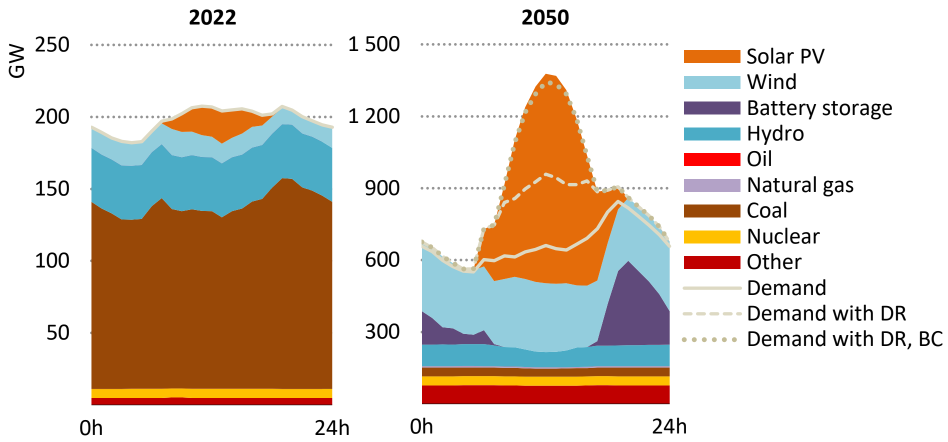
[3] Flexibility is defined as the ability of a power system to reliably and cost effectively manage the variability of demand and supply. It ranges from ensuring the instantaneous stability of the power system to supporting long-term security of supply.

Rising flexibility needs and changes in the global power plant fleet – with the phase-out of unabated coal in many regions – see the share of short-term flexibility provided by thermal power plants drop from around 60% today to one-third by 2030 in the APS. Thermal power plants, including unabated fossil fuel plants and low-emissions technologies (such as nuclear, fossil fuels with carbon capture, utilisation and storage, bioenergy, hydrogen and ammonia), remain important providers of seasonal flexibility through to 2040. It is only by 2050 that their share in the flexibility mix drops to about 10%. The share of hydropower in the supply of short-term flexibility falls as needs increase rapidly, but it remains an important source of seasonal flexibility and is the main source of the seasonal balancing required after 2040. Market designs and regulations need to ensure that the dispatch of pumped storage, reservoir hydropower and other forms of long-term energy storage is aligned with the long-term flexibility needs of the system.



Demand response is set to play an increasingly important part in the provision of short-term flexibility as the contribution made by thermal power plants wanes. Expanding use of electric heat pumps, air conditioners and EVs makes demand more variable, but it also creates additional opportunities for demand-side response. Making the most of these opportunities depends on the creation of a supportive regulatory environment which is underpinned by adequate price signals, digital tools and smart controls. Effective demand-response policies and instruments can also help consumers reduce their electricity bills (Box 4.3). In the APS, demand response meets around one-third of short-term flexibility needs by 2030.

**Figure 4.14 ▷ Hourly electricity generation by source for a sample day in India in August in the APS, 2022 and 2050**





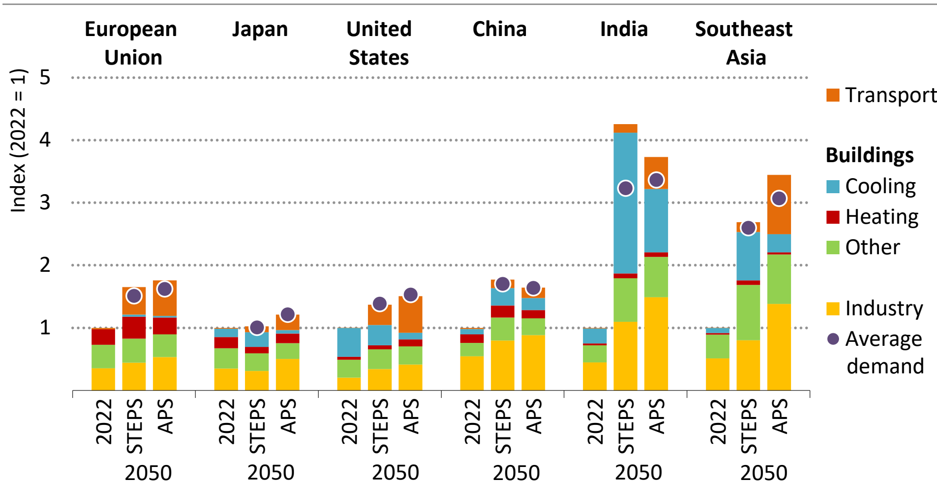

***Electricity systems need to become more flexible to cope with large increases in electricity consumption and a rising share of electricity from variable renewables***

Notes: GW = gigawatt; DR = demand response; BC = battery charging. Demand response includes the flexible operation of electrolysers.

Batteries are emerging as a crucial means of providing short-term flexibility alongside demand-response measures. Utility-scale battery storage capacity increases nearly 85-fold in the STEPS, rising to more than 2 terawatts (TW) by 2050. In the APS it increases to just over 3 TW by 2050 and provides roughly one-third of the short-term flexibility needed in 2050. Batteries are a good match for the daily cycle of solar PV-based electricity generation in particular. On a typical day in India in 2050, for example, batteries could charge using excess solar generation during the daytime and discharge at night, reducing curtailment and the need to cycle thermal power plants over the course of a day (Figure 4.14).

There are also other options for the provision of both short-term and seasonal flexibility. Low-emissions hydrogen and ammonia can be used in thermal power plants to provide backup capacity, acting in effect as seasonal storage of renewable electricity. Grid-connected electrolysers can offer significant amounts of both short-term and seasonal flexible capacity: electrolysers provide roughly a quarter of the seasonal flexibility needed in 2050 in the APS. In systems with high shares of variable renewables, it may also be economical to curtail some of the surplus wind or solar PV generation to provide additional flexibility if other sources of flexibility are unavailable or more costly to dispatch.

**Figure 4.15 ▷ Electricity peak demand in selected regions and countries and contributions by sector, 2022-2050**




IEA. CC BY 4.0.

*Peak electricity demand increases in all regions; it rises faster than average demand in most regions*

Notes: Peak demand here is the average of demand for the 500 highest load hours of the year, before activation of demand response. Heating includes water heating.

Changing patterns of consumption as electricity use increases have a significant impact on peak electricity demand over the year (Figure 4.15). In the STEPS, peak demand increases by

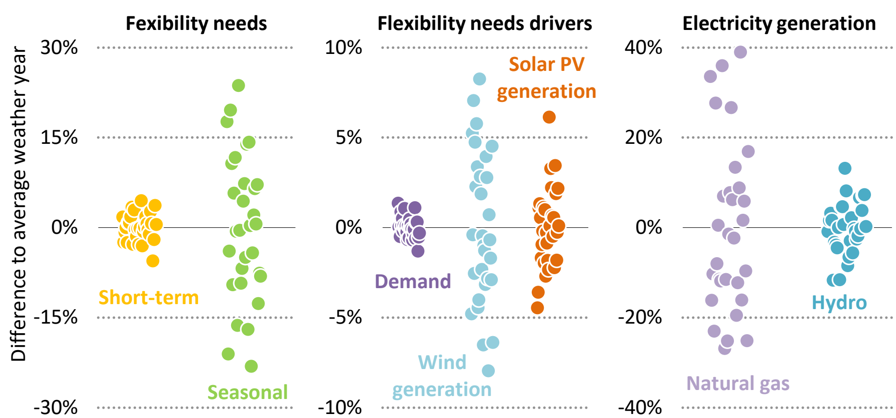
37% in the United States and 65% in the European Union to 2050. The increase is more pronounced in countries with significant space cooling needs as more people start to use air conditioners. In India, for example, there is a fourfold increase in peak electricity demand by 2050 as a result of expanding electrification, increased use of air conditioners and EV charging.

Energy efficiency has a vital part to play in mitigating the increase in peak demand and reducing stress on electricity networks. The contribution of air conditioning to peak demand, for example, is cut by half in India and by two-thirds in the United States in the APS compared with the STEPS in 2050 by more stringent minimum energy performance standards and more efficient building designs. Since a large share of the increase in peak demand is driven by end-uses with significant flexibility potential, such as EVs, air conditioners and heat pumps, increases in uncontrolled peak demand can be also mitigated by demand-side response measures.

4

### Box 4.1 ▹ Impacts of weather on power systems: Case study of Europe

**Figure 4.16 ▹ Variability of flexibility needs and generation for different weather years in Europe in the APS, 2030**






*Seasonal flexibility needs can vary significantly, leading to large differences in the load factor of the dispatchable power plant fleet from one year to the next*

Note: A weather year is a set of weather parameters such as temperature, solar radiation, wind speed and precipitation compiled from historical records to create curves of hourly loads and renewables output.

To examine how seasonal flexibility needs could vary across years, we analysed how the power system in Europe would need to evolve in the APS to 2030 and 2050 to be able to handle 30 different possible weather years (Figure 4.16). As the share of wind and solar PV in power generation increases at the expense of fossil fuels the frequency and duration of low wind periods coinciding with cloudy skies and low temperatures is a significant contributor to seasonal flexibility needs. This has a substantial impact on the operation of the dispatchable power fleet, notably natural gas-fired plants and hydropower, which must absorb most of the variation between seasons and years. In 2030, the most extreme conditions in a weather year could induce a 40% upward or downward variation in the annual use of gas-fired power plants in Europe compared with an average weather year. The resultant uncertainty about revenues for these plants and about their profitability could act as a drag on investment in them, despite their essential role as providers of system adequacy and flexibility. Adapting market designs and establishing instruments to ensure sufficient investment is essential for security of supply.

Short-term flexibility needs more than quadruple by 2050 in the APS compared with the current level, mainly because of the integration of variable renewables. For 2030, differences between weather years have less impact on the magnitude of these requirements: they vary by around 5% upwards or downwards compared with an average weather year.

### *Will grids be ready in time to enable power sector transitions?*

There are approximately 80 million kilometres (km) of electricity networks worldwide today. Significant grid enhancements are needed in all scenarios to meet the increasing pace of electrification and accelerated deployment of renewable energy sources. [4] New transmission lines are necessary to connect large-scale wind and solar PV projects to demand centres, sometimes over long distances, and offshore substations and cabling are needed to connect the new and planned offshore wind farms to the mainland. Distribution lines also need to be expanded to accommodate increasing electricity demand and the rapid growth of distributed solar PV capacity. Further links within and between countries and regions are needed to reduce the requirement for flexibility from alternative sources and to facilitate the integration of further potential flexibility providers. Total grid line lengths increase by about 18% from 2022 to 2030 in the STEPS and APS, and by 20% in the NZE Scenario.

In addition to the extension of power lines, investment in digitalisation, smart systems and advanced high power semiconductor technologies is needed to improve the control and stability of electricity flows. Smart grids and grid components such as flexible alternating current (AC) transmission systems make it easier to accommodate the increasing share of variable generation from solar PV and wind. They also present an opportunity to improve grid management and to make new investment in grids more targeted and efficient.

This means that a major increase in investment is required to ensure grid reliability, support clean energy transitions and achieve universal electricity access (Box 4.2). Some new

[4] See *Electricity Grids and Secure Energy Transitions* (IEA, 2023b) for a comprehensive analysis on the role of grids.

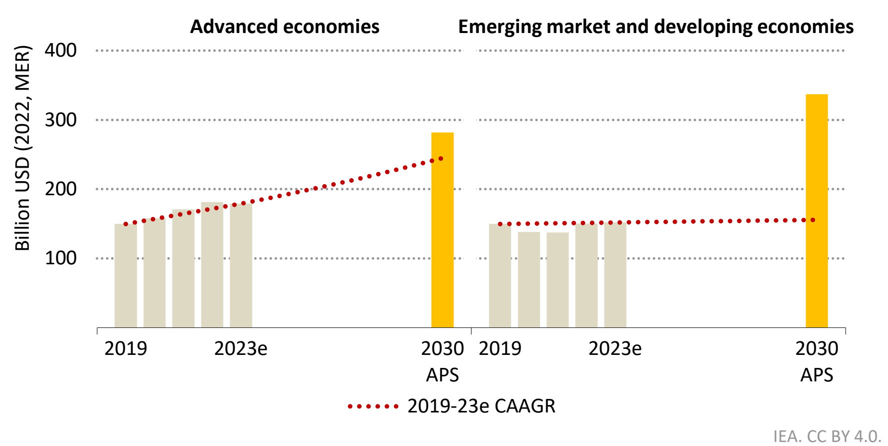
investment is already planned: the pipeline of announced high voltage direct current (HVDC) projects is set to lead to an increase in the length of HVDC lines by around 45% to 2030. Obtaining the necessary new investment and building the new grid infrastructure required in the APS and the NZE Scenario is challenging but feasible. However, early action and holistic planning are needed to avoid delays in connecting sources of renewable energy, given that grid projects can take more than a decade and typically have much longer timelines than renewable energy projects, and measures to expedite permitting processes for new grid infrastructure would help a great deal.



**Box 4.2 ▹ Scaling up investment in electricity networks**

There is a gap between current grid spending trends and the investment required to reach climate goals, especially in emerging market and developing economies. Annual investment in grids worldwide is set to reach USD 330 billion in 2023. This climbs to USD 565 billion by 2030 in the STEPS, but it needs to rise further to around USD 620 billion in the APS and USD 680 billion in the NZE Scenario. Based on recent trends, spending in 2030 in emerging market and developing economies would be less than half the investment needs of the APS (USD 335 billion), while the gap in advanced economies is far smaller (Figure 4.17).

**Figure 4.17 ▹ Investment trends in grids versus needs in the APS**




*Recent trends in grid investment leave a large gap with the required levels by 2030, especially in emerging market and developing economies*

Note: MER = market exchange rate; CAAGR = compound average annual growth rate; 2023e = estimated values for 2023.

Many advanced economies, including Italy, Spain, United Kingdom and United States, are suffering from grid connection queues for wind and solar projects. Permitting rules, planning and remuneration for investments are the key issues requiring policy attention.

However, the biggest challenges are in emerging market and developing economies, where responsibility for investment often lies with cash-constrained and heavily indebted public utilities. For example, the South Africa utility, Eskom, has around USD 20 billion of guaranteed debt at risk of default, raising South Africa's risk premium and borrowing costs.

Concessional funding from international development finance institutions (DFIs) offers one way out of this impasse. This needs to be accompanied by reforms that aim to create healthier utilities and business models. It is not easy to bring about such reforms: many developing country utilities have a majority of low income customers which cannot afford higher electricity prices, and innovative approaches will be needed. In the case of Eskom, the National Treasury in South Africa has developed a debt-relief arrangement of around USD 15 billion as an interest-free sub-ordinated loan, which will improve the debt-equity ratio and balance sheet.

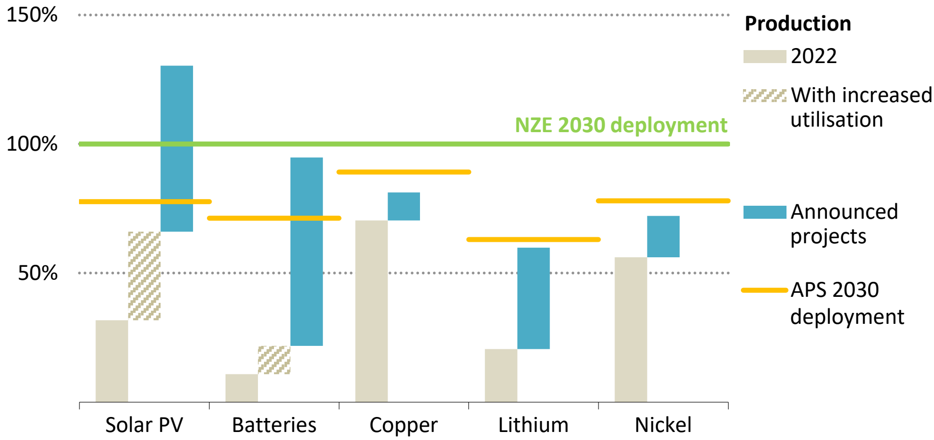
Despite a heavy reliance on public funding when developing concessional finance and reform packages, there is scope for DFIs and governments to develop business models that allow the private sector to participate in grid development and strengthening. For example, independent power transmission (IPT) projects are designed to offer rights over a specific transmission line through a tendering process. Governments and state-owned enterprises can be involved in the ownership and operational risk of the project, depending on the type of IPT contract. This model has recently been introduced in Africa, and similar arrangements have previously been implemented successfully in Brazil and Colombia.

### *4.3.3 Clean energy supply chains and critical minerals*

The development of clean energy technology supply chains has made impressive progress since 2015, boosted recently by stimulus spending related to the Covid-19 pandemic, the response from governments to the global energy crisis, and growing commercial and geopolitical competition. Progress has been particularly fast in the manufacturing segment, notably for solar panels and batteries, where new facilities are benefiting from standardisation and short lead times. The pipeline of announced manufacturing projects is expanding rapidly. If all announced solar PV module manufacturing projects come to fruition, their combined output globally, together with that from the increased utilisation of existing capacity, would exceed the deployment needs of the NZE Scenario in 2030; EV and grid storage battery needs for 2030 would almost be met on the same basis (Figure 4.18).

The expected pace of growth in critical mineral supplies does not match that of clean energy technology manufacturing capacity additions, although an increasing number of new projects have recently been announced. The overall pace of transition is usually determined by the slowest-moving component, and that makes it important to strengthen efforts to scale up investment in critical mineral supplies.

**Figure 4.18 ⊳ Announced project throughput, and deployment and supply needs for key clean energy technologies and minerals in 2030**






*Progress on the development of clean energy supply chains has been uneven*

Notes: Announced pipeline includes both committed and preliminary projects. For critical minerals, the NZE Scenario deployment needs refer to the primary supply requirements (total demand less secondary supply).

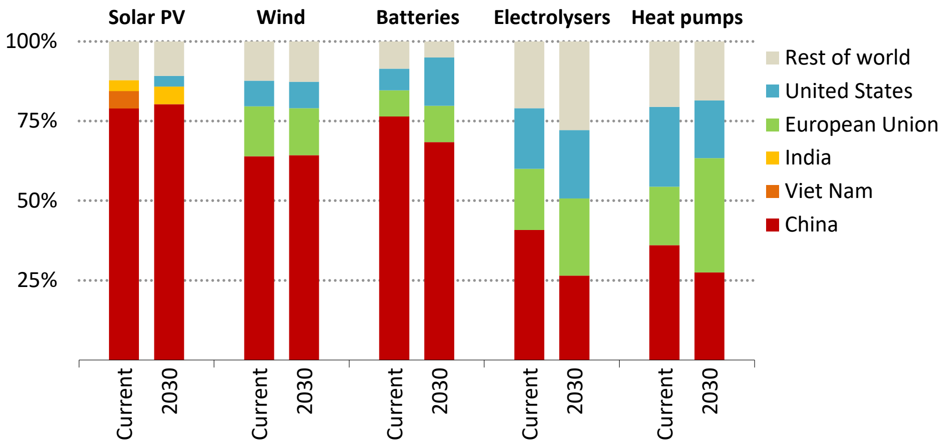
A high degree of supply chain concentration remains a major concern for both clean energy technology manufacturing and critical minerals as it can make the entire supply chain vulnerable to individual country policy choices, company decisions, natural disasters or technical failures.

### *How can we accelerate the diversification of clean energy manufacturing?*

Clean energy technology supply chains today are more geographically concentrated than fossil fuel supply chains. China has an outsized presence in most of them, and they are generally dominated by a small number of countries. For key clean energy technologies such as solar PV, batteries and electrolysers, for example, the largest three regions account for 80-90% of global capacity, with the largest single producer accounting for up to 80% (IEA, 2023c).

Many countries are competing to secure their place in the new global energy economy. The pipeline of announced projects for clean energy technology manufacturing shows some positive signs in terms of diversification, but the situation varies by technology (Figure 4.19). In the case of batteries, electrolysers and heat pumps, many projects are now being developed, notably in the United States and Europe, which – if they all come to fruition – would lead to a moderate decrease in China's share of the market. However, China is set to maintain a dominant position for solar PV and wind this decade.

**Figure 4.19 ▷ Share of top three manufacturing regions for key clean energy technologies in 2023 and 2030 based on announced projects**






*Announced projects – if all realised – will alter the global distribution of manufacturing capacity for batteries, electrolysers and heat pumps*

Notes: Wind = onshore nacelles. Electrolysers only includes projects with available location data. Figure for 2023 refers to installed capacity as of Q1 2023; figure for 2030 refers to production in 2030 from all existing and projects announced to date.

To accelerate progress on diversifying supply chains, countries need both to develop dedicated industrial strategies and to strengthen international co-operation. It is clearly crucial in this context to identify and monitor the major clean energy technology supply chain risks that could delay or disrupt deployment, given that supply chains are only as strong as their weakest link. Building strategic partnerships is also crucial. It is not realistic or efficient for most countries to seek to compete in all parts of all supply chains. Identifying relative strengths and seeking complementary partnerships should be at the heart of the development of industrial strategies for clean technology manufacturing. More attention also needs to be paid to opportunities to support in-country energy transitions and socioeconomic development in emerging market and developing economies.

### *Are we on track to ensure diversified and resilient critical mineral supplies?*

Critical minerals, which are essential for a range of clean energy technologies, have risen up the policy agenda in recent years in the wake of increasing demand, volatile price movements, supply chain bottlenecks and geopolitical concerns. Demand for critical minerals for clean energy technologies is set to increase rapidly in all of the scenarios. In the APS, demand almost triples by 2030. In the NZE Scenario, a faster deployment of clean energy technologies implies an almost fourfold increase in demand for critical minerals in 2030, compared with today. EVs and battery storage are the main drivers of demand growth, but there are also major contributions from low-emissions power generation and electricity networks. As demand for clean energy applications expands faster than other uses, the share of clean energy in total demand for key minerals rises considerably: in the APS, it reaches over 80% for lithium, nearly 60% for cobalt and around 40% for nickel and copper in 2030.

Meeting these demands requires a significant ramp-up in mining and refining activities, especially in geographically diversified regions. Inadequate mineral supplies could make energy transitions slower or more expensive, and the reversal in 2021 and 2022 of a decade-long reduction in clean energy technology costs served as a reminder that steady increases in supply and decreases in price cannot be taken for granted. Concerns about security of supply have already prompted many countries to introduce a range of policies designed to secure or promote mineral supplies. Many downstream companies such as EV manufacturers and battery cell makers are also becoming involved in the critical mineral value chain through strategic investments in mining and refining operations. Long-term off-take agreements have become the norm, and there has been a notable increase in direct investment activities since 2021 (Table 4.1).

**Table 4.1 ⊳ Involvement of top-seven EV and battery makers in the critical minerals supply chain**

| EV makers | Long-term off-take | Mining | Refining | Battery makers | Long-term off-take | Mining | Refining |
|---|---|---|---|---|---|---|---|
| BYD | ○ | ○ ● | ○ ● | CATL | | ○ ● | ○ ● |
| Tesla | ○ ● | ● | ● | LG Energy Solution | ○ ● | ● | ○ ● |
| Volkswagen | ○ ● | ● | ● | BYD | | ○ ● | ○ ● |
| General Motors | ● | ● | ● | Panasonic | ○ ● | | |
| Stellantis | ● | ● | | SK On | ○ ● | ● | ● |
| Hyundai | ● | | | Samsung SDI | ○ ● | | |
| BMW | ○ ● | | ● | CALB | | | |

○ Before 2021 ● Since 2021

Note: CATL = Contemporary Amperex Technology Company Limited.

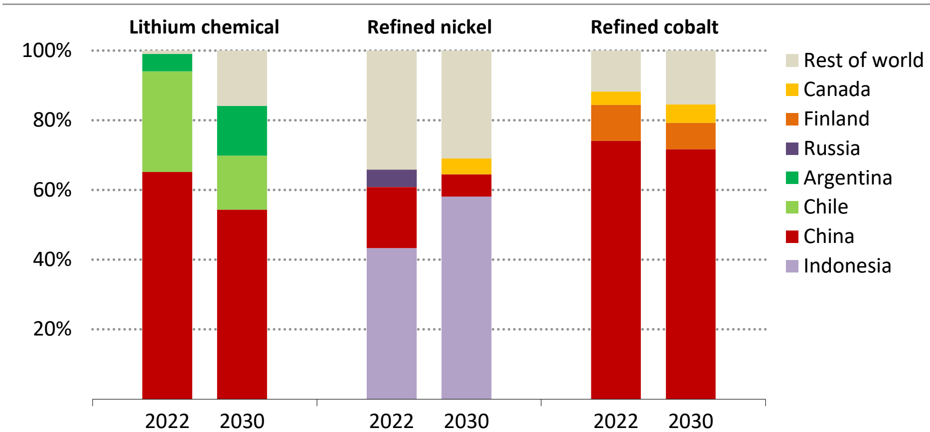
Source: IEA analysis based on company announcements and news articles.

There are some positive signs in terms of new supply. Investment in critical minerals development rose by 30% in 2022, and this followed a 20% increase in 2021. Exploration spending also rose by 20% in 2022, driven by record growth in lithium exploration, especially in Canada and Australia. Critical minerals start-ups raised a record USD 1.6 billion in 2022, a 160% increase from 2021, despite headwinds in the wider venture capital sector (IEA, 2023c).

These increases in capital spending indicate that supply is catching up with national clean energy ambitions as reflected in the APS. Meeting the requirements in the NZE Scenario depends however on further projects coming through. Moreover, the adequacy of planned future supply is far from assured. Delays and cost overruns have occurred regularly in the past. The supply of battery-grade and high-quality products may still be constrained even when an overall balance of supply and demand is achieved. And new mining plays often come with higher production costs, which could push up marginal costs and prices.

While some progress has been made in increasing supplies, limited progress has been made in diversifying supply sources; the situation has even worsened in some cases. The share of the top-three producers in 2022 is either unchanged or has increased from 2019 levels, especially for nickel and cobalt. Our analysis of project pipelines indicates that concentration levels in 2030 are set to remain high, especially for refining operations, which is where the current geographical concentration is strongest. Many planned projects are being developed in the current dominant regions, with China holding half of planned lithium chemical plants and Indonesia representing nearly 90% of planned nickel refining facilities (Figure 4.20). This heightens consumer exposure to various geopolitical events as highlighted by the export curbs on gallium and germanium from China in August 2023. From Africa to Latin America and the Caribbean, many resource-holding nations are seeking positions further up the value chain while many consuming countries want to diversify their source of refined metal supplies. However, the world has not yet successfully connected the dots to build diversified midstream supply chains.

**Figure 4.20 ⊳ Geographic concentration of refined key mineral supply in 2022 and in 2030 based on announced projects**






***Project pipelines indicate that, in most cases, the geographical concentration of mineral refining operations is likely to remain high to 2030***

Note: Figure for 2030 refers to production in 2030 from all existing and projects announced to date.

Sources: IEA analysis based on S&P Global (2023); Wood Mackenzie (2023); Benchmark Mineral Intelligence (2023).

Market balances do not just depend on supply. There is significant scope for actions on the demand side to ease potential strains, via recycling, technology development, smaller EVs and so on. For example, the average battery size for passenger electric cars has been on a rising trend in nearly every major market as the desire for larger vehicles as in conventional car markets is replicated in the EV market. If this trend persists, it would push up material demand for batteries by 15% in 2030 in the NZE Scenario. On the other hand, the faster adoption of technologies such as sodium-ion batteries or lithium-ion phosphate chemistries could reduce material demand by 7% in 2030.

Progress towards improving sustainable and responsible practices has been mixed. Our assessment of the environmental and social performance of major companies shows that companies are making headway on social indicators such as community investment, worker safety and gender balance. However, environmental indicators such as GHG emissions, waste and water use are not improving at the same rate, and there are few signs that end-users are prioritising cleaner production pathways in their sourcing and investment decisions, although some downstream companies have started to give preference to minerals with lower climate impact.



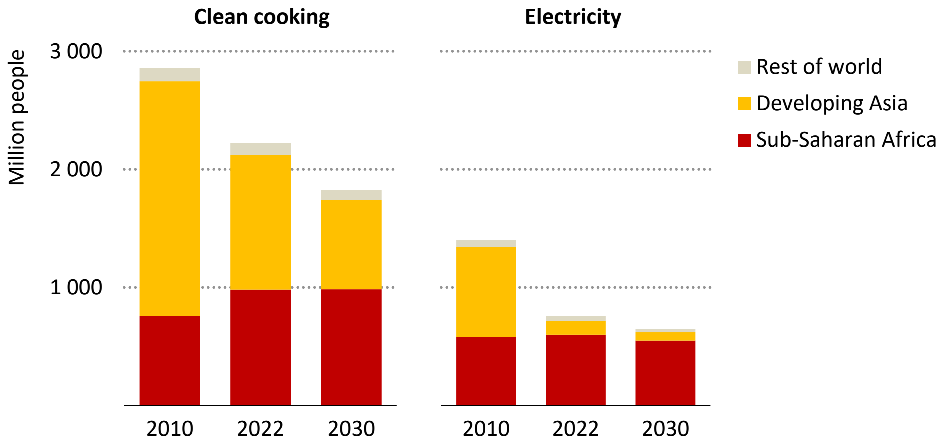
Every country's strategy on critical minerals will inevitably reflect its specific circumstances, but key components are likely to include investment, innovation, recycling and rigorous sustainability standards. More co-operative approaches between producers and consumers could help to build more diverse supply chains and ensure fair access to raw materials. More support for further technological innovation and recycling, which has already shown its ability to relieve some of the pressure on primary supplies, could bring further improvements.

## 4.4 People-centred transitions

### *4.4.1 Energy access*

The number of people without access to electricity worldwide has decreased by more than 45% since 2010, primarily driven by progress in developing Asia, but 760 million people still lack access today (Figure 4.21). The situation is most pressing in countries in sub-Saharan Africa, where around 80% of people without access to electricity live. While there have been some recent improvements in access in sub-Saharan Africa, these have not kept pace with population growth, with the result that there has been a 2.5% increase in the number of people without access since 2010. In the STEPS, current policies reduce the global number of people without access to electricity by around 125 million in 2030, although population growth means there are still around 650 million people without access in 2030. In the APS, the number of people without access to electricity falls to 270 million by 2030, and the number of people without access in countries in sub-Saharan Africa is cut by two-thirds. In the NZE Scenario, universal access to electricity is achieved by 2030.

**Figure 4.21 ▷ Population without access to modern energy in the STEPS**






***Number of people without access to clean cooking declines by just over 15% to 2030 in the STEPS and progress on access to electricity is also slow***

Note: Sub-Saharan Africa excludes South Africa.

Almost 2.3 billion people today use traditional biomass, coal or kerosene for their cooking needs; most of these are in countries in sub-Saharan Africa and developing Asia. In the STEPS, the number of people without access to clean cooking facilities falls by just over 15% to 2030. If all national clean cooking targets were achieved by 2030, as assumed in the APS, the number of people without access would fall by two-thirds, but around 735 million people would remain without access. In the NZE Scenario, universal access to clean cooking is achieved by 2030, as it is for access to electricity.

### *Are off-grid solutions the key driver behind recent progress in access to electricity?*

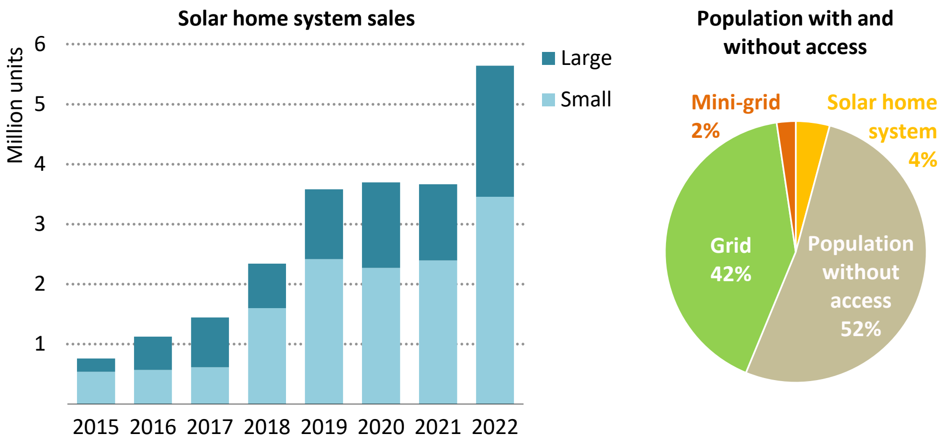
Over the years, solar home systems (SHS) have demonstrated their viability as a reliable electricity source for households, particularly in rural areas in sub-Saharan Africa that do not have access to reliable grid connections. Since 2015, annual sales of SHS with capacities above 11 Watt-peak (Wp) have increased more than sevenfold in the sub-Saharan region (Figure 4.22). Such systems can provide sufficient electricity for a bundle of basic energy services, including lighting, phone charging and a radio, though only systems above 50 Wp are considered as providing essential access.[5]

Today, more than 45 million people use SHS above 11 Wp in sub-Saharan Africa, accounting for just under 10% of the population with access to electricity. In 2022, SHS contributed to more than half of the increase in access to electricity in sub-Saharan Africa (IEA, 2023d).

[5] An essential bundle includes four light bulbs for four hours per day, a fan for three hours per day, and a television for two hours per day, which equates to roughly 500 kilowatt-hours per household per year.

Off-grid connections play a central role in bringing about universal access by the end of this decade in the NZE Scenario. Over time households in all but the most remote settlements will gradually transition from off-grid to grid connections by 2050.

**Figure 4.22 ▷ Sales of off-grid solar systems in sub-Saharan Africa since 2015 and share of population with and without access in 2022**






*Annual sales of solar home systems have increased more than sevenfold since 2015, providing more than 45 million people with access to electricity*

Notes: Small solar home systems are equipped with a solar panel rated from 11 to 49 Watt-peak (Wp). Large solar home systems are equipped with a solar panel rated above 50 Wp. Sub-Saharan Africa excludes South Africa.

Source: IEA analysis based on sales databases of the Global Off-Grid Lighting Association (GOGLA, 2023).

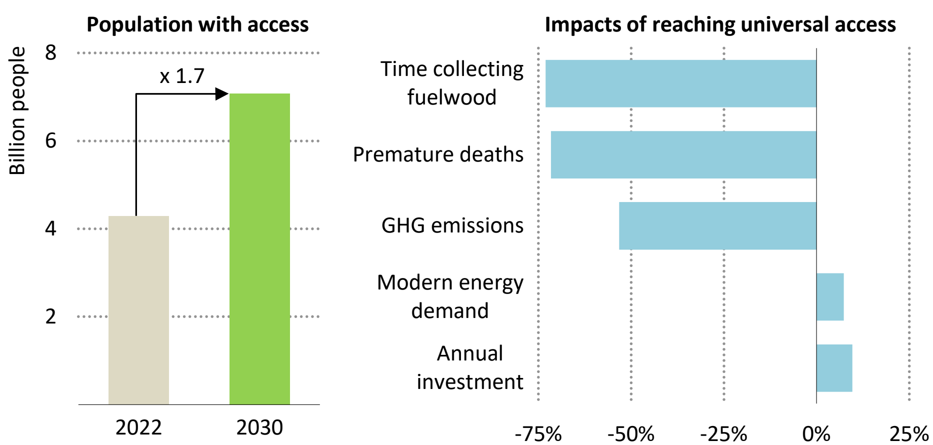
Despite recent rising equipment costs for solar home systems, sales remained relatively stable throughout the Covid-19 pandemic, and they are still typically more affordable than grid connections in many sub-Saharan countries. In 2022, sales of SHS surged by around 50% in sub-Saharan Africa and were double the level achieved in 2018. Pay-as-you-go systems that remove the upfront cost barrier play an essential role where affordability is the main concern and access to loans remains low. These systems currently account for nearly 95% of sales of SHS in the region among key distributers. However, pay-as-you-go systems rely on mobile phone services, posing significant challenges in regions with weak network coverage and reliability.

### *How can universal access to clean cooking be achieved by 2030?*

The number of people without access to clean cooking globally has fallen by around 650 million people since 2010, but the Covid-19 pandemic and the energy crisis have caused slow-downs and setbacks. In sub-Saharan Africa countries, the population without access has risen continuously, despite efforts by countries such as Kenya and Nigeria. Achieving universal access to clean cooking, as in the NZE Scenario, requires actions to be taken that enable nearly 2.4 billion additional people to use modern cooking fuels by the end of this decade.

Developments in Asia demonstrate that progress can be achieved quickly. In India, for example, more than 450 million people gained access over just ten years as a result of liquefied petroleum gas (LPG) focussed policies. However, limitations in terms of import, storage and transport infrastructure for LPG and lower population densities in sub-Saharan Africa in the near term imply that improved biomass cookstoves need to play a much larger transitional role before rural households move to modern cooking fuels (IEA, 2023e).

**Figure 4.23 ▷ Impacts of achieving universal access to clean cooking in emerging market and developing economies, 2022-2030**






***Boosting access to clean cooking provides multiple benefits ranging from improved health and productivity to reduced GHG emissions***

Note: Impacts on annual investment, energy demand and GHG emissions refer to the buildings sector.

Universal access to clean cooking could be achieved with annual investment of around USD 8 billion between today and 2030 along with a set of initiatives to incentivise the adoption of clean fuels and stoves. This would yield immense benefits in terms of improved health, improved gender equity and increased productivity (Figure 4.23). For example, the number of premature deaths due to indoor air pollution would be cut by over 70%, and GHG emissions associated with cooking would be cut by half, as people would no longer rely on the extremely inefficient use of traditional biomass. A further benefit would be to free up the substantial amount of time currently spent on collecting wood for use as fuel each day, a burden mainly carried by women.

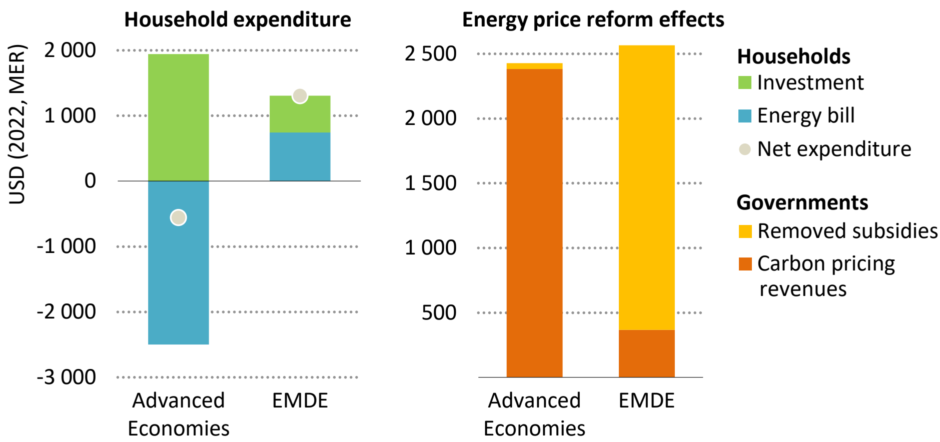
### 4.4.2 Energy affordability

Today, households in advanced economies on average consume nearly three-times more modern energy than households in emerging market and developing economies.[6] This reflects major income-driven differences in appliance ownership, size of living space and levels of comfort. For example, heating and cooling needs are largely met in advanced economies, whereas the majority of people with space cooling needs in emerging market and developing economies cannot afford adequate means to cool their residences (IEA, 2022). Transport fuel use is even more unequal, as car ownership per capita is five-times lower in emerging market and developing economies than in advanced economies. These differences in energy consumption decrease in all of our scenarios as households in emerging market and developing economies become wealthier and consume more energy services.

4

In advanced economies, household energy bills fall by nearly 20% in the STEPS to 2030 as a result of energy efficiency gains and lower wholesale energy prices. In the NZE Scenario, bills fall by close to 40% to 2030 mainly thanks to higher energy efficiency gains from home retrofits, heat pumps, more efficient appliances and faster uptake of EVs. While these all require additional upfront capital costs, on average they generate larger savings over their lifetimes (Figure 4.24).

**Figure 4.24 ▷ Cumulative energy expenditure and energy price reform effects per household in the NZE Scenario relative to the STEPS, 2023-2030**






*Expenditure is lower in the NZE Scenario in advanced economies; it is higher in emerging market and developing economies, mainly because of subsidy reform*

Notes: MER = market exchange rate; EMDE = emerging market and developing economies. Energy bills per household include expenditure for energy use in the residence and for transport fuels. Investment per household includes spending on measures such as energy efficiency retrofits, heat pumps, EVs and other clean energy technology investments.

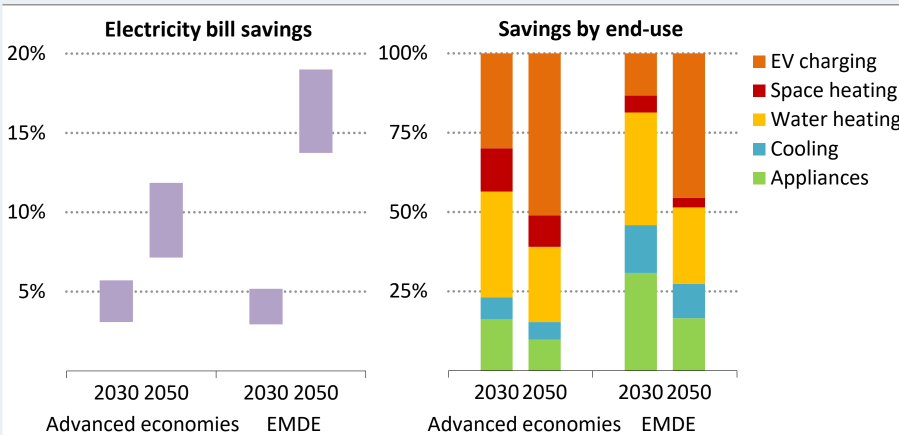
[6] Modern energy excludes the traditional use of biomass.

In emerging market and developing economies, energy bills are higher in the NZE Scenario than in the STEPS by 2030, partly because of higher energy service demands and partly because of expansion and strengthening of carbon pricing schemes and the phasing out of inefficient fossil fuel subsidies. These policy changes need to be carefully designed to limit impacts on household budgets and to sustain support for the clean energy transition (Box 4.3). Some of the revenues from carbon pricing, for example, could be used to help lower income consumers meet the upfront capital costs of clean energy appliances. Phasing out inefficient fossil fuel subsidies lowers the burden on government budgets: some of the savings could be used to provide more effective and better targeted support for the energy costs of low income households through direct payment schemes or other means.

**Box 4.3 ▷ Demand-side response as a tool to cut energy bills**

Recent pilot programmes in the United Kingdom and Australia demonstrate that demand-response policies and instruments can help consumers significantly reduce their electricity bills. Responsive technologies and electricity tariffs allow consumers to respond to market signals by increasing electricity consumption when prices are low and reducing it during peak hours, for example by charging an EV overnight when electricity demand and prices are lower. Demand-side response can also help limit curtailment of solar PV and wind at times of higher generation.

**Figure 4.25 ▷ Electricity bill savings from demand response for households and by end-use in the NZE Scenario, 2030 and 2050**






*Demand-side response measures can help consumers cut energy bills by up to nearly 20% by 2050 in particular by shifting EV charging and water heating patterns*

Notes: EMDE = emerging market and developing economies. Demand response refers to the ability of a consumer to shift consumption in time with no or limited impact on comfort. Estimates of the potential of demand-response measures account for technology and acceptability limitations.

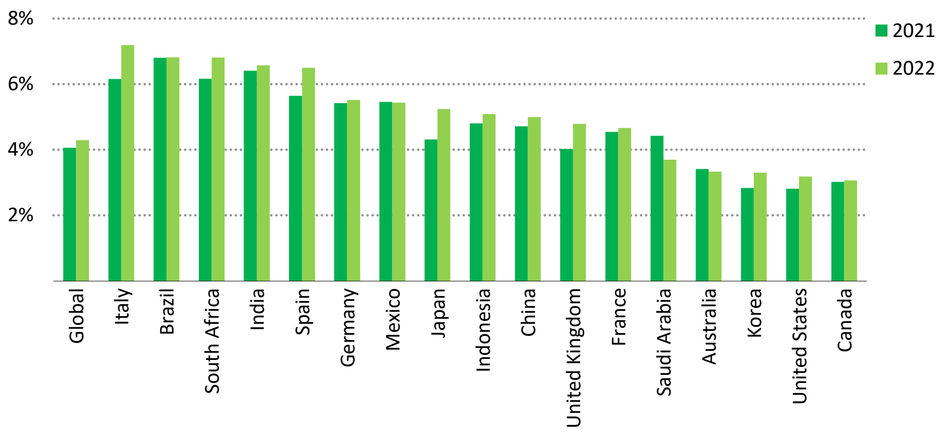
In the NZE Scenario, demand-response measures reduce the average household electricity bill in advanced economies by 3-6% in 2030 and 7-12% in 2050 (Figure 4.25). In emerging market and developing economies, bills could be reduced by up to 20% by 2050. The key in many countries is the rising use of solar PV, which incentivises a shift of energy consumption to daylight hours where possible. Major end-uses such as EV charging and water heating provide the largest contributions. Additional savings come from operating appliances such as washing machines and refrigerators flexibly in line with price signals.



### *Did short-term affordability measures help tame energy price spikes in 2022?*

In 2022, household budgets were squeezed around the world as a result of soaring energy prices. Wholesale prices for electricity, natural gas and other fuels were already increasing in 2021, but they rose further after Russia's invasion of Ukraine. Government interventions helped limit the impact on retail energy prices through measures such as grants and vouchers for consumers, compensation for utilities that kept prices down, and exemptions from energy taxes and charges (IEA, 2023f). The majority of short-term affordability spending was in Europe and other advanced economies. Wholesale energy prices have now passed their peak, but retail prices are falling more slowly and many support measures remain in place. While support measures had an important part to play in avoiding unsustainable burdens on households during a period of crisis, they are a major burden for governments and risk diminishing the incentive to use energy efficiently or to switch to cleaner fuels.

**Figure 4.26 ▷ Household energy expenditure in average household income in selected countries, 2021 and 2022**






***Energy prices increased sharply in 2022, though support measures, mild weather and behaviour change cushioned the impact on household incomes***

Note: Residential energy expenditure for average households reflects energy bill rebates and relief payments.

The global average share of household income spent on household energy bills increased marginally in 2022. In Japan and South Africa and some countries in Europe, expenditure shares increased by one percentage point on average, with much larger increases for lower income households (Figure 4.26). Energy expenditure would have been even higher in some cases had residential demand not decreased. Government-led campaigns in a number of countries in Europe, encouraged consumers to adjust their thermostats, though some vulnerable households had no choice in any case but to cut back on heating their homes in view of skyrocketing energy prices.

The share of income directly spent on home energy bills remained flat or even declined in countries where there was substantial government support to keep retail bills down or a relatively low level of dependence on imported fossil fuels for power generation, although household budgets were still squeezed by higher transport fuel costs. In most emerging market and developing economies, higher prices for transport fuel imposed a major burden on households, as did rising food prices. Around 60% of the financial support provided by governments in emerging market and developing economies targeted high transport fuel prices.

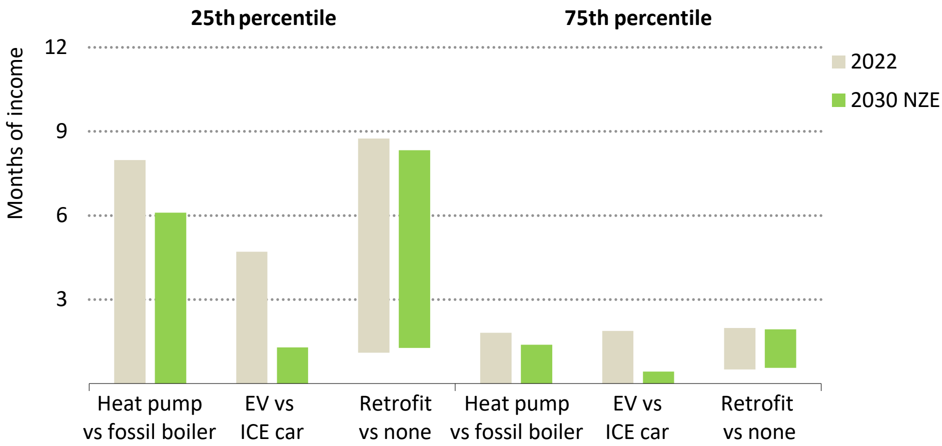
### *Are clean energy technologies affordable for all consumers?*

Consumers play a key role in shaping the clean energy transition when they choose to buy clean energy technologies in order to benefit from lower energy bills. However, it remains challenging for many consumers to find the money for important clean energy goods such as EVs and heat pumps or to fund energy efficiency retrofits in buildings. In the United States, for example, high income households are ten-times more likely to own an EV than the lowest income groups, and they also tend to have more solar panels and use more efficient appliances and lighting technologies (Davis, 2023). One way of making clean energy technologies more affordable is to use general energy taxation to encourage cleaner and more efficient consumer choices, aiming incentives at lower income households in particular.

Some clean energy technologies are already competitive with fossil fuel alternatives, or are very nearly so. In the United States, for example, air source heat pumps often do not cost significantly more than gas boilers and can provide substantial savings over their lifetime. In some markets, such as Sweden, they can even cost less than fossil fuel-powered alternatives. Heat pump ownership is still typically less among low income households where upfront cost barriers persist, which is the case in many parts of Europe. EVs, in particular smaller models and two-wheelers, are often an exception: in some countries, such as China, they are already available at prices that are comparable with (and sometimes lower than) those of gasoline or diesel fuel options.

Energy efficiency retrofits in buildings require substantial upfront investment. This can be equivalent to up to nine months of income for poorer households, and can represent a barrier for most other households as well. As a result, few such retrofits take place, even though they bring down energy bills for decades (Figure 4.27). Well-designed financial incentives remain crucial to scale up retrofits with high upfront costs across all income groups: they can be gradually phased out for well-off households as purchase costs decrease.

**Figure 4.27 ▷ Purchase cost premium of clean energy solutions relative to months of income in selected major economies**






***Upfront cost burdens of clean energy solutions remain high for lower income households, but relative costs are set to fall by 2030 in the NZE Scenario***

Notes: ICE = internal combustion engine. Cost premiums based on data for average size cars, residential dwellings and heat pumps in China, France, Japan, United Kingdom and United States. Subsidies are not included. In China, electric cars on average are cost competitive with ICE cars.

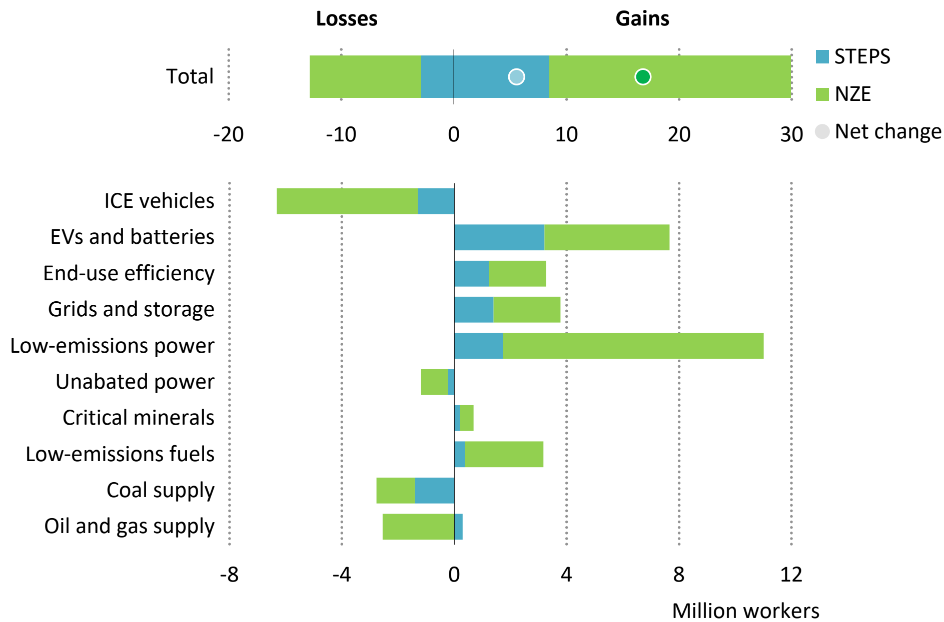
Source: IEA analysis based on World Inequality Database (2022) and JATO Dynamics (2021).

### *4.4.3 Energy employment*

Nearly 67 million people worked in the energy industry worldwide in 2022, with clean energy – including low-emissions fuels, low-emissions power generation, power grids and storage, energy efficiency, and EVs and batteries – accounting for over half of all jobs. End-use sectors, including energy efficiency and vehicle manufacturing, have the largest employment base (24 million workers), followed by the supply of fuels and critical minerals (22 million workers) and the power sector (20 million workers). Most energy workers are in the Asia Pacific region, with China alone accounting for almost 30% of all energy jobs. North America, Europe and India account for just over 10% each.

In all the scenarios, job creation associated with clean energy technologies comfortably outweighs job losses in fossil fuel and related industries through to 2030. In the NZE Scenario, 17 million additional jobs are generated in total (Figure 4.28). In some cases, jobs lost in one sector could transfer to others. For example, many workers involved in the assembly of internal combustion engine (ICE) vehicles could switch to assembling EVs. In other cases, however, new jobs created such as renewable power generation require training, may not pay the same wages and may not be in the same places as the jobs lost in fossil fuel industries such as coal mining. In such cases, targeted action by national and local governments, workers organisations and industry are needed to mitigate the social costs of the energy transition and ensure that no workers are left behind.

**Figure 4.28 ▷ Changes in global energy employment by sector in the STEPS and NZE Scenario, 2022-2030**






*Gains in clean energy employment more than compensate for job losses in declining sectors in both scenarios to 2030*

Notes: ICE vehicles = internal combustion engine vehicles; EVs = electric vehicles; unabated power = unabated fossil fuel power. Critical minerals include only extractive activities.

### *Are labour shortages a barrier to meeting transition goals?*

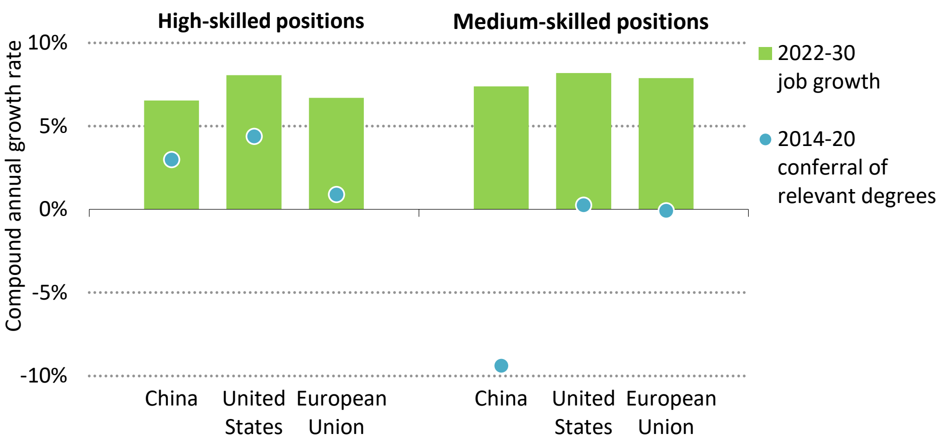
The success of the energy transition will depend not only on technological innovation and the mobilisation of capital but also on the millions of workers that will build and operate clean energy installations. The availability of properly skilled labour for the jobs that are being created is already emerging as a potential bottleneck to achieve transition goals in the near to medium term.

Construction represents the largest segment of clean energy employment today and by far the most significant source of job growth through 2030 in the APS and NZE Scenario. However, construction worker shortages are already threatening the pace of clean energy installations in dozens of markets worldwide. It is also proving difficult to recruit adequate numbers of tradespeople such as electricians, plumbers and welders, millions of which will be needed for jobs across the entire energy value chain. The manufacturing sector, another substantial area of energy employment growth, is also encountering staffing issues as labour demand increases. Even in manufacturing-intensive economies such as China, factors including shrinking working populations and a preference for white-collar jobs are preventing the manufacturing workforce from increasing quickly enough to meet future demand.

A variety of measures will be necessary to attract the workers that are needed for the future. Pay and working conditions will clearly be important, as will the provision of relevant education and training. In the STEPS, more than one-third of clean energy jobs created through 2030 are high-skilled and will generally require tertiary education, such as university degrees, while an even higher share of medium-skilled jobs will necessitate vocational or apprentice style training. Vocational education in construction, engineering and other critical areas has so far not managed to keep pace with the rising demand for this type and degree of skills (Figure 4.29). Industry and educational institutions need to collaborate to fill this gap and prepare the next generation of workers.

4

**Figure 4.29 ▷ Jobs by skill level in selected countries in the NZE Scenario**






***Construction is the largest source of clean energy employment today; action is needed to resolve labour shortages and meet expanding clean energy labour needs***

Notes: Relevant degrees for high-skilled positions are bachelor degrees in science, technology, engineering and mathematics; and for medium-skilled positions are vocational degrees including energy, engineering, mechanics and construction. Precise degrees included vary by country.

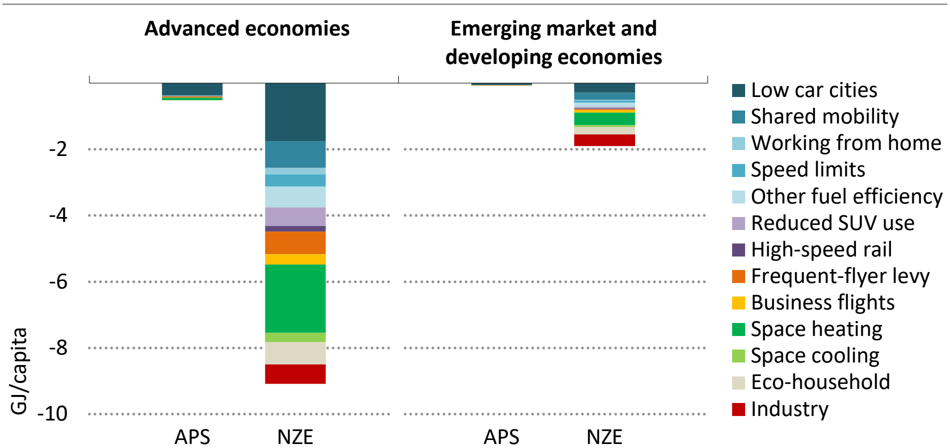
Sources: IEA analysis based on based on OECD (2023); China Ministry of Education (2021); US National Center for Education Statistics (2020).

### 4.4.4 Behavioural change

Energy demand depends on the behavioural choices of billions of consumers worldwide. Behavioural changes are actions that energy consumers take to reduce wasteful or unnecessary energy consumption and so help cut energy intensity. Many of these changes take place as part and parcel of daily life, and involve using energy differently or using less of it. These changes depend in part on individual choices and evolving socio-cultural norms. However, it is systemic transformations brought about by targeted and well-designed policy interventions that count most in changing consumer behaviour, and these often depend on the availability of infrastructure of one kind or another.

Technical options to reduce energy use are accelerated in the APS and maximised in the NZE Scenario, but the pace of stock turnover imposes inherent constraints on what can be achieved by 2035. The behavioural changes in the APS reflect those incorporated into net zero emissions pledges. These are mainly concerned with road transport, for example including traffic reduction measures in cities. The behavioural changes in the NZE Scenario are more wide ranging and systemic in nature, and include boosting shared mobility, reducing speed limits, discouraging sport utility vehicle ownership and use, adjusting heating and cooling temperatures in buildings, and switching from planes to trains or videoconferencing where possible (Figure 4.30). The NZE Scenario also integrates financial incentives and disincentives, for example including frequent flyer levies to reduce aviation demand in an equitable way.

**Figure 4.30 ▹ Energy savings per capita from behavioural changes by measure and scenario, 2035**





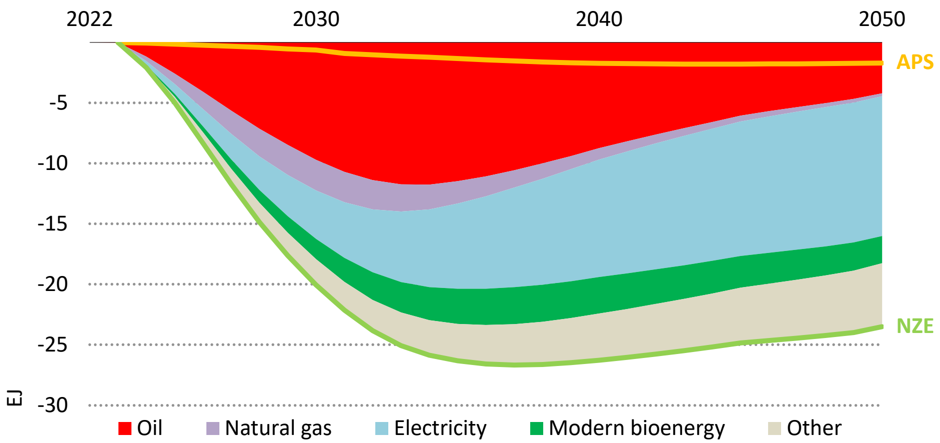

*Energy savings per capita from behavioural changes in the APS are 6% of those in the NZE Scenario; in both scenarios these savings happen mostly in advanced economies*

Notes: GJ = gigajoule. Eco-household measures include: line drying clothes instead of using a dryer; reducing laundry temperatures; switching off lights in unoccupied rooms; unplugging appliances when not in use and reducing water heating temperatures. See IEA (2022, 2021a) for details of other measures.

Behavioural changes in the NZE Scenario happen sooner and to a larger extent in wealthier parts of the world where there are the biggest opportunities to curb wasteful or excessive energy consumption, as evidenced by the finding that the top 10% of emitters in the global population were responsible for almost half of all energy-related $CO_2$ emissions in 2021 (IEA, 2023g). Behavioural changes in the NZE Scenario help to bring about a more equitable and just energy transition. In 2035, on a per capita basis, the energy savings from behavioural changes in aviation are about nine-times bigger in advanced economies than in emerging market and developing economies; in road transport and buildings they are about five-times larger.

The role of behavioural changes in the energy transition shifts over time (Figure 4.31). In the near term, behavioural changes are particularly important to address the decarbonisation challenges of locked-in emissions from carbon-intensive assets, such as ICE cars on the road or fossil fuel boilers in homes. In 2030, they cut oil demand by 6% and natural gas demand by 3% in the NZE Scenario compared with the STEPS. In the longer term, their impact on emissions fades as the energy system becomes increasingly clean, but they still significantly reduce energy use in 2050.

**Figure 4.31 ⊳ Energy savings from behavioural changes by fuel, 2022-2050**






***Behavioural changes help reduce emissions by cutting fossil fuel use in the near term and by curbing energy demand growth in the longer term***

### *Are there best practice policies emerging to trigger behavioural change?*

The energy crisis of 2022 prompted behavioural interventions by European governments seeking to reduce supply risk. For example, countries including Denmark, Germany, Ireland and Sweden launched national energy savings campaigns. The *Sobriété Energétique* (Energy Sobriety) programme in France introduced a host of behavioural measures, for example, reducing speed limits to 110 kilometres per hour on highways for government employees, stipulating that lighting for businesses, offices and billboards must be switched off at night, increasing cash incentives for remote working, and promoting carpooling.

**Table 4.2 ⊳ Impacts of selected behavioural changes in the NZE Scenario and similar existing measures**

| Measures in NZE Scenario | Global impact in NZE Scenario in 2030 | Selected measures and their impacts |
|---|---|---|
| **Low car cities** | Reduction in private car activity by up to 15%. | • London: 18% reduction in private car travel with ultra-low-emissions zones.<br>• Paris: 45% reduction in car journeys since 1990. |
| | Reduction in total road transport $CO_2$ emissions by 5%. | • Milan: 35% reduction in local $CO_2$ emissions with low-emissions zones. |
| | Increase in public transport. | • London: 33% increase in bus travel with ultra-low-emissions zones.<br>• Madrid: 9% increase in public transport use with low-emissions zones. |
| | Private car sales reduced by 9%. | • United States: around 4% decrease of vehicle sales per capita following shared mobility schemes. |
| | Improved well-being from:<br>• More active transport<br>• Less congested roads<br>• Lower noise and air pollution<br>• Improved health and safety. | • Jakarta: 1 000% increase in cyclists related to 300 km of new cycle lanes.<br>• London: 30% less congestion with ultra-low-emissions zones.<br>• Milan: 18% reduction in particulate and $NO_X$ pollution with low-emissions zones; 24% decrease in road casualties. |
| **Shift short-haul flights to high-speed rail** | Reduction in $CO_2$ emissions from domestic aviation by 2%. | • France: 3% reduction of $CO_2$ emissions from domestic aviation with ban on short-haul flights (estimated); 77-times less $CO_2$ emissions per passenger on impacted routes. |
| | Reduction in noise and air pollution. | • United States: 3 500 tonnes of harmful pollutants avoided through the California High-Speed Rail Authority Project when in operation. |
| **Avoid flights for business when not necessary** | Reduction in long-haul flights for business purposes by 43%. | • China: 26% reduction in business trips compared to pre-Covid pandemic levels (survey).<br>• Brazil: 44% reduction in business trips compared to pre-pandemic levels (survey). |
| **Save electricity with eco-household measures** | Household electricity consumption reduced by 7%. | • Japan: 7% saving in residential electricity consumption due to campaigns.<br>• France: electricity savings of 9-22% relative to 2022 due to the Energy Sobriety plan. |
| **Moderate space heating to 19-20 °C** | Household natural gas consumption reduced by 10%. | • Germany: 10-42% reduction in natural gas consumption in households and businesses relative to projected.<br>• France: 17% reduction in natural gas demand relative to 2021 levels. |
| **Moderate space cooling to 24-25 °C** | Reduction in electricity space cooling demand by 7%. | • India: an estimated 8% reduction in electricity demand for space cooling due to pre-purchase default temperature setting of 24 °C. |

Notes: Eco-household measures include: line drying clothes instead of using a dryer; reducing laundry temperatures; switching off lights in unoccupied rooms; unplugging appliances when not in use; and reducing water heating temperatures. See IEA (2022, 2021a) for details of other measures.

Globally, behavioural policies are being employed by governments at an accelerating rate. In the Group of 20 (G20), for example, the number of policies supporting behavioural changes has more than doubled since 2021. Around 50 countries have included behavioural measures to some extent in their NDCs or strategies to reach net zero emissions targets. For example, the NDCs of Bangladesh and Türkiye include targets for modal shifts from road transport to rail, while Colombia and Austria have set percentage increase targets for bicycle use. There is increasing awareness of the potential for policy interventions to encourage and facilitate behavioural change, alongside a recognition that clean energy transitions cannot happen without the consent, active support and engagement of people.

In terms of their design, scope and impact, the behavioural changes in the NZE Scenario are similar to many of the recent measures enacted by governments and sub-national jurisdictions (Table 4.2). For example, private car activity declines by up to 15% in the NZE Scenario by 2030 – a reduction similar in size to the one seen in London since the introduction of an Ultra-Low-Emissions Zone in 2019 (18%) – and far lower than the drop seen in Paris (45%) stemming from measures such as the addition of more than 300 km of bicycle lanes and limits on the road space available for private cars.



## 4.5 Investment and finance needs

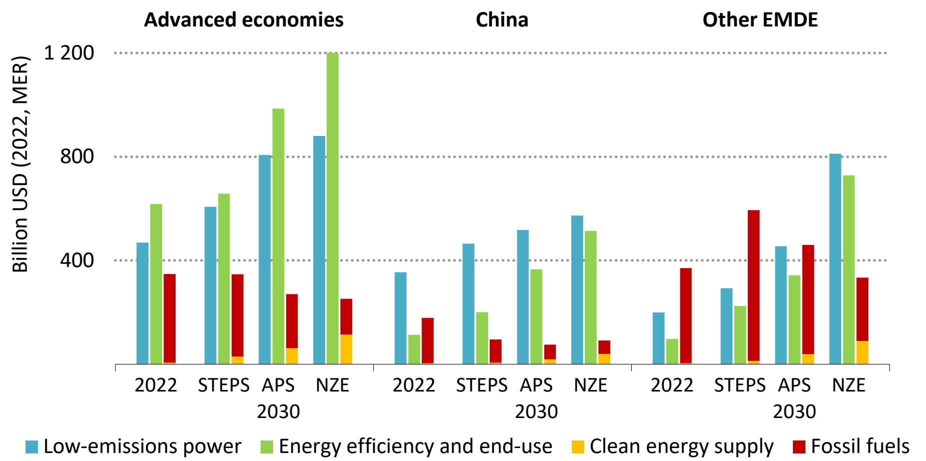
Energy investment is crucially important in each of our scenarios. In the STEPS, global energy investment rises to USD 3.2 trillion in 2030, nearly 15% higher than estimated levels for 2023 (USD 2.8 trillion). Clean energy investment accounts for all the increase, with fossil fuel investment falling slightly to USD 1.1 trillion. The total increase in investment is larger in the APS (a 40% increase from 2022 levels by 2030) and NZE Scenario (a 80% increase from 2022 levels by 2030) given the need for more upfront capital for clean energy investment. Clean energy accounts for USD 3.1 trillion of the USD 3.8 trillion invested in 2030 in the APS, and USD 4.2 trillion of the USD 4.7 trillion invested in 2030 in the NZE Scenario (Figure 4.32).

Advanced economies more than double their clean energy investment by 2030 in the NZE Scenario, while investment in China nearly doubles from its current level. The rise in other emerging market and developing economies is much larger, with clean energy investment rising in the NZE Scenario in 2030 to five-times today's level. The scale of the increase that is required in part reflects the difficulties that the countries in question have so far found in ramping up clean energy investment. Scaling up clean energy investment in these economies is a key challenge for orderly and just transitions and requires actions in three inter-related areas:

- A clearly-articulated and ambitious vision for clean energy, underpinned by effective changes to policy and regulatory regimes.
- Investment in human and institutional capacity and strong energy sector governance to help generate a pipeline of well-structured programmes and projects.

- Enhanced international support, including significantly more concessional finance and technical assistance to mitigate country and project risks and to act as an anchor for new instruments and platforms capable of attracting domestic and international investment capital at scale. Bilateral and multilateral development banks have an important role to play in advising on policy frameworks, financing and helping to develop early-stage projects, and using concessional capital to mobilise larger multiples of private capital.

**Figure 4.32 ⊳ Annual energy sector investment by scenario, 2030**






***Clean energy investment gaps are largest in emerging and developing economies other than China***

Note: MER = market exchange rate; EMDE = emerging market and developing economies.

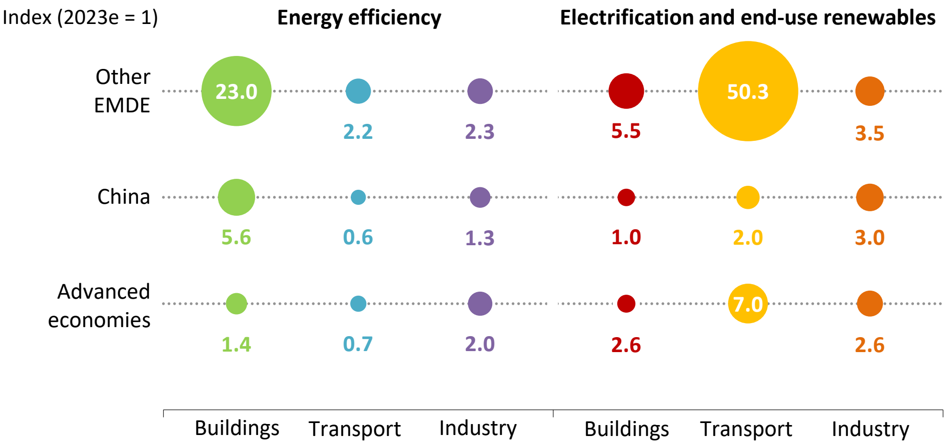
### *Are we investing enough in energy efficiency and end-use decarbonisation?*

Demand-side investment is sometimes overlooked in discussions on energy transitions, but it has a crucial part to play. It includes in particular investment to boost energy efficiency and encourage behavioural change; to accelerate expanded electrification of mobility and heat via EVs and heat pumps; and to increase the direct use of renewables for heating, cooling and industrial processes, for example by using solar water heaters and by deploying thermal energy storage to electrify industrial heat processes.

Current trends in these areas are mixed. Investment in electrified end-use applications is rising rapidly, reflecting the burgeoning sales of EVs and heat pumps, mainly in Europe, China and North America. Investment in efficiency received something of a boost from stimulus packages related to the Covid-19 pandemic, and also from exceptionally high energy prices in 2022 that provided signals to consumers to adopt more energy efficient solutions. But there are signs that efficiency investment is flattening in 2023 amid a slowdown in construction activity, higher borrowing costs and strains on household and corporate budgets.

There is a large gap between current trends and the investment required to get on track for the NZE Scenario. The NZE Scenario sees a doubling of investment in energy efficiency measures by 2030 and a broad-based rise in end-use electrification (Figure 4.33). This not only helps to reduce emissions but improves health outcomes, insulates consumers from fuel price volatility, and improves energy security and the balance of payments for countries dependent on imported fuels. Many of the largest gaps in efficiency investment are in emerging market and developing economies, reflecting the difficulty that many households and businesses face in managing upfront costs, and the relative weakness of policy frameworks and enforcement in many countries.

**Figure 4.33 ▷ Energy efficiency and end-use decarbonisation spending by sector In the NZE Scenario in 2030 relative to 2023e**






*Clean energy spending for end-uses such as EVs and heat pumps ramps up rapidly, especially in emerging market and developing countries other than China*

Note: 2023e = estimated values for 2023; EMDE = emerging market and developing economies.

Energy efficiency in the buildings sector stands out as in particular need of higher investment: in the NZE Scenario, it requires a sixfold increase in spending by 2030 in China and a 23-fold rise in other emerging market and developing economies. The urban population is increasing rapidly in most developing economies, and ensuring that new buildings meet high performance standards for heating and cooling presents a huge opportunity to minimise future strains on energy supply and to limit emissions. However, relatively few developing economies other than India have so far put energy efficiency building codes in place.

When it comes to electrification of energy end-uses, more investment is needed in all regions in the NZE Scenario. In recent years, more than half of global EV sales took place in China, but it will still need to double investment by 2030 (USD 150 billion) and advanced economies will need to increase spending by a factor of seven to meet investment levels in the

NZE Scenario (USD 370 billion). Emerging market and developing economies other than China will need to increase investment to USD 110 billion, which is more than 50-times higher than current levels. Electric two/three-wheelers are widely available in many developing economies, as are electric buses, but in most cases EV deployment levels are only just starting to rise: the share of electric cars in total sales was 3% in Thailand in 2022, and 1.5% in India and Indonesia (IEA, 2023h).

Rising debt levels and higher borrowing costs mean that few developing economies will have the budgetary space to replicate the EV purchase subsidies that have driven the EV boom in China and advanced economies, and they will need international support to increase the uptake of EVs. The concessional funding needed for emerging market and developing economies other than China to support transport energy efficiency and decarbonisation in the NZE Scenario is estimated at around USD 10 billion annually by the early 2030s. This could focus initially on reducing the cost of electric two/three-wheelers, e-buses and taxi fleets to make them more affordable with provision of concessional finance and grants: it will also need to support investment in charging infrastructure. Not all potential actions depend on the availability of concessional finance (Box 4.4). For light-duty vehicles, for example, governments in emerging market and developing economies could introduce differentiated import duties that favour EVs. They could also consider policy packages that include vehicle efficiency standards, pollution emissions standards and differential fuel taxation measures.

### Box 4.4 ▷ Role of finance in energy transitions

Achieving the increase in investment in clean energy in the NZE Scenario by 2050 requires a major reallocation of capital across the energy sector and a reconfiguration of the global financial infrastructure to accommodate this shift. This holds particularly true if the investment gap in emerging market and development economies is to be closed, as about 80% of the world's financial assets today are currently held in advanced economies. Finding mechanisms that will enable the channelling of funds at scale to emerging market and development economies is no easy task, and few proven models exist today. The challenge is made more difficult by the high upfront costs of key technologies that are needed as part of clean energy transitions, notably in the power and end-use sectors. This makes the ability to borrow and service a larger share of debt and ensure adequate risk-adjusted returns on investment for equity holders critical to attract investment.

Equity has underpinned the majority of annual energy investments to date and plays a pivotal role in funding clean energy transitions (IEA, 2021b). It is typically used to fund early-stage business models, new technologies with high upfront risks and projects that require long lead times. The availability of equity financing also often underpins investment in end-use sectors such as energy efficiency or electrification, such as heat pumps, where transaction sizes are generally smaller but where small and medium size enterprises face higher lending rates than larger corporate entities.

Although equity funding remains crucial, the capital structure of investment seen in the NZE Scenario relies on a significant increase in debt financing, with sustainable finance playing an increasingly important role in channelling funds from capital markets into clean energy projects. Green and sustainable debt has been developing rapidly in recent years – it reached USD 1.5 trillion in 2022 – but it still accounts for a small share of global bond issuances (5% in 2022) and is disproportionately concentrated in advanced economies (80% of issuances in 2022) (IEA, 2023i). Where issuances in emerging market and developing economies do occur, they are still dominated by hard currency, exposing them to foreign exchange risk. In the NZE Scenario, improvements in regulatory standards in emerging market and developing economies and the rise of large-scale sovereign issuances mean that green debt products quickly translate into new investment in clean energy in those countries.

In addition to a rise in debt financing, the NZE Scenario sees more private sector backed financing, more financing from domestic sources, and more concessional finance provided by DFIs and specialised mechanisms such as climate finance or carbon markets. These all contribute to some extent to closing the investment gap in emerging market and development economies.



### *What are the implications of our scenarios for investment in oil and gas?*

Determining the appropriate level of investment in oil and gas is a fraught and emotive issue in the energy debate. Some, including large resource-holders and certain oil and gas companies, maintain that the world is prematurely turning away from investment in oil and gas, and that the payback for today's underinvestment, as they see it, will be a period of sharp fuel price spikes and volatility down the road. Others argue that oil and gas investment is already unacceptably high given the imperative to tackle climate change, and that further overinvestment, as they see it, will lock the world to a pathway that pushes global average temperatures well beyond 1.5 °C.

What do the scenarios tell us about this crucial issue? Four key findings are highlighted:

- The oil and gas investment message from our analysis of the outlook in the STEPS has evolved. Until this year, we saw a gap between the amounts being invested in oil and gas and the future requirements of this scenario. Our recommended solution was to scale up clean energy spending and thereby reduce the requirement for oil and gas. What has happened in practice is that oil and gas investment has risen, while the level of oil and gas investment needed in the STEPS in 2030 has fallen as a result of lower projections of future oil and gas demand. As a result, current investment levels are adequate to meet projected supply needs in the STEPS. There is no longer a need – in any of the scenarios that we model – for oil and gas investment in 2030 to be higher than it is today Sentiment in the industry seems to be broadly aligned with this view: less than half of the available cashflows from record revenues in 2022 went back into new oil and gas investment, and current upstream spending remains below where it was in 2019.

- The invasion of Ukraine disrupted the global energy system and resulted in a lower level of exports of oil and gas from Russia. Consumers needed to adjust to this, and that has now happened. Shortfalls in supply from Russia are no longer a reason to argue for higher oil and gas investment.
- Today's level of investment in all fossil fuels, including oil and gas, is significantly higher than what is needed in the APS and double what is needed in the NZE Scenario in 2030. This implies that fossil fuel investors think that the STEPS describes the likely future more accurately than the APS or the NZE Scenario. The current level of investment creates the clear risk of locking in fossil fuel use and putting the 1.5 °C goal out of reach. However, simply cutting spending on oil and gas will not get the world on track for the NZE Scenario – the key is to scale up investment in all aspects of a clean energy system, especially in emerging market and developing economies, and to meet rising demand for energy services in a sustainable way.
- Both overinvestment and underinvestment in oil and gas carry risks for secure energy transitions. Evaluating the implications of investments is not straightforward: among other things, any assessment needs to take into account the source of investment and the likely efficiency of the spending. Policy makers also need to keep a watchful eye in this context on trends that could point to a future concentration in supply or other energy security risks. But when it comes to the overall adequacy of spending, our analysis suggests that the risks are weighted more towards overinvestment in oil and gas than the opposite.

# Regional insights

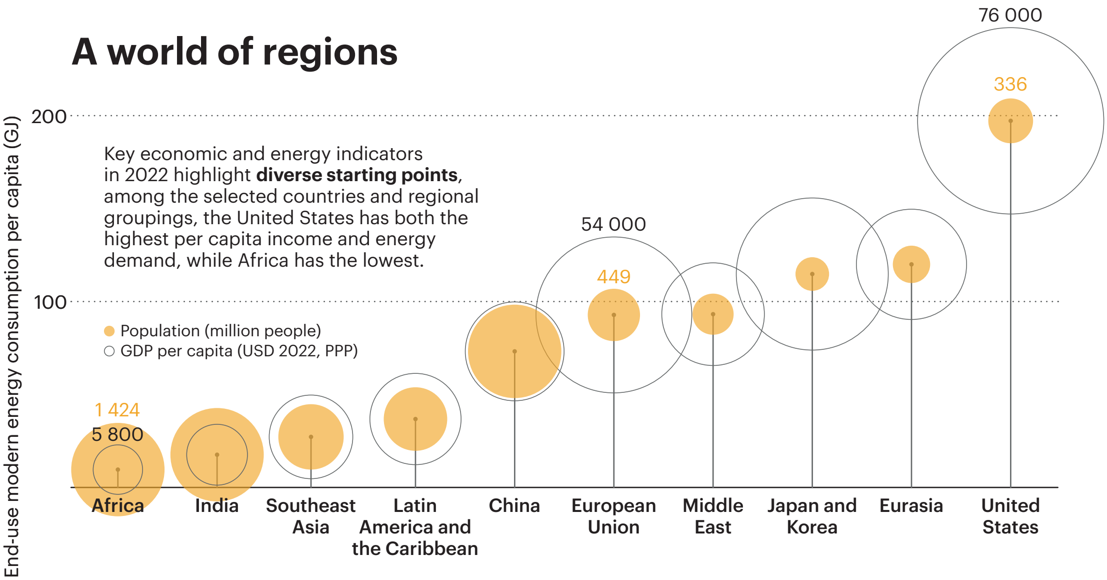
## Different starting points, different pathways


S U M M A R Y

- This chapter focuses on the prospects for selected countries and regions over the period to 2050 under the Stated Policies Scenario (STEPS), which considers the current policy landscape and market conditions, and the Announced Pledges Scenario (APS), which assumes all long-term commitments are met in full and on time. Together these selected countries and regions account for nearly 90% of global energy consumption today.
- The global energy crisis prompted a range of new initiatives, notably in advanced economies and China, that aim to increase the pace of clean energy deployment. Measures vary from region to region, but they all tend to place greater emphasis on boosting the share of renewables in electricity generation, incentivising electric car sales and improving energy efficiency.
- Energy needs in many emerging market and developing economies are increasing rapidly, which require major new investment in energy infrastructure ranging from electricity generation and grids to electric vehicle charging stations. Levels of ambition vary, but there is a widespread recognition that clean energy technologies can offer cost-effective solutions for a range of development objectives. Some emerging market and developing economies face difficulties to obtain financing. Concessional funding has a role to play in this regard, as do initiatives such as the Just Energy Transition Partnerships.
- Several countries have adopted policies that encourage the diversification of supply chains for clean energy technologies. This includes policies to promote clean energy technology manufacturing, for instance, the Inflation Reduction Act in the United States, the Net Zero Industry Act in the European Union and the Production Linked Incentives scheme in India.
- Despite moves by countries to reduce dependence on imported fuels and on geographically concentrated clean energy technology supply chains, the need for international trade and co-operation remains strong. No country can expect to be wholly self-sufficient, and most will continue to depend on imports and exports. International collaboration on innovation in particular will remain vital in the development of clean energy technologies.
- Today, a number of countries rely heavily on revenue from oil and gas production, and they face the prospect that these revenues will decline as clean energy transitions advance. This underlines the need for broader economic diversification to compensate for falling fossil fuel export revenue in the APS. Some countries are already taking steps in that direction.

# A world of regions

Key economic and energy indicators in 2022 highlight **diverse starting points**, among the selected countries and regional groupings, the United States has both the highest per capita income and energy demand, while Africa has the lowest.




With the deployment of clean energy technologies **reshaping the future energy supply mix** across the world, international co-operation for security, trade and innovation will continue to remain prominent.

**45%** of the electricity generated in the United States in 2030 is from renewables, up from 22% today

Total energy supply

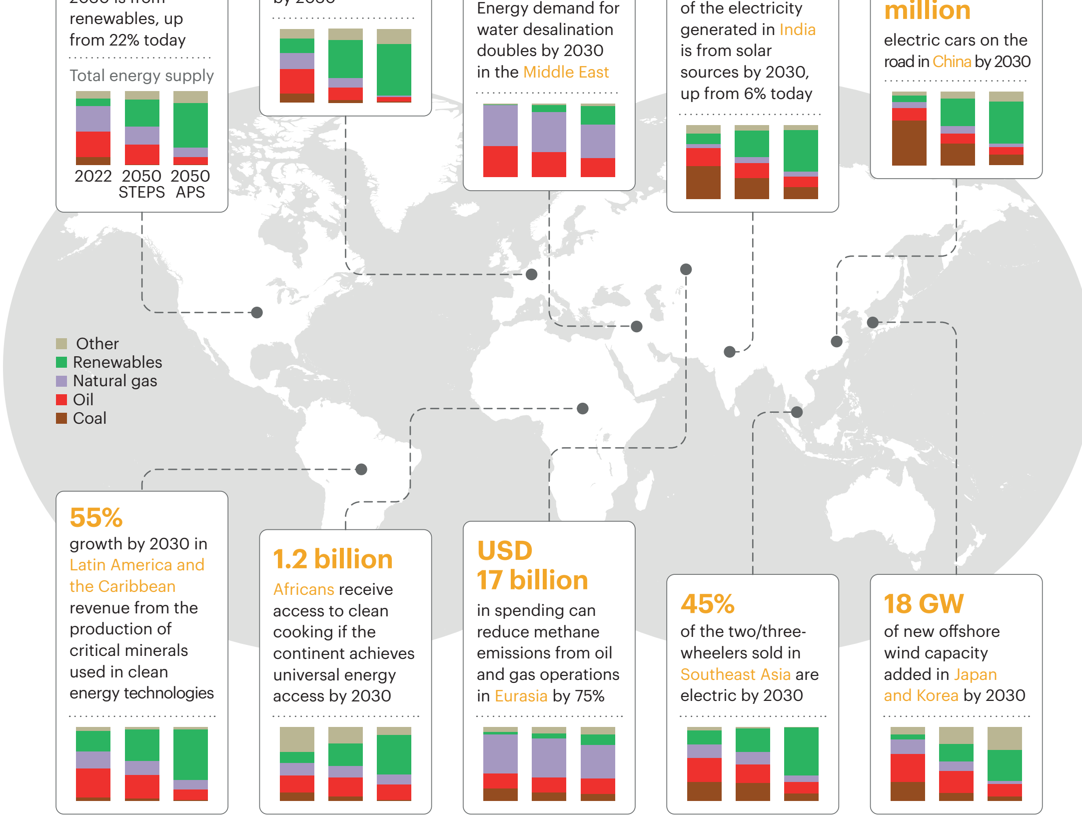
2022 | 2050 STEPS | 2050 APS

**65%** of all cars sold in the European Union are electric by 2030

**2X** Energy demand for water desalination doubles by 2030 in the Middle East

**18%** of the electricity generated in India is from solar sources by 2030, up from 6% today

**100 million** electric cars on the road in China by 2030




**55%** growth by 2030 in Latin America and the Caribbean revenue from the production of critical minerals used in clean energy technologies

**1.2 billion** Africans receive access to clean cooking if the continent achieves universal energy access by 2030

**USD 17 billion** in spending can reduce methane emissions from oil and gas operations in Eurasia by 75%

**45%** of the two/three-wheelers sold in Southeast Asia are electric by 2030

**18 GW** of new offshore wind capacity added in Japan and Korea by 2030

Note: The numbers in yellow reflect the STEPS, except for Latin America and the Caribbean (APS), and Eurasia and Africa (NZE Scenario).

## 5.1 Introduction

The chapter examines selected regions and countries which together account for nearly 90% of global GDP, population and energy demand. It highlights the specific issues and dynamics that affect them, taking account of their very different specific circumstances and ambitions. Starting points for the analysis vary widely and depend on a host of factors that include population, urbanisation, per capita income, economic structure, availability of natural resources and geography. Each section includes some common elements that describe the overarching trajectories for energy and emissions, key findings and the main factors that help to explain them. Each section also provides insights on one or two topical issues that highlight distinctive aspects of the projections. Table 5.1 highlights key indicators for the selected countries and regions.



**Table 5.1 ▷ Key economic and energy indicators by region/country, 2022**

| | Population (million) | Total energy supply (EJ) | Electricity demand (kWh per capita) | Cars per thousand people | $CO_2$ emissions (Gt) | $CO_2$ emissions (t per capita) |
|---|---|---|---|---|---|---|
| United States | 336 | 94 | 12 133 | 682 | 4.7 | 14 |
| Latin America and the Caribbean | 658 | 37 | 2 253 | 137 | 1.7 | 3 |
| European Union | 449 | 56 | 5 521 | 557 | 2.7 | 6 |
| Africa | 1 425 | 36 | 508 | 25 | 1.4 | 1 |
| Middle East | 265 | 36 | 4 190 | 175 | 2.1 | 8 |
| Eurasia | 238 | 42 | 5 051 | 193 | 2.4 | 10 |
| China | 1 420 | 160 | 5 612 | 201 | 12.1 | 9 |
| India | 1 417 | 42 | 926 | 31 | 2.6 | 2 |
| Japan and Korea | 177 | 29 | 8 703 | 490 | 1.7 | 9 |
| Southeast Asia | 679 | 30 | 1 592 | 63 | 1.7 | 3 |

Note: EJ = exajoules; kWh = kilowatt-hours; Gt = gigatonnes; t = tonnes.

### *Notes to key energy and emissions trends across regions*

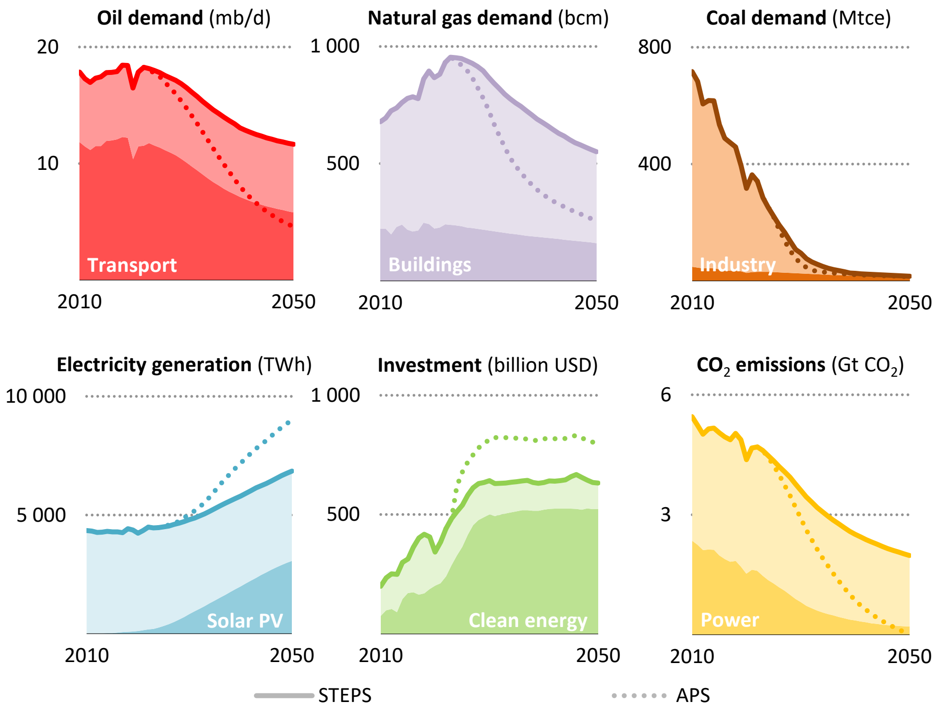
Each section in this chapter has a key trends figure that shows trajectories for oil, natural gas and coal primary energy demand, electricity supply, investment and carbon dioxide ($CO_2$) emissions. In all figures, the STEPS outlook for a particular sector or technology is shown more prominently in a darker colour, with the lighter area representing the remaining contribution of other sectors or technologies. Investment data are presented in real terms in year-2022 US dollars (USD) converted at market exchange rates.

$CO_2$ emissions refer to net energy-related carbon dioxide emissions. Common units and acronyms used in the figures include: mb/d = million barrels per day; Mt = million tonnes; Mtce = million tonnes of coal equivalent; bcm = billion cubic metres; GW = gigawatts; GWh = gigawatt-hours; TWh = terawatt-hours; EJ = exajoules; Gt $CO_2$ = gigatonnes of carbon dioxide; PV = photovoltaics.

## 5.2 United States

### *5.2.1 Key energy and emissions trends*

**Figure 5.1 ⊳ Key trends in the United States, 2010-2050**






The United States has mobilised unprecedented levels of government support to boost clean energy and reduce greenhouse gas (GHG) emissions (Table 5.2). The principal legislative vehicles are the Bipartisan Infrastructure Investment and Jobs Act of 2021, which invests around USD 190 billion for clean energy and mass transit, and the US Inflation Reduction Act of 2022, which provides an estimated USD 370 billion in funding to promote energy security and combat climate change. In the STEPS, these and other initiatives result in a reduction of nearly 40% in $CO_2$ emissions by 2030, relative to the 2005 level (Figure 5.1).

The largest impact of the increased government support is in the power sector, followed by transport and industry. In the STEPS, $CO_2$ emissions in 2030 in the power sector are 50% lower than today. This is largely the result of tax credits that accelerate the deployment of solar photovoltaics (PV) and wind. The reduction in emissions also reflects support for lifetime extensions of nuclear power plants, as well as batteries and carbon capture, utilisation and storage (CCUS) technology. In the transport sector, tax credits for electric cars and investment in charging infrastructure lead to annual sales of electric cars rising from 1 million in 2022 and 1.6 million in 2023 to close to 8 million in 2030, by which they account for 50% of new car registrations. Technologies that aid emissions reductions in hard-to-abate industrial sectors, such as CCUS and low-emissions hydrogen, are eligible for substantial tax credits, which can lay the foundation for strong growth in the years ahead. By attracting private capital, these incentives collectively support a doubling in clean energy investment in the United States by 2030 over 2022 levels. There is also a notable increase in cross-cutting investment in technology innovation.

These investments further accelerate reductions in demand for coal, which faces increasingly strong competition from renewables and natural gas. In the STEPS, coal demand falls by almost three-quarters by 2030 relative to the current level, largely thanks to solar PV and wind increasing their share of electricity generation. Natural gas demand is higher than the level in 2022 for several years, but peaks in the mid-2020s and then begins to decline, mostly as a result of lower demand in the power and buildings sectors. Oil demand falls by nearly 2 million barrels per day (mb/d) by 2030 from around 18 mb/d today, largely due to rising electric vehicle (EV) sales and fuel economy improvements.



**Table 5.2 ▹ Key policy initiatives in the United States**

| Policy | Description |
|---|---|
| Inflation Reduction Act | • Commits nearly USD 370 billion for energy security and climate change. |
| Bipartisan Infrastructure Investment and Jobs Act | • Commits around USD 550 billion in total federal investment, including around USD 190 billion for clean energy and mass transit infrastructure. |
| Methane Emissions Reduction Action Plan | • Focuses on cutting methane emissions from the largest sources, including oil and natural gas production, landfills and the agricultural sector. |
| Updated Nationally Determined Contribution | • Aiming to reduce GHG emissions by 50-52% by 2030 from 2005 levels.<br>• National target to reach net zero GHG emissions by 2050. |
| State-level clean electricity targets | • 100% carbon-free electricity or energy targets by 2050 in 22 states plus Puerto Rico and Washington DC. |
| Fuel economy standards | • Requirements to improve by 8% per year for light-duty vehicles for model years 2024-2025 and by 10% for model year 2026 relative to 2021 levels. |
| Zero emissions vehicles (ZEV) targets | • California ZEV mandate for cars beginning in 2026 and rising to 100% of sales in 2035 (Advanced Clean Cars II). Other states have adopted this mandate.<br>• California regulations to boost the deployment of medium- and heavy-duty ZEVs (Advanced Clean Trucks). Other states followed the same example. |

Exports of oil and gas from the United States are set to pick up in the coming years, in part because of lower export volumes from Russia (notably for natural gas). In the STEPS, the United States maintains its status as the world's largest natural gas exporter through to 2030. Liquefied natural gas (LNG) exports from the United States increase by 75% from 2022 levels to reach 185 billion cubic metres (bcm) by 2030, of which 95 bcm is transported to the European Union. Efforts to reduce methane emissions, along with efficiency and fuel switching policies, increase the availability and value proposition of US oil and gas exports.

The updated Nationally Determined Contribution (NDC) of the United States shows a substantial increase in ambition to 2030 in line with its pledge to reach net zero emissions by

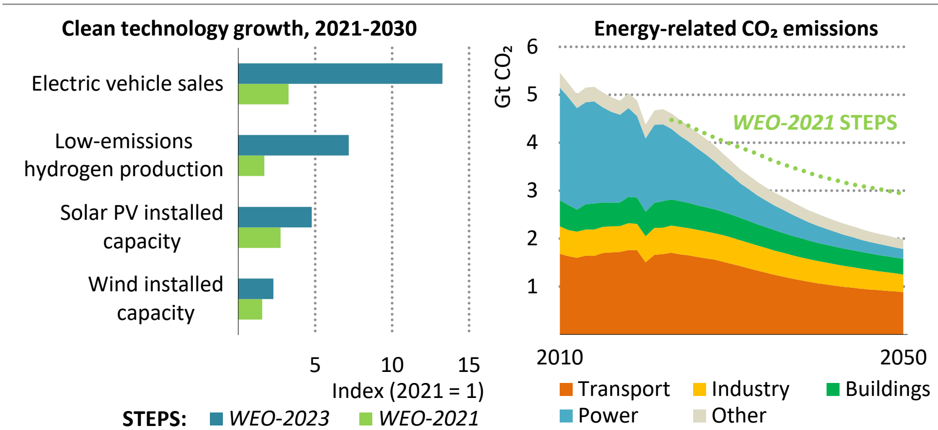
2050. Its commitment to reduce GHG emissions by 50-52% in 2030 from 2005 levels requires continuing efforts to accelerate deployment of renewables and other low-emissions technologies. Scaling up batteries and other forms of storage will also be important, as well as action to modernise, digitalise and expand grids in a timely manner.

### 5.2.2 How much have the US Inflation Reduction Act and other recent policies changed the picture for clean energy transitions?

The Inflation Reduction Act, the Bipartisan Infrastructure Investment and Jobs Act and other recent policies have reshaped the US energy outlook. Targeting a broad set of technologies across many sectors, the incentives now available are making clean energy investment more attractive, prompting faster deployment of clean energy technologies and the development of new clean energy manufacturing capacities in the United States. Our updated assessment in the STEPS clearly demonstrates the significant impact of these policies when compared to the outlook prior to these policies in the Stated Policies Scenario from the *World Energy Outlook-2021* (*hereinafter referenced as WEO-2021* STEPS) (IEA, 2021).

*Clean energy deployment and $CO_2$ emissions*

**Figure 5.2 ▷ Clean energy technology growth and energy-related $CO_2$ emissions in the United States in the STEPS**



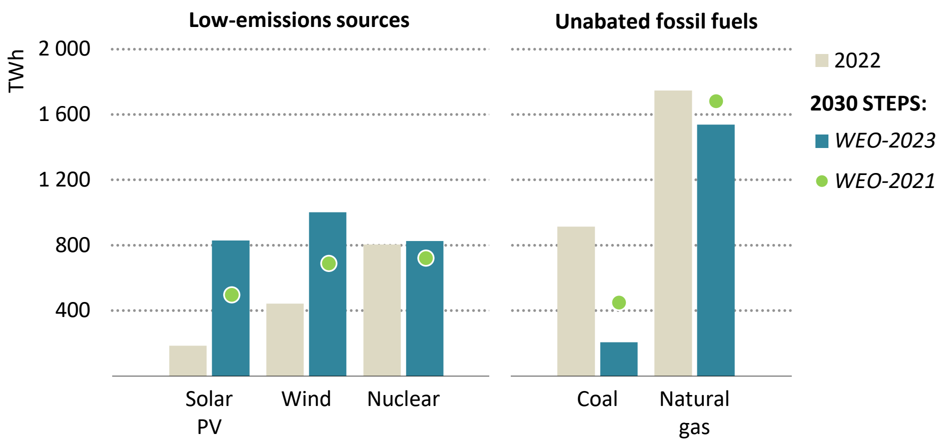



*The Inflation Reduction Act spurs clean energy technology deployment and accelerates the pace of $CO_2$ emissions reductions*

The Inflation Reduction Act and other recent policies have significantly improved the outlook for a host of clean energy technologies. Electric vehicle sales in 2030 are projected in this *World Energy Outlook* (*WEO-2023*) STEPS to be 13-times the 2021 level, compared with just a threefold increase in *WEO-2021* STEPS (Figure 5.2). Carbon capture projects completed by 2030 in the STEPS, including those under construction, are set to capture three-times the volume of $CO_2$ emissions as in 2021, double the increase projected prior to the Inflation

Reduction Act, while low-emissions hydrogen is now expected to gain much more than the modest foothold projected in the *WEO-2021*. Wind and solar PV have also benefited significantly from the support now available for clean energy technologies. As a result of these changes, energy-related $CO_2$ emissions decline to 3.6 gigatonnes (Gt) by 2030 in the STEPS, 10% below the level in 2030 projected in the *WEO-2021* STEPS. The power sector accounts for most of the difference, followed by transport and industry, but all sectors make a contribution. The accelerated progress made by 2030 also paves the way for more rapid progress in succeeding years: emissions in 2050 are now projected to be one-third below the level expected before the Inflation Reduction Act came into force.

**Figure 5.3 ▷ Electricity generation from selected sources in the United States in the STEPS, 2022 and 2030**






*The Inflation Reduction Act accelerates deployment of solar PV and wind, supports nuclear lifetime extensions and leads to an 80% reduction in unabated coal power by 2030*

In the power sector, the boost provided by the Inflation Reduction Act for both existing and new low-emissions sources of electricity accelerates the transition away from coal-fired generation and reduces $CO_2$ emissions. If all the conditions are met to receive the maximum available tax credits for solar and wind, then the levelised cost to consumers of new solar PV and wind in the United States is expected to be lower than anywhere else in the world. These incentives are attracting private investors. By 2030, solar PV output surpasses 800 terawatt-hours (TWh) in the STEPS (two-thirds above the level projected in *WEO-2021* STEPS) and wind reaches 1 000 TWh (almost 50% above the level in the *WEO-2021* STEPS) (Figure 5.3). Tax credits in the Inflation Reduction Act also support lifetime extensions of nuclear power plants, which are one of the cheapest sources of low-emissions electricity. As a result of these various incentives, unabated coal-fired power falls by about 80% in the STEPS, compared with about 50% in the *WEO-2021* STEPS. Unabated natural gas-fired generation also declines by more than projected prior to the Inflation Reduction Act.

### *Clean energy manufacturing*

In recent years, clean energy manufacturing has been insufficient to meet domestic needs in the United States. For example, in 2022, the domestic content of wind turbine blades and hubs was about half and only one-third of solar PV modules were produced domestically. While imports of clean energy components will continue, and would benefit from more supply diversity, the Inflation Reduction Act provides significant incentives to boost domestic clean energy manufacturing in the interests of maximising the domestic benefits of the transition to clean energy and of national security. These incentives have resulted in a number of announcements from companies looking to develop new clean energy manufacturing capabilities in the United States, including plans for the production of hydrogen, batteries, solar PV and wind turbines (Table 5.3). The United States has witnessed a surge in announcements of large manufacturing facilities over the past year. Gigafactory capacity, expected to remain operational until 2030, increased from 750 gigawatt-hours (GWh) in July 2022 to 1.2 TWh by September 2023, due in large part to the support in the Inflation Reduction Act (Benchmark Minerals Intelligence, 2023).

**Table 5.3 ▷ New announcements for clean energy technology manufacturing in the United States**

| Technology | Description |
|---|---|
| Hydrogen production | • Aim to reach over 5.5 Mt of hydrogen by 2030 (mainly coupled with CCUS).<br>• Top-five projects account for around half of the capacity target. The largest project would produce 1 Mt of hydrogen per year and be online in 2028. |
| Batteries | • Aim for production capacity of 1.2 TWh by 2030, about 12-times the current level.<br>• Top-five projects account for one-third of the capacity target. Tesla alone has announced 260 GWh production capacity by 2030. |
| Solar PV | • Exceeding 40 GW production capacity for solar modules by 2030, up from 7 GW today. |
| Wind | • 1.5 GW production capacity of offshore nacelles by the end of this decade. |

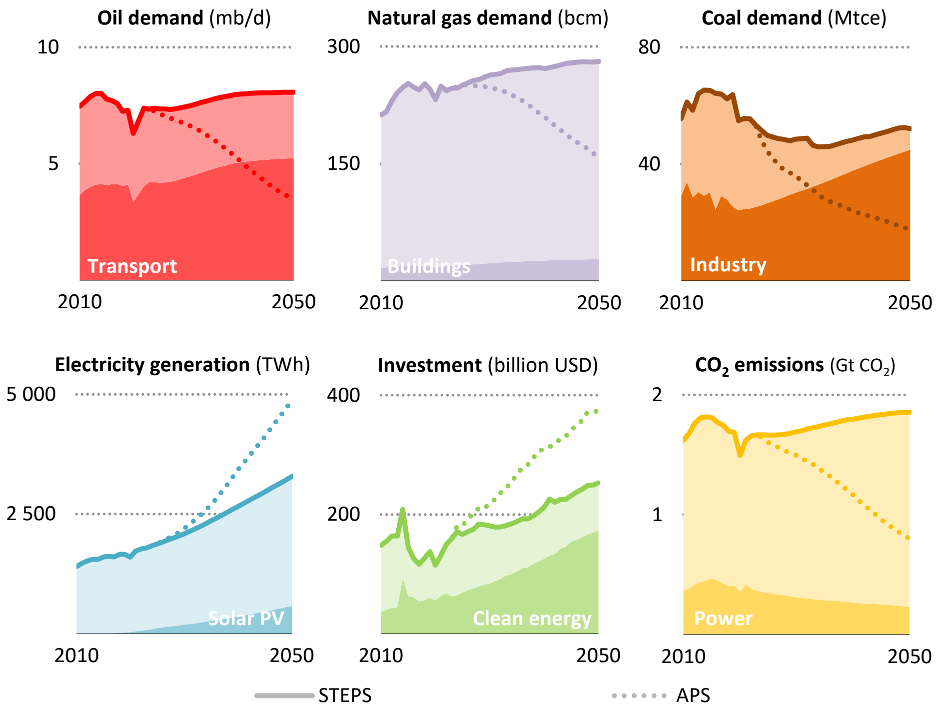
Sources: IEA analysis based on BNEF (2023a, 2023b), Wood Mackenzie (2023), SPV Market Research (2023) and Benchmark Minerals Intelligence (2023).

An increase in manufacturing capacities will help the United States to create more resilient supply chains for clean energy technologies, though these will inevitably take time to develop. Around USD 150 billion in planned investment has been announced so far for key technologies, including batteries, EVs, charging infrastructure, offshore wind, and solar (US Department of Energy, 2023). With these investments, the United States is likely to be able to meet all or most of its domestic needs for hydrogen electrolysers, EV and stationary battery deployment by 2030. However, even with a sixfold increase in solar PV module manufacturing, the United States would still only produce about 10% of what is needed for 2030 deployment in the STEPS. The figure for wind is even lower, and there have been few announcements so far about planned increases in domestic manufacturing capacity for wind power components. Ensuring resilient and diverse international supply chains is therefore going to remain important as clean energy deployment ramps up.

## 5.3 Latin America and the Caribbean

### *5.3.1 Key energy and emissions trends*

**Figure 5.4 ⊳ Key trends in Latin America and the Caribbean, 2010-2050**






Latin America and the Caribbean (LAC) is a diverse and strategically important region with strong connections to major global markets. It comprises 8% of the world population and 7% of global GDP and is one of the most highly urbanised regions in the world, with 82% of its people living in cities. Its economy today is closely tied to the production of fuels, minerals and food for export, exposing it to volatility in international markets and price cycles. The region is coming out of a "lost decade" of economic growth punctuated by the Covid-19 pandemic and the global energy crisis. Curbing high inflation and pursuing opportunities in the new energy economy could help to spur an economic rebound.

Half of the countries in LAC have pledged to achieve net zero emissions by mid-century or earlier. They account for around 65% of the LAC GDP and 60% of its energy-related $CO_2$ emissions. To reach these goals, LAC countries need not only to speed up the deployment of clean energy technologies but also to tackle deforestation. While energy accounts for about less than half of total GHG emissions in the region, agriculture and land-use change play an outsized role, and they are responsible respectively for 25% and 20% of total GHG emissions.

**Table 5.4 ▷ Key policy initiatives in Latin America and the Caribbean**

| Policy | Description |
|---|---|
| Net zero emissions targets | • In place in 16 out of 33 countries, representing 65% of GDP and 60% of $CO_2$ emissions from fuel combustion. |
| Nationally Determined Contributions (NDCs) | • Submitted by all 33 countries, including 29 with updated targets, translating into a level of $CO_2$ emissions from fuel combustion of 1.7-1.8 Gt $CO_2$ in 2030. |
| Environmental governance | • Fifteen countries ratified the Escazú Agreement – Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters. |
| Deforestation targets | • In place in 8 countries (Brazil, Chile, Colombia, Costa Rica, Dominica, Guatemala, Mexico and Suriname). |
| Hydrogen strategy | • In place in 8 countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Panama, Uruguay) and 4 countries with strategies announced but still in preparation (Bolivia, Paraguay, Peru, Trinidad and Tobago). |
| Access targets | • Set in 11 countries for electricity access (24 out of 33 countries have already reached 95% access rate); 7 countries for clean cooking (12 out of 33 countries have already reached 95% access rate). |
| Zero emissions vehicle policies | • In place in 16 countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Mexico, Nicaragua, Panama, Paraguay, Trinidad and Tobago, Uruguay). |

Total energy supply in LAC is set to increase as a result of population and economic growth. In the STEPS, energy supply increases by 10% from 2022 to 2030 and 35% by 2050, with the share of supply that comes from fossil fuels decreasing slightly as deployment of renewables increases. The slight decrease in the share of fossil fuels in energy supply is not enough to prevent energy-related $CO_2$ emissions in the region from rising 10% higher than current levels in 2050 (Figure 5.4).

In the STEPS, electricity demand rises over time, twice as fast as fossil fuels. Final energy consumption in LAC today is primarily oil, most of which is used in transport, but the share of oil is set to decline as countries seek alternative transport fuels: Brazil leads in biofuel adoption, while Chile, Colombia, Costa Rica and Mexico are prioritising the rapid uptake of EVs. Expanding ownership of appliances and air conditioners leads to higher use of electricity in LAC households: by 2050, two-thirds of energy in the buildings sector is electricity. The industry sector in LAC is less energy intensive than the global average, with non-energy intensive sectors (especially the food sector) accounting for 45% of industrial energy demand (compared to 30% globally), and their use of electricity also increases. Electricity in LAC today is primarily from hydropower and natural gas, but solar PV and wind make up the vast majority of new electricity supply in the STEPS. Low-emissions sources, which accounted for over 60% of total generation in 2022, rise to over 80% by 2050. Natural gas remains the largest fossil fuel, and it is the only fossil fuel that sees an increment on its output of almost 25%, while coal and oil use decline by at least 75% over the period.

In the APS, meeting NDCs and net zero emissions targets cuts energy-related $CO_2$ emissions by 10% by 2030 and 50% by 2050, relative to the 2022 level (Table 5.4). Energy efficiency plays a key role in moderating electricity demand increases in the buildings sector, while further electrification of transport helps to reduce the share of fossil fuels in total primary energy supply from two-thirds today to below 60% in 2030. As a result, LAC makes significant contributions to global clean energy transitions, accounting for almost 10% of the global reduction in oil use by 2050 and about 5% of the reduced use of natural gas. Cleaner energy sources, more stringent environmental policies and better access to clean cooking also help to reduce air pollution, a major cause of poor health in the region. The new energy economy that emerges in the APS sets the stage for LAC to tap its abundant renewable energy resources to produce low-emissions hydrogen for both domestic use and export.

### *5.3.2 What role for Latin America and the Caribbean in maintaining traditional oil and gas security through energy transitions?*



The global energy crisis has raised energy security questions for many net importing countries, potentially creating an opportunity for producers and resource-rich countries in the LAC region to step up their own production and export. This section examines how these opportunities play out in our scenarios, and also considers some of the commercial and environmental risks.

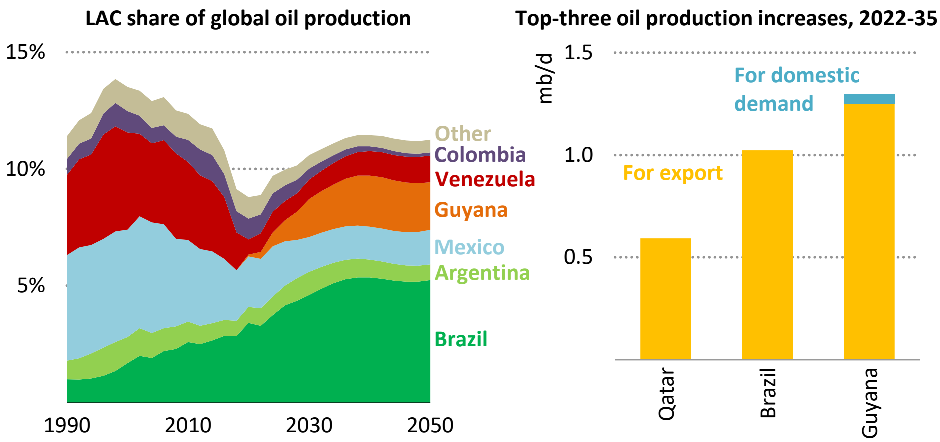
Today the region is already a net crude oil exporter: in the STEPS and APS it is poised to play a growing role in global oil production and trade. In the APS, oil production increases while oil demand declines up to 2035 in LAC, raising net exports from 0.6 mb/d in 2022 to 2.3 mb/d in 2035. The growth is concentrated in Guyana and Brazil. Reliance on export markets makes these projections highly sensitive to the pace of global transitions, which vary substantially across our scenarios depending on the strength of government policies. Demand in the APS continues to allow for some new upstream developments if they are competitive on cost and exhibit low-emissions intensities, but new oil and gas fields around the world would face major commercial risks if global demand follows the Net Zero Emissions by 2050 (NZE) Scenario pathway that limits global warming to 1.5 degrees Celsius.

Guyana discovered very large oil reserves offshore in 2015 and accounted for more than half of LAC crude discoveries and 7% of global crude discoveries from 2015 to 2023. In the APS, Guyana increases oil production by 1.3 mb/d from 2022 to 2035 (Figure 5.5), the largest increase of any country in this scenario. With a population under 1 million, nearly all of Guyana's expanded oil production is available for export. The boost in oil exports generates more diversity of oil supply even as overall global demand starts to decline. It also provides an opportunity to support Guyana's development if a comprehensive governance framework for the sector is in place (Balza et al., 2020) Guyana quadrupled oil exports from 2020 to 2022, with about half of delivered cargoes in 2022 going to the European Union to help replace Russian oil and a further one-third to Asia.

Brazil accounts for the second-largest increase in oil production in the world to 2035, at around 1 mb/d. Brazil has been the largest oil producer in LAC since 2016, having overtaken both Venezuela and Mexico: it continues to hold this position through to 2050 in the APS, accounting for about 5% of global production from 2030 to 2050. All the additional oil produced in Brazil is likely to go for export: current key export markets include China, European Union, India and United States.

Argentina has the potential to significantly expand its production of natural gas, which would have the effect of reducing net imports to the LAC region. Higher output in Argentina would compensate for reduced output in several other producers. Trinidad and Tobago is the second-largest natural gas producer in LAC today and a major exporter of LNG, but its 2022 production was 20% below a recent high in 2019, and it falls by another 30% to 2030 in the APS. Overall, LAC remains a net importer of natural gas in the APS, though the import volumes declines sharply after 2030, making more than 50 bcm available to other markets.

**Figure 5.5 ▷ Oil production in Latin America and the Caribbean relative to global production in the APS, 1990-2050**






*Guyana and Brazil rank as the first two countries in the world in oil production growth to 2035, with their combined output rising by 2.3 mb/d, mostly for export*

## 5.3.3 Do critical minerals open new avenues for Latin America and the Caribbean's natural resources?

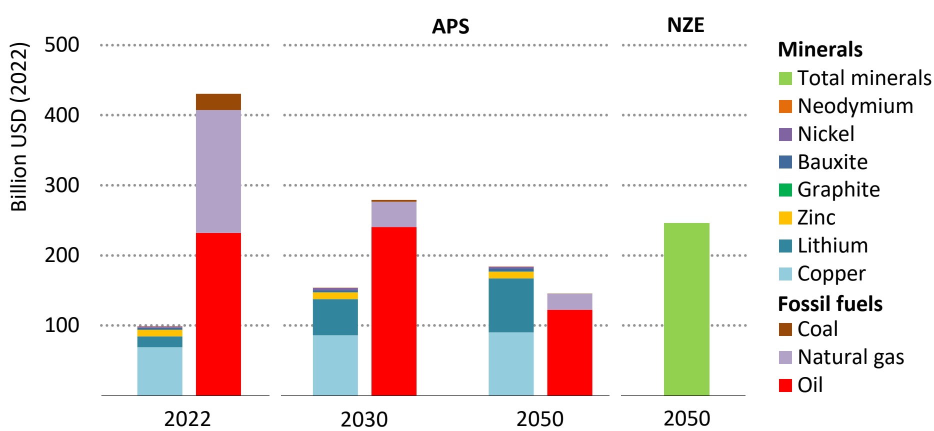
Rising demand for clean energy technologies offers significant scope for LAC to expand production and export of critical minerals, building on its well-established mining sector and significant minerals reserves. In doing so, it could help the global economy avoid the supply bottlenecks that might threaten clean energy transitions. The region already produces large quantities of lithium, which is essential for almost all types of EVs and storage batteries today, and of copper, which underpins the expansion of renewables and electricity networks. LAC could expand into a range of other materials such as nickel – a key component in batteries and electrolysers – and the rare earth elements that are required for EV motors and wind turbines. There are three key opportunities in this respect: scale up production, including undeveloped resources; improve practices for responsible and sustainable supply; and move from the production of ores to processed products.

LAC accounts for 40% of global production of copper, led by Chile (24%) and Peru (10%). Copper production started to pick up in 2022 after several flat years. Both countries made a sizeable contribution to production growth and now have expansion projects underway. A mega-port is under construction in Peru to facilitate exports. The national mining plan in Chile includes a copper production target of 7 Mt by 2030, up from 5.7 Mt today, and 9 Mt by 2050, alongside a doubling in annual investment in greenfield exploration.

LAC supplies 35% of global lithium and holds around half of lithium reserves. It is home to the so-called "lithium triangle" – a lithium-rich region that spans Argentina, Bolivia and Chile. Today, Chile accounts for 30% and Argentina for 5% of global lithium production. Bolivia also has substantial lithium resources: a lack of infrastructure has so far hindered them from being economically lucrative, but CATL, a Chinese firm, plans to invest over USD 1 billion in a lithium project in Bolivia. So far, lithium mining has been concentrated on the salt flats of Chile, but the Kachi mine is expected to begin operations in Argentina in 2024, and the Grota do Cirilos mine has just started production in Brazil.

5

**Figure 5.6 ▷ Revenue from production of selected critical minerals and fossil fuels in Latin America and the Caribbean, 2030 and 2050**






*Revenue from critical minerals production expands 1.5-times by 2030 in the APS and surpasses the level of revenue from fossil fuels by 2050 in both scenarios*

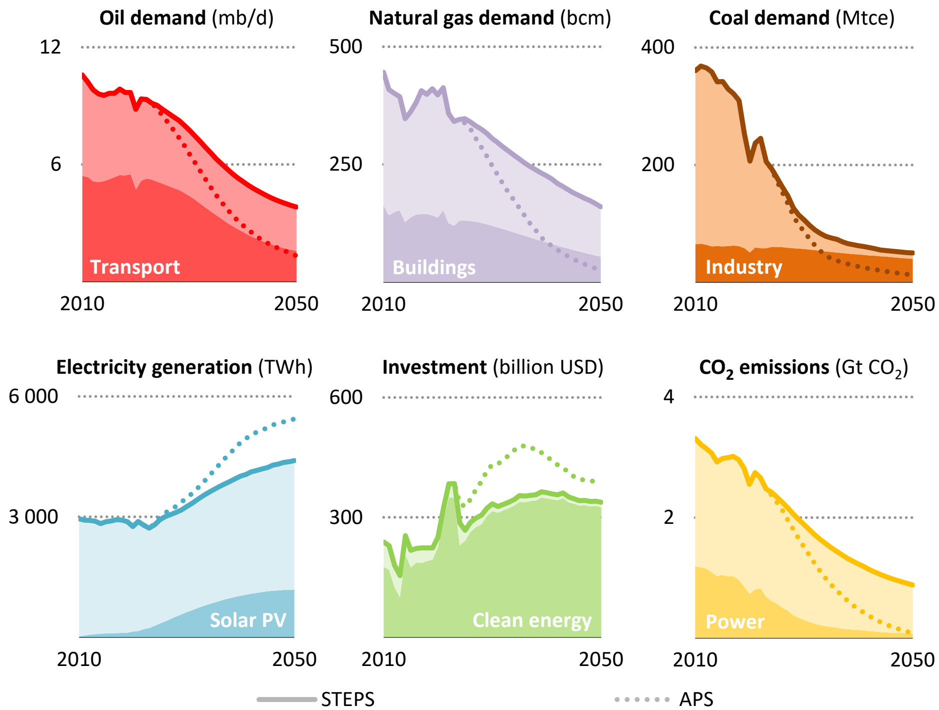
Notes: Revenue is total proceeds from domestic sales and exports. Assumes average 2022 prices for minerals in 2030 and 2050, and current LAC market share in global minerals production.

Revenue from the production of critical minerals (graphite, bauxite, nickel, zinc, lithium, copper and neodymium) in LAC totalled around USD 100 billion in 2022 (Figure 5.6). With rising demand for these minerals, LAC revenue from their sales increases 1.5-times by 2030 in the APS. By 2050 in the APS, critical minerals production revenue overtakes that of combined fossil fuel production in the region, which falls to USD 145 billion as countries around the world deliver on announced pledges to limit the impacts of climate change. In the NZE, the revenues from critical minerals production rise further to USD 246 billion by 2050.

## 5.4 European Union

### *5.4.1 Key energy and emissions trends*

**Figure 5.7 ▷ Key trends in the European Union, 2010-2050**




IEA. CC BY 4.0.

Russia's invasion of Ukraine has had profound effects on the energy sector in the European Union. Vast sums were spent on energy in 2022: the European Union paid over USD 300 billion for natural gas imports in 2022, a threefold increase compared to the average of the previous five years. This fed through to much higher end-user prices for both natural gas and electricity. Even though governments made far-reaching interventions to cushion the impacts and reduce demand, and the well-integrated EU energy markets helped to manage supply risks, spending on energy use in buildings, transport and industry in the EU in 2022 rose above USD 2 trillion, equivalent to 12% of GDP.

In response to the energy crisis, the European Union raised its clean energy ambitions, while placing energy security at the forefront of its transition plans. This is already visible in the STEPS: oil and gas demand is projected to come down by 15% by 2030 from 2022 levels, and coal demand by 55%. Large legislative packages and a raft of national and EU-level incentives, representing almost USD 500 billion in enacted funding for clean energy investment are reflected in the STEPS; renewables make up two-thirds of electricity generation in 2030, up from 39% in 2022, with wind and solar PV accounting for over 85% of the new capacity built in this period. In the APS, the more ambitious EU Fit for 55 package targets are largely met, ensuring that the European Union achieves a 55% reduction in GHG emissions by 2030 relative to 1990 levels, and also meets the REPowerEU goal of eliminating dependence on Russian natural gas before 2030. This requires a 20% increase in renewables deployment compared to the STEPS in 2030.

**Table 5.5 ▷ Key policy initiatives in the European Union**

| Policy | Description |
|---|---|
| Fit for 55 | • Implementation framework for the European Green Deal.<br>• Supported by the Renewable Energy Directive, Energy Efficiency Directive, EU Emissions Trading System reform and Carbon Border Adjustment Mechanism.<br>• Includes packages for electricity market design, hydrogen and decarbonised gases, creating harmonised rules for a single energy market.<br>• 100% $CO_2$ emissions reduction for both new cars and vans from 2035, emissions standards for heavy-duty vehicles and FuelEU maritime initiative.<br>• Increases the minimum energy performance standards for existing buildings, and requires all new buildings to be zero emissions by 2028. |
| Sustainable recovery | • Member states have committed close to USD 500 billion towards a sustainable recovery through national recovery plans and EU-level packages such as the Recovery and Resilience Facility. |
| REPowerEU | • Sets out a pathway to cut reliance on Russian natural gas via energy savings, diversification of supply and accelerated roll out of renewable energy. |
| Net Zero Industry Act | • Aims to boost clean energy technology manufacturing, targets technology areas such as solar and wind, bioenergy, hydrogen, CCUS, battery storage, grids and heat pumps; covers support for alternative fuels and nuclear. |
| EU Taxonomy | • Classification system sets out criteria for investment activities aligned with net zero emissions goals, using technical screening criteria. |

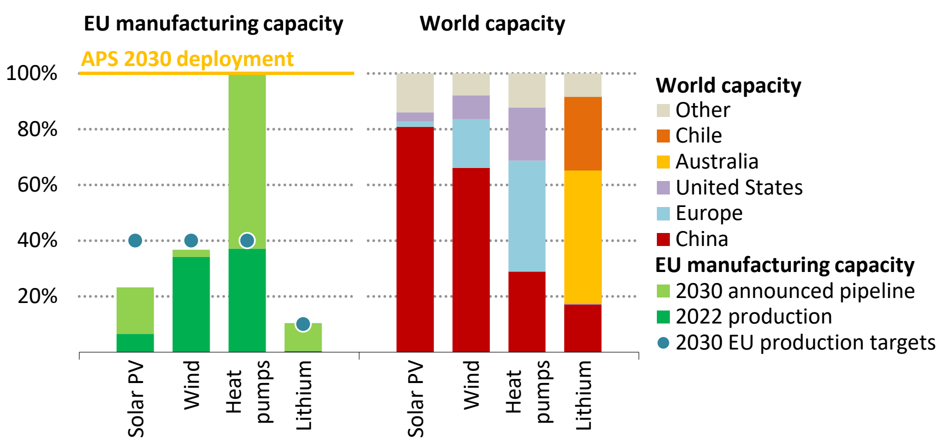
Electrification of the energy economy in the European Union occurs in parallel with decarbonisation of the power sector. The share of electricity in total final energy consumption in 2030 is 25% in the STEPS and nearly 30% in the APS, compared with 21% in 2022. EVs account for 55% of electricity demand growth by 2050: in the STEPS, there are 200 million electric cars on the road by 2050 compared with around 6 million today; 85% of the vehicles on the road are electric. In the APS, this share reaches nearly 90%. Demand for heat in the buildings sector is also electrified: more than 330 GW of heat pumps are deployed by 2030 in the APS.

Strong support for building retrofits, appliance efficiency standards and fuel switching incentives remains crucial to complement the electrification of heating in the buildings sector, given that over 70% of the residential buildings stock in 2050 already stands today. The energy intensity of the buildings stock improves by about 30% per square metre in the STEPS by 2050 and almost 50% in the APS.

### 5.4.2 Can the European Union deliver on its clean energy and critical materials targets?

The European Union's clean energy ambitions require a large quantity of raw materials, and it is currently highly dependent on imports. Like many other regions responding to post-Covid-19 pressures on supply chains and the fallout from the global energy crisis, the European Union has sought to promote investment in domestic production as a way to increase the resilience of energy supply chains. While recognising the benefits of trade and the importance of international co-operation, the proposed EU Net Zero Industry Act (NZIA) would require the EU clean manufacturing capacity to reach at least 40% of deployment needs by 2030, while the proposed European Critical Raw Materials Act (CRMA) would require 10% of the EU annual consumption to be extracted in the region, and less than 65% of its annual consumption of each mineral to have been processed in a third country.

**Figure 5.8 ▷ Manufacturing capacity in the European Union as share of APS deployment levels and global capacity by region, 2030**






*Wind and heat pump project pipelines are in line with EU minimum domestic manufacturing targets, but most technologies would still rely heavily on imports*

Notes: Country share in world technology manufacturing is estimated based on current project pipeline for 2030. Lithium supply mix is based on 2022 extraction data. EU production targets reflect minimum domestic manufacturing and extraction targets from the Net Zero Industry and the Critical Raw Materials Acts.

Around 10% of the 40 GW of solar PV modules that were added in the European Union in 2022 were manufactured in the region. By 2030, if all planned projects are commissioned on time and in full, this share would be just over 20% when benchmarked against the deployments needs of the APS, where solar PV capacity additions reach over 50 GW in 2030 (Figure 5.8). For wind, EU production of nacelles – the generating components on the top of turbines – came close to matching the 14 GW of capacity added in 2022. The current pipeline for new wind manufacturing capacity however is much smaller than for PV, and so the projected near-tripling of wind capacity additions in the APS by 2030 would mean the EU manufactured share falls just short of 40% by that date. Significant additional investment in manufacturing capacity in the European Union, particularly solar PV, would be needed to meet the goals of the NZIA and CRMA. Imports remain crucial in any scenario, with overall cross-border trade dictated by cost competitiveness and the pipeline of manufacturing capacity in other parts of the world: current plans suggest that China is likely to retain its strong position in wind and solar PV manufacturing.

The European Union is better placed to meet increased demand for heat pumps. There is already enough capacity to meet close to 40% of the heat pump sales that are required in the APS in 2030, and a sizeable pipeline of additional projects means that aggregate EU production capacity is roughly equivalent to projected demand in this scenario.

Current lithium extraction capacity in the European Union would meet less than 0.5% of its needs in 2030. Several new projects have been announced in recent years, including Czech Republic, Finland, Germany and Portugal. If all announced projects come online as planned, EU regional extraction capacity could meet 10% of deployment rates in the APS, thereby delivering on the CRMA target. Nevertheless, most of the lithium that the European Union requires will still need to be imported. In both its raw and refined forms, global lithium production is highly concentrated, with raw supply dominated by Chile, Australia and China, and refined lithium produced almost exclusively by China. This suggests a need to strengthen efforts to form strategic partnerships to develop projects that will diversify supply chains.



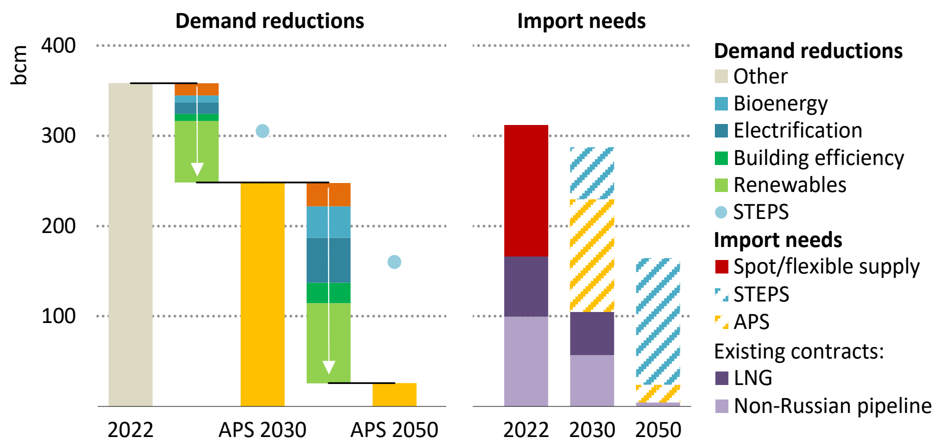
### *5.4.3 What next for the natural gas balance in the European Union?*

In the wake of Russia's invasion of Ukraine, the European Union reduced its natural gas demand by an historic 55 bcm in 2022, equivalent to 13% of total demand in 2021. In the STEPS, continued efforts to decrease demand yield a further 50 bcm reduction by 2030. In the APS, acceleration in end-use electrification, efficiency and renewables expansion means demand is 60 bcm lower still in 2030 and falls below 30 bcm by 2050.

This trajectory raises the question of how to satisfy the EU near-term need for additional natural gas supplies without compromising long-term emissions reduction goals, and what the appropriate contracting and investment strategies should look like. Currently, the gap between firm contracted supply and projected import requirements in the STEPS lies in a range between 160 bcm and 180 bcm annually over the projection period. If no further contracts are signed, this implies a continued high level of reliance on spot markets or short-term contracts, underpinned primarily by flexible volumes of LNG. This gap also exists in the APS in the near term, though it narrows sharply after 2030. While these outcomes illustrate that EU gas buyers face a good deal of uncertainty about future requirements, a remaining gap of 20 bcm in the APS in 2050 suggests there is still space to contract more gas without falling foul of the European Union net zero emissions by 2050 target (Figure 5.9).

Whether these contracts are at odds with global ambitions to reach net zero emissions is another matter. The global LNG market looks amply supplied in the second-half of the 2020s, and no new projects are necessary in the APS or the NZE Scenario, so sourcing additional gas from existing projects may be better aligned with near-term security goals and global climate ambitions than signing contracts supporting new long lead time projects. EU gas buyers could contract for flexible supply on a long-term basis and redirect it elsewhere if it is not needed, but this would increase their risk exposure if global demand for gas fell in line with a rapid transition to clean energy along the lines of the NZE Scenario. Buyers might instead be comfortable with a high reliance on spot markets; the crisis has revealed Europe's willingness to pay a premium for LNG and the market's ability to respond by sourcing the supplies necessary to fill storage and meet demand. However, this strategy could have knock-on impacts on other importing countries, damaging their security of supply and risking increased use of coal as a fallback option.

**Figure 5.9 ▷ Drivers of natural gas demand reduction and import needs by scenario in the European Union**





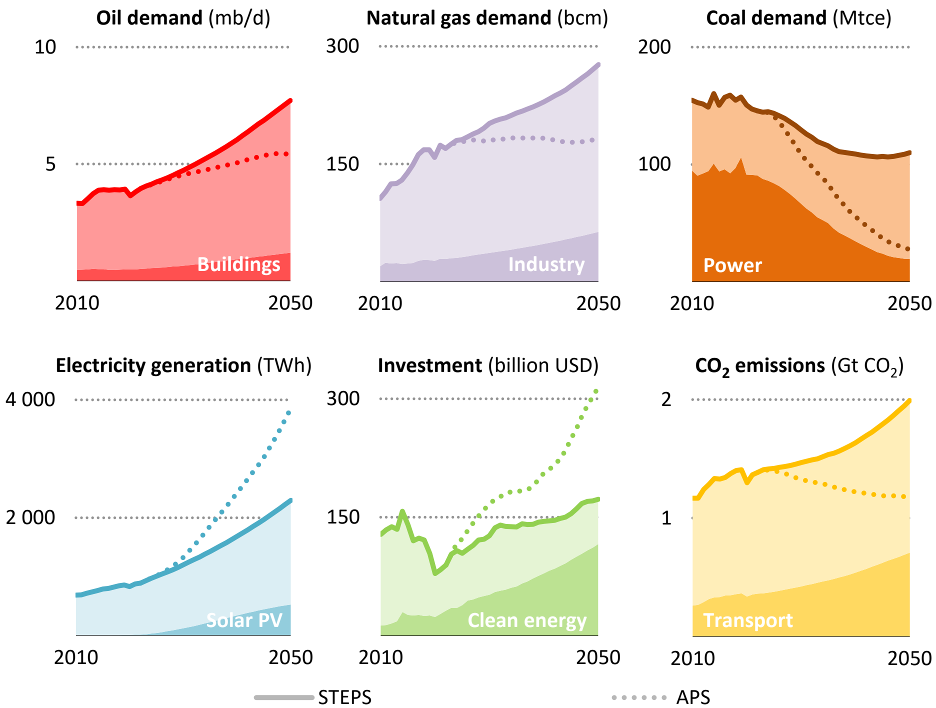

*The EU's natural gas contract balance is determined by the pace and scale of demand reductions and the willingness of EU buyers to rely on global spot markets*

The question of whether the scramble to build new LNG import terminals and reinforce pipeline links in Europe ends up locking in emissions is also an important one. Investment costs for such infrastructure are relatively modest by comparison with those involved in developing export infrastructure, and import terminals and pipeline links do not necessarily require high rates of utilisation over a long period of time. Where import takes the form of floating storage and regasification units, it is also relatively flexible and can be moved as demand for natural gas evolves. In the STEPS, cumulative spending on LNG import capacity between 2022 and 2030 is USD 55 billion, and this rises to USD 70 billion in the APS. A figure in the range of USD 55-70 billion represents around 0.3% of total EU spending on energy over this period, and arguably provides important energy security benefits over the transition period. There is also the possibility that some gas infrastructure could be repurposed in the future to transport hydrogen.

## 5.5 Africa

### *5.5.1 Key energy and emissions trends*

**Figure 5.10 ▷ Key trends in Africa, 2010-2050**




IEA. CC BY 4.0.

The Covid-19 pandemic and subsequent energy crisis contributed to an emerging debt crisis in Africa and a worsening economic outlook. One consequence is that energy investment is set to remain low in the STEPS, contributing to slow progress in extending access to electricity and clean cooking in sub-Saharan Africa (Figure 5.10). Today, more than 40% of people living in Africa lack access to electricity and 70% lack access to clean cooking. Africa will be home to one-fifth of the world's population by 2030 and providing access to modern energy for all while keeping pace with rising energy demand remains a primary focus for African governments (IEA, 2022a).

Recent policy efforts have focussed on reversing flagging investment with support from multilateral development banks and development finance institutions (IEA, 2023a). Climate commitments among international lenders have made renewable power projects easier to finance than most others, and renewables account for half of all capacity additions since the pandemic. With solar leading the way, renewables are set to contribute over 80% of new power generation capacity to 2030 in the STEPS, a figure which rises to around 85% in the

APS. Natural gas power plants make up most of the balance outside of South Africa: in addition to providing power, they help shore up grid stability and provide scope for the operation of regional power pools such as the West African Power Pool. In the APS, new natural gas power still comes online in sub-Saharan Africa, however, North Africa sees limited growth to 2030, relying largely on renewables to meet incremental energy demand consistent with long-term climate pledges.

In South Africa, representing 27% of current electricity demand in Africa, load-shedding has intensified as a result of unplanned outages at numerous coal plants, prompting a substantial uptick in renewables investment in the STEPS, even though other aspects of the South African Just Energy Transition Partnership (JETP) remain undecided. Despite supply shortages, no new coal-fired power plants are started in the STEPS, consistent with international commitments to end investment in new coal plants. By 2030, the share of low-emissions electricity generation reaches over 40% in the STEPS in South Africa, rising from 12% today. This rises further to over half in the APS.

**Table 5.6 ⊳ Key policy initiatives in Africa**

| Policy | Description |
|---|---|
| Just Energy Transition Partnerships | • Senegal and South Africa JETP accelerate renewables in the power sector. Implementation details are pending. |
| Regulation of imported second-hand light-duty vehicles | • 28 countries have implemented restrictions on the import of used light-duty vehicles with emissions standards of Euro 3 or higher and set an age limit of eight years or less (UNEP, 2021). |
| Clean cooking access policies | • 8 African countries have official targets to achieve universal access to clean cooking by 2030; 23 countries have set less ambitious targets. |
| Electricity access policies | • 22 African countries have set official national targets to achieve universal access by or before 2030; 19 countries have set less ambitious targets. |
| Net zero emissions targets | • 15 Africa countries had stated net zero emissions targets in 2023. |

Africa's growing energy needs will mean a degree of reliance on fossil fuels for some time before a full transition takes place to clean energy technologies. These fossil fuels include oil for transport, liquefied petroleum gas (LPG) for cooking and natural gas for industry. In the STEPS, an expanding vehicle fleet increases road transport demand for oil by 15% in 2030. Except for two/three-wheelers, vehicle electrification makes little progress by 2030, hindered by high upfront costs and unreliable grids. In the APS, the market share of electric cars reaches 5% by 2030, with age limits on imported vehicles starting to bring second-hand electric cars into the market. LPG demand rises slowly in the absence of well-funded clean cooking policies: it would need to increase twofold, and threefold in sub-Saharan Africa to be consistent with universal access to clean cooking by 2030. Africa's industries use a range of fuels but rely in particular on the use of natural gas, especially for fertiliser production, water desalination, plus the steel and cement industries.

While demand for oil and gas in Africa continues to climb, prospects for new oil and gas projects are changing due to global trends, which carries implications for current and future producers. Africa currently produces 7 mb/d of crude oil, of which around 40% is exported. Oil production is projected to decline, with limited new oil discoveries coming online that will not outpace declines from producing fields. Africa becomes a net importer of oil in the mid-2030s in the STEPS. In the APS, oil production is 0.5 mb/d lower than in STEPS by 2030. Many African countries rely on imports of refined products, although a new 650 000 barrels per day refinery in Nigeria helps meet incremental oil product demand growth in the next decade.

Prospects for new natural gas developments fare better. In the STEPS, natural gas production reaches 280 bcm by 2030, from a level around 260 bcm today. Large discoveries have been made across the continent over the last decade, and many African countries are looking to develop these resources, both for export and domestic use. Net income from oil and gas production averages USD 140 billion each year in the STEPS between 2022 and 2030, which falls to 130 billion in the APS.



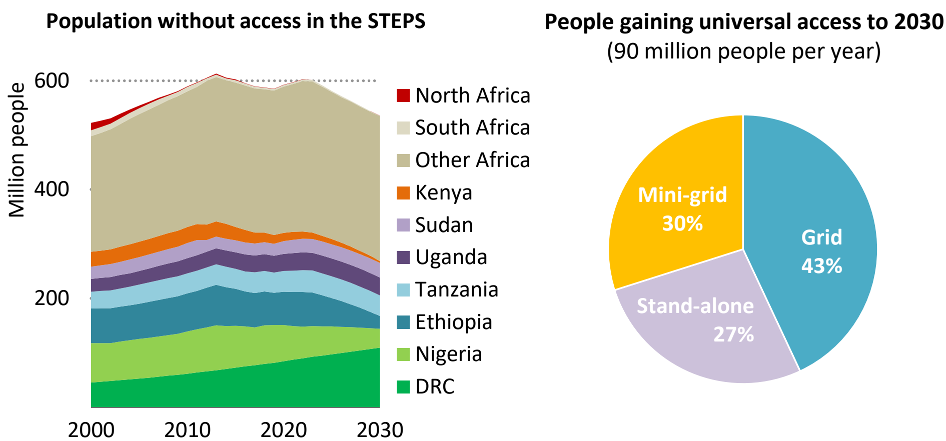
The decline in oil and gas export revenues in the APS could be problematic for a number of current and prospective producer economies, but clean energy technologies and the critical minerals on which they depend hold great promise for Africa, and some countries are well positioned to become future producers. Today Africa accounts for 13% of global copper and battery metals revenue, and this could rise: a number of countries have expressed interest in attracting international investment to develop and process their resources.

### *5.5.2 Recharging progress towards universal energy access*

The Covid-19 pandemic, the energy crisis, debt problems and political instability have nearly eliminated progress in Africa on reducing the number of people without access to electricity since its peak in 2013. Today there are around 600 million people without access to electricity in Africa (Figure 5.11), and they constitute around 80% of the global population without access. Although preliminary data suggest that the number of people without access in Africa might stabilise in 2023 after three years of increases, efforts need to scale up quickly to reach global access goals. The STEPS sees leading countries such as Côte d’Ivoire, Kenya, Ghana and Senegal reach or get very close to their targets, but the number of those without electricity access continue to rise in many others. While utility debts and supply chain constraints have slowed grid electricity access investment, solar home systems sales rose to record levels in 2022 and contributed to half of the increase of people with access in sub-Saharan Africa in 2022. Solar home systems now provide access to electricity to more than 8% of households in sub-Saharan Africa that have access, and they are set to play an increasingly important role this decade in providing first-time access to households in Africa.

The number of people without access to clean cooking in Africa reached almost 990 million in 2022. It is still rising, and many African countries are not on course to achieve universal access to clean cooking even by 2050. Reaching universal access to clean cooking by 2030 in line with Sustainable Development Goal 7 requires the rapid scaling up of all clean cooking technologies. As a feasible, low cost technology, LPG is set to play a leading role: it provides clean cooking to 40% of those gaining access. Electric cooking also has an important role: it provides access to 12% of homes in sub-Saharan Africa and has the additional benefit of not requiring fuel imports (IEA, 2023b). Between now and 2030, improved biomass cookstoves provide clean cooking to more than one-third of those gaining access, mainly in rural areas. For many, however, this is a transitional step before they gain access to clean cooking at a later date through LPG, electricity, biodigesters or ethanol cookstoves. Switching to any clean cooking solution in sub-Saharan Africa reduces GHG emissions, even after taking account of increased $CO_2$ emissions from fossil fuel consumption, and this makes clean cooking a prime candidate for climate finance.

**Figure 5.11 ▷ Population in Africa without access to electricity in the STEPS and gains by technology type to reach universal access by 2030**






*Some countries reach near universal electricity access this decade, while others see no progress; off-grid systems play an important role to provide universal access*

Note: DRC = Democratic Republic of the Congo.

### 5.5.3 What can be done to enhance energy investment in Africa?

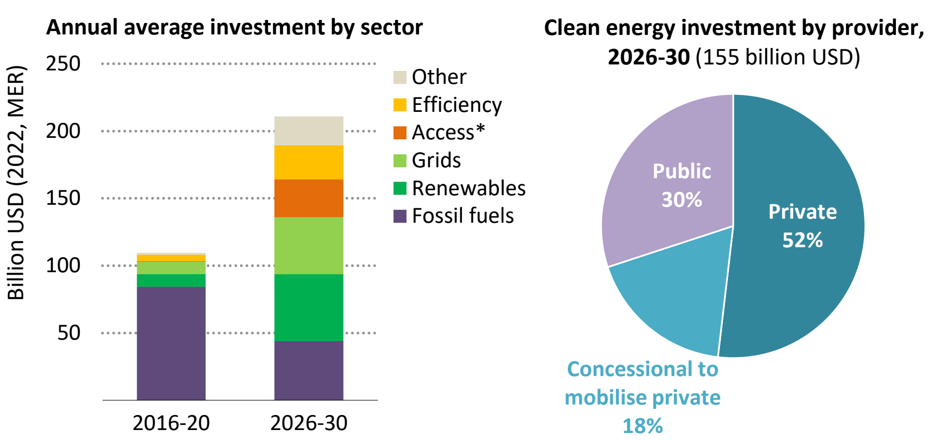
Meeting Africa's rising energy demand, providing universal access to modern energy by 2030 and achieving energy and climate goals means more than doubling energy investment this decade. This requires over USD 200 billion per year from 2026 to 2030, with two-thirds going to clean energy (Figure 5.12). Bringing access to electricity and clean cooking for all Africans requires investment of USD 25 billion per year – a relatively small part of the total – and equivalent to just 1% of current global energy investment.

Energy investment in Africa, however, has fallen by almost 45% from highs in 2014 largely as a result of a slowdown in oil and gas investment. While export-oriented oil and gas projects are able to attract commercial financing, there are fewer bankable clean energy projects, and those that are put forward struggle to secure financing. Potential investors are often concerned by risks stemming from relatively weak regulatory environments or the poor financial health of utilities. These risks can reduce the commercial viability of projects, particularly in countries with nascent clean energy sectors. They can also push up the cost of borrowing to at least two- to three-times the level in advanced economies for similar projects (IEA, 2023c).

As a result, many projects in Africa require concessional support either to act as a demonstration project or to facilitate the mobilisation of private capital. By the end of the decade, concessional finance to mobilise private capital needs to reach around USD 28 billion per year if all energy and climate goals in Africa are to be achieved. This total would be higher in the NZE Scenario. The limited availability of domestic public financing means that additional grant and concessional support are also necessary to support non-commercial activities such as early-stage financing and the development of early-stage technologies. The communique issued by African governments at the Africa Climate Summit in Nairobi in September 2023 called for advanced economies to meet their climate finance commitments and for reform of the multilateral finance system to address the lack of energy investment on the continent today.

5

**Figure 5.12 ▷ Investment needs to meet Africa's sustainable goals by 2030**






*Energy investment needs to double to achieve energy and climate goals, with concessional capital reaching USD 28 billion each year by the end of this decade*

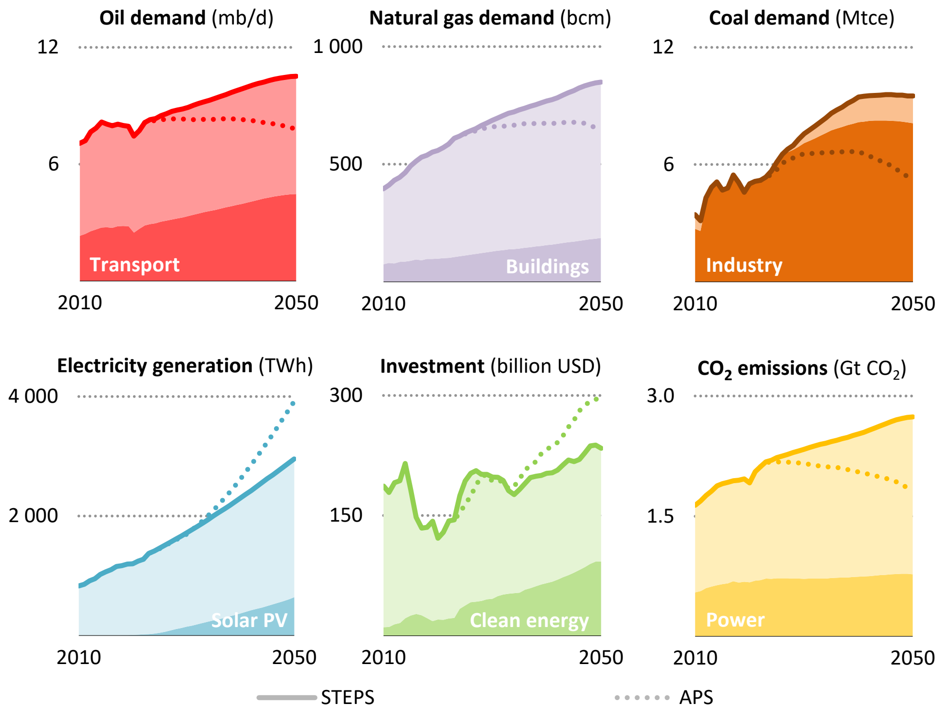
* Access includes investment related to fossil fuel sources.

Note: MER = market exchange rate; Other = low-emissions fuels, nuclear, battery storage, fossil fuel power with CCUS, and non-efficiency investment in the buildings, industry and transport sectors.

## 5.6 Middle East

### *5.6.1 Key energy and emissions trends*

**Figure 5.13 ▷ Key trends in the Middle East, 2010-2050**




IEA. CC BY 4.0.

Among emerging market and developing economies, the Middle East collectively is at the upper end of income and energy consumption levels, although there is a wide degree of variation among countries within the region. As a group, GDP per capita in the Middle East region is 80% higher than in emerging market and developing economies on average, while energy demand per capita is over twice as high. Countries such as Saudi Arabia and the United Arab Emirates are at the higher end of per capita incomes and energy consumption, while others such as Yemen and Syria are at the lower end.

The GDP growth rate of 6.6% in 2022 in the Middle East was nearly twice as high as the average for emerging market and developing economies as a whole. Saudi Arabia, the largest economy in this region, grew nearly 9% in 2022. Regional GDP is on track to increase by nearly 30% by the end of the decade and about 2.4-times the current levels by 2050, leading to energy demand growth in the STEPS of more than 15% by 2030 and 50% by 2050. The region would have the second-largest oil demand growth and the largest natural gas demand growth of any region, together with 30% increase in annual $CO_2$ emissions by 2050.

Natural gas and oil made up 94% of the regional electricity mix in 2022. In the STEPS, power generation from natural gas increases, but the overall share of oil and gas nevertheless decreases to just over 60% by mid-century as a result of an over twenty-fold rise in generation by renewables, led by solar PV. By 2030, solar power generation rises ninefold in the STEPS, and its share of generation rises from 1% today to nearly 10%.

Natural gas and oil also make up the bulk of current energy investment spending in the Middle East region, with clean energy investment accounting for just 15% of total investment. In the STEPS, clean energy investment increases fourfold to over USD 90 billion by 2050, by which time it represents over a third of the total. This falls short of the trajectory implied by the region's decarbonisation goals, including national net zero emissions commitments. In the APS, which assumes that all these commitments are met, clean energy investment increases fourfold to reach nearly USD 80 billion by 2030, taking the share of clean energy investment to nearly half of the total. In power generation, this investment leads to renewables accounting for a sharply rising share of generation, 15% of the electricity generation by 2030 and a two-thirds share by 2050, with solar PV alone responsible for nearly half of all the electricity generated by 2050. In transport, sales of electric cars in total car sales increase to 13% by 2030 in the APS, compared with 5% in the STEPS.



In the APS, oil and gas demand in the region remains flat, but $CO_2$ emissions nevertheless fall by 12% from current levels by 2050 as a result of energy efficiency improvements and a larger share of oil being used for chemical feedstocks and therefore not being combusted. The decline in $CO_2$ emissions in the region is much less than that for the emerging market and developing economies as a whole, where it falls by nearly 60% in the APS by 2050; the difference reflects a relatively slower uptake of clean energy in the Middle East.

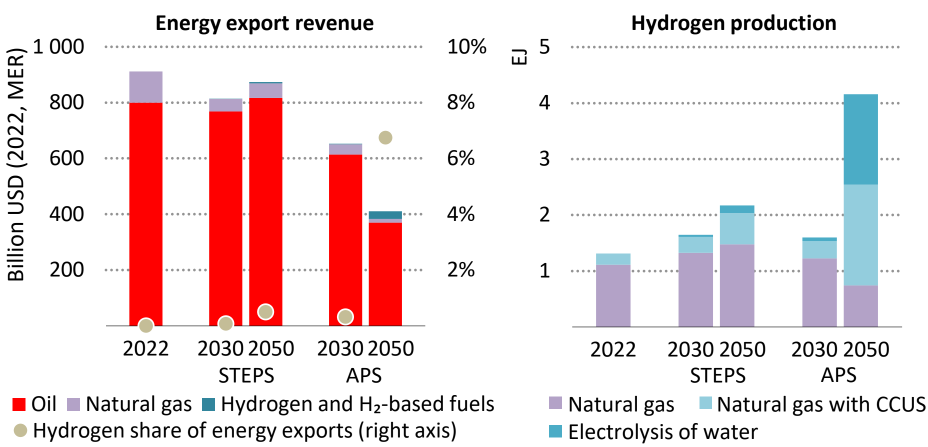
**Table 5.7 ▷ Key policy initiatives in the Middle East**

| Policy | Description |
|---|---|
| **Net zero ambitions** | • Saudi Arabia, Bahrain and Kuwait have announced goals to reach net zero emissions by 2060, while the United Arab Emirates (UAE) and Oman target 2050. |
| **Petroleum subsidies** | • Some countries in the region such as Kuwait announced plans in 2023 to extend existing petroleum subsidies to shield consumers from higher prices. Kuwait budgeted Kuwaiti dinar 1.159 billion (USD 3.8 billion) in petroleum product subsidies for 2023. |
| **Hydrogen ambitions and partnerships** | • In 2023, six low-emissions hydrogen electrolysis projects were announced in Oman following a Royal Decree defining the scope of such hydrogen projects.<br>• United Arab Emirates 2021 Hydrogen Leadership Roadmap includes a target of acquiring a 25% market share in low-emissions hydrogen by 2030 in the key export markets of Europe, India, Japan and Korea. Saudi Arabia is investing in new low-emissions hydrogen projects including via the NEOM Green Hydrogen Company. |
| **UAE's updated Nationally Determined Contribution** | • United Arab Emirates has set a 19% emissions reduction target for 2030 relative to 2019 levels. |

### 5.6.2 Shifting fortunes for energy exports

The Middle East has five of the world's top-ten oil producers – Saudi Arabia, Iraq, United Arab Emirates, Iran and Kuwait. In 2022, the Middle East produced 31 mb/d of oil, of which nearly three-quarters was exported, accounting for over four-in-ten barrels of global oil exports. The region is also a major producer of natural gas with three of the world's top-ten producers. Around 85% of gas production is used within the region, while only 26% in the case of oil, which accounts for the vast majority of energy export earnings. In the STEPS, the share of the Middle East in global oil production increases steadily, and this is reflected in higher export earnings by mid-century. These exports are increasingly directed to Asia: the route between the Middle East and Asia already accounts for around 40% of total seaborne crude oil trade, and in the STEPS this rises to 50% by 2050.

**Figure 5.14 ▷ Revenue from energy exports by fuel and scenario, and hydrogen production by source and scenario in the Middle East**






***Despite strong growth of hydrogen production in the Middle East, revenues from their exports do not offset the decline in oil and gas export revenues in the APS even by 2050***

Note: $H_2$ = hydrogen; MER = market exchange rate.

Strengthened climate commitments by countries around the world imply marked changes in revenue streams from oil and gas in the Middle East. Shrinking global oil demand in the APS substantially reduces export demand, resulting in a reduction of more than USD 80 billion in energy export revenues by 2030 and over USD 300 billion by 2050, which is equivalent to less than half of today's levels (Figure 5.14). To compensate, several countries in the region are actively pursuing diversification strategies that aim to open new industrial and export opportunities such as hydrogen production.

The Middle East has significant potential for the production of low-emissions fuels, and this is an important pillar in many transition strategies. Oman, for example, aims to produce at least 1 million tonnes (Mt) of low-emissions hydrogen a year by 2030 and almost 4 Mt by 2040. The 2040 hydrogen target would represent 80% of Oman's current LNG exports in energy-equivalent terms. In the APS, the share of hydrogen in the region's energy exports grows larger still. The revenue stream from hydrogen trade, however, is not sufficient to make up for declining oil and gas revenues. The larger prize is the potential to attract investment in higher value-added industrial sectors, based on the region's large potential for low-cost renewables and for storing $CO_2$.

### *5.6.3 How is the desalination sector changing in times of increasing water needs and the energy transition?*

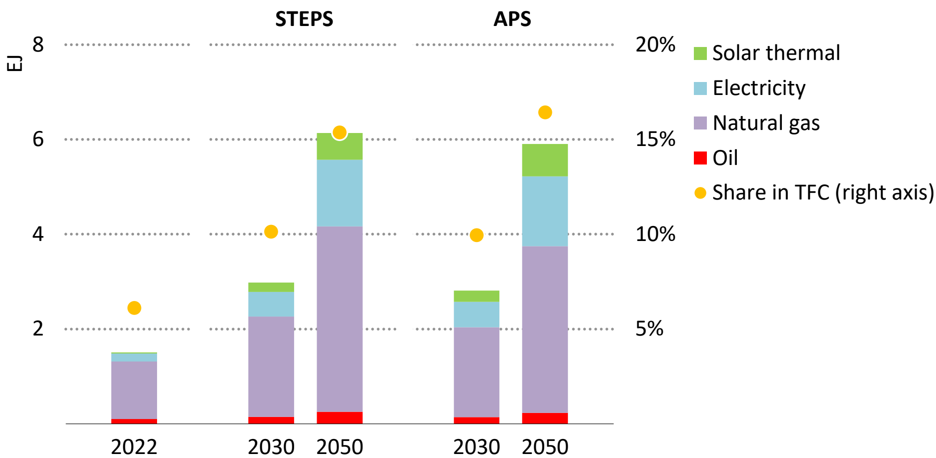


The Middle East has one of the lowest levels of fresh water on a per capita basis in the world: climate change is likely to impose further constraints on water supply in the future. With a growing population and easy access to sea water, desalination is increasingly being used to tackle water scarcity. Some 21 000 seawater desalination plants are currently in operation worldwide, and the Middle East accounts for 50% of the installed capacity (IFRI, 2022). Moreover, multiple large projects are underway that will increase desalination capacity in the region: Jordan is planning a major plant on the Gulf of Aqaba that will increase its desalination capacity from 4 billion to 350 billion litres each year; Saudi Arabia plans to construct a new city with 9 million people in the northwest by 2045 which will depend on desalinated water from the Red Sea and the Gulf of Aqaba (Al-Masri and Chenoweth, 2023).

Plans to invest in low-emissions hydrogen production will add to water demand. Production plans in Oman are based on producing hydrogen from desalinated sea water, for example (IEA, 2023d). Typically, between 30 and 60 litres of purified water are needed to produce 1 kilogramme (kg) of hydrogen from electrolysis, including feedstock water and process water for cooling. However, while electrolytic hydrogen production would increase water demand, a reduction in fossil fuel production could decrease water consumption for oil and gas extraction and processing.

Desalination is also highly energy intensive. The main energy-related needs for desalinated water are for cooling thermal plants and for upstream oil and gas operations. The 1.5 EJ currently consumed every year for municipal desalination in the Middle East is equivalent to a third of the energy needs of the region's massive chemical sector, and accounts for 6% of the total energy consumption in the Middle East (Figure 5.15). Although membrane technologies such as reverse osmosis that use electricity are the most common desalination technologies installed worldwide, the Middle East is an exception: the low cost of oil and gas and the prevalence of co-generation facilities for power and water mean the region relies heavily on fossil fuel-based thermal desalination such as multi-stage flash or multiple-effect desalination. Today, two-thirds of the water produced from seawater desalination in the region is from fossil fuel-based thermal desalination, and much of the membrane-based desalination uses electricity produced with natural gas. Overall, the Middle East accounts for roughly 90% of the thermal energy used for desalination worldwide, led by the United Arab Emirates and Saudi Arabia.

**Figure 5.15 ▷ Energy demand for municipal desalination for hydrogen production in the Middle East**






***Announced pledges affect the energy mix of desalination only marginally, but a clean technology shift is needed as hydrogen production boosts rising water demand***

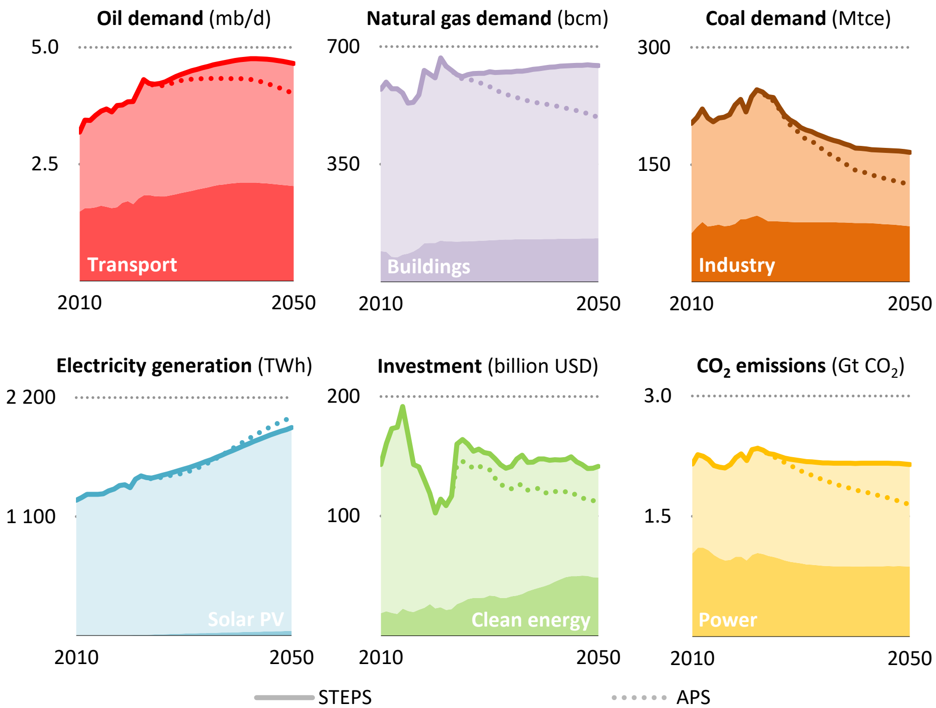
Note: TFC = total final consumption.

In the STEPS, growing desalination demand pushes the share of desalination in total energy consumption to 10% in 2030 and 15% in 2050. Although the share of membrane-based desalination using electricity expands to almost 20% by 2030, demand for fossil fuels for desalination still rises by 70% to 2.3 EJ. In the APS, a smaller temperature increase translates into reduced demand for water, and as a result energy demand for desalination is 6% lower in 2030 than in the STEPS. However, there is still considerable scope to move further towards a more efficient and cleaner membrane-based desalination and to make more use of concentrating solar power to meet rising water needs. There are also other ways of reducing demand for water. There is considerable potential to minimise the water required in hydrogen production by optimising the electrolysis cooling process. Pricing has a role to play too: consistent under-pricing of both water and energy has encouraged the inefficient use of water and contributed to unsustainable levels of withdrawals from non-renewable groundwater resources. Policies that explicitly encourage the conservation of water could temper the growth for desalination demand further. In the APS, these shifts reduce $CO_2$ emissions from desalination in 2030 by almost 15 Mt compared with the STEPS.

## 5.7 Eurasia

### *5.7.1 Key energy and emissions trends*

**Figure 5.16 ▷ Key trends in Eurasia, 2010-2050**




IEA. CC BY 4.0.

The countries of the Caspian region and Russia (referred to here as Eurasia) are facing multiple pressures on their energy sectors, intensified by Russia's invasion of Ukraine. Traditional energy relationships have been fractured or, in some cases, have broken down completely. Russia is pivoting to new markets in Asia, but lacks infrastructure to reach them. Starting points vary, but the region as a whole has yet to deploy clean energy at scale. At 175 gigajoules (GJ) of total energy supplied per person, per capita energy consumption in Eurasia is high compared to the global average of about 80 GJ per person, and the average of other emerging market and developing economies at 60 GJ per person. This level of energy consumption in part reflects cold winters, but it also stems from widespread inefficiencies in energy supply and use.

GDP per capita in Eurasia is around 30% higher than the global average. The region is highly dependent on industry, which accounts for nearly 40% of its GDP. The power sector is the biggest energy consumer, accounting for 44% of total energy demand; buildings and industry make up around a quarter of total energy demand each. The region is heavily reliant on fossil fuels, which accounted for 90% of total energy supply in 2022. This share is projected to decline slowly over time as deployment of renewables accelerates and additional nuclear power plants are commissioned: by 2050, it comes down to about 85% in the STEPS and 75% in the APS. The relatively high proportion of fossil fuel use in 2050 in both scenarios and the relatively small difference between the two scenario outcomes are a reflection of the weakness of the region's stated climate ambitions in the energy sector.

In the STEPS, natural gas demand across Eurasia stays almost unchanged until 2050 at around 640 bcm. Small reductions in natural gas use in power generation are offset by increases in other end-use sectors, notably in industry. Oil consumption rises by 8% to reach 4.7 mb/d by mid-century. The only fossil fuel that sees a large decline in the STEPS is coal, which drops by a third to 165 million tonnes of coal equivalent (Mtce) in 2050. In the APS, natural gas use sees a reduction of one-quarter by 2050, mostly owing to lower gas use in the power and buildings sectors. Oil demand declines by 8% over the same period as the buildings sector reduces oil use by a third and the power sector by nearly 75%. Coal demand declines by 50% as coal use in the power sector is cut by more than half and consumption in industry drops by nearly a third.

Electricity consumption is projected to increase by around 45% in the STEPS, rising from about 1 050 TWh today to more than 1 500 TWh by 2050. It climbs slightly higher in the APS as a result of increased electrification of end-uses in that scenario. The share of low-emissions sources in the electricity mix increases relatively slowly from 34% in 2022 to nearly 45% by 2050 in the STEPS and nearly 60% in the APS. The difference between the outcomes in these scenarios reflects a more rapid deployment of wind and solar PV in the APS, which sees these two technologies together provide about 20% of electricity by 2050.

**Table 5.8 ⊳ Key policy initiatives in Eurasia**

| Policy | Description |
|---|---|
| Kazakhstan: National Methane Emissions Inventory and Reduction Programme | • Accelerate the abatement of GHG emissions through the development of a National Methane Emissions Inventory and Reduction Programme.<br>• European Bank for Reconstruction and Development will assist the government to join the Global Methane Pledge, which aims to reduce global methane emissions by 30% by 2030. |
| Azerbaijan and European Union memorandum of understanding to increase energy co-operation | • Contains a commitment to double the capacity of the Southern Corridor gas pipeline to the European Union to over 20 bcm a year by 2027.<br>• European Union to support reduction in methane flaring and venting, as well as Azerbaijan's accession to the Global Methane Pledge. |
| Russia: Strategy of socio-economic development | • Reduce GHG by 80% by 2050 compared to 1990 level, with a strong reliance on negative emissions from land use, land-use change and forestry.<br>• Achieve net zero GHG emissions by 2060. |
| Kazakhstan: Strategy on Achieving Carbon Neutrality by 2060 | • Goal to achieve carbon neutrality by 2060.<br>• Identifies key sectors and technologies needed to achieve decarbonisation. |

Energy-related $CO_2$ emissions in Eurasia amounted to nearly 2.4 Gt in 2022. In the STEPS, clean energy investment more than doubles between 2022 and 2050. Annual emissions are set to decline slightly by 2050, with the majority of the reduction taking place before 2030. In the APS, clean energy investment more than triple, accounting for over 60% of total energy investment by 2050. $CO_2$ emissions fall by nearly a third to 1.6 Gt $CO_2$ by 2050. Cutting $CO_2$ emissions is not the only imperative: reducing methane emissions from the regional oil and gas infrastructure is also a key challenge, and one that is the focus of several policy initiatives.

### 5.7.2 What's next for oil and gas exports from Eurasia?

#### *Russia*

Russia has continued to export large volumes of oil since its invasion of Ukraine, but the cast of buyers has changed. Exports that previously went to the European Union and North America have mostly been redirected to other markets, notably India and China. In our scenarios, Russian attempts to pivot to Asia and other non-European markets are hampered in future years by the global peak in oil and gas demand and the long-term effects of sanctions, which are felt mainly in parts of Russian oil and gas industry that could benefit most from Western equipment or specialisation. In the case of oil, exports fall by 1 mb/d to 2030 in the STEPS and 2 mb/d in the APS. In the case of natural gas, overall Russian exports in the STEPS are 40% below pre-invasion levels by 2030. Pipeline exports to Europe fell by nearly half in 2022; a gradual ramp up of deliveries to China through the Power of Siberia and Eastern routes is not enough to make up for the lost volumes, and in our scenarios there is no need for additional pipeline links between Russia and China, given the trajectory of demand in China. Russia may look to LNG to diversify its supply options, but that is a very crowded field: around 250 bcm of new projects are under construction, all targeting start-up between 2025 and 2030. Russia's share of internationally traded gas, which stood at 30% in 2021, falls to 15% by 2030 in the STEPS and APS. Net income from gas sales falls from around USD 100 billion in 2021 to less than USD 40 billion in 2030 in all scenarios.

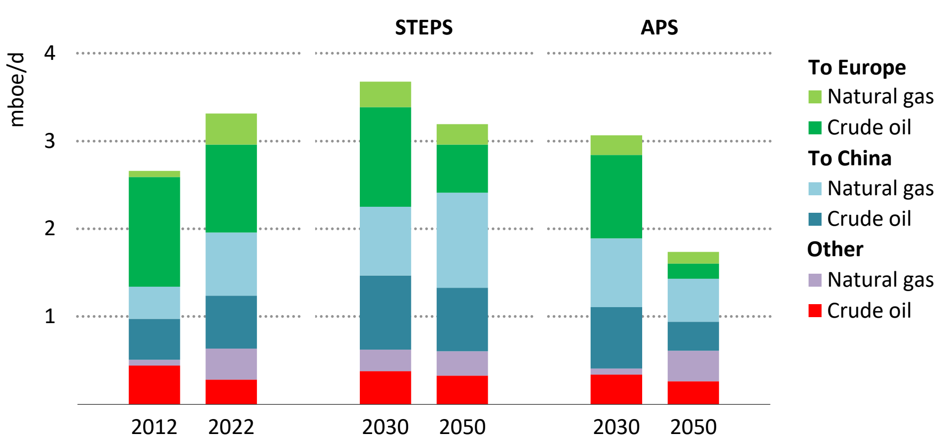
#### *Caspian*

The Caspian region is rich in oil and natural gas resources, but for a long time has faced challenges over how best to transport them to export markets. This traditional challenge has been resolved, at least in part, with new infrastructure projects linking Azerbaijan, and to some extent Kazakhstan, to European markets, and Kazakhstan and Turkmenistan to markets in China. In 2022, the Caspian region as a whole exported 2 mb/d of crude oil and oil products and 70 bcm of natural gas; China has been the major growth market, accounting for 40% of total exports in 2022 compared with 30% in 2012. But the prospects for further growth, in all directions, are clouded by complex energy relationships with Russia and by the challenging commercial case for pipeline projects at a time when the pace of global energy transitions is picking up. Some parts of the energy infrastructure in the Caspian are also in need of modernisation and repair, and there are supply chokepoints in Kazakhstan and Uzbekistan that undermine domestic energy security and make exports difficult.

The projected peak in global oil and gas demand before 2030 in the STEPS raises questions about the viability of plans to monetise a larger share of the Caspian's untapped oil and gas resources in the future. There is some potential for an increase in oil and gas exports to China, but this is moderated by stagnating demand in China beyond 2030 in both scenarios. There likewise is some modest potential for further westward Azerbaijani exports as Europe looks to replace gas previously imported from Russia. Looking further ahead, however, Europe's limited need for gas is not well-matched with the long lead times and significant upfront investment involved in developing new upstream resources and matching large-scale gas pipelines. A growing and dynamic global LNG market appears well-placed to satisfy incremental demand growth in both Asia and Europe, and Russian cuts to its pipeline deliveries to Europe appear to have reinforced importer preferences for the flexibility that comes with seaborne trade over the rigid politics of pipelines.

There has also been much discussion about other potential market-expanding infrastructure, such as the Turkmenistan-Afghanistan-Pakistan-India pipeline, or the Trans-Caspian Gas Pipeline Project linking Turkmen and Azeri gas fields. However, these are hindered by the complex web of geopolitical and economic interests that need to be reconciled to secure the permits and the capital necessary to greenlight projects. And Russia looms large in the background, making use of its substantial infrastructure connections in the region to further its own political and economic interests.

**Figure 5.17 ▷ Caspian crude oil and natural gas exports in the STEPS and APS**






*Caspian oil and gas exports to Europe decline and China is the main source of growth in the STEPS; total exports decline by 45% by 2050 in the APS*

Note: mboe/d = million barrels of oil equivalent per day, 1 mboe/d = 60 billion cubic metres.

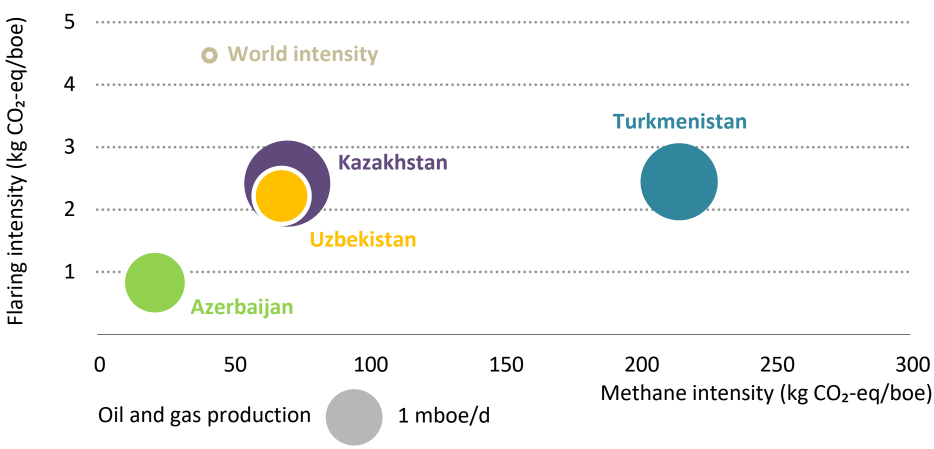
In the STEPS, Caspian oil and gas exports climb to about 4 million barrels of oil equivalent per day (mboe/d) over the period to 2030 in response to robust oil and gas demand in China.

Declining crude exports to Europe after 2030 offset marginal eastward growth, resulting in a slight contraction in total exports by 2050. In the APS, meeting the climate ambitions announced by countries around the world reduces the need for around 0.9 mb/d of new upstream oil projects and around 80 bcm of new gas projects, compared with the STEPS, and this lowers the level of oil and gas exports by nearly half in 2050. Lower export volumes in the APS are accompanied by lower oil and gas prices, with the result that net income from exports in 2050 fall to less than USD 30 billion, around half the level of the STEPS.

The environmental performance of Caspian oil and gas supply is another factor weighing on its future prospects. Ageing infrastructure and relatively poor maintenance at production sites at present are causing high levels of loss, and satellites are detecting particularly large methane leaks from Turkmenistan. Partly as a result of these losses, the emissions intensity of a barrel of oil in the Caspian is estimated at around 150 kilogrammes of carbon dioxide per barrel of oil equivalent (kg $CO_2$/boe); for natural gas it is around 120 kg $CO_2$/boe. This puts the region 40% higher than the global average intensity for oil and nearly double for natural gas, leaving it at a disadvantage in a world increasingly concerned about the emissions associated with oil and gas supply (Figure 5.18).

5

**Figure 5.18 ▷ Flaring and methane intensity of oil and gas production in selected Caspian countries, 2022**





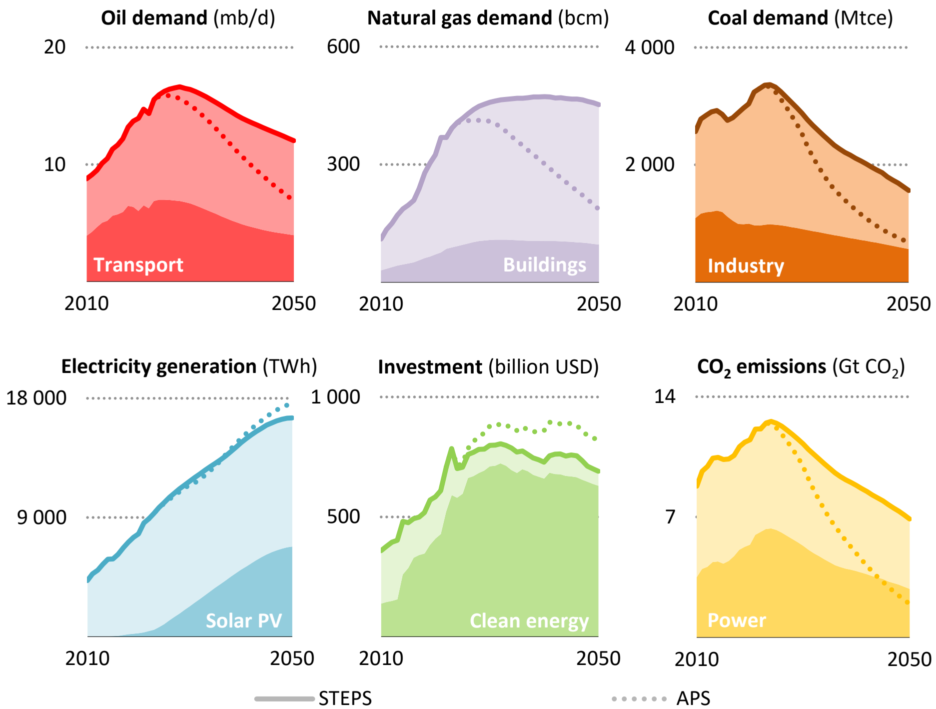

***Caspian oil and gas production is much more emissions-intensive than the global average, primarily due to a high level of methane venting in upstream operations***

Notes: kg $CO_2$-eq/boe = kilogrammes of carbon dioxide equivalent per barrel of oil equivalent; mboe/d = million barrels of oil equivalent per day. Bubble size indicates oil and gas production in 2022 in mboe/d.

# 5.8 China

## 5.8.1 Key energy and emissions trends

**Figure 5.19 ▷ Key trends in China, 2010-2050**






China has shaped trends across many parts of the energy sector in recent years. Its influence remains strong in all our scenarios but evolves in line with structural changes in its economy and energy system (see Chapter 1, section 1.2). As things stand, China is by far the largest producer and consumer of coal, and a major consumer of oil and gas, which makes it the world's largest $CO_2$ emitter, accounting for one-third of the global total. Its total $CO_2$ emissions were 12.1 Gt in 2022, the bulk of which stemmed from the use of coal in electricity generation and industry. But China is also the largest user in the world of many clean energy technologies, accounting in 2022 for 60% of global sales of electric cars, 50% of wind capacity additions, 45% of global solar PV capacity additions and 30% of nuclear capacity additions. Electric cars have already achieved a 29% market share, and clean energy is advancing so quickly that China is on track to exceed its 2030 Nationally Determined Contribution (NDC) target of 1 200 GW of solar and wind capacity five years ahead of schedule.

China also dominates many aspects of clean energy technology supply chains. In technology manufacturing, it is currently the largest producer of solar PV, wind, batteries, heat pumps and electrolysers for hydrogen production, with plans for further scale up (IEA, 2023e). It also produces more aluminium and steel than any other country, and leads the world in the processing of cobalt, lithium, copper, graphite and rare earths. Mining of critical minerals is one of the few areas where it does not lead in clean technology supply chains (IEA, 2023f).

China's 14th Five-year Plan sets the course for its energy sector to 2025, and envisages continued scaling up of clean energy (Table 5.9). In the STEPS, China's total $CO_2$ emissions peak around 2025 and then decline at a pace of about 2.3% per year to 2050, falling to 7 Gt (Figure 5.19). Despite this, China remains the largest emitter in the world in 2050. But it also remains the leader in deployment of several clean energy technologies on the back of average investment in clean energy technologies of well over USD 650 billion per year, and by 2050 it accounts for half of global solar PV capacity, 40% of wind capacity, one-third of all nuclear power capacity and 40% of the global electric car fleet. In addition, China is set to be a leader in electrolytic hydrogen production and heat pump manufacturing.



**Table 5.9 ▷ Key policy initiatives in China**

| Policy | Description |
|---|---|
| Updated Nationally Determined Contribution | • Aims to peak $CO_2$ emissions before 2030; carbon neutrality before 2060.<br>• Lower $CO_2$ intensity of GDP by 60% by 2030 from 2005 levels.<br>• Reach 1 200 GW of installed solar and wind capacity by 2030. |
| 14th Five-year Plan for Energy | • Reduce $CO_2$ intensity of GDP by 18% by 2025 relative to 2020.<br>• Reduce energy intensity of GDP by 13.5% by 2025 relative to 2020.<br>• 20% non-fossil fuel share of energy mix by 2025, and 25% by 2030. |
| 14th Five-year Plan for Renewables | • Targets 3 300 TWh of renewables electricity generation by 2025.<br>• Over 50% of electricity consumption growth by 2025 met by renewables. |
| 14th Five-year Plan for Buildings | • Efficiency retrofits for 350 million square metres ($m^2$) of existing buildings and 50 million $m^2$ of near-zero-energy buildings constructed by 2025.<br>• Solar PV capacity of 50 GW by 2025 in new buildings.<br>• Geothermal energy for more than 100 million $m^2$ of buildings by 2025. |
| Made in China 2025 | • Supports innovation capability, digitalisation and greening manufacturing.<br>• Raising domestic share of core components and materials to 70% by 2025. |
| New Energy Vehicle Industry Development Plan | • Promotes widespread adoption of new energy and clean energy vehicle sales, targeting 25% of new vehicle sales by 2025. |
| Carbon peaking and neutrality blueprint for urbanisation and rural development | • Carbon emissions from urban and rural construction peak before 2030.<br>• Retrofits for public buildings in key cities to be collectively 20% more energy efficient by 2030.<br>• Electricity accounts for 65% of energy demand in urban buildings by 2030. |

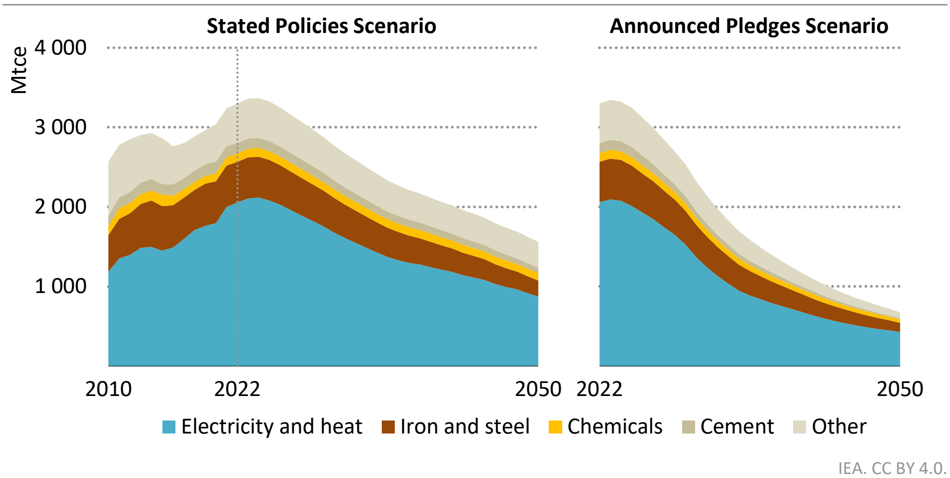
China is a market mover for all fossil fuels due to the scale of its energy use. In 2022, it was the world's largest coal consumer, producer and importer, though its imports decline almost 30% by 2030 in the STEPS, falling behind the level of imports in India. It is also one of the largest oil consumers in the world, accounting for 15% of global demand in 2022, and oil imports are projected to increase to 2030. It recently also became the world's largest natural gas importer and has contracted large volumes from global LNG markets as well as key pipeline suppliers, including Russia. Despite growing deployment of clean energy technologies, China remains the largest consumer of fossil fuels through to 2050 in the STEPS. Its coal use peaks around 2025, then starts a long-term decline to 50% below the peak by 2050. Natural gas use continues to grow strongly to 2030 before eventually peaking in 2040 at about one-quarter higher than the level today. Oil consumption peaks at 16.6 mb/d before 2030, ending decades of growth, and then declines steadily to 12 mb/d in 2050.

China's updated NDC targets, which include reaching carbon neutrality before 2060, are fully reflected in the APS. In this scenario, China's total $CO_2$ emissions peak before 2025, with faster progress on energy efficiency, renewables and nuclear power leading to an earlier peak in coal use, and faster deployment of EVs helping to curb oil demand. The unabated use of coal is cut by two-thirds by 2040 and almost 90% by 2050. Natural gas use still increases to 2030 before entering a long-term decline, but less of it is used is all sectors in the APS: some of the biggest differences are power (about 90 bcm lower in 2050 than in the STEPS), followed by industry (80 bcm lower), buildings (60 bcm lower) and transport (20 bcm). China has amassed a considerable portfolio of contracted LNG and pipeline imports in recent years. With lower demand in the APS, around 80 bcm of a 270 bcm portfolio of contracted gas is surplus to requirements in 2030. Oil demand in China also peaks earlier in the APS, at 15.9 mb/d in the mid-2020s, and then gradually falls to 6.9 mb/d in 2050.

### *5.8.2 How soon will coal use peak in China?*

The question of when coal use in China will peak is an important one for the global clean energy transition because China is responsible for such a large share of global coal use. In 2022, China consumed more coal than all other countries combined, and combustion of coal emitted 8.6 Gt $CO_2$, accounting for about 70% of China's total emissions and one-quarter of global energy-related emissions.

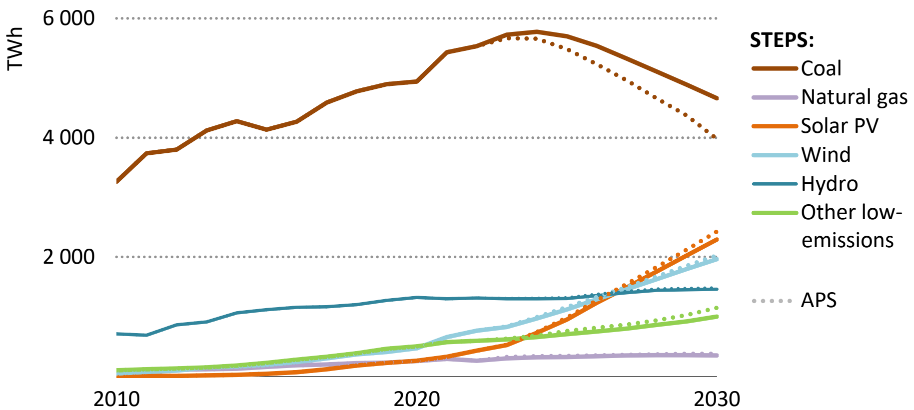
**Figure 5.20 ▷ Coal consumption by sector in China by scenario, 2022-2050**




*Coal consumption peaks in the mid-2020s and thereafter declines by 3% per year in the STEPS and 6% per year in the APS*

The power sector accounts for over 60% of China's coal use today (Figure 5.21). Coal accounted for over 60% of electricity generation in China in 2022. While high, this share of generation is far below the peak of 81% in 2007 and the average over the last 20 years of 73%. Increasing demand for electricity has nevertheless led to China completing almost 40 GW of new coal capacity on average per year over the past five years, more than the rest of the world combined in the same period. In 2022, close to 90 GW of new coal-fired capacity was approved to start construction plus another 50 GW planned, adding to the nearly 100 GW under construction as of the end of the year, indicating that total coal capacity in China will continue to increase to 2030. However, output from coal-fired power plants in China peaks around 2025 and declines before 2030 in both the STEPS and APS. This happens because the average capacity factor of coal plants in China declines to just over 40% in 2030 in the STEPS and 35% in the APS, compared with 53% in 2022, on the basis that China will gradually use its coal-fired power more to provide flexibility and less to deliver bulk energy, though there is inevitably some uncertainty about the speed and degree of this shift. After 2030, the pathways for unabated coal-fired generation rapidly diverge, with coal use falling further and faster in the APS than in the STEPS.

**Figure 5.21 ▷ Electricity generation by source in China in the STEPS and APS, 2010-2030**





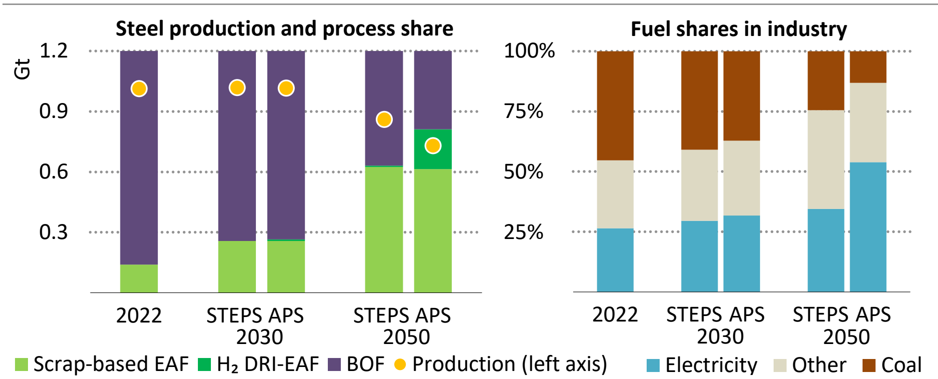

*Coal-fired electricity generation is set to decrease from the mid-2020 in the APS while solar PV capacity grows rapidly and passes 2 500 GW by 2030*

The extent to which coal-fired power and related emissions decline in the long run varies by scenario as it is highly dependent on the ability of renewables growth to outpace overall demand growth. Central to renewables growth is the ability to continue scaling up solar PV and wind deployment in China. Manufacturing capacity, particularly for solar PV, creates a huge opportunity to do so (see Chapter 1). In the APS, solar PV installed capacity nears 5 400 GW by 2030. It could go even faster, though successfully integrating more solar PV requires overcoming a number of challenges: the electricity system has to be equipped to integrate solar PV and wind output in full, and that requires expansion of electricity transmission, modernisation of distribution grids, storage technologies and a number of operational changes.

Coal use in the industry sector has been increasing rapidly since the turn of the millennium. It accounted for 45% of industrial total consumption of energy in 2022 and was responsible for 30% of total coal consumption in China. The iron and steel sub-sector is the largest industrial coal user today, consuming more than 500 Mtce of the total 970 Mtce used by industry in China. Almost 90% of its steel is produced in integrated blast furnace basic oxygen furnace (BF-BOF) steel plants where coking coal is used both as reagent to transform iron ore into iron and as a fuel to heat iron to its melting point (more than 1 500 °C). Iron and steel coal use peaked in 2014 and declines from 2022 in both the STEPS and APS as scrap becomes more widely available for secondary production, which is much less energy-intensive and uses electric arc furnaces to provide heat rather than coal (Figure 5.22). Coal use is also widespread in other heavy industries, from cement to chemicals, as well as in light industries. Strategies to switch away from coal in industry sectors are explored in Chapter 3 of *Coal in Net Zero Transitions* (IEA, 2022b).

Because coal combustion in China accounts for around one-quarter of total energy-related $CO_2$ emissions, cuts in its coal use have a major impact on the global outlook for emissions. In the APS, $CO_2$ emissions from coal combustion in China decline from 8.6 Gt in 2022 to 1.1 Gt in 2050. This covers 30% of the global $CO_2$ emissions reductions that are needed in this scenario to meet the emissions reduction targets announced by countries all around the world. While this would be a significant achievement, much more needs to be done in China and other countries to enable a faster transition away from unabated fossil fuels use if the world is to achieve global net zero emissions by 2050.

**Figure 5.22 ▷ Steel production by process and fuel shares in industry in China by scenario, 2022-2050**




IEA. CC BY 4.0.

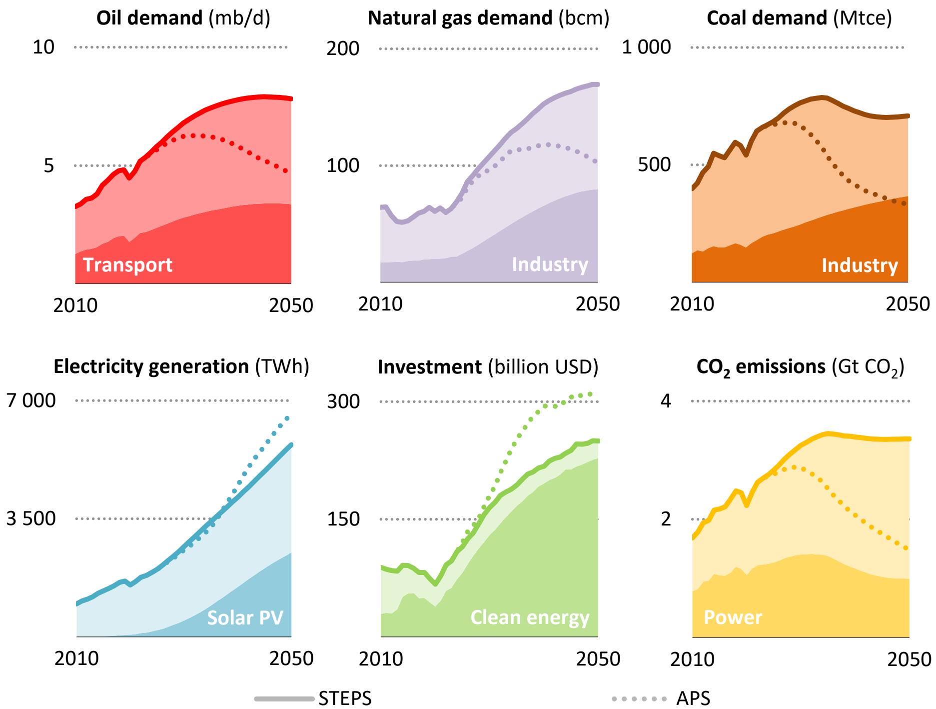
***Coal use in industry plummets as electrification progresses in most sub-sectors. Steel increases reliance on secondary production and hydrogen-based iron production.***

Note: Scrap-based EAF = steel production from scrap in electric arc furnace; $H_2$ DRI-EAF = steel production in electric arc furnace using iron from hydrogen-based direct reduced iron; BOF = steel production in basic oxygen furnace using iron from a blast furnace or from a smelting reduction furnace.

# 5.9 India

## *5.9.1 Key energy and emissions trends*

**Figure 5.23 ▷ Key trends in India, 2010-2050**




IEA. CC BY 4.0.

Through much of its modern history, India has worked to build power generation and refining capacity, provide affordable access to energy and ensure security of supply. A lot has been achieved in the past few decades. Since 2000, India has brought electricity to 810 million people, larger than the population of the European Union and the United States combined. India has also brought clean cooking access to 655 million people over the same period, although 430 million people continue to live in households that use traditional biomass today. Over the past five years, solar PV has accounted for nearly 60% of new generation capacity. India has had the single largest light-emitting diode (LED) adoption campaign in the world, with around 370 million LEDs distributed through the UJALA scheme by 2023. India has also achieved self-sufficiency in petroleum refining capacity despite being a net crude oil importer, although certain petroleum products continue to be imported.

India is moving into a dynamic new phase in its energy development marked by a long-term net zero emissions ambition, increased regulatory sophistication, a focus on clean energy deployment, and the creation of domestic clean energy technology supply chains.

Recognising the potential to transform its energy sector and reduce the import burden of fossil fuels while reducing $CO_2$ emissions, India has announced a net zero emissions target by 2070, and has put in place policies to scale up clean energy supply and clean technology manufacturing. While clean energy investment in India more than doubles in the STEPS by 2030 from around USD 60 billion in 2022, investment needs to nearly triple by the end of this decade to be on a trajectory to meet its net zero emissions target, which is reflected in the APS (Figure 5.23).

In the STEPS, India sees the largest energy demand growth of any country or region in the world over the next three decades. Although India's population growth has slowed to reach replacement levels, its urban population increases by 74% and per capita income triples by 2050. Industrial output expands rapidly, for example through a tripling of output of iron and steel, and doubling of cement, plus there is a ninefold increase in residential air conditioner ownership by 2050. As a result, demand for oil and natural gas increases in the STEPS by nearly 70% between 2022 and 2050, while coal demand increases by 10%, even as solar PV makes inroads into electricity generation. As a result, India's annual $CO_2$ emissions still rise nearly 30% by 2050, which is one of the largest increases in the world.

In the APS, the increase in clean energy investment changes the outlook. In the STEPS, solar provides nearly 45% of total generated power by 2050; in the APS, it crosses 50%. In both the STEPS and APS, India achieves its target of 50% non-fossil power generation capacity by 2030. Clean energy investment in the APS over and above those in the STEPS also drives faster growth in electromobility, low-emissions hydrogen, grid expansions and other clean energy infrastructure. As a result, India's annual $CO_2$ emissions fall sharply in the APS by over 40% from current levels by 2050, even though its GDP quadruples over this period.

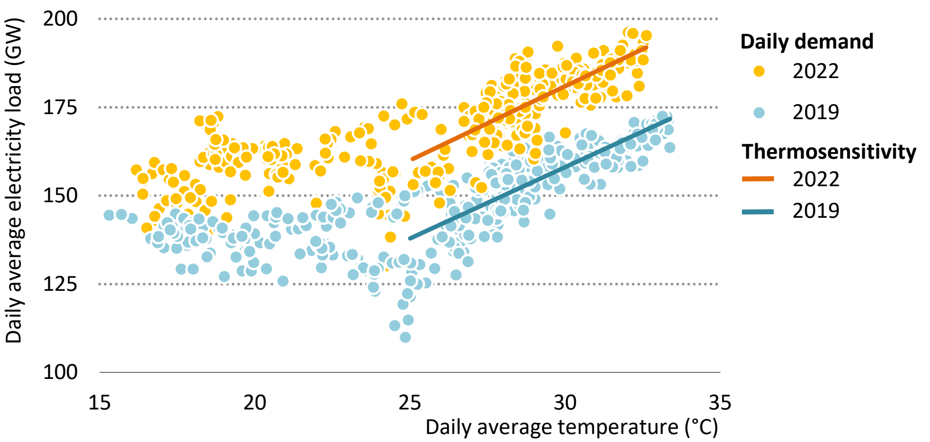
**Table 5.10 ▷ Key policy initiatives in India**

| Policy | Description |
|---|---|
| Net Zero Emissions by 2070 | • India announced the ambition to reach net zero emissions by 2070 in 2021. It was formally adopted as a part of its updated Nationally Determined Contribution in 2022. |
| Renewable energy and transmission targets | • Aims to have 50% of power generation capacity fuelled by non-fossil sources by 2030, compared to 41% in 2022. It has also set a target of 500 GW of non-fossil capacity by 2030.<br>• The Green Energy Corridor project aims to create transmission capacity to integrate a rising share of variable renewable power. Its transmission plan targets the integration of 500 GW of renewable capacity by 2030. |
| Production Linked Incentives | • Provide subsidies towards the creation of new manufacturing capacity of solar PV modules and modern batteries. |
| National Green Hydrogen Mission | • Targets low-emissions hydrogen production capacity of 5 Mt per year (with an associated renewable energy capacity addition of 125 GW). This is to be accompanied by policies to generate demand for low-emissions hydrogen, particularly from industry. |
| Carbon Market | • Passed a law in 2022 that sets the stage for the creation of the Indian Carbon Market, a carbon credit trading scheme. |

### 5.9.2 Impact of air conditioners on electricity demand in India

Over the past five decades, India has witnessed over 700 heat wave events, which have claimed over 17 000 lives (Ray et al., 2021). Fuelled by its geographic and meteorological conditions, air conditioner ownership in India has been steadily rising with growing incomes, tripling since 2010 to reach 24 units per 100 households. The impact of cooling needs on electricity consumption is already clear. Electricity demand is sensitive to temperatures, and in India's case there is a sharp increase in demand as temperatures cross the 25 °C threshold (Figure 5.24). Electricity consumption due to space cooling increased 21% between 2019 and 2022, and today nearly 10% of electricity demand comes from space cooling requirements.

**Figure 5.24 ▻ Daily average electricity load versus daily temperature in India, 2019 and 2022**

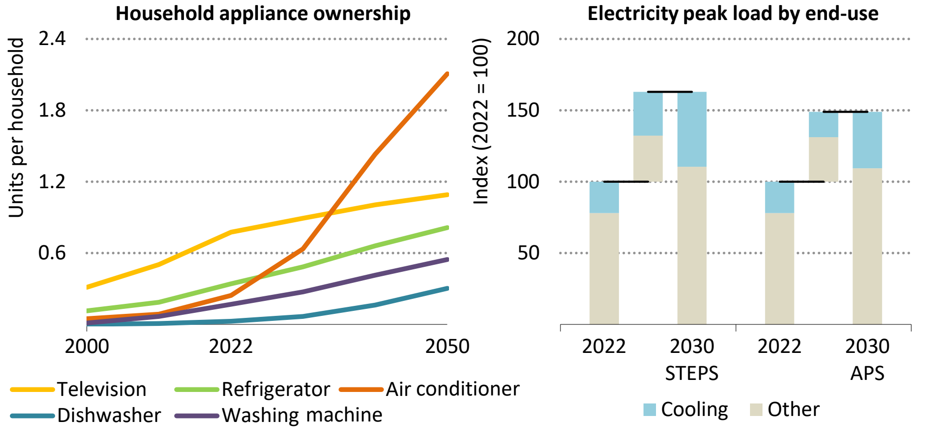





*Electricity demand rises sharply with temperatures above 25 °C; use of more space cooling appliances is pushing electricity demand up*

Household air conditioner ownership is estimated to expand ninefold by 2050 across the IEA scenarios, outpacing the growth in ownership of every other major household appliance including televisions, refrigerators and washing machines (Figure 5.25). Residential electricity demand from cooling increases ninefold in the STEPS by 2050. By 2050, India's total electricity demand from residential air conditioners in the STEPS exceeds total electricity consumption in the whole of Africa today. In the APS, however, electricity demand for air conditioners is nearly 15% lower in 2050 as it is in the STEPS as a result of increased use of energy-efficient air conditioners and thermal insulation in buildings. This reduction itself is larger than the total electricity generation by several countries today, such as that of the Netherlands.

**Figure 5.25 ▷ Household appliance ownership in India to 2050 and contribution of cooling to peak electrical load by scenario, 2030**






***Air conditioners are projected to be the fastest growing household appliance, which drives half of the growth in peak electricity demand to 2030 in the STEPS***

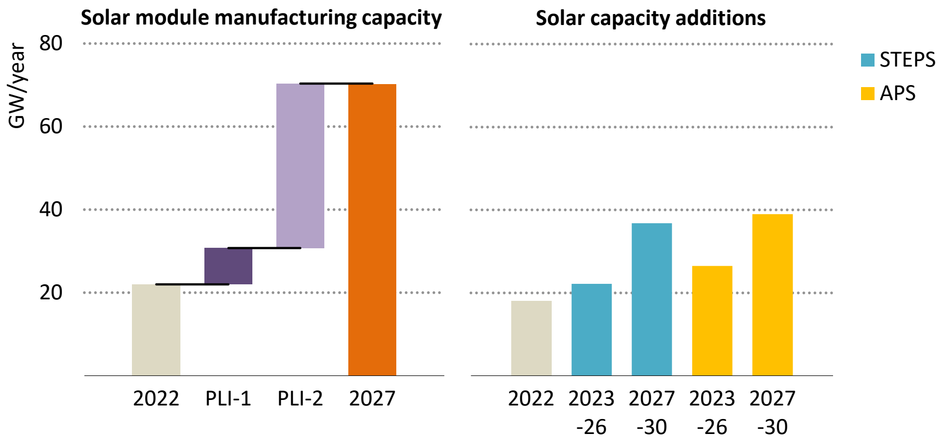
The growth in ownership and use of air conditioners and other cooling equipment is also one of the key drivers of the increase in peak electricity demand in India. In the STEPS, peak electricity demand rises around 60% from the 2022 level by 2030 and cooling accounts for nearly half of this increase. In the APS, however, the implementation of building codes, the use of more efficient appliances and the adoption of demand response measures enable the same cooling needs to be met with less energy. This reduces peak electricity demand growth by nearly one-quarter compared to the STEPS. Given that the electricity system is sized to meet peak demand, lower peak demand helps to lower electricity investment needs and system costs. Although solar PV matches well with daytime cooling needs, cooling demand is also significant in India during the late evening and at night. Lowering cooling demand through energy efficiency policies therefore reduces the need for investment in batteries or expensive standby generation capacity, and thus helps to integrate renewables more cost effectively.

### *5.9.3 Will domestic solar PV module manufacturing keep pace with solar capacity growth in India?*

India has historically been a net importer of fossil fuels, and it has now become an importer of modern clean energy technologies as it scales up solar and wind power generation capacity. For example, its imports of solar PV modules in 2021-2022 were valued at USD 3.4 billion (MCI, 2023). Recognising this import dependence and mindful of the high levels of concentration in clean energy technology supply chains, the national government launched the Production Linked Incentives (PLI) programme in 2020 to support domestic manufacturing in a range of critical sectors, including solar PV modules and advanced chemistry cell battery manufacturing.

The PLI programme for solar PV module manufacturing budgeted nearly USD 2.5 billion in subsidies with the aim of creating 65 GW per year of new manufacturing capacity. Manufacturing companies were selected in two tranches in 2023 and a total of 48 GW of new capacity was deemed eligible for subsidy awards once manufacturing begins. These new production lines are expected to come online within two to three years.

**Figure 5.26 ⊳ Solar PV module manufacturing capacity and solar PV capacity additions in India by scenario to 2030**






***If planned solar PV module manufacturing capacity additions under the Production Linked Incentives materialise, they would be adequate to meet domestic demand this decade***

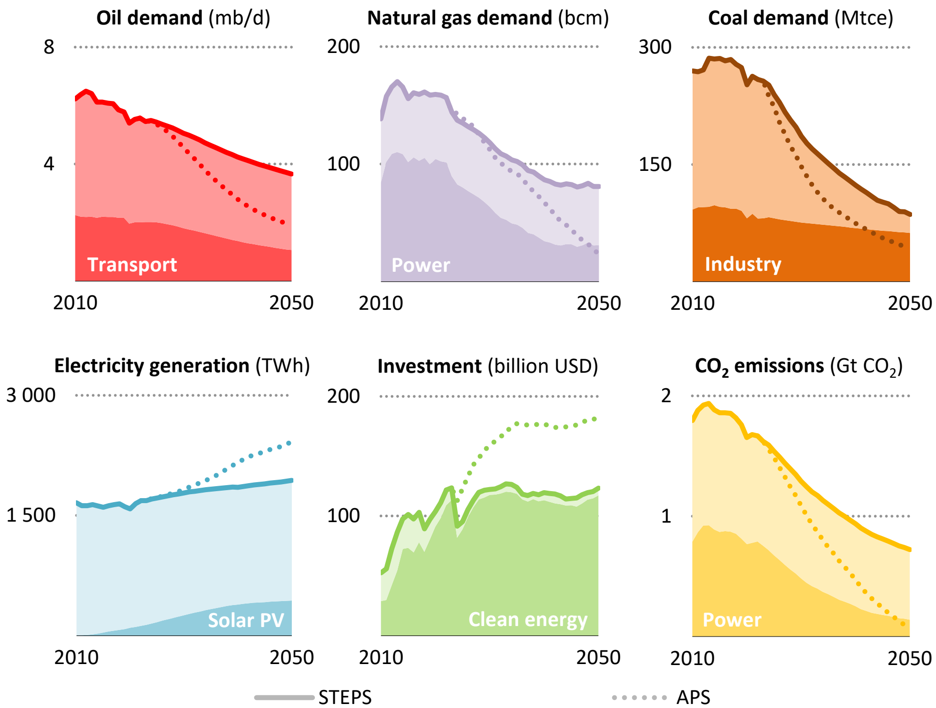
Note: PLI-1 and PLI-2 refer to the two tranches of the Production Linked Incentives programme under which solar manufacturers were selected to receive subsidies in lieu of creating new manufacturing capacity.

India is expected to meet its 2030 target to have half of its electricity capacity be non-fossil well before the end of the decade. If the new solar PV module manufacturing capacity under the PLI programme comes fully online by 2026, it would progress the solar PV module manufacturing capacity in India to well over what is needed until the end of this decade not just in the STEPS but also in the APS (Figure 5.26). Solar PV module imports could continue for a few years because developers will source the cheapest panels available, because the capacity utilisation factor remains lower than the nameplate capacity, and because there are lags between the nameplate capacity coming online and the panels being manufactured, shipped and installed. Nonetheless, as domestic production ramps up, solar PV module imports will decline and it will help to establish India as a reliable exporter.

## 5.10 Japan and Korea

### 5.10.1 Key energy and emissions trends

**Figure 5.27 ▷ Key trends in Japan and Korea, 2010-2050**






Japan and Korea continue to map out secure pathways to reach net zero emissions pledges by 2050, but it remains challenging to decarbonise large industrial economies that have historically relied heavily on imported fossil fuels.

In the STEPS, the share of coal and natural gas in the power mix of the two countries – currently at 65% – falls sharply over the next few decades as Japan's Green Transformation policy and Korea's Basic Plan for Long-term Electricity Supply and Demand dramatically increase the share of low-emissions fuels in generation, including solar PV, wind and nuclear. The share of generation from low-emissions technologies of both countries combined rises from 30% today to around 85% by 2050 in the STEPS. Natural gas demand almost halves by mid-century, with remaining widespread use in the power, building and industrial sectors, while coal use declines by two-thirds, largely in industry (Figure 5.27). Reduced oil demand is shaped by increased adoption of zero emissions vehicles (ZEV), sales of which rise sharply as government support schemes in both countries incentivise their uptake: ZEVs account for

65% of new vehicles sold by 2050, bringing oil demand down from nearly 6 mb/d today to less than 4 mb/d by 2050.

The APS incorporates the pledges stated by Japan and Korea to reach climate neutrality by 2050. Japan's Green Growth Strategy and Korea's Carbon Neutrality and Green Growth Act envisage full decarbonisation of the power sector. Japan also aims for all new cars and vans sold to be either battery electric, plug-in hybrid, hybrid or fuel cell vehicles, with a target date of 2035 for cars and 2040 for vans. Korea has set a target for more than 80% of car sales to be low-emissions vehicles by 2030. Both countries have also introduced guidelines for new buildings to meet zero-carbon standards by the end of this decade. As a result, investment in clean energy technologies in the APS rapidly scales up to over USD 175 billion by 2050.

**Table 5.11 ▷ Key policy initiatives in Japan and Korea**

| Policy | Description |
|---|---|
| **Japan: Basic Hydrogen Strategy** (updated in 2023) | • Aims to accelerate public and private investment in the hydrogen supply chain with JPY 15 trillion (USD 114 billion) over the next 15 years.<br>• Plans to install around 15 GW of electrolysers by Japanese companies both domestically and abroad by 2030. |
| **Japan: Green Transformation** (GX) **basic policy** | • Aims to achieve decarbonisation, energy security and economic growth with public and private investment of JPY 150 trillion (USD 1 trillion) over the next ten years.<br>• Intends to fund the promotion of renewable energy, i.e. R&D offshore wind cost reduction, and transition, i.e. building mass hydrogen supply chain, and extend the lifetime of existing nuclear reactors. |
| **Korea: 10th Basic Plan for Long-term Electricity Supply and Demand** | • Seeks to increase the share of renewables and nuclear – a shift from previous phase-out plans – in the power mix to 31% and 35% respectively and reduce the share of coal to 15% by 2036.<br>• Plans to expand the power generation capacity from 148 GW level in 2023 to 239 GW by 2036. |
| **Korea: 1st National Basic Plan for Carbon Neutrality and Green Growth** | • Includes 2023 NDC updates of the 2021 NDC which maintains the same GHG reduction target at 40% from 2018 levels but with adjusted sectoral targets.<br>• Intends to strengthen the power sector reduction target to 45.9% by 2030 from 2018 levels, with increased roles for nuclear and renewables, and to reduce the target for the industry sector to a 11.4% cut by 2030 from 14.5% in the previous NDC. |

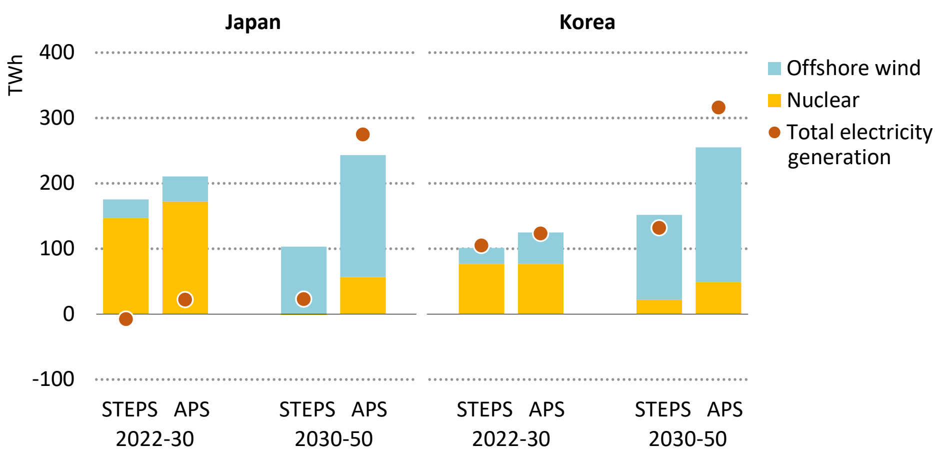
Note: JPY = Japanese yen; NDC = Nationally Determined Contribution.

Japan and Korea both have small land areas relative to the size of their populations and industrial sectors: this is a disadvantage when it comes to deploying renewables such as solar PV and onshore wind. Their distinct geographical settings require the two countries to explore a diversified mix of clean technologies which includes major roles for imported low-emissions hydrogen and hydrogen-rich fuels, floating offshore wind and nuclear.

### 5.10.2 Challenges and opportunities of nuclear and offshore wind

Both Korea and Japan need to determine their specific path and mix of technologies to achieve secure clean energy transitions. In the power sector, both countries have been investing in solar PV, which expanded significantly between 2010 and 2022. Today, however, fossil fuels still account for two-thirds of power generation in both countries, mainly from coal and natural gas. Further acceleration of efforts on clean electricity generation is necessary to achieve their goals for clean energy transitions. Nuclear power and offshore wind have the potential to make a significant contribution to decarbonising the power sector, and in our scenarios their role in electricity generation rises rapidly (Figure 5.28). The share of nuclear power in electricity generation in Japan and Korea increases by 75% in both STEPS and APS by 2050. Maintaining effective and efficient safety regulations is clearly essential in this context.

**Figure 5.28 ▷ Growth in nuclear and offshore wind electricity relative to total electricity generation growth by scenario, 2022-2050**






***Nuclear plays a major role in increased electricity generation by 2030 while offshore wind is expected to develop rapidly after 2030***

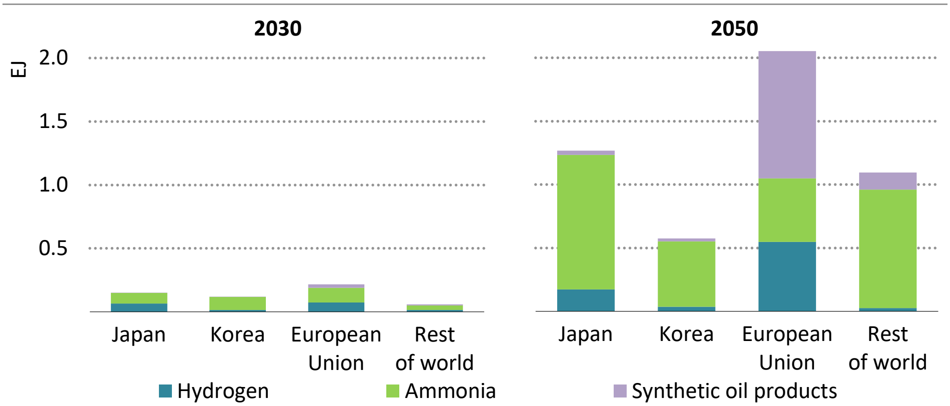
Offshore wind could unlock the enormous energy potential of large ocean areas surrounding both countries and become a major source of renewable energy. Offshore wind capacity in Japan and Korea totals only 0.3 GW today, due largely to a lack of transmission capacity and the high cost of facilities. The unique geographical characteristics of Korea and Japan add to the challenges: the sea surrounding both countries is more than 50 metres deep in many places and has steep slopes which make it impossible to deploy traditional seabed-mounted offshore wind installations. Technological development and cost reductions in floating systems could accelerate expansion of offshore wind, which is in the early deployment stage today. Government support is planned, as accelerating the full-scale roll-out of floating systems requires extensive funding for R&D and for efforts to de-risk investment in early projects. Policies for offshore wind in Japan and Korea aim to tackle the challenges by simplifying project approval processes, building resilient supply chains and developing efficient low cost structures that can adapt to the particular geographical and climatic environment. In the STEPS, combined for Japan and Korea offshore wind increases its contribution to generation from less than 0.1% today to 15% by 2050. In the APS, its contribution in electricity generation increases to 20%, which reaches the share of solar PV, and offshore wind and nuclear together account for nearly 45% of total generation by 2050 in the APS.

### 5.10.3 What role can hydrogen play in the energy mix and how can the governments deploy it?



In the APS, Japan and Korea import significant quantities of hydrogen and hydrogen-based fuels for use in the power sector and for direct use in industry. By 2050, Korea and Japan account for almost 40% of global hydrogen imports (Figure 5.29).

**Figure 5.29 ▷ Imported hydrogen and hydrogen-based fuels in the APS, 2030 and 2050**

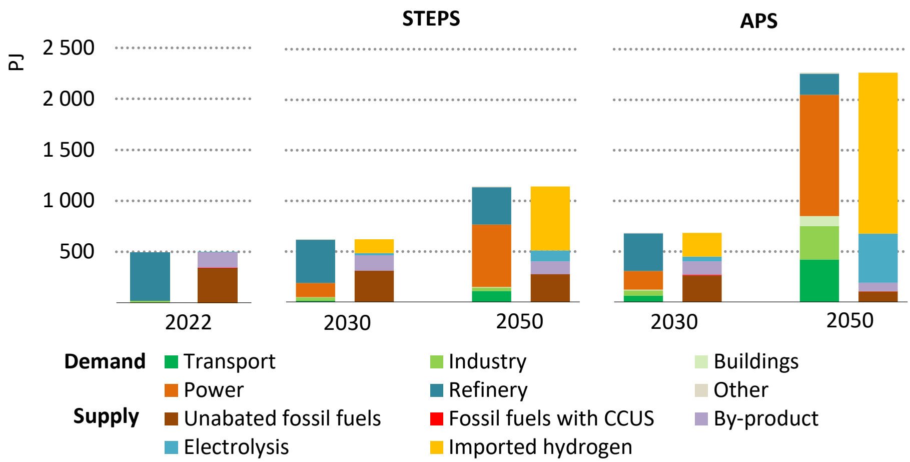





*Japan and Korea become the second-largest importers of hydrogen and hydrogen-based fuels after the European Union*

Today Japan and Korea's share of hydrogen in total final consumption is close to 0%. It is mainly produced through natural gas reforming and consumed in oil refineries. Both governments aim to expand its use in coming decades with 20% ammonia co-firing by 2030 (50% by 2035 in Japan) to reduce the carbon intensity of the existing coal-fired fleet. After the power sector, demand for hydrogen will be driven by hard-to-abate sectors such as long-distance trucking, aviation, shipping and heavy industry (Figure 5.30). In aviation and shipping, demand is likely to be focussed on synthetic kerosene and ammonia. By 2050, hydrogen accounts for 2% of total final consumption in the STEPS and up to 9% in the APS.

**Figure 5.30 ▷ Hydrogen supply by source and demand by sector in Japan and Korea by scenario**






***Fossil fuel-based hydrogen is used on an interim basis until low-emissions hydrogen supply scales up mostly for co-firing and in hard-to-abate sectors***

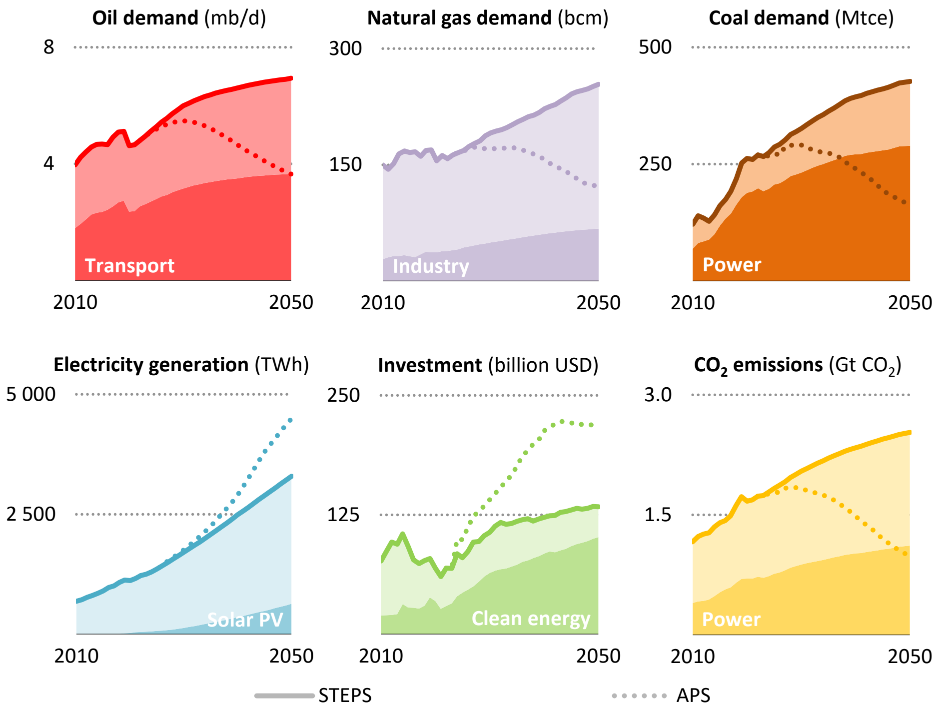
Notes: Transformation includes co-firing in power generation, hydrogen as an input to hydrogen-based fuels and use in biofuel production. Imported hydrogen includes hydrogen from cracking of imported ammonia, imports of liquefied hydrogen and synthetic oil products. By-product refers to hydrogen produced in naphtha reformers in refineries and petrochemical facilities.

While unabated fossil fuel-based hydrogen meets most existing demand today, Japan and Korea are looking for low-emissions hydrogen supply to meet new demand and replace existing unabated production capacities. In the APS, hydrogen produced from electrolysis ramps up significantly, accounting for nearly three-quarters of domestic production in the two countries in 2050. To help develop and secure the low-emissions hydrogen that they need, Japan and Korea are actively seeking partnerships with potential exporting countries and technology providers. Long-term investment and contracts are required across hydrogen value chains, from upstream (fertilisers and providers of renewable electricity, electrolysers and $CO_2$ capture) to transportation and storage (including ships, ports and plants to convert different hydrogen commodities). Progress is being made in creating reliable demand, but more needs to be done on that front to support long-distance transport and industrial uses where off-take risks are hindering the adoption of new equipment and processes. The development of international standards, certification arrangements and emissions accounting frameworks all could help the scaling up that is needed and to assist governments to achieve emissions reduction target through the use of imported hydrogen.

## 5.11 Southeast Asia

### 5.11.1 Key energy and emissions trends

**Figure 5.31 ⊳ Key trends in Southeast Asia, 2010-2050**






Southeast Asia is home to nearly 9% of the world population and accounts for 6% of global GDP. It is a major engine of economic growth and has an outsized influence in global energy. The collective GDP of countries in Southeast Asia has nearly tripled since 2000, outpacing growth in global GDP over this period. As a result, energy demand growth in the region has also outpaced the global average, and that is set to continue: in the STEPS, the region experiences the second-highest energy demand growth in the world after India until 2050, driven by an increasing population, rising standards of living and rapid urbanisation.

As a result of its continued reliance on fossil fuels, Southeast Asia also sees the largest absolute growth of $CO_2$ emissions of any region in the world. Its emissions increase by 46% from 2022 levels by 2050 in the STEPS, with coal responsible for much of the rise. Southeast Asia is one of the few regions in the world where electricity generation from coal increases in the STEPS through to 2050. While the share of coal in power generation falls to less than one-third by 2050 in the STEPS, it is still the second-highest of any region in the world by 2050.

Today Southeast Asia relies heavily on coal for electricity generation. Two ambitious Just Energy Transitions Partnerships (JETP) were established in Southeast Asia in 2022, one with Indonesia and another with Viet Nam. The partnerships promise better access to international financing to accelerate transitions away from unabated coal-fired power to help reduce emissions. In Viet Nam, the latest power development plan seeks to reshape its energy system, including by moving away from unabated coal use and by scaling up the use of low-emissions hydrogen and ammonia in the power sector.

**Table 5.12 ▷ Key policy initiatives in Southeast Asia**

| Policy | Description |
|---|---|
| Net zero emissions ambitions | • Commitments to net zero emissions by 2050 (Laos, Malaysia, Singapore, Viet Nam, Brunei Darussalam), by 2060 (Indonesia) and by 2065 (Thailand).<br>• Indonesia, Malaysia, Philippines, Viet Nam, Singapore and Cambodia have committed to the Global Methane Pledge. |
| Just Energy Transition Partnership | • Just Energy Transition Partnerships with Indonesia (USD 20 billion) and Viet Nam (USD 15.5 billion). |
| Regional initiatives | • ASEAN Plan for Action on Energy Co-operation sets out aspirational targets including a reduction of energy intensity by 32% in 2025 based on 2005 levels, and an increase of renewables to 23% by 2025 in the region.<br>• ASEAN Power Grid collaboration which will be carried out by the ASEAN Center for Energy and the US Agency for International Development.<br>• Asia Zero Emissions Community initiative by Japan to bring together economies towards transitions to net zero emissions – USD 8 billion by 2030 towards clean energy projects in participating Southeast Asian countries including Indonesia, Philippines, Thailand and Viet Nam. |
| Support to EVs | • Multiple policies to support EV use, such as reduced value-added tax and subsidies (Indonesia); tax incentives for companies renting EVs and subsidies for EV charger manufacturing (Malaysia); and cell manufacturing (Thailand). |

Note: ASEAN = Association of Southeast Asian Nations.

Southeast Asia has emerged as a global hub for clean energy technology manufacturing, with Viet Nam and Indonesia joining the ranks of exporters of equipment such as solar PV modules. However, the race to build industrial capacity risks leading to rapid development of captive coal projects, such as for nickel processing in Indonesia. Overall, clean energy investment in the region was nearly USD 30 billion in 2022, which looks to more than double by the end of this decade. Nevertheless, there is more to do to be on track to deliver longer term ambitions as reflected in the APS. For this to happen, clean energy investment needs to nearly quadruple by 2030 and continue rising afterwards. Investment on this scale in the APS leads to solar power increasing almost sixfold by 2030 and to coal-fired power generation halving by 2050 from 2022 levels, reducing overall $CO_2$ emissions by over 40%, even as the region's economy grows by well over two-and-half-times larger.

### 5.11.2 How can international finance accelerate clean energy transitions in Southeast Asia?

Marshalling the necessary finance to fulfil clean energy transition objectives can be challenging for emerging market and developing economies as they tend to rely heavily on public investment by governments or state-owned enterprises. They face relatively high borrowing costs, and stepping up investment calls for multiple sources of finance: both domestic and international private finance have pivotal roles to play. Mobilising this capital requires international co-operation, involvement of international and development finance institutions, and reforms to domestic policy and regulatory frameworks that facilitate private investment.

Just Energy Transition Partnerships, launched at COP26 in Glasgow in 2021, attempt to address this challenge. They are a financing co-operation mechanism between advanced economies and a coal-dependent emerging market and developing economy which commits to ambitious emissions reduction targets and defines a credible national transition pathway. The JETP framework includes multilateral development banks, national development banks and private lenders. The aim is to make available a mix of financing, some at concessional terms, with the goal of mobilising more resources by catalysing international private investment.

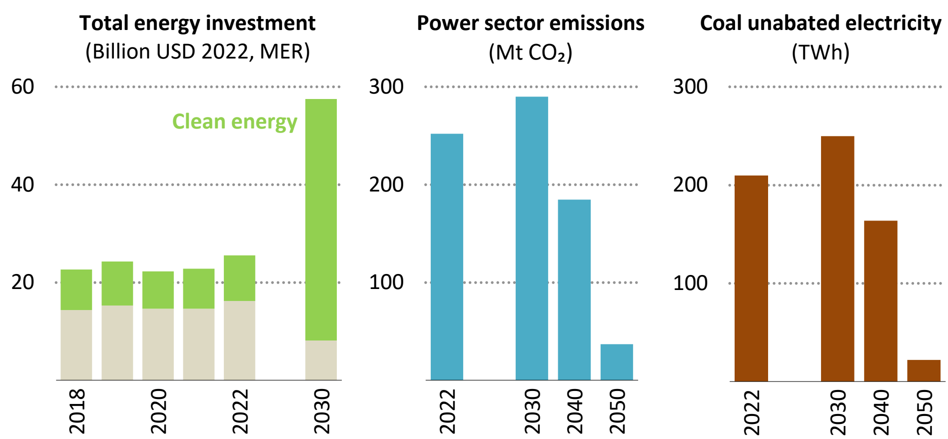


The JETP between Indonesia and the International Partners Group (IPG) – which includes Canada, Denmark, European Union, France, Germany, Italy, Japan, Norway, United Kingdom and United States – was developed to help Indonesia get on track to bring emissions to net zero by 2060. The JETP helped strengthen Indonesia's ambitions, bringing its pledges in line with the milestones set out in the *Energy Sector Roadmap to Net Zero Emissions in Indonesia* (IEA, 2022c), which was prepared in co-operation with the Indonesian Ministry of Energy and Mineral Resources. Putting the economy on a trajectory consistent with reaching net zero emissions by 2060 necessitates more than doubling total annual investment in the energy sector by 2030, raising the share of renewables in the power sector to one-third by 2030 (Figure 5.32). It also means power sector emissions peaking at no more than 290 Mt in 2030, and unabated coal-fired electricity generation peaking at around the same time.

In pursuit of these objectives, the Indonesia JETP aims to secure an initial USD 20 billion in financing over three to five years from both public and private sources. USD 10 billion consists of public sector finance backed by the International Partners Group, with the remainder to be obtained through a combination of market-rate loans and private investment. Another objective of the partnership is to help Indonesia update its technical and regulatory frameworks in order to overcome barriers to investment, facilitate the deployment of support and mobilise further domestic and international capital to speed up the transition to net zero emissions.

The JETP between Viet Nam and the IPG was developed to support the country in pursuit of its target to reach net zero emissions by 2050. It reflects its ambition to accelerate its transition to a carbon neutral energy system, including its intention to bring about a peak in emissions by 2030, to cease issuing permits for the construction of new coal-fired power plants, to promote the development of renewables and to improve energy efficiency, while ensuring energy remains secure and affordable. The Viet Nam JETP aims to mobilise at least USD 15.5 billion over the next five years. Half of this, nearly USD 8 billion, will be public sector finance backed by the IPG. As with Indonesia, the aim is for international funding to help catalyse additional private sector finance that at least matches the level of public sector finance, and to help Viet Nam attract the capital it needs as its clean energy transition moves forward.

**Figure 5.32 ▷ Energy sector investment and key milestones in the clean energy transition in Indonesia in the APS**




IEA. CC BY 4.0.

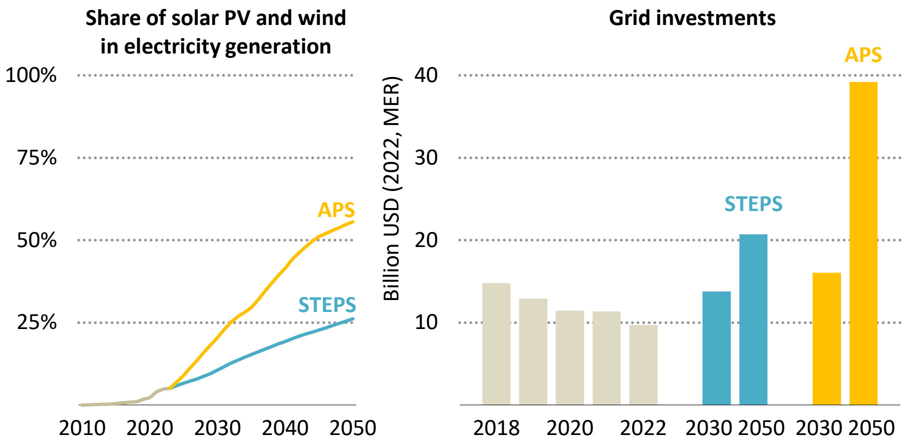
*To get on track for net zero emissions by 2060 and meet the JETP target to peak emissions in the power sector by 2030, total annual energy investment needs to double by 2030*

Viet Nam's Power Development Plan (PDP) 8, approved in May 2022, sets out its increased ambition and details a pathway for power sector development to 2030. It also includes a longer term vision to 2050. In line with JETP commitments, coal-fired capacity is planned to peak at about 30 GW in 2030, down from 55 GW in the previous PDP. Beyond 2030, coal plants would have to close when they are 40 years old unless converted to run on ammonia or biomass. Significantly raising the share of variable renewables in the electricity mix is another key component of the plan, and is accompanied by a recognition that substantial investment in grids is needed to make this work. Offshore wind is planned to play an important role, reflecting the fact that Viet Nam is home to some of the best offshore wind resources in Southeast Asia.

### 5.11.3 How can regional integration help integrate more renewables?

Clean energy transitions in Southeast Asia, supported by the JETP programme, will reshape power systems and help to strengthen energy security. Establishing markets and mechanisms for renewables deployment, scaling up clean energy investment and limiting coal-fired power will be crucial in the period to 2030. Integrating rising wind and solar PV capacity into electricity systems will become an increasingly central task after 2030, as their share of the overall generation mix rises from 20% in 2030 to over 50% in 2050 in the APS, compared with just 5% in 2022 (Figure 5.33).

**Figure 5.33 ▷ Wind and solar PV in total electricity generation and grid investment in Southeast Asia by scenario**






*Grid investment requirements quadruple in the APS by 2050 as the share of variable renewable energy in electricity supply increases*

Enhanced regional integration through strengthened electricity grids can improve electricity security and aid renewables integration in Southeast Asia in several ways. Flexibility needs can be reduced through regional integration by enabling electricity demand to be balanced over larger areas, which tends to smooth out variability and can moderate peak loads. Flexibility needs can also be reduced by linking systems that rely on wind and solar PV to varying degrees and that have different production profiles. Regional integration can also boost the available supply of flexibility by facilitating the pooling of a wider set of resources, including hydropower, fossil fuel-based capacity and energy storage. Better integrated systems could also mitigate the risk of outages and increase system resilience.

Regional integration requires the scaling up of investment in electricity grids, including in interconnections between countries. In Southeast Asia, grid investment rises from around USD 10 billion in 2022 to USD 16 billion in 2030 and USD 40 billion in 2050 in the APS. There is already growing momentum for increasing regional integration of the electricity network in Southeast Asia. Programmes such as the ASEAN Power Grid have boosted collaboration between countries and brought greater awareness of the advantages of integration for the region.

# ANNEXES

**Box A.1 ▹** *World Energy Outlook* **links**

## WEO homepage

***WEO-2023* information** iea.li/weo23

## *WEO-2023* datasets

Data in Annex A is available to download free in electronic format at:
**iea.li/weo-data**

An extended dataset, including the data behind figures, tables and the *WEO-2023* slide deck is available to purchase at:
**iea.li/weo-extended-data**

## Modelling

**Documentation and methodology / Investment costs**
iea.li/model

## Recent analysis

| | |
|---|---|
| **Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach** | iea.li/netzero |
| **Electricity Grids and Secure Energy Transitions** | iea.li/grids |
| **Global EV Outlook 2023** | iea.li/GEVO2023 |
| **World Energy Investment 2023** | iea.li/wei2023 |
| **Financing clean energy in Africa** | iea.li/AfricaEnergyFinancing |
| **Scaling up Private Finance for Clean Energy in Emerging and Developing Economies** | iea.li/finance-emde |
| **Global Methane Tracker 2023** | iea.li/methane-tracker23 |
| **Critical Minerals Market Review 2023** | iea.li/critical-minerals23 |
| **The Future of Heat Pumps** | iea.li/heatpumps |

## Databases

| | |
|---|---|
| **Policy Databases** | iea.li/policies-database |
| **Sustainable Development Goal 7** | iea.li/SDG |
| **Energy subsidies: Tracking the impact of fossil-fuel subsidies** | iea.li/subsidies |

# Tables for scenario projections

## *General note to the tables*

This annex includes global historical and projected data by scenario for the following five datasets:

- A.1: World energy supply
- A.2: World final energy consumption
- A.3: World electricity sector: gross electricity generation and electrical capacity.
- A.4: World $CO_2$ emissions: carbon dioxide ($CO_2$) emissions from fossil fuel combustion and industrial processes.
- A.5: World economic and activity indicators: selected economic and activity indicators.

Each dataset is given for the following scenarios: (a) Stated Policies Scenario (STEPS) [Tables A.1a. to A.5a]; (b) Announced Pledges Scenario (APS) [Tables A.1b. to A.5b]; and (c) Net Zero Emissions by 2050 (NZE) Scenario [Tables A.1c. to A.5c].

This annex also includes regional historical and projected data for the STEPS and the APS for the following datasets:

- Tables A.6 – A.7: Total energy supply, renewables energy supply in exajoules (EJ).
- Tables A.8 – A.11: Oil production, oil demand, world liquids demand, and refining capacity and runs in million barrels per day (mb/d).
- Tables A.12 – A.13: Natural gas production, natural gas demand in billion cubic metres (bcm).
- Tables A.14 – A.15: Coal production, coal demand in million tonnes of coal equivalent (Mtce).
- Tables A.16 – A.22: Electricity generation by total and by source (renewables, solar photovoltaics [PV], wind, nuclear, natural gas, coal) in terawatt-hours (TWh).
- Tables A.23 – A.26: Total final consumption and consumption by sector (industry, transport and buildings) in exajoules (EJ).
- Tables A.27 – A.28: Hydrogen demand (PJ) and the low-emissions hydrogen balance in million tonnes of hydrogen equivalent (Mt $H_2$ equivalent).
- Tables A.29 – A.31: Total carbon dioxide ($CO_2$) emissions, electricity and heat sectors $CO_2$ emissions, final consumption in million tonnes of $CO_2$ emissions (Mt $CO_2$).

Tables A.6 to A.31 cover: World, North America, United States, Central and South America, Brazil, Europe, European Union, Africa, Middle East, Eurasia, Russia, Asia Pacific, China, India, Japan and Southeast Asia.

The definitions for regions, fuels and sectors are in Annex C.

Abbreviations/acronyms used in the tables include: CAAGR = compound average annual growth rate; CCUS = carbon capture, utilisation and storage; EJ = exajoule; GJ = gigajoule; GW = gigawatt; Mt $CO_2$ = million tonnes of carbon dioxide; TWh = terawatt-hour. Use of fossil fuels in facilities without CCUS is classified as "unabated".

Both in the text of this report and in these annex tables, rounding may lead to minor differences between totals and the sum of their individual components. Growth rates are calculated on a compound average annual basis and are marked "n.a." when the base year is zero or the value exceeds 200%. Nil values are marked "-".

Box A.1 provides details on where to download the *World Energy Outlook (WEO)* tables in Excel format. In addition, Box A.1 lists the links relating to the main *WEO* website, documentation and methodology of the Global Energy and Climate Model, investment costs, policy databases and recent *WEO Special Reports*.

### *Data sources*

The Global Energy and Climate Model is a very data-intensive model covering the whole global energy system. Detailed references on databases and publications used in the modelling and analysis may be found in Annex E.

The formal base year for this year's projections is 2021, as this is the most recent year for which a complete picture of energy demand and production is available. However, we have used more recent data wherever available, and we include our 2022 estimates for energy production and demand in this annex. Estimates for the year 2022 are based on the IEA *$CO_2$ Emissions in 2022* report in which data are derived from a number of sources, including the latest monthly data submissions to the IEA Energy Data Centre, other statistical releases from national administrations, and recent market data from the IEA *Market Report Series* that cover coal, oil, natural gas, renewables and power. Investment estimates include the year 2022 data, based on the IEA *World Energy Investment 2023* report.

Historical data for gross power generation capacity (Table A.3) are drawn from the S&P Global Market Intelligence World Electric Power Plants Database (March 2023 version) and the International Atomic Energy Agency PRIS database.

### *Definitional note: Energy supply and transformation tables*

Total energy supply (TES) is equivalent to electricity and heat generation plus the *other energy sector*, excluding electricity, heat and hydrogen, plus total final consumption, excluding electricity, heat and hydrogen. TES does not include ambient heat from heat pumps or electricity trade. *Solar* in TES includes solar PV generation, concentrating solar power (CSP) and final consumption of solar thermal. *Biofuels conversion losses* are the conversion losses to produce biofuels (mainly from modern solid bioenergy) used in the energy sector. *Low-emissions hydrogen production* is merchant low-emissions hydrogen production (excluding onsite production at industrial facilities and refineries), with inputs referring to total fuel inputs and outputs to produce hydrogen. While not itemised separately, *geothermal* and *marine* (tidal and wave) energy are included in the *renewables* category of TES and *electricity and heat sectors*. While not itemised separately, *non-renewable waste* and *other sources* are included in TES.

### *Definitional note: Energy demand tables*

Sectors comprising total final consumption (TFC) include *industry* (energy use and feedstock), *transport* and *buildings* (residential, services and non-specified other). While not itemised separately, *agriculture* and *other non-energy use* are included in TFC. While not itemised separately, non-renewable waste, *solar thermal* and *geothermal* energy are included in *buildings*, *industry* and *TFC*. *Aviation* and *shipping* include both domestic and international energy demand. Energy demand from international marine and aviation bunkers are included in global transport totals and TFC.

### *Definitional note: Fossil fuel production and demand tables*

Oil production and demand is expressed in million barrels per day (mb/d). Tight oil includes tight crude oil and condensate production except for the United States, which includes tight crude oil only (US tight condensate volumes are included in natural gas liquids). Processing gains cover volume increases that occur during crude oil refining. Biofuels and their inclusion in liquids demand is expressed in energy-equivalent volumes of gasoline and diesel. Natural gas production and demand is expressed in billion cubic metres (bcm). Coal production and demand is expressed in million tonnes of coal equivalent (Mtce). Differences between historical production and demand volumes for oil, gas and coal are due to changes in stocks. Bunkers include both international marine and aviation fuels. Refining capacity at risk is defined as the difference between refinery capacity and refinery runs, with the latter including a 14% allowance for downtime. Projected shutdowns beyond those publicly announced are also counted as capacity at risk.

### *Definitional note: Electricity tables*

Electricity generation expressed in terawatt-hours (TWh) and installed electrical capacity data expressed in gigawatts (GW) are both provided on a gross basis, i.e. includes own use by the generator. Projected gross electrical capacity is the sum of existing capacity and additions, less retirements. While not itemised separately, *other sources* are included in total electricity generation. Hydrogen and ammonia are fuels that can provide a low-emissions alternative to natural gas- and coal-fired electricity generation – either through co-firing or full conversion of facilities. Blending levels of hydrogen in gas-fired plants and ammonia in coal-fired plants are represented in the scenarios and reported in the tables. The electricity generation outputs in the tables are based on fuel input shares, while the hydrogen and ammonia capacity is derived based on a typical capacity factor.

### *Definitional note: $CO_2$ emissions tables*

Total $CO_2$ includes carbon dioxide emissions from the combustion of fossil fuels and non-renewable wastes; from industrial and fuel transformation processes (process emissions); and from flaring and $CO_2$ removal. $CO_2$ removal includes: captured and stored emissions from the combustion of bioenergy and renewable wastes; from biofuels production; and from direct air capture. *Aviation* and *shipping* include both domestic and international emissions.

The first two entries are often reported as bioenergy with carbon capture and storage (BECCS). Note that some of the $CO_2$ captured from biofuels production and direct air capture is used to produce synthetic fuels, which is not included as $CO_2$ removal.

Total $CO_2$ captured includes the carbon dioxide captured from CCUS facilities, such as electricity generation or industry, and atmospheric $CO_2$ captured through direct air capture, but excludes that captured and used for urea production.

### *Definitional note: Economic and activity indicators*

The emissions intensity expressed in grammes of carbon dioxide per kilowatt-hour (g $CO_2$ per kWh) is calculated based on electricity-only plants and the electricity component of combined heat and power (CHP) plants.[1] *Primary chemicals* include ethylene, propylene, aromatics, methanol and ammonia. Industrial production data for *aluminium* excludes production based on internally generated scrap. Heavy-duty trucks activity includes freight activity of medium freight trucks and heavy freight trucks. *Aviation* activity includes both domestic and international flight activity. *Shipping* activity refers to international shipping activity.

Abbreviations used include: GDP = gross domestic product; GJ = gigajoule; $m^2$ = square metres; Mt = million tonnes; pkm = passenger-kilometres; PPP = purchasing power parity; tkm = tonnes-kilometres.

### *Definitional note: Hydrogen tables*

Total hydrogen demand includes merchant (or offsite) hydrogen demand and hydrogen demand in industry and refineries covered by onsite production. It also includes hydrogen used in the production of hydrogen-based fuels (ammonia, synthetic hydrocarbon fuels). The hydrogen balance table A.28 is expressed in million tonnes of hydrogen equivalent, which means for hydrogen-based fuels the equivalent mass of hydrogen that would contain the energy content of these fuels. Hydrogen demand in end-use sectors includes total final consumption of hydrogen and hydrogen-based fuels as well as hydrogen demand in industry covered by onsite production within industrial facilities. Low-emissions hydrogen trade as a share of production represents the percentage of produced low-emissions hydrogen (including merchant hydrogen and that which is produced onsite in industry and refining) which is exported from the region as hydrogen or as an energy product.

[1] To derive the associated electricity-only emissions from CHP plants, we assume that the heat production of a CHP plant is 90% efficient and the remainder of the fuel input is allocated to electricity generation.

### *Annex A licencing*

## Table A.1a: World energy supply

| | | | | Stated Policies Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total energy supply** | 541 | 624 | 632 | 668 | 678 | 692 | 725 | 100 | 100 | 100 | 0.7 | 0.5 |
| Renewables | 43 | 71 | 75 | 120 | 150 | 178 | 227 | 12 | 18 | 31 | 6.0 | 4.0 |
| Solar | 1 | 5 | 7 | 23 | 35 | 49 | 70 | 1 | 3 | 10 | 17 | 8.8 |
| Wind | 1 | 7 | 8 | 19 | 27 | 33 | 42 | 1 | 3 | 6 | 12 | 6.3 |
| Hydro | 12 | 15 | 16 | 18 | 19 | 20 | 23 | 2 | 3 | 3 | 1.6 | 1.3 |
| Modern solid bioenergy | 23 | 33 | 35 | 44 | 48 | 51 | 57 | 6 | 7 | 8 | 3.0 | 1.7 |
| Modern liquid bioenergy | 2 | 4 | 4 | 6 | 7 | 8 | 9 | 1 | 1 | 1 | 4.4 | 2.7 |
| Modern gaseous bioenergy | 1 | 1 | 1 | 2 | 3 | 5 | 8 | 0 | 0 | 1 | 7.7 | 6.7 |
| Traditional use of biomass | 25 | 24 | 24 | 19 | 18 | 18 | 16 | 4 | 3 | 2 | -3.0 | -1.4 |
| Nuclear | 30 | 31 | 29 | 37 | 40 | 43 | 48 | 5 | 6 | 7 | 2.9 | 1.8 |
| Unabated natural gas | 115 | 146 | 144 | 148 | 145 | 143 | 142 | 23 | 22 | 20 | 0.3 | -0.0 |
| Natural gas with CCUS | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 0 | 0 | 0 | 10 | 6.2 |
| Oil | 173 | 182 | 187 | 195 | 191 | 187 | 186 | 30 | 29 | 26 | 0.5 | -0.0 |
| Non-energy use | 25 | 31 | 32 | 38 | 40 | 41 | 41 | 5 | 6 | 6 | 2.3 | 0.9 |
| Unabated coal | 153 | 167 | 170 | 147 | 130 | 119 | 101 | 27 | 22 | 14 | -1.8 | -1.8 |
| Coal with CCUS | - | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 23 | 13 |
| **Electricity and heat sectors** | 200 | 244 | 247 | 263 | 275 | 291 | 321 | 100 | 100 | 100 | 0.8 | 0.9 |
| Renewables | 20 | 39 | 41 | 77 | 102 | 126 | 166 | 17 | 29 | 52 | 8.0 | 5.1 |
| Solar PV | 0 | 4 | 5 | 19 | 31 | 43 | 62 | 2 | 7 | 19 | 20 | 9.7 |
| Wind | 1 | 7 | 8 | 19 | 27 | 33 | 42 | 3 | 7 | 13 | 12 | 6.3 |
| Hydro | 12 | 15 | 16 | 18 | 19 | 20 | 23 | 6 | 7 | 7 | 1.6 | 1.3 |
| Bioenergy | 4 | 9 | 9 | 14 | 16 | 17 | 21 | 4 | 5 | 6 | 4.8 | 2.9 |
| Hydrogen | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Ammonia | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Nuclear | 30 | 31 | 29 | 37 | 40 | 43 | 48 | 12 | 14 | 15 | 2.9 | 1.8 |
| Unabated natural gas | 47 | 57 | 57 | 55 | 51 | 49 | 49 | 23 | 21 | 15 | -0.5 | -0.6 |
| Natural gas with CCUS | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Oil | 11 | 8 | 8 | 5 | 4 | 4 | 3 | 3 | 2 | 1 | -5.1 | -3.3 |
| Unabated coal | 91 | 108 | 110 | 89 | 75 | 66 | 52 | 45 | 34 | 16 | -2.7 | -2.6 |
| Coal with CCUS | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 15 |
| **Other energy sector** | 50 | 64 | 65 | 68 | 69 | 69 | 73 | 100 | 100 | 100 | 0.7 | 0.4 |
| **Biofuels conversion losses** | - | 5 | 6 | 8 | 8 | 9 | 10 | 100 | 100 | 100 | 3.6 | 1.9 |
| **Low-emissions hydrogen (offsite)** | | | | | | | | | | | | |
| Production inputs | - | 0 | 0 | 1 | 2 | 3 | 4 | 100 | 100 | 100 | n.a. | n.a. |
| Production outputs | - | 0 | 0 | 1 | 1 | 2 | 3 | 100 | 100 | 100 | 83 | 25 |
| For hydrogen-based fuels | - | - | - | 0 | 0 | 1 | 1 | - | 27 | 29 | n.a. | n.a. |

## Table A.2a: World final energy comsumption

| | | | | Stated Policies Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total final consumption** | **383** | **436** | **442** | **482** | **496** | **509** | **536** | **100** | **100** | **100** | **1.1** | **0.7** |
| Electricity | 64 | 87 | 89 | 108 | 121 | 135 | 159 | 20 | 22 | 30 | 2.5 | 2.1 |
| Liquid fuels | 154 | 168 | 172 | 186 | 184 | 183 | 185 | 39 | 39 | 34 | 0.9 | 0.2 |
| Biofuels | 2 | 4 | 4 | 6 | 7 | 8 | 9 | 1 | 1 | 2 | 4.4 | 2.7 |
| Ammonia | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Synthetic oil | - | - | - | - | - | - | - | - | - | - | n.a. | n.a. |
| Oil | 151 | 164 | 168 | 180 | 177 | 175 | 176 | 38 | 37 | 33 | 0.8 | 0.2 |
| Gaseous fuels | 58 | 72 | 71 | 78 | 80 | 82 | 85 | 16 | 16 | 16 | 1.2 | 0.6 |
| Biomethane | 0 | 0 | 0 | 1 | 1 | 2 | 4 | 0 | 0 | 1 | 13 | 11 |
| Hydrogen | - | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 58 | 22 |
| Synthetic methane | - | - | - | - | - | - | - | - | - | - | n.a. | n.a. |
| Natural gas | 57 | 72 | 70 | 76 | 78 | 79 | 78 | 16 | 16 | 15 | 1.1 | 0.4 |
| Solid fuels | 95 | 92 | 93 | 90 | 88 | 87 | 84 | 21 | 19 | 16 | -0.4 | -0.3 |
| Solid bioenergy | 38 | 39 | 40 | 38 | 39 | 39 | 40 | 9 | 8 | 7 | -0.6 | -0.0 |
| Coal | 56 | 52 | 52 | 51 | 49 | 47 | 44 | 12 | 11 | 8 | -0.2 | -0.6 |
| Heat | 12 | 15 | 15 | 16 | 16 | 16 | 16 | 3 | 3 | 3 | 1.1 | 0.3 |
| **Industry** | **143** | **167** | **167** | **187** | **194** | **201** | **207** | **100** | **100** | **100** | **1.4** | **0.8** |
| Electricity | 27 | 37 | 38 | 44 | 47 | 50 | 56 | 23 | 23 | 27 | 1.8 | 1.4 |
| Liquid fuels | 29 | 33 | 32 | 39 | 41 | 42 | 43 | 19 | 21 | 21 | 2.4 | 1.0 |
| Oil | 29 | 33 | 32 | 39 | 41 | 42 | 43 | 19 | 21 | 21 | 2.4 | 1.0 |
| Gaseous fuels | 24 | 31 | 30 | 34 | 36 | 38 | 39 | 18 | 18 | 19 | 1.6 | 1.0 |
| Biomethane | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 16 | 12 |
| Hydrogen | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 61 | 20 |
| Unabated natural gas | 24 | 31 | 30 | 34 | 35 | 36 | 37 | 18 | 18 | 18 | 1.5 | 0.7 |
| Natural gas with CCUS | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 8.5 |
| Solid fuels | 58 | 58 | 59 | 62 | 62 | 62 | 60 | 35 | 33 | 29 | 0.6 | 0.1 |
| Modern solid bioenergy | 8 | 10 | 11 | 13 | 14 | 15 | 17 | 7 | 7 | 8 | 2.2 | 1.5 |
| Unabated coal | 49 | 47 | 47 | 48 | 47 | 46 | 43 | 28 | 26 | 21 | 0.2 | -0.4 |
| Coal with CCUS | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.7 | 7.2 |
| Heat | 5 | 7 | 7 | 8 | 8 | 8 | 8 | 4 | 4 | 4 | 1.0 | 0.3 |
| Chemicals | 38 | 48 | 48 | 57 | 60 | 62 | 63 | 29 | 31 | 31 | 2.2 | 1.0 |
| Iron and steel | 31 | 37 | 35 | 36 | 37 | 37 | 37 | 21 | 20 | 18 | 0.5 | 0.1 |
| Cement | 9 | 12 | 12 | 12 | 12 | 12 | 12 | 7 | 7 | 6 | 0.4 | 0.0 |
| Aluminium | 5 | 7 | 7 | 7 | 7 | 7 | 7 | 4 | 4 | 3 | 0.5 | -0.0 |

## Table A.2a: World final energy comsumption (continued)

| | | | | Stated Policies Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Transport** | **102** | **112** | **116** | **127** | **129** | **131** | **139** | **100** | **100** | **100** | **1.1** | **0.6** |
| Electricity | 1 | 1 | 2 | 5 | 8 | 11 | 15 | 1 | 4 | 11 | 15 | 8.6 |
| Liquid fuels | 97 | 106 | 110 | 117 | 115 | 114 | 117 | 94 | 92 | 84 | 0.8 | 0.2 |
| Biofuels | 2 | 4 | 4 | 6 | 7 | 7 | 8 | 4 | 5 | 6 | 4.3 | 2.6 |
| Oil | 95 | 102 | 105 | 111 | 108 | 106 | 108 | 91 | 87 | 78 | 0.6 | 0.1 |
| Gaseous fuels | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 5 | 5 | 5 | 1.1 | 1.1 |
| Biomethane | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 9.7 | 7.4 |
| Hydrogen | - | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 57 | 22 |
| Natural gas | 4 | 5 | 5 | 5 | 6 | 6 | 5 | 4 | 4 | 4 | 0.6 | 0.2 |
| Road | 76 | 87 | 89 | 93 | 92 | 92 | 94 | 76 | 73 | 68 | 0.6 | 0.2 |
| Passenger cars | 38 | 44 | 45 | 43 | 41 | 40 | 38 | 38 | 34 | 28 | -0.4 | -0.5 |
| Heavy-duty trucks | 21 | 26 | 27 | 31 | 33 | 35 | 39 | 23 | 25 | 28 | 2.0 | 1.4 |
| Aviation | 11 | 9 | 11 | 17 | 19 | 20 | 24 | 10 | 13 | 17 | 5.5 | 2.7 |
| Shipping | 10 | 11 | 11 | 12 | 13 | 13 | 16 | 10 | 10 | 11 | 1.0 | 1.2 |
| **Buildings** | **117** | **131** | **133** | **139** | **142** | **147** | **159** | **100** | **100** | **100** | **0.6** | **0.7** |
| Electricity | 35 | 45 | 46 | 55 | 62 | 68 | 80 | 35 | 40 | 50 | 2.3 | 2.0 |
| Liquid fuels | 13 | 13 | 13 | 12 | 10 | 9 | 9 | 10 | 9 | 5 | -1.3 | -1.5 |
| Biofuels | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Oil | 13 | 13 | 13 | 12 | 10 | 9 | 9 | 10 | 9 | 5 | -1.4 | -1.5 |
| Gaseous fuels | 27 | 31 | 31 | 33 | 33 | 32 | 32 | 23 | 24 | 20 | 0.7 | 0.2 |
| Biomethane | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 14 | 11 |
| Hydrogen | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Natural gas | 26 | 31 | 30 | 32 | 32 | 31 | 30 | 23 | 23 | 19 | 0.6 | -0.0 |
| Solid fuels | 35 | 32 | 32 | 26 | 25 | 24 | 23 | 24 | 19 | 14 | -2.5 | -1.3 |
| Modern solid bioenergy | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 3 | 4 | 4 | 2.5 | 1.2 |
| Traditional use of biomass | 25 | 24 | 24 | 19 | 18 | 18 | 16 | 18 | 14 | 10 | -3.0 | -1.4 |
| Coal | 6 | 4 | 4 | 2 | 1 | 1 | 0 | 3 | 2 | 0 | -7.2 | -8.6 |
| Heat | 6 | 7 | 7 | 8 | 8 | 8 | 8 | 5 | 6 | 5 | 1.3 | 0.4 |
| Residential | 83 | 93 | 93 | 94 | 96 | 98 | 106 | 71 | 68 | 67 | 0.0 | 0.4 |
| Services | 34 | 38 | 39 | 45 | 47 | 49 | 53 | 29 | 32 | 33 | 1.7 | 1.1 |

# Table A.3a: World electricity sector

| | | | | Stated Policies Scenario (TWh) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total generation** | **21 533** | **28 346** | **29 033** | **35 802** | **40 494** | **45 418** | **53 985** | **100** | **100** | **100** | **2.7** | **2.2** |
| Renewables | 4 209 | 7 964 | 8 599 | 16 915 | 23 051 | 28 721 | 37 973 | 30 | 47 | 70 | 8.8 | 5.4 |
| Solar PV | 32 | 1 023 | 1 291 | 5 405 | 8 657 | 11 961 | 17 220 | 4 | 15 | 32 | 20 | 9.7 |
| Wind | 342 | 1 865 | 2 125 | 5 229 | 7 502 | 9 275 | 11 801 | 7 | 15 | 22 | 12 | 6.3 |
| Hydro | 3 456 | 4 299 | 4 378 | 4 981 | 5 293 | 5 554 | 6 351 | 15 | 14 | 12 | 1.6 | 1.3 |
| Bioenergy | 309 | 666 | 687 | 1 073 | 1 241 | 1 410 | 1 746 | 2 | 3 | 3 | 5.7 | 3.4 |
| *of which BECCS* | - | - | - | 4 | 5 | 5 | 5 | - | 0 | 0 | n.a. | n.a. |
| CSP | 2 | 15 | 16 | 46 | 91 | 161 | 322 | 0 | 0 | 1 | 14 | 11 |
| Geothermal | 68 | 96 | 101 | 175 | 247 | 317 | 439 | 0 | 0 | 1 | 7.1 | 5.4 |
| Marine | 1 | 1 | 1 | 6 | 20 | 44 | 93 | 0 | 0 | 0 | 24 | 18 |
| Nuclear | 2 756 | 2 810 | 2 682 | 3 351 | 3 665 | 3 886 | 4 353 | 9 | 9 | 8 | 2.8 | 1.7 |
| Hydrogen and ammonia | - | - | - | 22 | 59 | 82 | 91 | - | 0 | 0 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 1 | 1 | 7 | 30 | 59 | 90 | 0 | 0 | 0 | 33 | 19 |
| Coal with CCUS | - | 1 | 1 | 4 | 14 | 22 | 29 | 0 | 0 | 0 | 25 | 14 |
| Natural gas with CCUS | - | - | - | 3 | 16 | 37 | 61 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 14 479 | 17 456 | 17 636 | 15 406 | 13 593 | 12 568 | 11 373 | 61 | 43 | 21 | -1.7 | -1.6 |
| Coal | 8 669 | 10 247 | 10 427 | 8 333 | 6 973 | 6 145 | 4 949 | 36 | 23 | 9 | -2.8 | -2.6 |
| Natural gas | 4 847 | 6 526 | 6 500 | 6 611 | 6 222 | 6 067 | 6 150 | 22 | 18 | 11 | 0.2 | -0.2 |
| Oil | 963 | 683 | 709 | 462 | 398 | 356 | 274 | 2 | 1 | 1 | -5.2 | -3.3 |

| | | | | Stated Policies Scenario (GW) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total capacity** | **5 187** | **8 230** | **8 643** | **14 168** | **17 923** | **21 328** | **25 956** | **100** | **100** | **100** | **6.4** | **4.0** |
| Renewables | 1 333 | 3 292 | 3 629 | 8 611 | 11 949 | 14 965 | 19 120 | 42 | 61 | 74 | 11 | 6.1 |
| Solar PV | 39 | 925 | 1 145 | 4 699 | 7 174 | 9 500 | 12 639 | 13 | 33 | 49 | 19 | 9.0 |
| Wind | 181 | 827 | 902 | 2 064 | 2 747 | 3 242 | 3 874 | 10 | 15 | 15 | 11 | 5.3 |
| Hydro | 1 027 | 1 360 | 1 392 | 1 571 | 1 681 | 1 801 | 2 028 | 16 | 11 | 8 | 1.5 | 1.4 |
| Bioenergy | 74 | 159 | 168 | 232 | 272 | 311 | 393 | 2 | 2 | 2 | 4.1 | 3.1 |
| *of which BECCS* | - | - | - | 1 | 1 | 1 | 1 | - | 0 | 0 | n.a. | n.a. |
| CSP | 1 | 6 | 7 | 16 | 29 | 46 | 85 | 0 | 0 | 0 | 11 | 9.4 |
| Geothermal | 10 | 15 | 15 | 27 | 37 | 47 | 63 | 0 | 0 | 0 | 7.4 | 5.3 |
| Marine | 0 | 1 | 1 | 3 | 9 | 18 | 36 | 0 | 0 | 0 | 17 | 15 |
| Nuclear | 403 | 413 | 417 | 482 | 521 | 557 | 622 | 5 | 3 | 2 | 1.8 | 1.4 |
| Hydrogen and ammonia | - | - | - | 8 | 17 | 24 | 19 | - | 0 | 0 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 0 | 0 | 2 | 12 | 22 | 31 | 0 | 0 | 0 | 41 | 22 |
| Coal with CCUS | - | 0 | 0 | 1 | 6 | 11 | 13 | 0 | 0 | 0 | 32 | 18 |
| Natural gas with CCUS | - | - | - | 1 | 6 | 11 | 18 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 3 439 | 4 480 | 4 535 | 4 498 | 4 364 | 4 216 | 3 800 | 52 | 32 | 15 | -0.1 | -0.6 |
| Coal | 1 614 | 2 200 | 2 236 | 2 126 | 1 956 | 1 795 | 1 363 | 26 | 15 | 5 | -0.6 | -1.8 |
| Natural gas | 1 389 | 1 854 | 1 875 | 2 071 | 2 139 | 2 185 | 2 259 | 22 | 15 | 9 | 1.2 | 0.7 |
| Oil | 436 | 426 | 423 | 301 | 269 | 236 | 178 | 5 | 2 | 1 | -4.2 | -3.0 |
| Battery storage | 1 | 27 | 45 | 552 | 1 047 | 1 531 | 2 352 | 1 | 4 | 9 | 37 | 15 |

# Table A.4a: World $CO_2$ emissions

| | | | | Stated Policies Scenario (Mt $CO_2$) | | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2030 | 2050 |
| **Total $CO_2$*** | **32 877** | **36 589** | **36 930** | **35 125** | **33 094** | **31 657** | **29 696** | **-0.6** | **n.a.** |
| **Combustion activities (+)** | **30 624** | **33 634** | **34 042** | **32 162** | **30 141** | **28 708** | **26 782** | **-0.7** | **-0.9** |
| Coal | 13 846 | 15 104 | 15 330 | 13 076 | 11 594 | 10 548 | 8 861 | -2.0 | -1.9 |
| Oil | 10 545 | 10 683 | 10 963 | 11 155 | 10 773 | 10 483 | 10 378 | 0.2 | -0.2 |
| Natural gas | 6 052 | 7 577 | 7 499 | 7 705 | 7 563 | 7 467 | 7 339 | 0.3 | -0.1 |
| Bioenergy and waste | 181 | 269 | 251 | 227 | 211 | 210 | 204 | -1.2 | -0.7 |
| **Other removals** (-)** | **-** | **1** | **2** | **21** | **32** | **45** | **80** | **37** | **15** |
| Biofuels production | - | 1 | 2 | 2 | 3 | 3 | 3 | 5.1 | 1.6 |
| Direct air capture | - | - | - | 18 | 29 | 43 | 77 | n.a. | n.a. |
| **Electricity and heat sectors** | **12 511** | **14 598** | **14 822** | **12 302** | **10 729** | **9 696** | **8 217** | **-2.3** | **-2.1** |
| Coal | 8 946 | 10 646 | 10 876 | 8 709 | 7 395 | 6 495 | 5 126 | -2.7 | -2.7 |
| Oil | 828 | 574 | 596 | 393 | 338 | 301 | 230 | -5.1 | -3.3 |
| Natural gas | 2 623 | 3 227 | 3 201 | 3 071 | 2 878 | 2 779 | 2 734 | -0.5 | -0.6 |
| Bioenergy and waste | 114 | 151 | 149 | 129 | 119 | 122 | 126 | -1.8 | -0.6 |
| **Other energy sector**** | **1 438** | **1 530** | **1 554** | **1 640** | **1 602** | **1 577** | **1 545** | **0.7** | **-0.0** |
| **Final consumption**** | **18 668** | **20 191** | **20 293** | **21 046** | **20 686** | **20 363** | **19 950** | **0.5** | **-0.1** |
| Coal | 4 699 | 4 355 | 4 352 | 4 263 | 4 100 | 3 958 | 3 646 | -0.3 | -0.6 |
| Oil | 9 087 | 9 552 | 9 815 | 10 206 | 9 903 | 9 672 | 9 669 | 0.5 | -0.1 |
| Natural gas | 2 842 | 3 566 | 3 500 | 3 788 | 3 855 | 3 877 | 3 804 | 1.0 | 0.3 |
| Bioenergy and waste | 66 | 118 | 102 | 98 | 93 | 88 | 78 | -0.4 | -0.9 |
| Industry** | 8 324 | 9 185 | 8 998 | 9 540 | 9 602 | 9 583 | 9 225 | 0.7 | 0.1 |
| Chemicals** | 1 201 | 1 329 | 1 330 | 1 461 | 1 472 | 1 458 | 1 378 | 1.2 | 0.1 |
| Iron and steel** | 2 083 | 2 733 | 2 623 | 2 685 | 2 675 | 2 650 | 2 547 | 0.3 | -0.1 |
| Cement** | 1 916 | 2 514 | 2 418 | 2 522 | 2 547 | 2 556 | 2 498 | 0.5 | 0.1 |
| Aluminium** | 185 | 261 | 265 | 275 | 272 | 270 | 245 | 0.4 | -0.3 |
| Transport | 7 014 | 7 599 | 7 874 | 8 282 | 8 092 | 7 954 | 8 060 | 0.6 | 0.1 |
| Road | 5 216 | 5 847 | 5 964 | 5 940 | 5 629 | 5 369 | 5 165 | -0.0 | -0.5 |
| Passenger cars | 2 609 | 2 930 | 2 975 | 2 716 | 2 414 | 2 177 | 1 935 | -1.1 | -1.5 |
| Heavy-duty trucks | 1 489 | 1 766 | 1 812 | 2 050 | 2 128 | 2 203 | 2 342 | 1.6 | 0.9 |
| Aviation | 754 | 661 | 792 | 1 195 | 1 313 | 1 415 | 1 583 | 5.3 | 2.5 |
| Shipping | 797 | 827 | 855 | 904 | 917 | 943 | 1 098 | 0.7 | 0.9 |
| Buildings | 2 891 | 2 973 | 2 979 | 2 802 | 2 580 | 2 427 | 2 307 | -0.8 | -0.9 |
| Residential | 1 961 | 2 013 | 1 997 | 1 791 | 1 638 | 1 526 | 1 402 | -1.4 | -1.3 |
| Services | 929 | 959 | 983 | 1 012 | 942 | 901 | 905 | 0.4 | -0.3 |
| **Total $CO_2$ removals**** | **-** | **2** | **2** | **24** | **37** | **51** | **89** | **39** | **15** |
| **Total $CO_2$ captured**** | **15** | **41** | **42** | **116** | **197** | **276** | **401** | **14** | **8.4** |

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

# Table A.5a: World economic and activity indicators

| | | | | Stated Policies Scenario | | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2030 | 2050 |
| **Indicators** | | | | | | | | | |
| Population (million) | 6 967 | 7 884 | 7 950 | 8 520 | 8 853 | 9 161 | 9 681 | 0.9 | 0.7 |
| GDP (USD 2022 billion, PPP) | 114 463 | 158 505 | 163 734 | 207 282 | 238 066 | 270 050 | 339 273 | 3.0 | 2.6 |
| GDP per capita (USD 2022, PPP) | 16 429 | 20 104 | 20 596 | 24 329 | 26 892 | 29 479 | 35 044 | 2.1 | 1.9 |
| TES/GDP (GJ per USD 1 000, PPP) | 4.7 | 3.9 | 3.9 | 3.2 | 2.9 | 2.6 | 2.1 | -2.2 | -2.1 |
| TFC/GDP (GJ per USD 1 000, PPP) | 3.2 | 2.6 | 2.6 | 2.2 | 2.0 | 1.8 | 1.5 | -1.8 | -1.8 |
| $CO_2$ intensity of electricity generation (g $CO_2$ per kWh) | 528 | 464 | 460 | 303 | 230 | 184 | 131 | -5.1 | -4.4 |
| **Industrial production (Mt)** | | | | | | | | | |
| Primary chemicals | 515 | 713 | 719 | 877 | 941 | 989 | 1 047 | 2.5 | 1.3 |
| Steel | 1 435 | 1 960 | 1 878 | 2 074 | 2 173 | 2 270 | 2 448 | 1.3 | 1.0 |
| Cement | 3 280 | 4 374 | 4 158 | 4 471 | 4 628 | 4 746 | 4 846 | 0.9 | 0.5 |
| Aluminium | 62 | 105 | 108 | 123 | 133 | 145 | 165 | 1.7 | 1.5 |
| **Transport** | | | | | | | | | |
| Passenger cars (billion pkm) | 18 984 | 25 679 | 26 535 | 31 804 | 35 827 | 39 760 | 46 411 | 2.3 | 2.0 |
| Heavy-duty trucks (billion tkm) | 23 364 | 29 482 | 30 479 | 38 977 | 44 344 | 49 991 | 61 107 | 3.1 | 2.5 |
| Aviation (billion pkm) | 4 923 | 3 673 | 6 025 | 12 198 | 13 973 | 16 061 | 20 388 | 9.2 | 4.4 |
| Shipping (billion tkm) | 77 101 | 115 830 | 124 272 | 148 064 | 170 250 | 196 465 | 279 868 | 2.2 | 2.9 |
| **Buildings** | | | | | | | | | |
| Households (million) | 1 798 | 2 175 | 2 208 | 2 439 | 2 579 | 2 715 | 2 963 | 1.2 | 1.1 |
| Residential floor area (million $m^2$) | 153 219 | 194 691 | 198 090 | 227 039 | 247 262 | 268 130 | 310 109 | 1.7 | 1.6 |
| Services floor area (million $m^2$) | 39 262 | 53 415 | 54 624 | 63 891 | 69 197 | 74 143 | 82 764 | 2.0 | 1.5 |

## Table A.1b: World energy supply

| | 2010 | 2021 | 2022 | Announced Pledges Scenario (EJ) 2030 | 2035 | 2040 | 2050 | Shares (%) 2022 | 2030 | 2050 | CAAGR (%) 2022 to: 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total energy supply** | 541 | 624 | 632 | 628 | 613 | 612 | 623 | 100 | 100 | 100 | -0.1 | -0.1 |
| Renewables | 43 | 71 | 75 | 142 | 195 | 245 | 327 | 12 | 23 | 52 | 8.2 | 5.4 |
| Solar | 1 | 5 | 7 | 27 | 48 | 70 | 106 | 1 | 4 | 17 | 19 | 10 |
| Wind | 1 | 7 | 8 | 22 | 34 | 46 | 66 | 1 | 4 | 11 | 14 | 8.0 |
| Hydro | 12 | 15 | 16 | 18 | 20 | 23 | 27 | 2 | 3 | 4 | 1.9 | 1.9 |
| Modern solid bioenergy | 23 | 33 | 35 | 51 | 59 | 65 | 74 | 6 | 8 | 12 | 4.8 | 2.7 |
| Modern liquid bioenergy | 2 | 4 | 4 | 9 | 12 | 14 | 14 | 1 | 2 | 2 | 11 | 4.3 |
| Modern gaseous bioenergy | 1 | 1 | 1 | 4 | 6 | 8 | 13 | 0 | 1 | 2 | 16 | 8.4 |
| Traditional use of biomass | 25 | 24 | 24 | 8 | 7 | 6 | 5 | 4 | 1 | 1 | -13 | -5.6 |
| Nuclear | 30 | 31 | 29 | 38 | 45 | 52 | 59 | 5 | 6 | 9 | 3.4 | 2.5 |
| Unabated natural gas | 115 | 146 | 144 | 130 | 111 | 96 | 71 | 23 | 21 | 11 | -1.2 | -2.5 |
| Natural gas with CCUS | 0 | 1 | 1 | 3 | 6 | 8 | 13 | 0 | 1 | 2 | 26 | 12 |
| Oil | 173 | 182 | 187 | 177 | 155 | 133 | 102 | 30 | 28 | 16 | -0.7 | -2.1 |
| Non-energy use | 25 | 31 | 32 | 36 | 36 | 36 | 34 | 5 | 6 | 6 | 1.7 | 0.3 |
| Unabated coal | 153 | 167 | 170 | 127 | 89 | 64 | 34 | 27 | 20 | 5 | -3.6 | -5.6 |
| Coal with CCUS | - | 0 | 0 | 0 | 4 | 6 | 11 | 0 | 0 | 2 | 47 | 26 |
| **Electricity and heat sectors** | 200 | 244 | 247 | 258 | 273 | 306 | 366 | 100 | 100 | 100 | 0.5 | 1.4 |
| Renewables | 20 | 39 | 41 | 88 | 130 | 174 | 248 | 17 | 34 | 68 | 9.9 | 6.6 |
| Solar PV | 0 | 4 | 5 | 23 | 40 | 59 | 87 | 2 | 9 | 24 | 22 | 11 |
| Wind | 1 | 7 | 8 | 22 | 34 | 46 | 66 | 3 | 9 | 18 | 14 | 8.0 |
| Hydro | 12 | 15 | 16 | 18 | 20 | 23 | 27 | 6 | 7 | 7 | 1.9 | 1.9 |
| Bioenergy | 4 | 9 | 9 | 16 | 21 | 26 | 34 | 4 | 6 | 9 | 7.0 | 4.7 |
| Hydrogen | - | - | - | 0 | 1 | 2 | 3 | - | 0 | 1 | n.a. | n.a. |
| Ammonia | - | - | - | 0 | 0 | 1 | 2 | - | 0 | 0 | n.a. | n.a. |
| Nuclear | 30 | 31 | 29 | 38 | 45 | 52 | 59 | 12 | 15 | 16 | 3.4 | 2.5 |
| Unabated natural gas | 47 | 57 | 57 | 50 | 41 | 35 | 25 | 23 | 19 | 7 | -1.7 | -2.9 |
| Natural gas with CCUS | - | - | - | 0 | 1 | 1 | 2 | - | 0 | 0 | n.a. | n.a. |
| Oil | 11 | 8 | 8 | 4 | 3 | 2 | 2 | 3 | 2 | 0 | -7.8 | -5.3 |
| Unabated coal | 91 | 108 | 110 | 75 | 48 | 33 | 17 | 45 | 29 | 5 | -4.7 | -6.4 |
| Coal with CCUS | - | 0 | 0 | 0 | 3 | 4 | 7 | 0 | 0 | 2 | 57 | 29 |
| **Other energy sector** | 50 | 64 | 65 | 65 | 65 | 66 | 72 | 100 | 100 | 100 | 0.1 | 0.4 |
| **Biofuels conversion losses** | - | 5 | 6 | 12 | 16 | 18 | 17 | 100 | 100 | 100 | 9.8 | 4.0 |
| **Low-emissions hydrogen (offsite)** | | | | | | | | | | | | |
| Production inputs | - | 0 | 0 | 4 | 9 | 15 | 32 | 100 | 100 | 100 | n.a. | n.a. |
| Production outputs | - | 0 | 0 | 2 | 6 | 11 | 23 | 100 | 100 | 100 | 116 | 35 |
| For hydrogen-based fuels | - | - | - | 1 | 2 | 4 | 10 | - | 27 | 46 | n.a. | n.a. |

# Table A.2b: World final energy consumption

| | | | | Announced Pledges Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total final consumption** | **383** | **436** | **442** | **451** | **442** | **433** | **429** | **100** | **100** | **100** | **0.2** | **-0.1** |
| Electricity | 64 | 87 | 89 | 109 | 125 | 143 | 176 | 20 | 24 | 41 | 2.6 | 2.5 |
| Liquid fuels | 154 | 168 | 172 | 175 | 160 | 143 | 118 | 39 | 39 | 28 | 0.2 | -1.3 |
| Biofuels | 2 | 4 | 4 | 9 | 12 | 14 | 14 | 1 | 2 | 3 | 11 | 4.3 |
| Ammonia | - | - | - | 0 | 1 | 1 | 2 | - | 0 | 1 | n.a. | n.a. |
| Synthetic oil | - | - | - | 0 | 0 | 1 | 3 | - | 0 | 1 | n.a. | n.a. |
| Oil | 151 | 164 | 168 | 165 | 147 | 127 | 99 | 38 | 37 | 23 | -0.2 | -1.9 |
| Gaseous fuels | 58 | 72 | 71 | 71 | 67 | 64 | 61 | 16 | 16 | 14 | -0.0 | -0.5 |
| Biomethane | 0 | 0 | 0 | 2 | 3 | 4 | 6 | 0 | 0 | 1 | 26 | 12 |
| Hydrogen | - | 0 | 0 | 1 | 2 | 4 | 10 | 0 | 0 | 2 | 86 | 31 |
| Synthetic methane | - | - | - | - | - | - | - | - | - | - | n.a. | n.a. |
| Natural gas | 57 | 72 | 70 | 67 | 61 | 54 | 44 | 16 | 15 | 10 | -0.5 | -1.7 |
| Solid fuels | 95 | 92 | 93 | 76 | 68 | 60 | 51 | 21 | 17 | 12 | -2.5 | -2.1 |
| Solid bioenergy | 38 | 39 | 40 | 30 | 30 | 30 | 31 | 9 | 7 | 7 | -3.4 | -0.9 |
| Coal | 56 | 52 | 52 | 45 | 37 | 30 | 19 | 12 | 10 | 4 | -1.8 | -3.5 |
| Heat | 12 | 15 | 15 | 15 | 14 | 13 | 11 | 3 | 3 | 3 | 0.1 | -1.1 |
| **Industry** | **143** | **167** | **167** | **179** | **180** | **179** | **175** | **100** | **100** | **100** | **0.9** | **0.2** |
| Electricity | 27 | 37 | 38 | 47 | 53 | 60 | 71 | 23 | 26 | 40 | 2.7 | 2.3 |
| Liquid fuels | 29 | 33 | 32 | 36 | 36 | 34 | 31 | 19 | 20 | 18 | 1.4 | -0.2 |
| Oil | 29 | 33 | 32 | 36 | 35 | 33 | 30 | 19 | 20 | 17 | 1.3 | -0.3 |
| Gaseous fuels | 24 | 31 | 30 | 31 | 31 | 31 | 28 | 18 | 17 | 16 | 0.4 | -0.2 |
| Biomethane | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 0 | 0 | 2 | 29 | 13 |
| Hydrogen | - | 0 | 0 | 0 | 1 | 2 | 3 | 0 | 0 | 2 | 95 | 33 |
| Unabated natural gas | 24 | 31 | 30 | 30 | 28 | 26 | 20 | 18 | 17 | 11 | 0.0 | -1.4 |
| Natural gas with CCUS | - | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 2 | 23 | 16 |
| Solid fuels | 58 | 58 | 59 | 57 | 52 | 47 | 39 | 35 | 32 | 22 | -0.3 | -1.5 |
| Modern solid bioenergy | 8 | 10 | 11 | 14 | 16 | 17 | 19 | 7 | 8 | 11 | 3.1 | 2.0 |
| Unabated coal | 49 | 47 | 47 | 43 | 35 | 28 | 15 | 28 | 24 | 9 | -1.3 | -3.9 |
| Coal with CCUS | - | 0 | 0 | 0 | 1 | 2 | 4 | 0 | 0 | 2 | 35 | 23 |
| Heat | 5 | 7 | 7 | 7 | 6 | 5 | 4 | 4 | 4 | 2 | -0.8 | -2.2 |
| Chemicals | 38 | 48 | 48 | 55 | 56 | 56 | 55 | 29 | 30 | 31 | 1.6 | 0.5 |
| Iron and steel | 31 | 37 | 35 | 35 | 34 | 33 | 31 | 21 | 20 | 17 | -0.0 | -0.5 |
| Cement | 9 | 12 | 12 | 12 | 12 | 12 | 11 | 7 | 7 | 6 | -0.0 | -0.2 |
| Aluminium | 5 | 7 | 7 | 7 | 7 | 7 | 6 | 4 | 4 | 3 | 0.2 | -0.7 |

## Table A.2b: World final energy consumption (continued)

| | 2010 | 2021 | 2022 | Announced Pledges Scenario (EJ) 2030 | 2035 | 2040 | 2050 | Shares (%) 2022 | 2030 | 2050 | CAAGR (%) 2022 to: 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transport** | **102** | **112** | **116** | **122** | **116** | **110** | **106** | **100** | **100** | **100** | **0.6** | **-0.3** |
| Electricity | 1 | 1 | 2 | 6 | 11 | 18 | 28 | 1 | 5 | 27 | 18 | 11 |
| Liquid fuels | 97 | 106 | 110 | 111 | 100 | 87 | 69 | 94 | 91 | 65 | 0.2 | -1.7 |
| Biofuels | 2 | 4 | 4 | 9 | 11 | 12 | 12 | 4 | 7 | 11 | 10.0 | 3.9 |
| Oil | 95 | 102 | 105 | 102 | 88 | 73 | 51 | 91 | 84 | 48 | -0.4 | -2.6 |
| Gaseous fuels | 4 | 5 | 5 | 5 | 5 | 6 | 9 | 5 | 4 | 9 | -0.6 | 1.9 |
| Biomethane | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 5.8 |
| Hydrogen | - | 0 | 0 | 0 | 1 | 2 | 7 | 0 | 0 | 6 | 78 | 30 |
| Natural gas | 4 | 5 | 5 | 4 | 4 | 3 | 2 | 4 | 4 | 2 | -2.2 | -3.2 |
| Road | 76 | 87 | 89 | 88 | 82 | 76 | 69 | 76 | 73 | 65 | -0.0 | -0.9 |
| Passenger cars | 38 | 44 | 45 | 41 | 36 | 32 | 27 | 38 | 34 | 26 | -1.0 | -1.8 |
| Heavy-duty trucks | 21 | 26 | 27 | 30 | 30 | 29 | 29 | 23 | 24 | 27 | 1.2 | 0.3 |
| Aviation | 11 | 9 | 11 | 17 | 18 | 20 | 22 | 10 | 14 | 21 | 5.2 | 2.5 |
| Shipping | 10 | 11 | 11 | 12 | 11 | 10 | 11 | 10 | 10 | 10 | 0.4 | -0.2 |
| **Buildings** | **117** | **131** | **133** | **122** | **119** | **117** | **122** | **100** | **100** | **100** | **-1.0** | **-0.3** |
| Electricity | 35 | 45 | 46 | 52 | 56 | 62 | 71 | 35 | 43 | 58 | 1.7 | 1.6 |
| Liquid fuels | 13 | 13 | 13 | 11 | 9 | 7 | 5 | 10 | 9 | 4 | -2.2 | -3.2 |
| Biofuels | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Oil | 13 | 13 | 13 | 11 | 9 | 7 | 5 | 10 | 9 | 4 | -2.2 | -3.2 |
| Gaseous fuels | 27 | 31 | 31 | 30 | 26 | 23 | 19 | 23 | 24 | 15 | -0.6 | -1.7 |
| Biomethane | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 0 | 1 | 2 | 32 | 14 |
| Hydrogen | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Natural gas | 26 | 31 | 30 | 28 | 23 | 20 | 14 | 23 | 23 | 12 | -1.0 | -2.6 |
| Solid fuels | 35 | 32 | 32 | 17 | 15 | 12 | 11 | 24 | 14 | 9 | -7.6 | -3.8 |
| Modern solid bioenergy | 4 | 4 | 4 | 7 | 7 | 6 | 6 | 3 | 6 | 5 | 7.0 | 1.2 |
| Traditional use of biomass | 25 | 24 | 24 | 8 | 7 | 6 | 5 | 18 | 7 | 4 | -13 | -5.6 |
| Coal | 6 | 4 | 4 | 2 | 1 | 0 | 0 | 3 | 1 | 0 | -10 | -11 |
| Heat | 6 | 7 | 7 | 8 | 8 | 7 | 7 | 5 | 6 | 6 | 0.9 | -0.2 |
| Residential | 83 | 93 | 93 | 81 | 78 | 76 | 79 | 71 | 66 | 64 | -1.8 | -0.6 |
| Services | 34 | 38 | 39 | 42 | 41 | 41 | 44 | 29 | 34 | 36 | 0.8 | 0.4 |

## Table A.3b: World electricity sector

| | | | | Announced Pledges Scenario (TWh) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total generation** | **21 533** | **28 346** | **29 033** | **36 370** | **42 933** | **51 710** | **66 760** | **100** | **100** | **100** | **2.9** | **3.0** |
| Renewables | 4 209 | 7 964 | 8 599 | 19 295 | 28 795 | 38 551 | 55 057 | 30 | 53 | 82 | 11 | 6.9 |
| Solar PV | 32 | 1 023 | 1 291 | 6 390 | 11 240 | 16 296 | 24 297 | 4 | 18 | 36 | 22 | 11 |
| Wind | 342 | 1 865 | 2 125 | 6 208 | 9 524 | 12 701 | 18 432 | 7 | 17 | 28 | 14 | 8.0 |
| Hydro | 3 456 | 4 299 | 4 378 | 5 071 | 5 653 | 6 284 | 7 432 | 15 | 14 | 11 | 1.9 | 1.9 |
| Bioenergy | 309 | 666 | 687 | 1 314 | 1 736 | 2 184 | 3 005 | 2 | 4 | 5 | 8.4 | 5.4 |
| *of which BECCS* | - | - | - | 32 | 158 | 302 | 538 | - | 0 | 1 | n.a. | n.a. |
| CSP | 2 | 15 | 16 | 84 | 278 | 581 | 1 101 | 0 | 0 | 2 | 23 | 16 |
| Geothermal | 68 | 96 | 101 | 217 | 335 | 448 | 677 | 0 | 1 | 1 | 10.0 | 7.0 |
| Marine | 1 | 1 | 1 | 11 | 29 | 56 | 113 | 0 | 0 | 0 | 36 | 18 |
| Nuclear | 2 756 | 2 810 | 2 682 | 3 496 | 4 086 | 4 701 | 5 301 | 9 | 10 | 8 | 3.4 | 2.5 |
| Hydrogen and ammonia | - | - | - | 78 | 229 | 344 | 606 | - | 0 | 1 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 1 | 1 | 48 | 328 | 566 | 949 | 0 | 0 | 1 | 70 | 29 |
| Coal with CCUS | - | 1 | 1 | 22 | 236 | 409 | 710 | 0 | 0 | 1 | 54 | 28 |
| Natural gas with CCUS | - | - | - | 27 | 92 | 157 | 239 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 14 479 | 17 456 | 17 636 | 13 356 | 9 407 | 7 458 | 4 759 | 61 | 37 | 7 | -3.4 | -4.6 |
| Coal | 8 669 | 10 247 | 10 427 | 6 976 | 4 249 | 2 932 | 1 534 | 36 | 19 | 2 | -4.9 | -6.6 |
| Natural gas | 4 847 | 6 526 | 6 500 | 6 028 | 4 896 | 4 314 | 3 080 | 22 | 17 | 5 | -0.9 | -2.6 |
| Oil | 963 | 683 | 709 | 352 | 262 | 212 | 144 | 2 | 1 | 0 | -8.4 | -5.5 |

| | | | | Announced Pledges Scenario (GW) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total capacity** | **5 187** | **8 230** | **8 643** | **15 285** | **20 332** | **25 195** | **32 100** | **100** | **100** | **100** | **7.4** | **4.8** |
| Renewables | 1 333 | 3 292 | 3 629 | 9 786 | 14 426 | 18 893 | 25 368 | 42 | 64 | 79 | 13 | 7.2 |
| Solar PV | 39 | 925 | 1 145 | 5 377 | 8 648 | 11 787 | 16 041 | 13 | 35 | 50 | 21 | 9.9 |
| Wind | 181 | 827 | 902 | 2 420 | 3 418 | 4 337 | 5 879 | 10 | 16 | 18 | 13 | 6.9 |
| Hydro | 1 027 | 1 360 | 1 392 | 1 620 | 1 804 | 1 991 | 2 304 | 16 | 11 | 7 | 1.9 | 1.8 |
| Bioenergy | 74 | 159 | 168 | 300 | 407 | 524 | 706 | 2 | 2 | 2 | 7.6 | 5.3 |
| *of which BECCS* | - | - | - | 8 | 32 | 56 | 94 | - | 0 | 0 | n.a. | n.a. |
| CSP | 1 | 6 | 7 | 29 | 86 | 165 | 295 | 0 | 0 | 1 | 19 | 14 |
| Geothermal | 10 | 15 | 15 | 34 | 51 | 67 | 100 | 0 | 0 | 0 | 11 | 7.0 |
| Marine | 0 | 1 | 1 | 5 | 12 | 23 | 44 | 0 | 0 | 0 | 27 | 15 |
| Nuclear | 403 | 413 | 417 | 497 | 587 | 677 | 769 | 5 | 3 | 2 | 2.2 | 2.2 |
| Hydrogen and ammonia | - | - | - | 31 | 134 | 174 | 195 | - | 0 | 1 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 0 | 0 | 8 | 71 | 121 | 206 | 0 | 0 | 1 | 70 | 30 |
| Coal with CCUS | - | 0 | 0 | 4 | 50 | 88 | 153 | 0 | 0 | 0 | 53 | 29 |
| Natural gas with CCUS | - | - | - | 5 | 21 | 34 | 53 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 3 439 | 4 480 | 4 535 | 4 225 | 3 725 | 3 289 | 2 432 | 52 | 28 | 8 | -0.9 | -2.2 |
| Coal | 1 614 | 2 200 | 2 236 | 2 036 | 1 749 | 1 474 | 911 | 26 | 13 | 3 | -1.2 | -3.2 |
| Natural gas | 1 389 | 1 854 | 1 875 | 1 905 | 1 743 | 1 613 | 1 371 | 22 | 12 | 4 | 0.2 | -1.1 |
| Oil | 436 | 426 | 423 | 283 | 234 | 202 | 150 | 5 | 2 | 0 | -4.9 | -3.6 |
| Battery storage | 1 | 27 | 45 | 725 | 1 377 | 2 029 | 3 121 | 1 | 5 | 10 | 41 | 16 |

# Table A.4b: World $CO_2$ emissions

| | 2010 | 2021 | 2022 | Announced Pledges Scenario (Mt $CO_2$) 2030 | 2035 | 2040 | 2050 | CAAGR (%) 2022 to: 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|---|
| **Total $CO_2$*** | **32 877** | **36 589** | **36 930** | **30 769** | **24 289** | **19 217** | **12 043** | **-2.3** | **n.a.** |
| **Combustion activities (+)** | **30 624** | **33 634** | **34 042** | **28 115** | **21 966** | **17 375** | **10 968** | **-2.4** | **-4.0** |
| Coal | 13 846 | 15 104 | 15 330 | 11 174 | 7 711 | 5 626 | 2 967 | -3.9 | -5.7 |
| Oil | 10 545 | 10 683 | 10 963 | 10 004 | 8 491 | 6 969 | 4 852 | -1.1 | -2.9 |
| Natural gas | 6 052 | 7 577 | 7 499 | 6 764 | 5 725 | 4 884 | 3 516 | -1.3 | -2.7 |
| Bioenergy and waste | 181 | 269 | 251 | 173 | 39 | - 104 | - 368 | -4.5 | n.a. |
| **Other removals** (-)** | **-** | **1** | **2** | **100** | **158** | **256** | **345** | **67** | **21** |
| Biofuels production | - | 1 | 2 | 78 | 130 | 220 | 284 | 62 | 20 |
| Direct air capture | - | - | - | 22 | 28 | 36 | 61 | n.a. | n.a. |
| **Electricity and heat sectors** | **12 511** | **14 598** | **14 822** | **10 597** | **7 197** | **5 352** | **3 004** | **-4.1** | **-5.5** |
| Coal | 8 946 | 10 646 | 10 876 | 7 388 | 4 677 | 3 278 | 1 712 | -4.7 | -6.4 |
| Oil | 828 | 574 | 596 | 310 | 234 | 190 | 128 | -7.8 | -5.3 |
| Natural gas | 2 623 | 3 227 | 3 201 | 2 797 | 2 286 | 1 982 | 1 427 | -1.7 | -2.8 |
| Bioenergy and waste | 114 | 151 | 149 | 102 | - 0 | - 98 | - 263 | -4.7 | n.a. |
| **Other energy sector**** | **1 438** | **1 530** | **1 554** | **1 215** | **898** | **539** | **121** | **-3.0** | **-8.7** |
| **Final consumption**** | **18 668** | **20 191** | **20 293** | **18 876** | **16 155** | **13 324** | **8 952** | **-0.9** | **-2.9** |
| Coal | 4 699 | 4 355 | 4 352 | 3 695 | 2 958 | 2 292 | 1 238 | -2.0 | -4.4 |
| Oil | 9 087 | 9 552 | 9 815 | 9 279 | 7 937 | 6 544 | 4 593 | -0.7 | -2.7 |
| Natural gas | 2 842 | 3 566 | 3 500 | 3 306 | 2 908 | 2 496 | 1 824 | -0.7 | -2.3 |
| Bioenergy and waste | 66 | 118 | 102 | 72 | 40 | - 5 | - 97 | -4.3 | n.a. |
| Industry** | 8 324 | 9 185 | 8 998 | 8 500 | 7 398 | 6 138 | 3 826 | -0.7 | -3.0 |
| Chemicals** | 1 201 | 1 329 | 1 330 | 1 289 | 1 130 | 909 | 501 | -0.4 | -3.4 |
| Iron and steel** | 2 083 | 2 733 | 2 623 | 2 474 | 2 153 | 1 805 | 1 119 | -0.7 | -3.0 |
| Cement** | 1 916 | 2 514 | 2 418 | 2 299 | 2 041 | 1 716 | 1 143 | -0.6 | -2.6 |
| Aluminium** | 185 | 261 | 265 | 253 | 226 | 173 | 63 | -0.6 | -5.0 |
| Transport | 7 014 | 7 599 | 7 874 | 7 555 | 6 505 | 5 370 | 3 786 | -0.5 | -2.6 |
| Road | 5 216 | 5 847 | 5 964 | 5 423 | 4 539 | 3 594 | 2 337 | -1.2 | -3.3 |
| Passenger cars | 2 609 | 2 930 | 2 975 | 2 466 | 1 902 | 1 404 | 844 | -2.3 | -4.4 |
| Heavy-duty trucks | 1 489 | 1 766 | 1 812 | 1 864 | 1 738 | 1 508 | 1 078 | 0.4 | -1.8 |
| Aviation | 754 | 661 | 792 | 1 129 | 1 131 | 1 097 | 979 | 4.5 | 0.8 |
| Shipping | 797 | 827 | 855 | 803 | 670 | 543 | 384 | -0.8 | -2.8 |
| Buildings | 2 891 | 2 973 | 2 979 | 2 475 | 1 963 | 1 578 | 1 176 | -2.3 | -3.3 |
| Residential | 1 961 | 2 013 | 1 997 | 1 605 | 1 260 | 990 | 683 | -2.7 | -3.8 |
| Services | 929 | 959 | 983 | 869 | 702 | 587 | 493 | -1.5 | -2.4 |
| **Total $CO_2$ removals**** | **-** | **2** | **2** | **128** | **289** | **517** | **848** | **72** | **25** |
| **Total $CO_2$ captured**** | **15** | **41** | **42** | **441** | **1 178** | **2 061** | **3 730** | **34** | **17** |

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

## Table A.5b: World economic and activity indicators

| | | | | Announced Pledges Scenario | | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2030 | 2050 |
| **Indicators** | | | | | | | | | |
| Population (million) | 6 967 | 7 884 | 7 950 | 8 520 | 8 853 | 9 161 | 9 681 | 0.9 | 0.7 |
| GDP (USD 2022 billion, PPP) | 114 463 | 158 505 | 163 734 | 207 282 | 238 066 | 270 050 | 339 273 | 3.0 | 2.6 |
| GDP per capita (USD 2022, PPP) | 16 429 | 20 104 | 20 596 | 24 329 | 26 892 | 29 479 | 35 044 | 2.1 | 1.9 |
| TES/GDP (GJ per USD 1 000, PPP) | 4.7 | 3.9 | 3.9 | 3.0 | 2.6 | 2.3 | 1.8 | -3.0 | -2.6 |
| TFC/GDP (GJ per USD 1 000, PPP) | 3.2 | 2.6 | 2.6 | 2.1 | 1.8 | 1.6 | 1.2 | -2.6 | -2.6 |
| $CO_2$ intensity of electricity generation (g $CO_2$ per kWh) | 528 | 464 | 460 | 255 | 143 | 87 | 36 | -7.1 | -8.7 |
| **Industrial production (Mt)** | | | | | | | | | |
| Primary chemicals | 515 | 713 | 719 | 854 | 902 | 933 | 952 | 2.2 | 1.0 |
| Steel | 1 435 | 1 960 | 1 878 | 2 030 | 2 058 | 2 081 | 2 123 | 1.0 | 0.4 |
| Cement | 3 280 | 4 374 | 4 158 | 4 375 | 4 407 | 4 400 | 4 393 | 0.6 | 0.2 |
| Aluminium | 62 | 105 | 108 | 122 | 129 | 136 | 149 | 1.5 | 1.2 |
| **Transport** | | | | | | | | | |
| Passenger cars (billion pkm) | 18 984 | 25 679 | 26 535 | 31 174 | 34 399 | 37 988 | 44 900 | 2.0 | 1.9 |
| Heavy-duty trucks (billion tkm) | 23 364 | 29 482 | 30 479 | 38 198 | 43 504 | 49 218 | 60 578 | 2.9 | 2.5 |
| Aviation (billion pkm) | 4 923 | 3 673 | 6 025 | 12 097 | 13 783 | 15 890 | 20 313 | 9.1 | 4.4 |
| Shipping (billion tkm) | 77 101 | 115 830 | 124 272 | 147 948 | 170 108 | 196 295 | 279 885 | 2.2 | 2.9 |
| **Buildings** | | | | | | | | | |
| Households (million) | 1 798 | 2 175 | 2 208 | 2 439 | 2 579 | 2 715 | 2 963 | 1.2 | 1.1 |
| Residential floor area (million m²) | 153 219 | 194 691 | 198 090 | 227 039 | 247 262 | 268 130 | 310 109 | 1.7 | 1.6 |
| Services floor area (million m²) | 39 262 | 53 415 | 54 624 | 63 891 | 69 197 | 74 143 | 82 764 | 2.0 | 1.5 |

## Table A.1c: World energy supply

| | 2010 | 2021 | 2022 | Net Zero Emissions by 2050 Scenario (EJ) 2030 | 2035 | 2040 | 2050 | Shares (%) 2022 | 2030 | 2050 | CAAGR (%) 2022 to: 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total energy supply** | **541** | **624** | **632** | **573** | **535** | **528** | **541** | **100** | **100** | **100** | **-1.2** | **-0.6** |
| Renewables | 43 | 71 | 75 | 166 | 241 | 306 | 385 | 12 | 29 | 71 | 10 | 6.0 |
| Solar | 1 | 5 | 7 | 35 | 66 | 97 | 138 | 1 | 6 | 26 | 23 | 11 |
| Wind | 1 | 7 | 8 | 25 | 43 | 61 | 84 | 1 | 4 | 16 | 16 | 9.0 |
| Hydro | 12 | 15 | 16 | 20 | 24 | 27 | 30 | 2 | 3 | 5 | 2.9 | 2.3 |
| Modern solid bioenergy | 23 | 33 | 35 | 55 | 65 | 71 | 73 | 6 | 10 | 13 | 5.8 | 2.6 |
| Modern liquid bioenergy | 2 | 4 | 4 | 11 | 13 | 13 | 11 | 1 | 2 | 2 | 13 | 3.3 |
| Modern gaseous bioenergy | 1 | 1 | 1 | 7 | 9 | 11 | 15 | 0 | 1 | 3 | 22 | 9.0 |
| Traditional use of biomass | 25 | 24 | 24 | - | - | - | - | 4 | - | - | n.a. | n.a. |
| Nuclear | 30 | 31 | 29 | 43 | 55 | 63 | 67 | 5 | 8 | 12 | 5.0 | 3.0 |
| Unabated natural gas | 115 | 146 | 144 | 113 | 68 | 40 | 14 | 23 | 20 | 3 | -3.0 | -8.1 |
| Natural gas with CCUS | 0 | 1 | 1 | 6 | 9 | 13 | 18 | 0 | 1 | 3 | 35 | 13 |
| Oil | 173 | 182 | 187 | 148 | 110 | 79 | 42 | 30 | 26 | 8 | -2.8 | -5.2 |
| Non-energy use | 25 | 31 | 32 | 35 | 34 | 33 | 30 | 5 | 6 | 6 | 1.3 | -0.1 |
| Unabated coal | 153 | 167 | 170 | 93 | 43 | 16 | 3 | 27 | 16 | 1 | -7.3 | -14 |
| Coal with CCUS | - | 0 | 0 | 2 | 7 | 10 | 12 | 0 | 0 | 2 | 87 | 27 |
| **Electricity and heat sectors** | **200** | **244** | **247** | **256** | **277** | **319** | **393** | **100** | **100** | **100** | **0.4** | **1.7** |
| Renewables | 20 | 39 | 41 | 103 | 167 | 228 | 306 | 17 | 40 | 78 | 12 | 7.4 |
| Solar PV | 0 | 4 | 5 | 29 | 56 | 80 | 112 | 2 | 11 | 29 | 26 | 12 |
| Wind | 1 | 7 | 8 | 25 | 43 | 61 | 84 | 3 | 10 | 21 | 16 | 9.0 |
| Hydro | 12 | 15 | 16 | 20 | 24 | 27 | 30 | 6 | 8 | 8 | 2.9 | 2.3 |
| Bioenergy | 4 | 9 | 9 | 17 | 24 | 30 | 36 | 4 | 6 | 9 | 7.3 | 4.9 |
| Hydrogen | - | - | - | 2 | 4 | 5 | 6 | - | 1 | 2 | n.a. | n.a. |
| Ammonia | - | - | - | 1 | 2 | 2 | 2 | - | 0 | 1 | n.a. | n.a. |
| Nuclear | 30 | 31 | 29 | 43 | 55 | 63 | 67 | 12 | 17 | 17 | 5.0 | 3.0 |
| Unabated natural gas | 47 | 57 | 57 | 49 | 25 | 11 | 1 | 23 | 19 | 0 | -1.7 | -13 |
| Natural gas with CCUS | - | - | - | 0 | 2 | 2 | 3 | - | 0 | 1 | n.a. | n.a. |
| Oil | 11 | 8 | 8 | 2 | 1 | 0 | 0 | 3 | 1 | 0 | -17 | -23 |
| Unabated coal | 91 | 108 | 110 | 53 | 16 | 0 | - | 45 | 21 | - | -8.9 | n.a. |
| Coal with CCUS | - | 0 | 0 | 2 | 5 | 6 | 7 | 0 | 1 | 2 | 102 | 29 |
| **Other energy sector** | **50** | **64** | **65** | **64** | **64** | **70** | **78** | **100** | **100** | **100** | **-0.2** | **0.7** |
| **Biofuels conversion losses** | - | 5 | 6 | 14 | 16 | 16 | 12 | 100 | 100 | 100 | 11 | 2.6 |
| **Low-emissions hydrogen (offsite)** | | | | | | | | | | | | |
| Production inputs | - | 0 | 0 | 9 | 20 | 33 | 54 | 100 | 100 | 100 | n.a. | n.a. |
| Production outputs | - | 0 | 0 | 6 | 14 | 23 | 39 | 100 | 100 | 100 | 144 | 38 |
| For hydrogen-based fuels | - | - | - | 2 | 5 | 10 | 17 | - | 31 | 43 | n.a. | n.a. |

## Table A.2c: World final energy consumption

| | | | | Net Zero Emissions by 2050 Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total final consumption** | 383 | 436 | 442 | 406 | 379 | 360 | 343 | 100 | 100 | 100 | -1.1 | -0.9 |
| Electricity | 64 | 87 | 89 | 113 | 133 | 154 | 183 | 20 | 28 | 53 | 3.0 | 2.6 |
| Liquid fuels | 154 | 168 | 172 | 150 | 120 | 94 | 62 | 39 | 37 | 18 | -1.7 | -3.6 |
| Biofuels | 2 | 4 | 4 | 11 | 13 | 13 | 11 | 1 | 3 | 3 | 13 | 3.3 |
| Ammonia | - | - | - | 1 | 2 | 2 | 4 | - | 0 | 1 | n.a. | n.a. |
| Synthetic oil | - | - | - | 0 | 1 | 2 | 6 | - | 0 | 2 | n.a. | n.a. |
| Oil | 151 | 164 | 168 | 138 | 104 | 76 | 41 | 38 | 34 | 12 | -2.4 | -4.9 |
| Gaseous fuels | 58 | 72 | 71 | 61 | 52 | 45 | 41 | 16 | 15 | 12 | -1.8 | -2.0 |
| Biomethane | 0 | 0 | 0 | 4 | 6 | 6 | 8 | 0 | 1 | 2 | 42 | 13 |
| Hydrogen | - | 0 | 0 | 2 | 5 | 8 | 16 | 0 | 1 | 5 | 113 | 33 |
| Synthetic methane | - | - | - | - | - | - | - | - | - | - | n.a. | n.a. |
| Natural gas | 57 | 72 | 70 | 54 | 41 | 29 | 15 | 16 | 13 | 4 | -3.2 | -5.3 |
| Solid fuels | 95 | 92 | 93 | 63 | 54 | 45 | 35 | 21 | 15 | 10 | -4.8 | -3.4 |
| Solid bioenergy | 38 | 39 | 40 | 24 | 26 | 26 | 28 | 9 | 6 | 8 | -6.1 | -1.2 |
| Coal | 56 | 52 | 52 | 38 | 27 | 18 | 7 | 12 | 9 | 2 | -3.9 | -6.9 |
| Heat | 12 | 15 | 15 | 12 | 11 | 9 | 6 | 3 | 3 | 2 | -2.1 | -3.2 |
| **Industry** | 143 | 167 | 167 | 175 | 173 | 169 | 159 | 100 | 100 | 100 | 0.6 | -0.2 |
| Electricity | 27 | 37 | 38 | 52 | 62 | 70 | 79 | 23 | 30 | 49 | 4.2 | 2.7 |
| Liquid fuels | 29 | 33 | 32 | 34 | 32 | 29 | 24 | 19 | 19 | 15 | 0.7 | -1.0 |
| Oil | 29 | 33 | 32 | 34 | 31 | 28 | 23 | 19 | 19 | 14 | 0.5 | -1.2 |
| Gaseous fuels | 24 | 31 | 30 | 30 | 28 | 25 | 21 | 18 | 17 | 13 | -0.1 | -1.3 |
| Biomethane | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 0 | 1 | 3 | 43 | 15 |
| Hydrogen | - | 0 | 0 | 1 | 2 | 4 | 5 | 0 | 1 | 3 | 137 | 36 |
| Unabated natural gas | 24 | 31 | 30 | 27 | 21 | 16 | 6 | 18 | 15 | 4 | -1.5 | -5.3 |
| Natural gas with CCUS | - | 0 | 0 | 1 | 2 | 3 | 5 | 0 | 1 | 3 | 46 | 18 |
| Solid fuels | 58 | 58 | 59 | 52 | 45 | 38 | 29 | 35 | 30 | 18 | -1.5 | -2.5 |
| Modern solid bioenergy | 8 | 10 | 11 | 15 | 18 | 20 | 22 | 7 | 9 | 14 | 4.2 | 2.5 |
| Unabated coal | 49 | 47 | 47 | 36 | 24 | 15 | 2 | 28 | 20 | 1 | -3.5 | -10 |
| Coal with CCUS | - | 0 | 0 | 1 | 2 | 4 | 5 | 0 | 0 | 3 | 71 | 25 |
| Heat | 5 | 7 | 7 | 5 | 4 | 3 | 1 | 4 | 3 | 1 | -3.9 | -6.1 |
| Chemicals | 38 | 48 | 48 | 54 | 55 | 55 | 51 | 29 | 31 | 32 | 1.6 | 0.2 |
| Iron and steel | 31 | 37 | 35 | 34 | 32 | 30 | 26 | 21 | 19 | 17 | -0.6 | -1.0 |
| Cement | 9 | 12 | 12 | 12 | 11 | 11 | 10 | 7 | 7 | 6 | -0.4 | -0.7 |
| Aluminium | 5 | 7 | 7 | 7 | 6 | 6 | 5 | 4 | 4 | 3 | -0.4 | -1.1 |

## Table A.2c: World final energy consumption (continued)

| | | | | Net Zero Emissions by 2050 Scenario (EJ) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Transport** | **102** | **112** | **116** | **105** | **89** | **79** | **76** | **100** | **100** | **100** | **-1.3** | **-1.5** |
| Electricity | 1 | 1 | 2 | 8 | 15 | 25 | 38 | 1 | 8 | 51 | 23 | 12 |
| Liquid fuels | 97 | 106 | 110 | 92 | 69 | 49 | 26 | 94 | 88 | 35 | -2.2 | -5.0 |
| Biofuels | 2 | 4 | 4 | 10 | 12 | 11 | 8 | 4 | 10 | 11 | 12 | 2.6 |
| Oil | 95 | 102 | 105 | 81 | 55 | 33 | 8 | 91 | 77 | 10 | -3.3 | -8.9 |
| Gaseous fuels | 4 | 5 | 5 | 5 | 4 | 5 | 11 | 5 | 4 | 15 | -1.9 | 2.7 |
| Biomethane | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 5.1 |
| Hydrogen | - | 0 | 0 | 1 | 2 | 4 | 10 | 0 | 1 | 14 | 98 | 32 |
| Natural gas | 4 | 5 | 5 | 3 | 2 | 1 | 0 | 4 | 3 | 0 | -5.6 | -11 |
| Road | 76 | 87 | 89 | 74 | 60 | 52 | 47 | 76 | 71 | 62 | -2.2 | -2.2 |
| Passenger cars | 38 | 44 | 45 | 32 | 22 | 17 | 15 | 38 | 30 | 20 | -4.1 | -3.7 |
| Heavy-duty trucks | 21 | 26 | 27 | 27 | 26 | 24 | 22 | 23 | 26 | 29 | 0.2 | -0.8 |
| Aviation | 11 | 9 | 11 | 15 | 14 | 14 | 15 | 10 | 14 | 20 | 3.5 | 1.2 |
| Shipping | 10 | 11 | 11 | 11 | 10 | 10 | 10 | 10 | 11 | 13 | 0.1 | -0.4 |
| **Buildings** | **117** | **131** | **133** | **100** | **92** | **89** | **89** | **100** | **100** | **100** | **-3.4** | **-1.4** |
| Electricity | 35 | 45 | 46 | 48 | 51 | 55 | 62 | 35 | 48 | 70 | 0.5 | 1.1 |
| Liquid fuels | 13 | 13 | 13 | 9 | 5 | 3 | 1 | 10 | 9 | 1 | -5.1 | -8.5 |
| Biofuels | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Oil | 13 | 13 | 13 | 9 | 5 | 3 | 1 | 10 | 9 | 1 | -5.2 | -9.5 |
| Gaseous fuels | 27 | 31 | 31 | 22 | 15 | 10 | 5 | 23 | 22 | 5 | -4.1 | -6.5 |
| Biomethane | 0 | 0 | 0 | 2 | 3 | 3 | 3 | 0 | 2 | 3 | 53 | 14 |
| Hydrogen | - | - | - | 0 | 0 | 0 | 0 | - | 0 | 0 | n.a. | n.a. |
| Natural gas | 26 | 31 | 30 | 19 | 11 | 5 | 0 | 23 | 19 | 0 | -5.8 | -22 |
| Solid fuels | 35 | 32 | 32 | 9 | 8 | 6 | 6 | 24 | 9 | 6 | -14 | -6.0 |
| Modern solid bioenergy | 4 | 4 | 4 | 8 | 8 | 6 | 6 | 3 | 8 | 6 | 8.4 | 1.0 |
| Traditional use of biomass | 25 | 24 | 24 | - | - | - | - | 18 | - | - | n.a. | n.a. |
| Coal | 6 | 4 | 4 | 1 | 0 | 0 | 0 | 3 | 1 | 0 | -14 | -26 |
| Heat | 6 | 7 | 7 | 7 | 6 | 6 | 5 | 5 | 7 | 5 | -0.5 | -1.7 |
| Residential | 83 | 93 | 93 | 65 | 59 | 57 | 58 | 71 | 65 | 65 | -4.4 | -1.7 |
| Services | 34 | 38 | 39 | 35 | 33 | 31 | 31 | 29 | 35 | 35 | -1.3 | -0.8 |

## Table A.3c: World electricity sector

| | | | | Net Zero Emissions by 2050 Scenario (TWh) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total generation** | **21 533** | **28 346** | **29 033** | **38 207** | **47 427** | **59 111** | **76 838** | **100** | **100** | **100** | **3.5** | **3.5** |
| Renewables | 4 209 | 7 964 | 8 599 | 22 532 | 36 739 | 50 459 | 68 430 | 30 | 59 | 89 | 13 | 7.7 |
| Solar PV | 32 | 1 023 | 1 291 | 8 177 | 15 439 | 22 241 | 31 237 | 4 | 21 | 41 | 26 | 12 |
| Wind | 342 | 1 865 | 2 125 | 7 070 | 11 923 | 16 826 | 23 442 | 7 | 19 | 31 | 16 | 9.0 |
| Hydro | 3 456 | 4 299 | 4 378 | 5 507 | 6 530 | 7 435 | 8 225 | 15 | 14 | 11 | 2.9 | 2.3 |
| Bioenergy | 309 | 666 | 687 | 1 313 | 1 885 | 2 396 | 3 056 | 2 | 3 | 4 | 8.4 | 5.5 |
| of which BECCS | - | - | - | 65 | 300 | 471 | 644 | - | 0 | 1 | n.a. | n.a. |
| CSP | 2 | 15 | 16 | 139 | 414 | 831 | 1 486 | 0 | 0 | 2 | 31 | 18 |
| Geothermal | 68 | 96 | 101 | 306 | 508 | 662 | 862 | 0 | 1 | 1 | 15 | 7.9 |
| Marine | 1 | 1 | 1 | 19 | 39 | 67 | 123 | 0 | 0 | 0 | 44 | 19 |
| Nuclear | 2 756 | 2 810 | 2 682 | 3 936 | 4 952 | 5 583 | 6 015 | 9 | 10 | 8 | 4.9 | 2.9 |
| Hydrogen and ammonia | - | - | - | 373 | 745 | 1 028 | 1 161 | - | 1 | 2 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 1 | 1 | 220 | 681 | 847 | 996 | 0 | 1 | 1 | 105 | 30 |
| Coal with CCUS | - | 1 | 1 | 156 | 455 | 547 | 644 | 0 | 0 | 1 | 97 | 28 |
| Natural gas with CCUS | - | - | - | 64 | 226 | 301 | 353 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 14 479 | 17 456 | 17 636 | 11 066 | 4 241 | 1 121 | 158 | 61 | 29 | 0 | -5.7 | -15 |
| Coal | 8 669 | 10 247 | 10 427 | 4 988 | 1 379 | - | - | 36 | 13 | - | -8.8 | n.a. |
| Natural gas | 4 847 | 6 526 | 6 500 | 5 943 | 2 834 | 1 119 | 158 | 22 | 16 | 0 | -1.1 | -12 |
| Oil | 963 | 683 | 709 | 135 | 28 | 2 | 1 | 2 | 0 | 0 | -19 | -23 |

| | | | | Net Zero Emissions by 2050 Scenario (GW) | | | | Shares (%) | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total capacity** | **5 187** | **8 230** | **8 643** | **16 180** | **23 067** | **29 354** | **36 956** | **100** | **100** | **100** | **8.2** | **5.3** |
| Renewables | 1 333 | 3 292 | 3 629 | 11 008 | 17 460 | 23 331 | 30 275 | 42 | 68 | 82 | 15 | 7.9 |
| Solar PV | 39 | 925 | 1 145 | 6 101 | 10 430 | 14 303 | 18 753 | 13 | 38 | 51 | 23 | 11 |
| Wind | 181 | 827 | 902 | 2 742 | 4 322 | 5 797 | 7 616 | 10 | 17 | 21 | 15 | 7.9 |
| Hydro | 1 027 | 1 360 | 1 392 | 1 765 | 2 054 | 2 313 | 2 612 | 16 | 11 | 7 | 3.0 | 2.3 |
| Bioenergy | 74 | 159 | 168 | 296 | 426 | 541 | 688 | 2 | 2 | 2 | 7.3 | 5.2 |
| *of which BECCS* | - | - | - | 15 | 59 | 87 | 114 | - | 0 | 0 | n.a. | n.a. |
| CSP | 1 | 6 | 7 | 48 | 134 | 251 | 427 | 0 | 0 | 1 | 27 | 16 |
| Geothermal | 10 | 15 | 15 | 48 | 78 | 99 | 129 | 0 | 0 | 0 | 16 | 8.0 |
| Marine | 0 | 1 | 1 | 8 | 16 | 27 | 48 | 0 | 0 | 0 | 34 | 16 |
| Nuclear | 403 | 413 | 417 | 541 | 688 | 813 | 916 | 5 | 3 | 2 | 3.3 | 2.9 |
| Hydrogen and ammonia | - | - | - | 129 | 367 | 447 | 427 | - | 1 | 1 | n.a. | n.a. |
| Fossil fuels with CCUS | - | 0 | 0 | 50 | 141 | 203 | 241 | 0 | 0 | 1 | 113 | 31 |
| Coal with CCUS | - | 0 | 0 | 36 | 95 | 131 | 153 | 0 | 0 | 0 | 104 | 29 |
| Natural gas with CCUS | - | - | - | 14 | 46 | 72 | 89 | - | 0 | 0 | n.a. | n.a. |
| Unabated fossil fuels | 3 439 | 4 480 | 4 535 | 3 423 | 2 453 | 1 710 | 892 | 52 | 21 | 2 | -3.5 | -5.6 |
| Coal | 1 614 | 2 200 | 2 236 | 1 457 | 910 | 548 | 242 | 26 | 9 | 1 | -5.2 | -7.6 |
| Natural gas | 1 389 | 1 854 | 1 875 | 1 746 | 1 402 | 1 088 | 611 | 22 | 11 | 2 | -0.9 | -3.9 |
| Oil | 436 | 426 | 423 | 220 | 141 | 75 | 39 | 5 | 1 | 0 | -7.8 | -8.2 |
| Battery storage | 1 | 27 | 45 | 1 018 | 1 949 | 2 841 | 4 199 | 1 | 6 | 11 | 48 | 18 |

A

# Table A.4c: World $CO_2$ emissions

| | 2010 | 2021 | 2022 | Net Zero Emissions by 2050 Scenario (Mt $CO_2$) 2030 | 2035 | 2040 | 2050 | CAAGR (%) 2022 to: 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|---|
| **Total $CO_2$*** | **32 877** | **36 589** | **36 930** | **24 030** | **13 375** | **6 471** | **-** | **-5.2** | **n.a.** |
| **Combustion activities (+)** | **30 624** | **33 634** | **34 042** | **21 958** | **12 017** | **5 820** | **655** | **-5.3** | **-13** |
| Coal | 13 846 | 15 104 | 15 330 | 8 173 | 3 541 | 1 200 | 171 | -7.6 | -15 |
| Oil | 10 545 | 10 683 | 10 963 | 7 910 | 5 325 | 3 219 | 824 | -4.0 | -8.8 |
| Natural gas | 6 052 | 7 577 | 7 499 | 5 795 | 3 327 | 1 780 | 358 | -3.2 | -10 |
| Bioenergy and waste | 181 | 269 | 251 | 80 | - 176 | - 379 | - 698 | -13 | n.a. |
| **Other removals** (-)** | **-** | **1** | **2** | **167** | **348** | **523** | **933** | **78** | **25** |
| Biofuels production | - | 1 | 2 | 98 | 186 | 227 | 312 | 67 | 21 |
| Direct air capture | - | - | - | 69 | 162 | 295 | 621 | n.a. | n.a. |
| **Electricity and heat sectors** | **12 511** | **14 598** | **14 822** | **8 113** | **2 854** | **411** | **- 275** | **-7.3** | **n.a.** |
| Coal | 8 946 | 10 646 | 10 876 | 5 156 | 1 545 | 42 | 21 | -8.9 | -20 |
| Oil | 828 | 574 | 596 | 135 | 45 | 23 | 0 | -17 | -23 |
| Natural gas | 2 623 | 3 227 | 3 201 | 2 781 | 1 401 | 604 | 78 | -1.7 | -12 |
| Bioenergy and waste | 114 | 151 | 149 | 41 | - 138 | - 257 | - 374 | -15 | n.a. |
| **Other energy sector**** | **1 438** | **1 530** | **1 554** | **782** | **322** | **108** | **- 198** | **-8.2** | **n.a.** |
| **Final consumption**** | **18 668** | **20 191** | **20 293** | **15 187** | **10 350** | **6 241** | **1 088** | **-3.6** | **-9.9** |
| Coal | 4 699 | 4 355 | 4 352 | 2 983 | 1 971 | 1 142 | 138 | -4.6 | -12 |
| Oil | 9 087 | 9 552 | 9 815 | 7 398 | 4 993 | 2 989 | 711 | -3.5 | -9.0 |
| Natural gas | 2 842 | 3 566 | 3 500 | 2 543 | 1 718 | 1 036 | 173 | -3.9 | -10 |
| Bioenergy and waste | 66 | 118 | 102 | 43 | - 26 | - 93 | - 205 | -10 | n.a. |
| Industry** | 8 324 | 9 185 | 8 998 | 7 158 | 5 111 | 3 222 | 440 | -2.8 | -10 |
| Chemicals** | 1 201 | 1 329 | 1 330 | 1 150 | 850 | 521 | 45 | -1.8 | -11 |
| Iron and steel** | 2 083 | 2 733 | 2 623 | 2 118 | 1 584 | 1 032 | 233 | -2.6 | -8.3 |
| Cement** | 1 916 | 2 514 | 2 418 | 1 911 | 1 343 | 875 | 79 | -2.9 | -12 |
| Aluminium** | 185 | 261 | 265 | 218 | 172 | 107 | 8 | -2.4 | -12 |
| Transport | 7 014 | 7 599 | 7 874 | 5 992 | 4 062 | 2 430 | 578 | -3.4 | -8.9 |
| Road | 5 216 | 5 847 | 5 964 | 4 213 | 2 718 | 1 491 | 236 | -4.2 | -11 |
| Passenger cars | 2 609 | 2 930 | 2 975 | 1 752 | 916 | 403 | 37 | -6.4 | -14 |
| Heavy-duty trucks | 1 489 | 1 766 | 1 812 | 1 610 | 1 284 | 856 | 178 | -1.5 | -8.0 |
| Aviation | 754 | 661 | 792 | 932 | 744 | 554 | 208 | 2.0 | -4.7 |
| Shipping | 797 | 827 | 855 | 695 | 495 | 313 | 112 | -2.6 | -7.0 |
| Buildings | 2 891 | 2 973 | 2 979 | 1 741 | 971 | 463 | 54 | -6.5 | -13 |
| Residential | 1 961 | 2 013 | 1 997 | 1 189 | 675 | 326 | 48 | -6.3 | -12 |
| Services | 929 | 959 | 983 | 552 | 296 | 137 | 6 | -7.0 | -16 |
| **Total $CO_2$ removals**** | **-** | **2** | **2** | **234** | **632** | **995** | **1 710** | **85** | **28** |
| **Total $CO_2$ captured**** | **15** | **41** | **42** | **1 024** | **2 421** | **3 724** | **6 040** | **49** | **19** |

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

## Table A.5c: World economic and activity indicators

| | | | | Net Zero Emissions by 2050 Scenario | | | | CAAGR (%) 2022 to: | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2035 | 2040 | 2050 | 2030 | 2050 |
| **Indicators** | | | | | | | | | |
| Population (million) | 6 967 | 7 884 | 7 950 | 8 520 | 8 853 | 9 161 | 9 681 | 0.9 | 0.7 |
| GDP (USD 2022 billion, PPP) | 114 463 | 158 505 | 163 734 | 207 282 | 238 066 | 270 050 | 339 273 | 3.0 | 2.6 |
| GDP per capita (USD 2022, PPP) | 16 429 | 20 104 | 20 596 | 24 329 | 26 892 | 29 479 | 35 044 | 2.1 | 1.9 |
| TES/GDP (GJ per USD 1 000, PPP) | 4.7 | 3.9 | 3.9 | 2.8 | 2.3 | 2.0 | 1.6 | -4.1 | -3.1 |
| TFC/GDP (GJ per USD 1 000, PPP) | 3.2 | 2.6 | 2.6 | 1.9 | 1.5 | 1.3 | 1.0 | -3.9 | -3.3 |
| $CO_2$ intensity of electricity generation (g $CO_2$ per kWh) | 528 | 464 | 460 | 186 | 48 | 3 | - 4 | -11 | n.a. |
| **Industrial production (Mt)** | | | | | | | | | |
| Primary chemicals | 515 | 713 | 719 | 861 | 905 | 916 | 878 | 2.3 | 0.7 |
| Steel | 1 435 | 1 960 | 1 878 | 1 973 | 1 966 | 1 958 | 1 957 | 0.6 | 0.1 |
| Cement | 3 280 | 4 374 | 4 158 | 4 264 | 4 140 | 4 022 | 3 934 | 0.3 | -0.2 |
| Aluminium | 62 | 105 | 108 | 120 | 128 | 136 | 146 | 1.4 | 1.1 |
| **Transport** | | | | | | | | | |
| Passenger cars (billion pkm) | 18 984 | 25 679 | 26 535 | 28 608 | 30 355 | 33 841 | 41 638 | 0.9 | 1.6 |
| Heavy-duty trucks (billion tkm) | 23 364 | 29 482 | 30 479 | 38 037 | 43 341 | 49 036 | 60 335 | 2.8 | 2.5 |
| Aviation (billion pkm) | 4 923 | 3 673 | 6 025 | 10 969 | 11 417 | 12 843 | 16 545 | 7.8 | 3.7 |
| Shipping (billion tkm) | 77 101 | 115 830 | 124 272 | 145 087 | 165 073 | 188 756 | 265 253 | 2.0 | 2.7 |
| **Buildings** | | | | | | | | | |
| Households (million) | 1 798 | 2 175 | 2 208 | 2 439 | 2 579 | 2 715 | 2 963 | 1.2 | 1.1 |
| Residential floor area (million $m^2$) | 153 219 | 194 691 | 198 090 | 227 039 | 247 262 | 268 130 | 310 109 | 1.7 | 1.6 |
| Services floor area (million $m^2$) | 39 262 | 53 415 | 54 624 | 63 891 | 69 197 | 74 143 | 82 764 | 2.0 | 1.5 |

## Table A.6: Total energy supply (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **541.3** | **624.0** | **632.0** | **667.9** | **725.0** | **627.7** | **622.9** |
| North America | 112.4 | 111.6 | 114.5 | 108.3 | 101.2 | 103.4 | 87.5 |
| United States | 94.0 | 91.7 | 93.8 | 87.3 | 79.2 | 83.4 | 70.4 |
| Central and South America | 26.6 | 28.5 | 29.1 | 32.6 | 40.7 | 32.2 | 38.4 |
| Brazil | 12.2 | 13.8 | 14.0 | 16.0 | 19.2 | 16.1 | 19.1 |
| Europe | 89.2 | 82.1 | 78.2 | 74.5 | 66.6 | 71.2 | 57.6 |
| European Union | 64.5 | 58.9 | 56.2 | 51.7 | 43.1 | 49.5 | 38.0 |
| Africa | 28.6 | 35.9 | 36.4 | 41.1 | 57.6 | 34.6 | 48.6 |
| Middle East | 27.1 | 34.8 | 36.4 | 42.0 | 54.6 | 40.0 | 49.7 |
| Eurasia | 35.2 | 42.0 | 41.6 | 40.4 | 42.5 | 38.6 | 36.9 |
| Russia | 28.5 | 34.6 | 34.0 | 31.9 | 31.6 | 30.7 | 27.6 |
| Asia Pacific | 206.9 | 276.1 | 281.0 | 309.5 | 334.8 | 289.0 | 286.7 |
| China | 107.3 | 157.6 | 159.7 | 167.7 | 156.9 | 157.5 | 132.9 |
| India | 27.9 | 39.7 | 42.0 | 53.7 | 73.0 | 47.6 | 60.3 |
| Japan | 20.9 | 16.7 | 16.6 | 15.2 | 12.5 | 14.8 | 11.3 |
| Southeast Asia | 22.8 | 29.6 | 30.3 | 37.6 | 52.0 | 36.1 | 46.0 |

## Table A.7: Renewables energy supply (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **43.3** | **71.1** | **75.5** | **120.0** | **227.1** | **142.1** | **327.0** |
| North America | 8.8 | 12.0 | 12.8 | 18.7 | 34.5 | 25.3 | 51.2 |
| United States | 6.6 | 9.5 | 10.1 | 15.2 | 29.1 | 20.5 | 42.5 |
| Central and South America | 7.7 | 9.5 | 10.0 | 12.9 | 19.6 | 14.9 | 28.0 |
| Brazil | 5.6 | 6.6 | 7.0 | 8.9 | 11.9 | 9.9 | 15.4 |
| Europe | 9.9 | 14.5 | 14.9 | 21.3 | 30.3 | 24.4 | 37.7 |
| European Union | 7.7 | 10.8 | 11.1 | 15.8 | 22.3 | 17.9 | 26.6 |
| Africa | 3.7 | 5.5 | 5.8 | 8.7 | 17.3 | 9.2 | 26.3 |
| Middle East | 0.1 | 0.2 | 0.3 | 1.2 | 5.3 | 1.5 | 12.5 |
| Eurasia | 1.0 | 1.3 | 1.3 | 1.6 | 3.1 | 2.0 | 5.1 |
| Russia | 0.7 | 1.0 | 1.0 | 1.2 | 2.3 | 1.4 | 2.9 |
| Asia Pacific | 12.1 | 28.0 | 30.5 | 55.3 | 115.9 | 64.1 | 162.1 |
| China | 4.6 | 13.7 | 14.9 | 29.7 | 59.3 | 33.8 | 76.1 |
| India | 2.8 | 5.7 | 6.2 | 10.6 | 26.4 | 11.5 | 34.2 |
| Japan | 0.8 | 1.2 | 1.4 | 2.2 | 3.5 | 2.5 | 5.0 |
| Southeast Asia | 2.8 | 5.5 | 5.8 | 8.6 | 16.7 | 10.5 | 29.7 |

## Table A.8: Oil production (mb/d)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World supply** | **85.3** | **92.6** | **97.1** | **101.5** | **97.4** | **92.5** | **54.8** |
| Processing gains | 2.2 | 2.3 | 2.3 | 2.4 | 2.9 | 2.4 | 1.6 |
| **World production** | **83.1** | **90.3** | **94.8** | **99.1** | **94.5** | **90.2** | **53.1** |
| Conventional crude oil | 67.4 | 60.2 | 62.8 | 61.3 | 58.2 | 54.9 | 29.8 |
| Tight oil | 0.7 | 7.5 | 8.3 | 11.1 | 10.2 | 10.3 | 6.9 |
| Natural gas liquids | 12.7 | 18.3 | 19.0 | 21.2 | 19.4 | 20.1 | 13.6 |
| Extra-heavy oil & bitumen | 2.0 | 3.5 | 3.7 | 4.4 | 5.5 | 3.9 | 2.5 |
| Other | 0.3 | 0.8 | 1.0 | 1.1 | 1.2 | 1.0 | 0.3 |
| Non-OPEC | 49.8 | 58.7 | 60.4 | 63.9 | 53.7 | 58.3 | 29.4 |
| OPEC | 33.3 | 31.6 | 34.4 | 35.1 | 40.8 | 31.9 | 23.7 |
| North America | 14.0 | 24.3 | 25.6 | 28.3 | 23.9 | 25.7 | 14.2 |
| Central and South America | 7.4 | 6.0 | 6.4 | 9.1 | 10.0 | 8.2 | 5.2 |
| Europe | 4.4 | 3.6 | 3.3 | 2.9 | 1.3 | 2.6 | 0.5 |
| European Union | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.1 |
| Africa | 10.2 | 7.4 | 7.1 | 6.0 | 5.7 | 5.5 | 2.9 |
| Middle East | 25.4 | 28.0 | 31.0 | 33.8 | 39.3 | 30.7 | 23.5 |
| Eurasia | 13.4 | 13.7 | 13.9 | 13.1 | 10.1 | 11.9 | 4.9 |
| Asia Pacific | 8.4 | 7.4 | 7.4 | 6.0 | 4.3 | 5.6 | 1.9 |
| Southeast Asia | 2.6 | 1.9 | 1.8 | 1.3 | 0.8 | 1.3 | 0.4 |

## Table A.9: Oil demand (mb/d)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **87.1** | **93.7** | **96.5** | **101.5** | **97.4** | **92.5** | **54.8** |
| North America | 22.1 | 21.5 | 22.2 | 20.4 | 15.2 | 18.1 | 6.0 |
| United States | 17.8 | 17.8 | 18.3 | 16.5 | 11.7 | 14.8 | 4.6 |
| Central and South America | 5.5 | 5.3 | 5.5 | 5.7 | 6.2 | 5.1 | 2.7 |
| Brazil | 2.2 | 2.3 | 2.4 | 2.4 | 2.4 | 2.2 | 1.1 |
| Europe | 13.9 | 12.5 | 12.4 | 10.8 | 6.3 | 9.2 | 2.4 |
| European Union | 10.6 | 9.4 | 9.3 | 7.8 | 3.8 | 6.5 | 1.3 |
| Africa | 3.3 | 3.8 | 4.0 | 4.7 | 7.7 | 4.5 | 5.4 |
| Middle East | 7.1 | 7.7 | 8.1 | 8.9 | 10.5 | 8.3 | 7.8 |
| Eurasia | 3.2 | 4.1 | 4.3 | 4.5 | 4.7 | 4.3 | 4.0 |
| Russia | 2.6 | 3.3 | 3.5 | 3.5 | 3.3 | 3.4 | 3.0 |
| Asia Pacific | 25.0 | 32.7 | 32.9 | 37.6 | 35.1 | 34.6 | 20.1 |
| China | 8.8 | 14.7 | 14.4 | 16.4 | 12.0 | 15.1 | 6.9 |
| India | 3.3 | 4.8 | 5.2 | 6.8 | 7.8 | 6.2 | 4.7 |
| Japan | 4.2 | 3.2 | 3.3 | 2.6 | 1.7 | 2.3 | 0.7 |
| Southeast Asia | 4.0 | 4.6 | 4.8 | 6.0 | 6.9 | 5.5 | 3.6 |
| International bunkers | 7.1 | 6.1 | 7.0 | 8.9 | 11.7 | 8.4 | 6.4 |

## Table A.10: World liquids demand (mb/d)

| | Historical | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **Total liquids** | **95.7** | **98.6** | **104.4** | **101.8** | **97.2** | **64.4** |
| Biofuels | 2.0 | 2.1 | 2.9 | 4.2 | 4.5 | 6.0 |
| Hydrogen based fuels | - | - | - | 0.2 | 0.2 | 3.6 |
| Total oil | 93.7 | 96.5 | 101.5 | 97.4 | 92.5 | 54.8 |
| CTL, GTL and additives | 0.8 | 0.9 | 0.9 | 1.1 | 0.9 | 0.2 |
| Direct use of crude oil | 1.1 | 1.0 | 0.6 | 0.3 | 0.5 | 0.2 |
| Oil products | 91.8 | 94.6 | 100.0 | 96.0 | 91.1 | 54.4 |
| LPG and ethane | 13.8 | 14.1 | 16.0 | 16.4 | 14.9 | 10.5 |
| Naphtha | 6.8 | 6.9 | 6.9 | 8.4 | 6.4 | 6.9 |
| Gasoline | 23.6 | 24.0 | 22.3 | 16.3 | 20.3 | 7.4 |
| Kerosene | 5.3 | 6.2 | 8.7 | 11.1 | 8.1 | 6.7 |
| Diesel | 26.4 | 26.7 | 28.0 | 27.5 | 25.2 | 12.7 |
| Fuel oil | 6.0 | 6.3 | 5.7 | 6.2 | 5.1 | 2.5 |
| Other products | 9.9 | 10.4 | 12.4 | 10.1 | 11.1 | 7.7 |
| Products from NGLs | 11.5 | 12.1 | 13.6 | 11.5 | 13.3 | 8.6 |
| Refinery products | 80.3 | 82.5 | 86.4 | 84.5 | 77.8 | 45.8 |
| *Refinery market share* | *84%* | *84%* | *83%* | *83%* | *80%* | *71%* |

Note: CTL = coal-to-liquids; GTL = gas-to-liquids; LPG = liquefied petroleum gas; NGLs = natural gas liquids.

## Table A.11: Refining capacity and runs (mb/d)

| | Refining capacity | | | | | Refinery runs | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | STEPS | | APS | | | STEPS | | APS | |
| | 2022 | 2030 | 2050 | 2030 | 2050 | 2022 | 2030 | 2050 | 2030 | 2050 |
| North America | 21.3 | 21.0 | 20.7 | 19.7 | 9.6 | 18.5 | 17.6 | 16.7 | 15.8 | 7.2 |
| Europe | 15.8 | 14.6 | 13.3 | 13.5 | 6.4 | 12.5 | 11.0 | 8.7 | 9.7 | 3.6 |
| Asia Pacific | 37.7 | 39.9 | 41.1 | 37.6 | 25.9 | 29.8 | 33.3 | 33.5 | 30.2 | 19.5 |
| Japan and Korea | 6.9 | 6.3 | 5.7 | 5.8 | 3.6 | 5.6 | 4.9 | 4.2 | 4.3 | 2.4 |
| China | 18.3 | 19.8 | 19.8 | 18.4 | 10.4 | 13.7 | 16.0 | 14.7 | 14.4 | 7.1 |
| India | 5.2 | 6.3 | 7.5 | 5.9 | 4.7 | 5.1 | 6.3 | 7.4 | 5.6 | 4.1 |
| Southeast Asia | 5.4 | 5.5 | 6.0 | 5.5 | 5.2 | 4.1 | 4.6 | 5.5 | 4.5 | 4.4 |
| Middle East | 10.5 | 11.9 | 12.7 | 11.2 | 8.5 | 8.5 | 9.9 | 10.4 | 8.7 | 6.2 |
| Russia | 7.0 | 6.7 | 6.4 | 6.4 | 4.1 | 5.5 | 4.8 | 3.8 | 4.3 | 2.1 |
| Africa | 3.2 | 4.0 | 4.3 | 4.0 | 3.4 | 1.8 | 2.6 | 3.3 | 2.5 | 2.3 |
| Brazil | 2.2 | 2.2 | 2.2 | 2.1 | 1.3 | 1.9 | 2.0 | 2.1 | 1.8 | 1.1 |
| Other | 5.0 | 4.9 | 5.1 | 4.9 | 3.7 | 2.3 | 2.7 | 3.1 | 2.5 | 2.1 |
| **World** | **102.7** | **105.2** | **105.8** | **99.4** | **62.9** | **80.8** | **83.9** | **81.6** | **75.5** | **44.1** |
| Atlantic Basin | 54.2 | 53.2 | 51.8 | 50.4 | 28.3 | 42.5 | 40.5 | 37.4 | 36.5 | 18.3 |
| East of Suez | 48.5 | 52.0 | 54.0 | 49.0 | 34.6 | 38.3 | 43.4 | 44.1 | 39.0 | 25.8 |

## Table A.12: Natural gas production (bcm)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **3 274** | **4 149** | **4 138** | **4 299** | **4 173** | **3 861** | **2 422** |
| Conventional gas | 2 769 | 2 968 | 2 871 | 2 894 | 3 016 | 2 742 | 1 940 |
| Tight gas | 274 | 296 | 301 | 275 | 122 | 187 | 39 |
| Shale gas | 154 | 795 | 873 | 1 031 | 942 | 854 | 420 |
| Coalbed methane | 77 | 82 | 80 | 75 | 67 | 54 | 22 |
| Other | - | 8 | 13 | 24 | 26 | 24 | 1 |
| North America | 811 | 1 189 | 1 240 | 1 313 | 936 | 1 121 | 418 |
| Central and South America | 160 | 151 | 153 | 144 | 159 | 129 | 95 |
| Europe | 341 | 239 | 248 | 196 | 155 | 162 | 47 |
| European Union | 148 | 51 | 47 | 34 | 22 | 20 | 3 |
| Africa | 203 | 265 | 262 | 283 | 360 | 266 | 240 |
| Middle East | 463 | 660 | 678 | 867 | 1 044 | 818 | 721 |
| Eurasia | 807 | 998 | 904 | 832 | 892 | 764 | 586 |
| Asia Pacific | 488 | 648 | 653 | 664 | 627 | 601 | 315 |
| Southeast Asia | 216 | 195 | 189 | 166 | 117 | 147 | 77 |

## Table A.13: Natural gas demand (bcm)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **3 326** | **4 218** | **4 159** | **4 299** | **4 173** | **3 861** | **2 422** |
| North America | 835 | 1 108 | 1 162 | 1 107 | 781 | 940 | 369 |
| United States | 678 | 881 | 930 | 868 | 551 | 731 | 256 |
| Central and South America | 147 | 160 | 156 | 169 | 178 | 152 | 100 |
| Brazil | 29 | 42 | 32 | 33 | 35 | 28 | 18 |
| Europe | 695 | 627 | 544 | 468 | 299 | 390 | 93 |
| European Union | 446 | 413 | 358 | 305 | 160 | 248 | 26 |
| Africa | 106 | 174 | 170 | 202 | 277 | 182 | 182 |
| Middle East | 395 | 570 | 585 | 686 | 849 | 658 | 647 |
| Eurasia | 573 | 667 | 642 | 625 | 644 | 581 | 490 |
| Russia | 467 | 549 | 520 | 494 | 474 | 462 | 370 |
| Asia Pacific | 575 | 911 | 900 | 1 034 | 1 119 | 954 | 536 |
| China | 110 | 369 | 369 | 458 | 452 | 410 | 185 |
| India | 64 | 64 | 60 | 107 | 169 | 96 | 102 |
| Japan | 95 | 98 | 97 | 66 | 44 | 60 | 19 |
| Southeast Asia | 150 | 162 | 158 | 191 | 254 | 171 | 122 |
| International bunkers | - | - | - | 8 | 26 | 4 | 4 |

## Table A.14: Coal production (Mtce)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **5 235** | **5 709** | **6 122** | **5 007** | **3 465** | **4 337** | **1 530** |
| Steam coal | 4 069 | 4 533 | 4 888 | 3 974 | 2 669 | 3 388 | 1 135 |
| Coking coal | 866 | 941 | 988 | 886 | 691 | 830 | 350 |
| Lignite and peat | 300 | 235 | 246 | 146 | 105 | 120 | 45 |
| North America | 818 | 441 | 442 | 175 | 82 | 124 | 35 |
| Central and South America | 79 | 59 | 59 | 31 | 33 | 25 | 3 |
| Europe | 331 | 190 | 188 | 107 | 58 | 69 | 8 |
| European Union | 220 | 134 | 136 | 43 | 6 | 32 | 1 |
| Africa | 210 | 196 | 202 | 173 | 155 | 151 | 44 |
| Middle East | 1 | 2 | 1 | 1 | 1 | 1 | - |
| Eurasia | 309 | 430 | 431 | 346 | 281 | 307 | 187 |
| Asia Pacific | 3 487 | 4 391 | 4 799 | 4 174 | 2 856 | 3 661 | 1 253 |
| Southeast Asia | 318 | 489 | 539 | 449 | 458 | 409 | 207 |

## Table A.15: Coal demand (Mtce)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **5 218** | **5 710** | **5 807** | **5 007** | **3 465** | **4 337** | **1 530** |
| North America | 768 | 388 | 371 | 110 | 27 | 71 | 19 |
| United States | 716 | 363 | 341 | 95 | 16 | 59 | 15 |
| Central and South America | 37 | 45 | 40 | 38 | 44 | 28 | 15 |
| Brazil | 21 | 24 | 20 | 22 | 27 | 17 | 11 |
| Europe | 539 | 362 | 368 | 220 | 163 | 173 | 49 |
| European Union | 361 | 238 | 245 | 107 | 50 | 88 | 13 |
| Africa | 155 | 147 | 146 | 130 | 110 | 109 | 27 |
| Middle East | 3 | 5 | 5 | 8 | 10 | 7 | 5 |
| Eurasia | 203 | 237 | 246 | 197 | 166 | 187 | 123 |
| Russia | 151 | 183 | 191 | 139 | 109 | 136 | 96 |
| Asia Pacific | 3 513 | 4 526 | 4 631 | 4 305 | 2 946 | 3 763 | 1 293 |
| China | 2 565 | 3 239 | 3 300 | 2 878 | 1 563 | 2 530 | 672 |
| India | 399 | 602 | 643 | 764 | 708 | 670 | 331 |
| Japan | 165 | 156 | 155 | 105 | 58 | 97 | 35 |
| Southeast Asia | 122 | 260 | 269 | 327 | 427 | 291 | 163 |

## Table A.16: Electricity generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **21 533** | **28 346** | **29 033** | **35 802** | **53 985** | **36 370** | **66 760** |
| North America | 5 233 | 5 377 | 5 524 | 5 945 | 8 381 | 6 235 | 10 986 |
| United States | 4 354 | 4 354 | 4 491 | 4 805 | 6 855 | 5 042 | 9 013 |
| Central and South America | 1 129 | 1 347 | 1 389 | 1 646 | 2 626 | 1 723 | 3 930 |
| Brazil | 516 | 656 | 677 | 779 | 1 199 | 779 | 1 428 |
| Europe | 4 119 | 4 126 | 3 996 | 4 708 | 6 419 | 4 989 | 7 964 |
| European Union | 2 955 | 2 885 | 2 795 | 3 256 | 4 403 | 3 473 | 5 441 |
| Africa | 686 | 874 | 890 | 1 203 | 2 294 | 1 327 | 3 859 |
| Middle East | 829 | 1 246 | 1 276 | 1 716 | 2 956 | 1 694 | 3 919 |
| Eurasia | 1 251 | 1 446 | 1 476 | 1 540 | 1 923 | 1 502 | 2 023 |
| Russia | 1 036 | 1 158 | 1 170 | 1 177 | 1 376 | 1 143 | 1 380 |
| Asia Pacific | 8 285 | 13 930 | 14 483 | 19 043 | 29 385 | 18 900 | 34 079 |
| China | 4 236 | 8 597 | 8 912 | 11 743 | 16 527 | 11 454 | 17 589 |
| India | 972 | 1 635 | 1 766 | 2 672 | 5 694 | 2 581 | 6 605 |
| Japan | 1 164 | 1 040 | 1 062 | 1 054 | 1 076 | 1 083 | 1 358 |
| Southeast Asia | 685 | 1 162 | 1 220 | 1 709 | 3 292 | 1 759 | 4 498 |

## Table A.17: Renewables generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **4 209** | **7 964** | **8 599** | **16 915** | **37 973** | **19 295** | **55 057** |
| North America | 856 | 1 374 | 1 497 | 2 828 | 6 526 | 3 538 | 9 261 |
| United States | 441 | 867 | 973 | 2 205 | 5 510 | 2 807 | 7 683 |
| Central and South America | 752 | 896 | 1 018 | 1 296 | 2 320 | 1 428 | 3 768 |
| Brazil | 437 | 508 | 594 | 700 | 1 102 | 732 | 1 378 |
| Europe | 954 | 1 601 | 1 620 | 3 081 | 5 180 | 3 438 | 6 834 |
| European Union | 653 | 1 081 | 1 085 | 2 177 | 3 713 | 2 407 | 4 720 |
| Africa | 116 | 201 | 210 | 486 | 1 505 | 711 | 3 453 |
| Middle East | 18 | 38 | 45 | 216 | 1 041 | 233 | 2 577 |
| Eurasia | 226 | 287 | 277 | 339 | 537 | 380 | 844 |
| Russia | 167 | 221 | 205 | 243 | 380 | 254 | 456 |
| Asia Pacific | 1 287 | 3 568 | 3 932 | 8 669 | 20 863 | 9 568 | 28 321 |
| China | 782 | 2 448 | 2 681 | 6 074 | 12 664 | 6 419 | 14 836 |
| India | 161 | 351 | 399 | 981 | 4 149 | 1 090 | 5 660 |
| Japan | 106 | 212 | 225 | 385 | 651 | 412 | 797 |
| Southeast Asia | 104 | 310 | 340 | 541 | 1 630 | 738 | 3 773 |

## Table A.18: Solar PV generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **32** | **1 023** | **1 291** | **5 405** | **17 220** | **6 390** | **24 297** |
| North America | 3 | 167 | 203 | 868 | 3 267 | 1 191 | 3 932 |
| United States | 3 | 148 | 185 | 829 | 3 069 | 1 126 | 3 366 |
| Central and South America | 0 | 35 | 53 | 160 | 422 | 256 | 1 255 |
| Brazil | 0 | 17 | 30 | 102 | 223 | 119 | 364 |
| Europe | 23 | 199 | 245 | 753 | 1 452 | 844 | 1 852 |
| European Union | 22 | 159 | 202 | 626 | 1 186 | 689 | 1 310 |
| Africa | 0 | 14 | 16 | 122 | 526 | 245 | 1 859 |
| Middle East | 0 | 13 | 17 | 147 | 643 | 141 | 1 574 |
| Eurasia | 0 | 5 | 6 | 18 | 44 | 25 | 110 |
| Russia | 0 | 2 | 3 | 6 | 16 | 7 | 41 |
| Asia Pacific | 6 | 589 | 750 | 3 336 | 10 868 | 3 688 | 13 715 |
| China | 1 | 327 | 429 | 2 294 | 6 801 | 2 428 | 7 889 |
| India | 0 | 76 | 105 | 480 | 2 499 | 534 | 3 145 |
| Japan | 4 | 86 | 95 | 162 | 234 | 171 | 245 |
| Southeast Asia | 0 | 38 | 45 | 126 | 633 | 213 | 1 293 |

## Table A.19: Wind generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **342** | **1 865** | **2 125** | **5 229** | **11 801** | **6 208** | **18 432** |
| North America | 105 | 438 | 500 | 1 107 | 2 209 | 1 421 | 3 998 |
| United States | 95 | 383 | 442 | 1 001 | 1 917 | 1 249 | 3 516 |
| Central and South America | 3 | 106 | 119 | 252 | 656 | 279 | 1 105 |
| Brazil | 2 | 72 | 82 | 158 | 406 | 165 | 466 |
| Europe | 154 | 500 | 557 | 1 304 | 2 382 | 1 518 | 3 489 |
| European Union | 140 | 387 | 420 | 985 | 1 790 | 1 121 | 2 594 |
| Africa | 2 | 23 | 25 | 90 | 302 | 128 | 593 |
| Middle East | 0 | 3 | 4 | 26 | 232 | 42 | 665 |
| Eurasia | 0 | 6 | 8 | 23 | 92 | 42 | 249 |
| Russia | 0 | 3 | 5 | 12 | 69 | 17 | 114 |
| Asia Pacific | 77 | 789 | 912 | 2 427 | 5 927 | 2 778 | 8 333 |
| China | 45 | 656 | 762 | 1 963 | 3 876 | 2 026 | 4 026 |
| India | 20 | 77 | 79 | 189 | 1 071 | 241 | 1 449 |
| Japan | 4 | 9 | 10 | 64 | 208 | 78 | 314 |
| Southeast Asia | 0 | 9 | 14 | 55 | 228 | 148 | 1 207 |

## Table A.20: Nuclear generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **2 756** | **2 810** | **2 682** | **3 351** | **4 353** | **3 496** | **5 301** |
| North America | 935 | 916 | 898 | 925 | 934 | 926 | 1 195 |
| United States | 839 | 812 | 804 | 825 | 804 | 825 | 1 023 |
| Central and South America | 22 | 26 | 23 | 31 | 75 | 35 | 83 |
| Brazil | 15 | 15 | 15 | 24 | 45 | 24 | 45 |
| Europe | 1 032 | 889 | 750 | 808 | 781 | 894 | 970 |
| European Union | 854 | 732 | 607 | 623 | 576 | 703 | 698 |
| Africa | 12 | 12 | 11 | 24 | 43 | 29 | 72 |
| Middle East | 0 | 15 | 26 | 45 | 89 | 51 | 146 |
| Eurasia | 173 | 225 | 226 | 238 | 306 | 238 | 315 |
| Russia | 170 | 223 | 224 | 236 | 297 | 236 | 297 |
| Asia Pacific | 582 | 726 | 748 | 1 281 | 2 125 | 1 322 | 2 520 |
| China | 74 | 408 | 418 | 642 | 1 247 | 661 | 1 483 |
| India | 26 | 47 | 50 | 128 | 337 | 125 | 355 |
| Japan | 288 | 71 | 60 | 207 | 206 | 232 | 289 |
| Southeast Asia | 0 | 0 | 0 | 0 | 8 | 0 | 12 |

## Table A.21: Natural gas generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **4 847** | **6 526** | **6 500** | **6 613** | **6 210** | **6 055** | **3 319** |
| North America | 1 217 | 1 933 | 2 039 | 1 916 | 885 | 1 584 | 366 |
| United States | 1 018 | 1 633 | 1 747 | 1 538 | 513 | 1 245 | 169 |
| Central and South America | 170 | 265 | 211 | 243 | 197 | 217 | 71 |
| Brazil | 36 | 87 | 42 | 39 | 42 | 20 | 5 |
| Europe | 946 | 888 | 847 | 489 | 217 | 404 | 75 |
| European Union | 589 | 546 | 547 | 334 | 104 | 252 | 8 |
| Africa | 234 | 366 | 369 | 449 | 638 | 369 | 275 |
| Middle East | 527 | 907 | 919 | 1 207 | 1 636 | 1 223 | 1 102 |
| Eurasia | 603 | 653 | 673 | 745 | 878 | 679 | 727 |
| Russia | 521 | 514 | 524 | 575 | 598 | 531 | 535 |
| Asia Pacific | 1 151 | 1 514 | 1 443 | 1 564 | 1 759 | 1 579 | 704 |
| China | 92 | 290 | 257 | 349 | 371 | 376 | 133 |
| India | 107 | 62 | 39 | 83 | 175 | 81 | 64 |
| Japan | 332 | 359 | 359 | 216 | 92 | 193 | 70 |
| Southeast Asia | 336 | 330 | 338 | 508 | 768 | 445 | 244 |

## Table A.22: Coal generation (TWh)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **8 669** | **10 247** | **10 428** | **8 337** | **4 978** | **6 998** | **2 244** |
| North America | 2 106 | 1 043 | 976 | 222 | 12 | 119 | 30 |
| United States | 1 994 | 992 | 914 | 206 | 12 | 104 | 30 |
| Central and South America | 41 | 67 | 51 | 31 | 19 | 11 | 1 |
| Brazil | 11 | 24 | 14 | 11 | 5 | 0 | 0 |
| Europe | 1 068 | 663 | 691 | 285 | 223 | 211 | 59 |
| European Union | 755 | 453 | 484 | 88 | 3 | 79 | 2 |
| Africa | 259 | 246 | 245 | 188 | 60 | 162 | 18 |
| Middle East | 0 | 1 | 1 | 3 | 4 | 3 | 3 |
| Eurasia | 235 | 267 | 288 | 212 | 198 | 199 | 132 |
| Russia | 166 | 187 | 206 | 117 | 98 | 117 | 89 |
| Asia Pacific | 4 958 | 7 961 | 8 176 | 7 396 | 4 463 | 6 292 | 2 000 |
| China | 3 263 | 5 432 | 5 536 | 4 662 | 2 213 | 3 978 | 1 044 |
| India | 658 | 1 170 | 1 270 | 1 472 | 1 029 | 1 280 | 495 |
| Japan | 317 | 322 | 333 | 196 | 66 | 190 | 60 |
| Southeast Asia | 185 | 508 | 527 | 645 | 874 | 563 | 267 |

## Table A.23: Total final consumption (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **382.7** | **436.2** | **442.4** | **482.0** | **535.8** | **451.0** | **429.0** |
| North America | 76.5 | 77.1 | 79.2 | 77.6 | 72.6 | 73.2 | 54.7 |
| United States | 63.8 | 64.9 | 66.4 | 64.3 | 58.1 | 60.8 | 44.1 |
| Central and South America | 19.2 | 20.2 | 21.0 | 23.7 | 29.4 | 22.5 | 23.8 |
| Brazil | 9.1 | 10.0 | 10.4 | 11.5 | 13.7 | 11.1 | 11.9 |
| Europe | 63.0 | 60.6 | 57.3 | 56.7 | 49.9 | 53.8 | 39.4 |
| European Union | 45.9 | 43.9 | 41.8 | 40.1 | 32.7 | 38.1 | 26.1 |
| Africa | 20.7 | 25.4 | 25.9 | 29.7 | 42.8 | 25.3 | 33.3 |
| Middle East | 19.3 | 23.7 | 24.6 | 29.4 | 39.9 | 28.2 | 35.9 |
| Eurasia | 23.6 | 28.4 | 28.5 | 29.1 | 31.3 | 27.9 | 26.9 |
| Russia | 19.0 | 23.4 | 23.4 | 22.9 | 23.2 | 22.1 | 19.8 |
| Asia Pacific | 145.3 | 187.7 | 190.9 | 216.2 | 242.8 | 201.2 | 193.2 |
| China | 76.3 | 106.1 | 106.9 | 116.4 | 112.9 | 110.2 | 90.5 |
| India | 19.0 | 27.4 | 29.3 | 38.0 | 55.7 | 33.4 | 43.3 |
| Japan | 14.1 | 12.0 | 12.0 | 11.0 | 9.3 | 10.5 | 7.5 |
| Southeast Asia | 16.1 | 19.2 | 19.8 | 24.7 | 33.8 | 23.0 | 27.0 |

## Table A.24: Industry consumption (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **143.0** | **166.7** | **166.6** | **186.8** | **207.3** | **179.2** | **175.4** |
| North America | 17.8 | 18.9 | 19.1 | 20.5 | 22.2 | 19.6 | 18.9 |
| United States | 14.0 | 15.0 | 15.2 | 16.1 | 17.1 | 15.4 | 14.5 |
| Central and South America | 7.2 | 6.8 | 6.9 | 7.8 | 9.4 | 7.5 | 8.4 |
| Brazil | 3.9 | 3.9 | 4.0 | 4.4 | 5.3 | 4.3 | 4.7 |
| Europe | 19.5 | 19.2 | 17.5 | 18.1 | 17.4 | 17.3 | 15.1 |
| European Union | 14.3 | 14.1 | 12.9 | 13.0 | 11.6 | 12.4 | 10.2 |
| Africa | 3.9 | 4.2 | 4.2 | 5.1 | 8.4 | 5.0 | 7.3 |
| Middle East | 8.0 | 9.6 | 10.1 | 11.8 | 14.2 | 11.5 | 13.2 |
| Eurasia | 8.4 | 9.6 | 9.5 | 9.7 | 10.6 | 9.6 | 9.7 |
| Russia | 6.8 | 8.4 | 8.3 | 8.2 | 8.4 | 8.1 | 7.8 |
| Asia Pacific | 78.2 | 98.5 | 99.3 | 113.9 | 125.0 | 108.8 | 102.8 |
| China | 49.5 | 62.6 | 62.6 | 68.0 | 63.6 | 65.0 | 51.4 |
| India | 7.9 | 12.5 | 13.4 | 19.0 | 29.8 | 17.7 | 23.5 |
| Japan | 6.1 | 5.3 | 5.2 | 4.9 | 4.4 | 4.8 | 3.9 |
| Southeast Asia | 6.2 | 8.6 | 8.8 | 11.1 | 15.1 | 10.7 | 13.4 |

## Table A.25: Transport consumption (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **101.7** | **112.4** | **116.5** | **127.5** | **139.2** | **121.8** | **106.3** |
| North America | 29.6 | 29.2 | 29.9 | 28.2 | 23.2 | 26.6 | 15.8 |
| United States | 25.0 | 25.3 | 25.6 | 23.9 | 18.9 | 22.5 | 13.3 |
| Central and South America | 6.1 | 7.1 | 7.4 | 8.7 | 11.3 | 8.3 | 8.0 |
| Brazil | 2.9 | 3.6 | 3.8 | 4.2 | 4.7 | 4.1 | 3.9 |
| Europe | 15.6 | 15.8 | 16.0 | 14.9 | 11.0 | 14.1 | 8.0 |
| European Union | 11.7 | 11.5 | 11.7 | 10.4 | 6.7 | 9.9 | 5.0 |
| Africa | 3.6 | 5.0 | 5.1 | 6.0 | 10.3 | 5.8 | 8.5 |
| Middle East | 4.9 | 5.6 | 6.0 | 7.0 | 9.7 | 6.7 | 7.7 |
| Eurasia | 4.7 | 5.1 | 5.1 | 5.3 | 5.7 | 5.2 | 5.0 |
| Russia | 4.0 | 4.1 | 4.1 | 4.0 | 3.6 | 3.9 | 3.2 |
| Asia Pacific | 22.0 | 31.5 | 32.1 | 38.0 | 41.1 | 36.2 | 31.6 |
| China | 8.3 | 14.6 | 14.3 | 16.4 | 13.2 | 15.8 | 10.7 |
| India | 2.7 | 4.3 | 4.7 | 6.6 | 9.2 | 6.2 | 7.2 |
| Japan | 3.3 | 2.7 | 2.6 | 2.2 | 1.7 | 2.1 | 1.1 |
| Southeast Asia | 3.7 | 5.1 | 5.5 | 7.1 | 8.9 | 6.7 | 6.5 |

## Table A.26: Buildings consumption (EJ)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **116.8** | **131.2** | **132.5** | **138.5** | **158.9** | **122.5** | **122.2** |
| North America | 23.7 | 23.9 | 24.8 | 23.3 | 21.7 | 21.6 | 15.6 |
| United States | 20.5 | 20.3 | 21.2 | 19.7 | 17.9 | 18.4 | 12.8 |
| Central and South America | 4.4 | 5.0 | 5.1 | 5.5 | 6.6 | 4.9 | 5.7 |
| Brazil | 1.4 | 1.7 | 1.8 | 1.9 | 2.6 | 1.8 | 2.3 |
| Europe | 24.3 | 22.3 | 20.6 | 20.5 | 18.6 | 19.2 | 14.0 |
| European Union | 17.6 | 16.0 | 14.8 | 14.4 | 12.4 | 13.6 | 9.4 |
| Africa | 12.4 | 15.4 | 15.7 | 17.6 | 22.5 | 13.6 | 16.1 |
| Middle East | 5.4 | 6.9 | 7.1 | 9.1 | 14.5 | 8.5 | 13.6 |
| Eurasia | 8.4 | 10.6 | 10.6 | 10.8 | 11.5 | 10.1 | 9.1 |
| Russia | 6.2 | 7.9 | 7.9 | 7.7 | 7.8 | 7.2 | 5.9 |
| Asia Pacific | 38.2 | 47.1 | 48.5 | 51.8 | 63.4 | 44.5 | 48.2 |
| China | 15.7 | 23.8 | 24.7 | 26.4 | 31.4 | 24.3 | 25.0 |
| India | 7.0 | 8.3 | 8.6 | 9.1 | 11.8 | 6.4 | 8.5 |
| Japan | 4.3 | 3.7 | 3.7 | 3.5 | 2.9 | 3.3 | 2.3 |
| Southeast Asia | 5.3 | 4.4 | 4.4 | 5.2 | 8.3 | 4.4 | 6.0 |

## Table A.27: Hydrogen demand (PJ)

| | Historical | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **11 129** | **11 425** | **13 219** | **16 631** | **13 915** | **35 596** |
| North America | 1 788 | 1 906 | 2 182 | 2 866 | 2 666 | 8 214 |
| United States | 1 466 | 1 570 | 1 743 | 2 317 | 2 228 | 7 252 |
| Central and South America | 333 | 356 | 483 | 776 | 597 | 2 499 |
| Brazil | 43 | 52 | 82 | 109 | 101 | 397 |
| Europe | 1 029 | 969 | 1 002 | 1 138 | 1 248 | 2 860 |
| European Union | 779 | 714 | 742 | 836 | 936 | 1 932 |
| Africa | 349 | 358 | 468 | 711 | 526 | 1 930 |
| Middle East | 1 386 | 1 479 | 1 859 | 2 404 | 1 789 | 4 300 |
| Eurasia | 850 | 842 | 881 | 899 | 851 | 850 |
| Russia | 778 | 774 | 806 | 807 | 777 | 744 |
| Asia Pacific | 5 394 | 5 515 | 6 453 | 8 184 | 6 373 | 15 361 |
| China | 3 278 | 3 290 | 3 623 | 3 763 | 3 549 | 6 772 |
| India | 963 | 1 006 | 1 321 | 2 123 | 1 227 | 2 902 |
| Japan | 211 | 230 | 216 | 259 | 274 | 901 |
| Southeast Asia | 418 | 447 | 538 | 812 | 544 | 2 340 |
| International bunkers | - | - | 4 | 38 | 29 | 508 |

## Table A.28: Low-emissions hydrogen balance (Mt $H_2$ equivalent)

| | | Stated Policies | | Announced Pledges | | Net Zero Emissions by 2050 | |
|---|---|---|---|---|---|---|---|
| | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Low-emissions hydrogen production | 1 | 7 | 30 | 25 | 246 | 70 | 420 |
| Water electrolysis | 0 | 5 | 22 | 16 | 189 | 51 | 327 |
| Fossil fuels with CCUS | 1 | 2 | 8 | 8 | 56 | 18 | 89 |
| Bioenergy and other | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Transformation of hydrogen | 0 | 5 | 15 | 14 | 116 | 40 | 200 |
| To power generation | - | 1 | 3 | 4 | 23 | 17 | 51 |
| To hydrogen-based fuels | - | 0 | 4 | 6 | 83 | 16 | 142 |
| In oil refining | 0 | 2 | 7 | 4 | 7 | 6 | 6 |
| To biofuels | 0 | 0 | 1 | 2 | 4 | 1 | 1 |
| Hydrogen demand for end-use sectors | 0 | 3 | 16 | 10 | 130 | 30 | 220 |
| Low-emissions hydrogen-based fuels | - | 0 | 3 | 3 | 62 | 12 | 104 |
| Total final consumption | - | 0 | 1 | 3 | 47 | 7 | 84 |
| Power generation | - | 0 | 2 | 0 | 15 | 4 | 20 |
| Trade | - | 1 | 6 | 5 | 42 | 14 | 58 |
| Trade as share of demand | | 18% | 21% | 18% | 17% | 21% | 14% |

## Table A.29: Total $CO_2$ emissions* (Mt $CO_2$)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| **World** | **32 877** | **36 589** | **36 930** | **35 125** | **29 696** | **30 769** | **12 043** |
| North America | 6 470 | 5 631 | 5 702 | 4 570 | 2 892 | 3 683 | 277 |
| United States | 5 456 | 4 669 | 4 697 | 3 608 | 1 982 | 2 900 | 10 |
| Central and South America | 1 153 | 1 185 | 1 178 | 1 205 | 1 333 | 1 044 | 542 |
| Brazil | 411 | 479 | 452 | 448 | 473 | 374 | 172 |
| Europe | 4 720 | 3 990 | 3 826 | 2 961 | 1 846 | 2 390 | 346 |
| European Union | 3 311 | 2 744 | 2 662 | 1 885 | 882 | 1 515 | 81 |
| Africa | 1 168 | 1 364 | 1 385 | 1 468 | 1 991 | 1 328 | 1 171 |
| Middle East | 1 637 | 2 056 | 2 119 | 2 333 | 2 737 | 2 151 | 1 816 |
| Eurasia | 2 153 | 2 330 | 2 348 | 2 193 | 2 144 | 2 066 | 1 644 |
| Russia | 1 688 | 1 846 | 1 856 | 1 645 | 1 470 | 1 569 | 1 192 |
| Asia Pacific | 14 450 | 19 051 | 19 260 | 18 982 | 14 883 | 16 788 | 5 269 |
| China | 8 799 | 12 110 | 12 135 | 11 261 | 6 897 | 9 949 | 1 946 |
| India | 1 685 | 2 462 | 2 627 | 3 252 | 3 363 | 2 875 | 1 481 |
| Japan | 1 201 | 1 057 | 1 062 | 763 | 442 | 684 | 42 |
| Southeast Asia | 1 163 | 1 690 | 1 733 | 2 047 | 2 530 | 1 836 | 982 |

*Includes industrial process and flaring emissions.

## Table A.30: Electricity and heat sectors $CO_2$ emissions (Mt $CO_2$)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| World | 12 511 | 14 598 | 14 822 | 12 302 | 8 217 | 10 597 | 3 004 |
| North America | 2 596 | 1 859 | 1 835 | 991 | 343 | 712 | - 32 |
| United States | 2 346 | 1 627 | 1 599 | 813 | 206 | 558 | - 102 |
| Central and South America | 235 | 262 | 222 | 171 | 111 | 126 | 34 |
| Brazil | 46 | 88 | 50 | 37 | 30 | 11 | 2 |
| Europe | 1 732 | 1 213 | 1 210 | 602 | 361 | 465 | 67 |
| European Union | 1 188 | 805 | 827 | 302 | 74 | 244 | - 5 |
| Africa | 421 | 464 | 468 | 418 | 329 | 360 | 153 |
| Middle East | 550 | 694 | 701 | 719 | 776 | 680 | 486 |
| Eurasia | 1 034 | 1 019 | 1 041 | 911 | 873 | 853 | 686 |
| Russia | 892 | 834 | 850 | 710 | 621 | 676 | 546 |
| Asia Pacific | 5 943 | 9 087 | 9 346 | 8 490 | 5 425 | 7 401 | 1 610 |
| China | 3 509 | 5 967 | 6 141 | 5 331 | 2 817 | 4 643 | 761 |
| India | 785 | 1 166 | 1 227 | 1 408 | 998 | 1 218 | 321 |
| Japan | 500 | 482 | 501 | 266 | 85 | 250 | - 6 |
| Southeast Asia | 398 | 705 | 726 | 879 | 1 115 | 792 | 350 |

## Table A.31: Total final consumption $CO_2$ emissions* (Mt $CO_2$)

| | Historical | | | Stated Policies | | Announced Pledges | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2021 | 2022 | 2030 | 2050 | 2030 | 2050 |
| World | 18 668 | 20 191 | 20 293 | 21 046 | 19 950 | 18 876 | 8 952 |
| North America | 3 455 | 3 343 | 3 419 | 3 128 | 2 182 | 2 697 | 436 |
| United States | 2 850 | 2 783 | 2 820 | 2 529 | 1 596 | 2 201 | 245 |
| Central and South America | 807 | 834 | 861 | 952 | 1 137 | 858 | 482 |
| Brazil | 342 | 371 | 382 | 396 | 433 | 356 | 172 |
| Europe | 2 813 | 2 628 | 2 476 | 2 236 | 1 399 | 1 859 | 281 |
| European Union | 2 009 | 1 839 | 1 736 | 1 498 | 749 | 1 227 | 80 |
| Africa | 561 | 723 | 743 | 886 | 1 496 | 835 | 993 |
| Middle East | 924 | 1 104 | 1 155 | 1 329 | 1 690 | 1 251 | 1 227 |
| Eurasia | 924 | 1 174 | 1 172 | 1 163 | 1 180 | 1 102 | 901 |
| Russia | 672 | 905 | 900 | 847 | 787 | 810 | 609 |
| Asia Pacific | 8 057 | 9 403 | 9 355 | 9 939 | 8 997 | 8 957 | 3 653 |
| China | 5 027 | 5 818 | 5 664 | 5 584 | 3 811 | 5 023 | 1 208 |
| India | 866 | 1 224 | 1 325 | 1 751 | 2 280 | 1 595 | 1 144 |
| Japan | 672 | 558 | 543 | 484 | 368 | 423 | 69 |
| Southeast Asia | 690 | 901 | 930 | 1 124 | 1 363 | 1 013 | 621 |

* Includes industrial process emissions.

# Design of the scenarios

The *World Energy Outlook-2023* (*WEO-2023)* explores three main scenarios in the analysis in the chapters. These scenarios are not predictions – the IEA does not have a single view on the future of the energy system. The scenarios are:

- The **Stated Policies Scenario** (STEPS) is designed to provide a sense of the prevailing direction of energy system progression, based on a detailed review of the current policy landscape. It explores how energy systems evolve under current policies and private sector momentum without additional policy implementation. The scenario is not developed with a particular outcome in mind, but rather aims to hold a mirror up to policy makers to understand where current efforts are likely to lead global energy systems. The STEPS does not take for granted that all government targets will be achieved. Instead, it takes a granular, sector-by-sector look at existing policies and measures, as of late August 2023. New this year, the STEPS takes into account industry action, including manufacturing capacity of clean energy technologies, and its impacts on market uptake beyond the policies in place or announced. A snapshot of the major policies considered in the STEPS is presented in Tables B.6 to B.11.

- The **Announced Pledges Scenario** (APS) assumes that governments will meet, in full and on time, the climate commitments they have made, including their Nationally Determined Contributions and longer-term net zero emissions targets. As with the STEPS, the APS is not designed to achieve a particular outcome, but instead provides a bottom-up assessment of how countries may deliver on climate pledges. Countries without ambitious long-term pledges are assumed to benefit in this scenario from the accelerated cost reductions and wider availability of clean energy technologies. The list of additional climate and energy targets met in the APS is presented in Tables B.6 to B.11. All net zero emissions pledges considered in the APS are included in the IEA Climate Pledges Explorer.[1]

- The **Net Zero Emissions by 2050** (NZE) **Scenario** depicts a narrow but achievable pathway for the global energy sector to reach net zero energy-related $CO_2$ emissions by 2050 by deploying a wide portfolio of clean energy technologies and without offsets from land-use measures. It recognises that achieving net zero energy sector $CO_2$ emissions by 2050 depends on fair and effective global co-operation, with advanced economies taking the lead and reaching net zero emissions earlier in the NZE Scenario than emerging market and developing economies. This scenario also achieves universal energy access by 2030, consistent with the energy-related targets of the United Nations Sustainable Development Goals. The NZE Scenario is consistent with limiting the global temperature rise to 1.5 °C (with at least a 50% probability) with limited overshoot.

[1] The IEA Climate Pledges Explorer is available at: http://www.iea.org/data-and-statistics/data-tools/climate-pledges-explorer

## B.1 Population

**Table B.1 ▷ Population assumptions by region**

| | Compound average annual growth rate | | | Population (million) | | | Urbanisation (share of population) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000-22 | 2022-30 | 2022-50 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 |
| North America | 0.9% | 0.6% | 0.4% | 505 | 528 | 565 | 83% | 84% | 89% |
| United States | 0.7% | 0.5% | 0.4% | 336 | 350 | 372 | 83% | 85% | 89% |
| C & S America | 1.0% | 0.7% | 0.5% | 529 | 559 | 601 | 82% | 83% | 88% |
| Brazil | 0.9% | 0.5% | 0.2% | 215 | 224 | 231 | 88% | 89% | 92% |
| Europe | 0.3% | 0.0% | -0.1% | 695 | 696 | 682 | 76% | 78% | 84% |
| European Union | 0.2% | -0.1% | -0.2% | 449 | 446 | 426 | 75% | 77% | 83% |
| Africa | 2.6% | 2.3% | 2.0% | 1 425 | 1 708 | 2 482 | 44% | 48% | 59% |
| Middle East | 2.2% | 1.4% | 1.1% | 265 | 297 | 364 | 73% | 75% | 81% |
| Eurasia | 0.4% | 0.3% | 0.2% | 238 | 243 | 253 | 65% | 67% | 73% |
| Russia | -0.1% | -0.3% | -0.3% | 143 | 140 | 132 | 75% | 77% | 83% |
| Asia Pacific | 1.0% | 0.6% | 0.3% | 4 295 | 4 489 | 4 734 | 50% | 55% | 64% |
| China | 0.5% | -0.1% | -0.3% | 1 420 | 1 410 | 1 307 | 64% | 71% | 80% |
| India | 1.3% | 0.8% | 0.6% | 1 417 | 1 515 | 1 670 | 36% | 40% | 53% |
| Japan | -0.1% | -0.6% | -0.6% | 125 | 119 | 105 | 92% | 93% | 95% |
| Southeast Asia | 1.2% | 0.8% | 0.5% | 679 | 723 | 787 | 51% | 56% | 66% |
| **World** | **1.2%** | **0.9%** | **0.7%** | **7 950** | **8 520** | **9 681** | **57%** | **60%** | **68%** |

Notes: C & S America = Central and South America. See Annex C for composition of regional groupings.

Sources: UN DESA (2018, 2022); World Bank (2023a); IEA databases and analysis.

- Population is a major determinant of many of the trends in the *Outlook*. We use the medium variant of the United Nations projections as the basis for population growth in all scenarios, but this is naturally subject to a degree of uncertainty.
- On average, the rate of population growth is assumed to slow over time, but the global population approaches 9.7 billion by 2050 (Table B.1).
- Around three-fifths of the increase over the projection period to 2050 is in Africa and around a further quarter is in the Asia Pacific region.
- The share of the world's population living in towns and cities has been rising steadily, a trend that is projected to continue over the period to 2050. In aggregate, this means that virtually *all* of the 1.7 billion increase in global population over the period is added to cities and towns.

## B.2 $CO_2$ prices

**Table B.2 ▷ $CO_2$ prices for electricity, industry and energy production in selected regions by scenario**

| USD (2022, MER) per tonne of $CO_2$ | 2030 | 2040 | 2050 |
|---|---|---|---|
| **Stated Policies Scenario** | | | |
| Canada | 130 | 150 | 155 |
| Chile and Colombia | 13 | 21 | 29 |
| China | 28 | 43 | 53 |
| European Union | 120 | 129 | 135 |
| Korea | 42 | 67 | 89 |
| **Announced Pledges Scenario** | | | |
| Advanced economies with net zero emissions pledges* | 135 | 175 | 200 |
| Emerging market and developing economies with net zero emissions pledges** | 40 | 110 | 160 |
| Other emerging market and developing economies | - | 17 | 47 |
| **Net Zero Emissions by 2050 Scenario** | | | |
| Advanced economies with net zero emissions pledges | 140 | 205 | 250 |
| Emerging market and developing economies with net zero emissions pledges | 90 | 160 | 200 |
| Selected emerging market and developing economies (without net zero emissions pledges) | 25 | 85 | 180 |
| Other emerging market and developing economies | 15 | 35 | 55 |

Note: Values are rounded.

*Includes all OECD countries except Mexico.

*Includes China, India, Indonesia, Brazil and South Africa.

- There are 73 direct carbon pricing instruments in place today, covering around 40 countries and over 30 subnational jurisdictions. Global carbon pricing revenues in 2022 increased by over 10% from 2021 levels, to around USD 95 billion (World Bank, 2023b).
- Existing and scheduled $CO_2$ pricing schemes are reflected in the STEPS, covering electricity generation, industry, energy production sectors and other end-use sectors, e.g. aviation, road transport and buildings, where applicable.
- In the APS, higher $CO_2$ prices are introduced across all regions with net zero emissions pledges. No explicit pricing is assumed in sub-Saharan Africa (excluding South Africa) and Other Asia regions. Instead, these regions rely on direct policy interventions to drive decarbonisation in the APS.
- In the NZE Scenario, $CO_2$ prices cover all regions and rise rapidly across all advanced economies as well as in prominent emerging market economies with net zero emissions pledges, including China, India, Indonesia, Brazil and South Africa. $CO_2$ prices are lower, but nevertheless rising in other emerging market and developing economies such as

North Africa, Middle East, Russia and Southeast Asia (excluding Indonesia). $CO_2$ prices are lower in the remaining developing economies, as it is assumed they pursue more direct policies to adapt and transform their energy systems.

- All scenarios consider the effects of other policy measures alongside $CO_2$ pricing, such as coal phase-out plans, efficiency standards and renewable targets (Tables B.6 - B.11). These policies interact with carbon pricing; therefore, $CO_2$ pricing is not the marginal cost of abatement as it is often the case in other modelling approaches.

## B.3 Fossil fuel resources

**Table B.3 ▹ Remaining technically recoverable fossil fuel resources, 2022**

| Oil (billion barrels) | Proven reserves | Resources | Conventional crude oil | Tight oil | NGLs | EHOB | Kerogen oil |
|---|---|---|---|---|---|---|---|
| North America | 220 | 2 392 | 235 | 215 | 146 | 797 | 1 000 |
| Central and South America | 303 | 854 | 247 | 57 | 49 | 497 | 3 |
| Europe | 14 | 111 | 56 | 19 | 28 | 3 | 6 |
| Africa | 125 | 451 | 312 | 54 | 83 | 2 | - |
| Middle East | 900 | 1 122 | 878 | 29 | 171 | 14 | 30 |
| Eurasia | 146 | 937 | 224 | 85 | 58 | 552 | 18 |
| Asia Pacific | 51 | 275 | 120 | 72 | 64 | 3 | 16 |
| **World** | **1 760** | **6 142** | **2 071** | **531** | **600** | **1 868** | **1 073** |

| Natural gas (trillion cubic metres) | Proven reserves | Resources | Conventional gas | Tight gas | Shale gas | Coalbed methane |
|---|---|---|---|---|---|---|
| North America | 17 | 147 | 50 | 10 | 81 | 7 |
| Central and South America | 9 | 84 | 28 | 15 | 41 | - |
| Europe | 5 | 46 | 18 | 5 | 18 | 5 |
| Africa | 19 | 101 | 51 | 10 | 40 | 0 |
| Middle East | 83 | 121 | 101 | 9 | 11 | - |
| Eurasia | 69 | 167 | 129 | 10 | 10 | 17 |
| Asia Pacific | 21 | 138 | 44 | 21 | 53 | 20 |
| **World** | **222** | **803** | **421** | **80** | **253** | **49** |

| Coal (billion tonnes) | Proven reserves | Resources | Coking coal | Steam coal | Lignite |
|---|---|---|---|---|---|
| North America | 257 | 8 389 | 1 119 | 5 751 | 1 519 |
| Central and South America | 14 | 60 | 3 | 32 | 25 |
| Europe | 137 | 982 | 164 | 414 | 403 |
| Africa | 15 | 343 | 46 | 296 | - |
| Middle East | 1 | 41 | 36 | 5 | - |
| Eurasia | 191 | 2 015 | 386 | 997 | 632 |
| Asia Pacific | 460 | 8 974 | 1 736 | 5 810 | 1 428 |
| **World** | **1 074** | **20 804** | **3 490** | **13 306** | **4 007** |

Notes: NGLs = natural gas liquids; EHOB = extra-heavy oil and bitumen. The breakdown of coal resources by type is an IEA estimate. Coal world resources exclude Antarctica.

Sources: BGR (2021); BP (2022); CEDIGAZ (2022); OGJ (2022); US EIA (2013, 2015, 2023); USGS (2012a, 2012b); IEA databases and analysis.

B

- The *World Energy Outlook* supply modelling relies on estimates of the remaining technically recoverable resource, rather than the (often more widely quoted) numbers for proven reserves. Resource estimates are subject to a considerable degree of uncertainty, as well as the distinction in the analysis between conventional and unconventional resource types.
- Overall, the remaining technical recoverable resources of fossil fuels remain similar to the *World Energy Outlook-2022*. All fuels are at a level comfortably sufficient to meet the projections of global energy demand growth to 2050 in all scenarios. Remaining technically recoverable resources of US tight oil (crude plus condensate) total more than 200 billion barrels.
- Overall, the gradual depletion of resources (at a pace that varies by scenario) means that operators have to develop more difficult and complex reservoirs. This tends to push up production costs over time, although this effect is offset by the assumed continuous adoption of new, more efficient production technologies and practices.
- World coal resources are made up of various types of coal: around 80% is steam and coking coal and the remainder is lignite. Coal resources are more available in parts of the world without substantial natural gas and oil resources, notably in Asia.

## B.4 Electricity generation technology costs

### Table B.4a ▷ Technology costs in selected regions in the Stated Policies Scenario

| | Capital costs (USD/kW) | | | Capacity factor (%) | | | Fuel, $CO_2$, O&M (USD/MWh) | | | LCOE (USD/MWh) | | | VALCOE (USD/MWh) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 |
| **United States** | | | | | | | | | | | | | | | |
| Nuclear | 5 000 | 4 800 | 4 500 | 90 | 90 | 90 | 30 | 30 | 30 | 105 | 105 | 100 | 105 | 105 | 100 |
| Coal | 2 100 | 2 100 | 2 100 | 35 | 15 | n.a. | 30 | 25 | 25 | 100 | 210 | n.a. | 100 | 205 | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 55 | 40 | 15 | 45 | 40 | 40 | 65 | 70 | 120 | 65 | 65 | 75 |
| Solar PV | 1 120 | 690 | 480 | 21 | 22 | 23 | 10 | 10 | 10 | 50 | 30 | 25 | 55 | 55 | 60 |
| Wind onshore | 1 220 | 1 160 | 1 110 | 42 | 43 | 44 | 10 | 10 | 10 | 30 | 30 | 30 | 35 | 40 | 40 |
| Wind offshore | 4 060 | 2 520 | 1 900 | 42 | 46 | 49 | 35 | 20 | 15 | 120 | 70 | 50 | 125 | 80 | 60 |
| **European Union** | | | | | | | | | | | | | | | |
| Nuclear | 6 600 | 5 100 | 4 500 | 70 | 75 | 80 | 35 | 35 | 35 | 160 | 130 | 110 | 160 | 130 | 110 |
| Coal | 2 000 | 2 000 | 2 000 | 30 | n.a. | n.a. | 125 | 150 | 160 | 205 | n.a. | n.a. | 190 | n.a. | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 20 | 10 | n.a. | 170 | 125 | 130 | 230 | 270 | n.a. | 205 | 190 | n.a. |
| Solar PV | 990 | 620 | 450 | 14 | 14 | 14 | 10 | 10 | 10 | 65 | 40 | 35 | 80 | 85 | 90 |
| Wind onshore | 1 750 | 1 670 | 1 610 | 29 | 30 | 30 | 20 | 15 | 15 | 60 | 55 | 55 | 65 | 65 | 60 |
| Wind offshore | 3 420 | 2 280 | 1 740 | 50 | 56 | 59 | 15 | 10 | 10 | 75 | 45 | 35 | 75 | 55 | 40 |
| **China** | | | | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 500 | 80 | 75 | 70 | 25 | 25 | 25 | 70 | 70 | 65 | 70 | 70 | 65 |
| Coal | 800 | 800 | 800 | 50 | 30 | 20 | 50 | 60 | 70 | 65 | 90 | 115 | 65 | 70 | 65 |
| Gas CCGT | 560 | 560 | 560 | 30 | 20 | 15 | 95 | 95 | 100 | 120 | 130 | 140 | 105 | 100 | 90 |
| Solar PV | 720 | 430 | 300 | 13 | 13 | 14 | 10 | 10 | 10 | 50 | 30 | 25 | 65 | 60 | 70 |
| Wind onshore | 1 100 | 1 040 | 1 000 | 26 | 27 | 28 | 10 | 10 | 10 | 45 | 40 | 35 | 50 | 50 | 50 |
| Wind offshore | 2 820 | 1 880 | 1 420 | 32 | 39 | 43 | 25 | 15 | 10 | 100 | 60 | 40 | 105 | 65 | 40 |
| **India** | | | | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 800 | 80 | 85 | 90 | 30 | 30 | 30 | 70 | 70 | 65 | 70 | 70 | 65 |
| Coal | 1 200 | 1 200 | 1 200 | 65 | 70 | 70 | 40 | 35 | 30 | 60 | 55 | 50 | 60 | 50 | 40 |
| Gas CCGT | 700 | 700 | 700 | 25 | 40 | 45 | 95 | 70 | 60 | 125 | 90 | 80 | 120 | 70 | 50 |
| Solar PV | 640 | 390 | 270 | 20 | 21 | 22 | 5 | 5 | 5 | 40 | 25 | 15 | 45 | 40 | 55 |
| Wind onshore | 1 120 | 1 060 | 1 010 | 26 | 28 | 30 | 15 | 10 | 10 | 55 | 45 | 40 | 60 | 50 | 55 |
| Wind offshore | 3 060 | 2 060 | 1 500 | 33 | 37 | 39 | 25 | 20 | 15 | 135 | 85 | 60 | 135 | 90 | 65 |

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; VALCOE = value-adjusted LCOE; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components, LCOE and VALCOE figures are rounded. Lower values for VALCOE indicate improved competitiveness.

Sources: IEA analysis; IRENA (2023).

B

**Table B.4b ▷ Technology costs in selected regions in the Announced Pledges Scenario**

| | Capital costs (USD/kW) | | | Capacity factor (%) | | | Fuel, $CO_2$ and O&M (USD/MWh) | | | LCOE (USD/MWh) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 |
| **United States** | | | | | | | | | | | | |
| Nuclear | 5 000 | 4 800 | 4 500 | 90 | 90 | 90 | 30 | 30 | 30 | 105 | 105 | 100 |
| Coal | 2 100 | 2 100 | 2 100 | 30 | n.a. | n.a. | 90 | 150 | 180 | 175 | n.a. | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 50 | 25 | n.a. | 70 | 90 | 95 | 95 | 135 | n.a. |
| Solar PV | 1 120 | 660 | 460 | 21 | 22 | 23 | 10 | 10 | 10 | 50 | 30 | 25 |
| Wind onshore | 1 220 | 1 150 | 1 080 | 42 | 43 | 44 | 10 | 10 | 10 | 30 | 30 | 30 |
| Wind offshore | 4 060 | 2 440 | 1 720 | 42 | 46 | 49 | 35 | 20 | 15 | 120 | 70 | 45 |
| **European Union** | | | | | | | | | | | | |
| Nuclear | 6 600 | 5 100 | 4 500 | 70 | 80 | 80 | 35 | 35 | 35 | 155 | 120 | 110 |
| Coal | 2 000 | 2 000 | 2 000 | 30 | n.a. | n.a. | 135 | 175 | 215 | 220 | n.a. | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 25 | 10 | n.a. | 170 | 130 | 140 | 220 | 270 | n.a. |
| Solar PV | 990 | 600 | 410 | 14 | 14 | 14 | 10 | 10 | 10 | 65 | 40 | 30 |
| Wind onshore | 1 750 | 1 650 | 1 570 | 29 | 30 | 30 | 20 | 15 | 15 | 60 | 55 | 50 |
| Wind offshore | 3 420 | 2 200 | 1 540 | 50 | 56 | 59 | 15 | 10 | 5 | 75 | 45 | 30 |
| **China** | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 500 | 75 | 70 | 70 | 25 | 25 | 25 | 70 | 70 | 65 |
| Coal | 800 | 800 | 800 | 50 | 25 | 15 | 55 | 85 | 150 | 70 | 125 | 220 |
| Gas CCGT | 560 | 560 | 560 | 35 | 30 | 20 | 100 | 110 | 125 | 120 | 130 | 160 |
| Solar PV | 720 | 420 | 290 | 13 | 13 | 14 | 10 | 10 | 5 | 50 | 30 | 25 |
| Wind onshore | 1 100 | 1 030 | 980 | 26 | 27 | 28 | 10 | 10 | 10 | 45 | 40 | 35 |
| Wind offshore | 2 820 | 1 820 | 1 280 | 32 | 39 | 43 | 25 | 15 | 10 | 100 | 55 | 35 |
| **India** | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 800 | 75 | 85 | 90 | 30 | 30 | 30 | 70 | 70 | 65 |
| Coal | 1 200 | 1 200 | 1 200 | 65 | 70 | 50 | 40 | 65 | 165 | 60 | 85 | 195 |
| Gas CCGT | 700 | 700 | 700 | 25 | 35 | 25 | 90 | 75 | 105 | 120 | 95 | 140 |
| Solar PV | 640 | 380 | 250 | 20 | 21 | 22 | 5 | 5 | 5 | 40 | 25 | 15 |
| Wind onshore | 1 120 | 1 050 | 980 | 26 | 28 | 30 | 15 | 10 | 10 | 55 | 45 | 40 |
| Wind offshore | 3 060 | 1 980 | 1 340 | 33 | 37 | 39 | 25 | 20 | 10 | 135 | 85 | 55 |

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components and LCOE figures are rounded.

Sources: IEA analysis; IRENA (2023).

**Table B.4c ⊳ Technology costs in selected regions in the Net Zero Emissions by 2050 Scenario**

| | Capital costs (USD/kW) | | | Capacity factor (%) | | | Fuel, $CO_2$ and O&M (USD/MWh) | | | LCOE (USD/MWh) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 | 2022 | 2030 | 2050 |
| **United States** | | | | | | | | | | | | |
| Nuclear | 5 000 | 4 800 | 4 500 | 90 | 90 | 85 | 30 | 30 | 30 | 105 | 105 | 105 |
| Coal | 2 100 | 2 100 | 2 100 | 30 | n.a. | n.a. | 90 | 155 | 220 | 185 | n.a. | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 50 | 25 | n.a. | 70 | 85 | 110 | 95 | 135 | n.a. |
| Solar PV | 1 120 | 640 | 440 | 21 | 22 | 23 | 10 | 10 | 10 | 50 | 30 | 25 |
| Wind onshore | 1 220 | 1 140 | 1 070 | 42 | 43 | 44 | 10 | 10 | 10 | 30 | 30 | 25 |
| Wind offshore | 4 060 | 2 360 | 1 640 | 42 | 46 | 49 | 35 | 20 | 15 | 120 | 65 | 45 |
| **European Union** | | | | | | | | | | | | |
| Nuclear | 6 600 | 5 100 | 4 500 | 70 | 75 | 65 | 35 | 35 | 35 | 160 | 130 | 125 |
| Coal | 2 000 | 2 000 | 2 000 | 25 | n.a. | n.a. | 140 | 185 | 250 | 235 | n.a. | n.a. |
| Gas CCGT | 1 000 | 1 000 | 1 000 | 25 | 10 | n.a. | 165 | 125 | 150 | 215 | 240 | n.a. |
| Solar PV | 990 | 580 | 410 | 14 | 14 | 14 | 10 | 10 | 10 | 65 | 40 | 30 |
| Wind onshore | 1 750 | 1 640 | 1 550 | 29 | 30 | 30 | 20 | 15 | 15 | 60 | 55 | 50 |
| Wind offshore | 3 420 | 2 140 | 1 500 | 50 | 56 | 59 | 15 | 10 | 5 | 75 | 45 | 30 |
| **China** | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 500 | 85 | 80 | 75 | 25 | 25 | 25 | 65 | 65 | 65 |
| Coal | 800 | 800 | 800 | 55 | n.a. | n.a. | 70 | 120 | 180 | 90 | n.a. | n.a. |
| Gas CCGT | 560 | 560 | 560 | 45 | 35 | n.a. | 110 | 125 | 145 | 120 | 140 | n.a. |
| Solar PV | 720 | 410 | 280 | 13 | 13 | 14 | 10 | 10 | 5 | 50 | 30 | 20 |
| Wind onshore | 1 100 | 1 030 | 960 | 26 | 27 | 28 | 10 | 10 | 10 | 45 | 40 | 35 |
| Wind offshore | 2 820 | 1 760 | 1 220 | 32 | 39 | 43 | 25 | 15 | 10 | 100 | 55 | 35 |
| **India** | | | | | | | | | | | | |
| Nuclear | 2 800 | 2 800 | 2 800 | 75 | 85 | 90 | 30 | 30 | 30 | 70 | 70 | 65 |
| Coal | 1 200 | 1 200 | 1 200 | 65 | n.a. | n.a. | 40 | 105 | 200 | 60 | n.a. | n.a. |
| Gas CCGT | 700 | 700 | 700 | 25 | 30 | n.a. | 80 | 75 | 110 | 110 | 100 | n.a. |
| Solar PV | 640 | 360 | 240 | 20 | 21 | 22 | 5 | 5 | 5 | 40 | 20 | 15 |
| Wind onshore | 1 120 | 1 040 | 960 | 26 | 28 | 30 | 15 | 10 | 10 | 55 | 45 | 40 |
| Wind offshore | 3 060 | 1 840 | 1 260 | 33 | 37 | 39 | 25 | 15 | 10 | 135 | 75 | 50 |

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components and LCOE figures are rounded.

Sources: IEA analysis; IRENA (2023).

- All costs are expressed in year-2022 dollars.
- Major contributors to the levelised cost of electricity (LCOE) include: overnight capital costs; capacity factor that describes the average output over the year relative to the maximum rated capacity (typical values provided); cost of fuel inputs; plus operation and maintenance. Economic lifetime assumptions are 25 years for solar PV, and onshore and offshore wind.
- Weighted average cost of capital (WACC) assumptions reflect market data and survey information provided through the *Cost of Capital Observatory* (IEA, 2023), updated analysis for utility-scale solar PV in the *World Energy Outlook-2020* (IEA, 2020), with a range of 4-7%, and for offshore wind analysis from the *Offshore Wind Outlook 2019* (IEA, 2019), with a range of 5-8%. Onshore wind was assumed to have the same WACC as utility-scale solar PV. A standard WACC was assumed for nuclear power, coal-fired and gas-fired power plants (8-9% based on the stage of economic development).
- The value-adjusted levelised cost of electricity (VALCOE) incorporates information on both costs and the value provided to the system. Based on the LCOE, estimates of energy, capacity and flexibility value are incorporated to provide a more complete metric of competitiveness for power generation technologies.
- Fuel, $CO_2$ and operation and maintenance costs reflect the average over the ten years following the indicated date in the projections (and therefore vary by scenario in 2022).
- Solar PV and wind costs do not include the cost of energy storage technologies, such as utility-scale batteries.
- The capital costs for nuclear power represent the "nth-of-a-kind" costs for new reactor designs, with substantial cost reductions from the first-of-a-kind projects.

## B.5 Other key technology costs

### Table B.5 ⊳ Capital costs for selected technologies by scenario

| | | Stated Policies | | Announced Pledges | | Net Zero Emissions by 2050 | |
|---|---|---|---|---|---|---|---|
| | 2022 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **Iron-based steel production** (USD/tpa) | | | | | | | |
| Conventional | 340-500 | 340-450 | 360-490 | 380-630 | 490-690 | 440-650 | 590-740 |
| Innovative | n.a | 590-770 | 570-730 | 590-780 | 540-700 | 600-760 | 570-720 |
| **Vehicles** (USD/vehicle) | | | | | | | |
| Hybrid cars | 16 800 | 15 300 | 15 400 | 15 200 | 15 300 | 15 100 | 15 200 |
| Battery electric cars | 20 500 | 16 600 | 14 700 | 16 100 | 14 100 | 15 600 | 13 700 |
| **Batteries and hydrogen** | | | | | | | |
| Hydrogen electrolysers (USD/kW) | 1 070-1 640 | 630-980 | 530-740 | 540-710 | 360-510 | 420-610 | 330-470 |
| Fuel cells (USD/kW) | 95 | 65 | 45 | 55 | 35 | 50 | 30 |
| Utility-scale stationary batteries (USD/kWh) | 315 | 185 | 140 | 180 | 135 | 175 | 130 |

Notes: kW = kilowatt; tpa = tonne per annum; kWh = kilowatt-hour; n.a. = not applicable. All values are in USD (2022).

Sources: IEA analysis; James et. al. (2018); Thompson, et al. (2018); Financial Times (2020); BNEF (2022); Cole et al. (2021); Tsiropoulos et al. (2018); JATO (2021).

- All costs represent fully installed/delivered technologies, not solely the module cost, unless otherwise noted. Installed/delivered costs include engineering, procurement and construction costs to install the module.
- Iron-based steel production costs display a range considering technology and regional differences and differentiate between conventional and innovative production routes. Conventional routes are blast furnace-basic oxygen furnace (BF-BOF) and direct reduced iron-electric arc furnace (DRI-EAF). The innovative routes are innovative smelting reduction with carbon capture, utilisation and storage (CCUS), DRI-EAF with CCUS, 100% electrolytic hydrogen-based DRI-EAF and iron ore electrolysis.
- Vehicle costs reflect production costs, not retail prices, to better reflect the cost declines in total cost of manufacturing, which move independently of final market prices for electric vehicles to customers.
- Electrolyser costs reflect a weighted average among different electrolysis technologies. The lower value for hydrogen electrolysers refers to China and the upper one to the rest of the world.
- Fuel cell costs are based on stack manufacturing costs only, not installed/delivered costs. The costs provided are for automotive fuel cell stacks for light-duty vehicles.
- Utility-scale stationary battery costs reflect the average installed costs of all battery systems rated to provide maximum power output for a four-hour period.

## B.6 Policies

The policy actions assumed to be taken by governments are key variables in this *World Energy Outlook (WEO)*. An overview of the policies and measures that are considered in the various scenarios is included in Tables B.6 to B.11. The tables do not include all policies and measures, but rather highlight the policies most prominent in shaping global energy demand today, while being derived from an exhaustive examination of announcements and plans in countries around the world.

The tables begin with broad cross-cutting policy frameworks, followed by more detailed policies by sector: power, industry, buildings and transport. The tables highlight policies and targets for both the Stated Policies Scenario (STEPS) and the Announced Pledges Scenario (APS). For the STEPS, the tables list both *new policies* enacted, implemented or revised since the publication of the *WEO-2022*, as well as *significant established long-term policies* that have a major influence on the outcomes in the STEPS. It does not take for granted that all government targets will be reached. Targets that are achieved or surpassed in the STEPS are listed, indicating the most recent IEA assessment that concrete implementation plans are able to deliver on the targets.

For the APS, targets not realised in the STEPS and announced policies to achieve these targets are listed. It indicates additional policy efforts to realise them. The APS assumes all policies included in the STEPS to remain in force.

Some regional policies have been included in the tables if they play a significant role in shaping the energy landscape at a global scale, e.g. regional carbon markets, efficiency standards in very large provinces or states. This *World Energy Outlook*, for the first time, includes various industry-led targets for energy and climate, presented in Table B.11. A more comprehensive list of energy-related policies by country can be viewed on the IEA Policies and Measures Database at: http://www.iea.org/policies.

**Table B.6 ▷ Cross-cutting policy assumptions for selected regions/countries by scenario**

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **United States** | STEPS | • Energy provisions in: Inflation Reduction Act (2022); Consolidated Appropriations Act (2021); and Infrastructure Investment and Jobs Act (2021).<br>• Defence Production Act deployment supporting domestic production of heat pumps, building insulation equipment, solar panel components, transformers and batteries.<br>• US Methane Emissions Reduction Action Plan. |
| | APS | • Updated NDC aiming to reduce GHG emissions by 50-52% by 2030 (from 2005 levels) and national target to reach net zero GHG emissions by 2050.<br>• 2021 US Methane Emissions Reduction Action Plan. Commitment to the Global Methane Pledge. |
| **Canada** | STEPS | • Energy and emissions reduction-related provisions in the 2020 Healthy Environment and a Healthy Economy Plan; extended Investing in Canada Infrastructure Programme; and Emissions Reduction Fund.<br>• Hydrogen Strategy and Strategic Innovation Fund.<br>• Regulation Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds. |
| | APS | • Commitment to reach net zero GHG emissions target by 2050.<br>• Commitment to the Global Methane Pledge, and to reduce methane emissions from the oil and gas sector by 40-45% by 2025, and further by 75% by 2030 relative to 2012. Measures in the Healthy Environment and Healthy Economy action plan. |
| **Latin America and the Caribbean** | STEPS | • Colombia: Energy provisions in the Ten Milestones in 2021 Plan and the National Strategy for Mitigation of Short-Lived Climate Pollutants.<br>• Chile: Energy Efficiency Law (2021), energy intensity reduction by at least 10% by 2030 compared to 2019.<br>• Brazil: National Methane emissions reduction programme. |
| | APS | • 16 pledges out of 33 countries to reach net zero emissions by 2050 or before, including Brazil, Chile, Costa Rica and Colombia.<br>• Updated NDCs from Uruguay (0.9 Mt $CO_2$ by 2030).<br>• Colombia: Main provisions of the announced Just Energy Transition roadmap.<br>• Nine countries committing to the Global Methane Pledge, including Argentina and Mexico. |
| **European Union** | STEPS | • Energy spending provisions in the European Green Deal and national recovery plans elaborated within the framework of the EU Recovery and Resilience Facility. |
| | APS | • Full implementation of the decarbonisation targets in the Fit for 55 package.<br>• Net zero emissions target by 2050 embedded in the 2021 European Climate Law.<br>• EU member country-level targets for carbon or climate neutrality before 2050: Finland by 2035; Austria by 2040; Germany, Portugal and Sweden by 2045.<br>• Green Deal Industrial Plan targets enhancing the competitiveness of EU net zero industry.<br>• Targets in the EU Hydrogen Strategy for a Climate Neutral Europe.<br>• Partial implementation of the targets set in the REPowerEU Plan, eliminate the import of Russian natural gas supply to the European Union well before 2030.<br>• 19 EU member states commitment to the Global Methane Pledge. |

**Table B.6 ▷ Cross-cutting policy assumptions for selected regions/countries by scenario** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **Other Europe** | STEPS | • United Kingdom: Ten Point Plan for a Green Industrial Revolution and provisions of the 2021 North Sea Transition Deal.<br>• Norway: 2021 Green Conversion Package. |
| | APS | • United Kingdom: Commitment to reach net zero emissions by 2050. Net Zero Strategy. Build Back Greener Plan. Energy Security Bill to provide public support for domestic manufacturing.<br>• Climate neutrality targets by 2040 (Iceland), and 2050 (Switzerland and Norway).<br>• Türkiye: Updated NDC pledge for a peak in emissions by 2038. Pledge to reach net zero emissions by 2053. |
| **Australia and New Zealand** | STEPS | • Australia: Spending and policy measures from the 2020 Climate Solutions Package; Powering Australia Plan; and Long-Term Emissions Reduction Plan. |
| | APS | • Australia: Full implementation of the 2022 Climate Change Bill emissions target, including net zero emissions by 2050, and 43% emissions reduction by 2030 relative to 2005.<br>• New Zealand: Net zero emissions target for all GHG except biogenic methane by 2050. Reduction by 50% relative to 2005 levels in the updated NDC. Commitment to the Global Methane Pledge. |
| **China** | STEPS | • Made in China 2025 transition from heavy industry to higher value-added manufacturing.<br>• 14th Five-Year Plan:<br>○ Reduce $CO_2$ intensity of the economy by 18% from 2021 to 2025.<br>○ Reduce energy intensity of the economy by 13.5% from 2021 to 2025.<br>○ 20% non-fossil share of the energy mix by 2025, 25% by 2030.<br>• Updated NDC and Action Plan for $CO_2$ to peak before 2030:<br>○ Aim to peak $CO_2$ emissions before 2030.<br>○ Lower $CO_2$ emissions per unit of GDP by over 65% from 2005 levels by 2030. |
| | APS | • Carbon neutrality target by 2060. |
| **India** | STEPS | • Energy-related elements of the Production Linked Incentives programme.<br>• Enhanced enforcement of energy efficiency policy under the 2022 amendments to the Energy Conservation Act.<br>• National Green Hydrogen Mission. |
| | APS | • Updated NDC to reduce national emissions intensity by 45% by 2030 from 2005 levels.<br>• Commitment to reach net zero emissions by 2070. |
| **Southeast Asia** | STEPS | • Indonesia: 23% share of renewable energy in primary energy supply by 2025 and 31% by 2050.<br>• Singapore: Green Plan 2030. |
| | APS | • Indonesia: Net zero emissions by 2060 or before.<br>• Brunei Darussalam, Malaysia, Singapore, Viet Nam: net zero emissions targets by 2050.<br>• Thailand: Climate neutrality by 2065.<br>• Just Energy Transition Partnerships in Indonesia and Viet Nam.<br>• Indonesia, Malaysia, Philippines and Viet Nam: Commitment to the Global Methane Pledge. |

**Table B.6 ⊳ Cross-cutting policy assumptions for selected regions/countries by scenario** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **Japan** | STEPS | • 2023 Green Transformation (GX) basic policy, promoting renewable energy, offshore wind cost reduction RD&D programmes, hydrogen supply chains and accelerated nuclear policies.<br>• 2023 Basic Hydrogen Strategy to accelerate public and private investment in the hydrogen supply chain. |
| | APS | • Climate neutrality target by 2050.<br>• Updated NDC: Reduce GHG emissions by 46% by 2030 from 2013 levels.<br>• Commitment to the Global Methane Pledge. |
| **Korea** | STEPS | • 2023 new budget for energy technology development.<br>• Korean New Deal provisions on clean energy technologies.<br>• 10th Basic Plan for Long-term Electricity Supply and Demand. |
| | APS | • Carbon Neutrality and Green Growth Act for Climate Change committing to carbon neutrality by 2050.<br>• Full implementation of the First National Basic Plan for Carbon Neutrality and Green Growth. |
| **Middle East** | APS | • Net zero emissions targets by 2050 in United Arab Emirates and Oman. Saudi Arabia, Bahrain and Kuwait aiming for 2060.<br>• United Arab Emirates: Commitment to reduce emissions by 19% by 2030 from 2019 levels.<br>• Iraq Zero Routine Flaring by 2030 initiative.<br>• Egypt and Oman: Commitment to the Global Methane Pledge. |
| **Eurasia** | APS | • All NDCs and net zero emissions targets, including Kazakhstan in 2060 and the Russian Federation net zero emissions pledge with a strong reliance on sinks from land-use, land-use change and forestry.<br>• Kazakhstan National Methane Emissions Inventory and Reduction Programme. |

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NDC = Nationally Determined Contribution (Paris Agreement); CCUS = carbon capture, utilisation and storage; GHG = greenhouse gases; GW = gigawatt; Gt = gigatonnes; Mt = megatonnes; RD&D = research development and demonstration.

**Table B.7 ⊳ Electricity sector policies and measures as modelled by scenario for selected regions/countries**

| Region/ country | Scenario | Assumptions |
|---|---|---|
| United States | STEPS | • Inflation Reduction Act (2022) grants and tax credits for renewables, nuclear power and CCUS.<br>• 100% carbon-free electricity or energy targets by 2050 in up to 21 states plus Puerto Rico and Washington DC.<br>• 30 GW offshore wind capacity by 2030.<br>• 22 updated renewable portfolio standard policies in 2022/23 (including Connecticut, Hawaii, Rhode Island, Minnesota). |
| | APS | • G7 commitment: Achieve predominantly decarbonised electricity sector by 2035. |
| Canada | STEPS | • Reach nearly 90% non-emitting renewables generation by 2030.<br>• Phase out conventional coal-fired plants by 2030. |
| | APS | • G7 commitment: Achieve predominantly decarbonised electricity sector by 2035. |
| European Union | STEPS | • 16 member states have coal phase-out commitments. Spain aims to phase out coal by 2025, five years earlier than its former announcement. Nine EU member states are already coal free.<br>• Updated development plans and targets for offshore wind by 2030, notably in Germany (30 GW) and the Netherlands (21 GW). |
| | APS | • Higher targets for renewables (42.5% renewables share of gross final consumption by 2030) within the Fit for 55 package.<br>• G7 commitment: Achieve predominantly decarbonised electricity sector by 2035. |
| Other Europe | APS | • United Kingdom: Energy Security Plan sets targets to expand offshore wind, solar PV and nuclear power.<br>• G7 commitment: Achieve predominantly decarbonised electricity sector by 2035. |
| Africa | STEPS | • Partial implementation of national electrification strategies.<br>• South Africa: Increased renewables capacity and reduced coal-fired capacity under the 2019 Integrated Resource Plan. |
| | APS | • Kenya: 100% renewable electricity by 2030.<br>• Senegal: 32% renewable grid-connected installed capacity by 2030.<br>• Full implementation of national electrification targets. |
| China | STEPS | • 14th Five-year Plan for Renewables targets for 3 300 TWh of renewables by 2025, a twofold increase in solar and wind generation, and for over 50% of incremental electricity consumption to be met by renewables.<br>• At least 1 200 GW of installed solar and wind capacity by 2030. |
| | APS | • Overall coal use to decline in the 15th Five-Year Plan period (2025-2030). |
| India | STEPS | • Updated Nationally Determined Contribution: 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.<br>• Reach 500 GW of non-fossil capacity by 2030. |
| Japan | STEPS | • Achieve electricity generation outlook by 2030 in the 6th Strategic Energy Plan.<br>• Restart nuclear power plants aligned with the 6th Strategic Energy Plan and the Green Transformation (GX) policy initiative. |
| | APS | • Accelerated nuclear expansion, including small modular reactors, under discussion in the Green Transformation (GX) Implementation Council.<br>• Green Growth Strategy: 30-45 GW of offshore wind capacity in 2040.<br>• 6th Strategic Energy Plan, with additional policies to support renewables in power generation to reach 2030 targets.<br>• G7 commitment: Achieve predominantly decarbonised electricity sectors by 2035. |

**Table B.7 ▷ Electricity sector policies and measures as modelled by scenario for selected regions/countries** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| Latin America and the Caribbean | STEPS | • Argentina: National Energy Transition Plan to 2030 aims at least 50% of renewable electricity, of which 1 GW is distributed power by 2030.<br>• Brazil: At least 23% renewables (excluding hydropower) in the power supply by 2030.<br>• Chile: Phase out unabated coal use by 2040.<br>• 24 out of 33 countries have targets to expand installed capacity of renewables. |
| | APS | • Colombia: New National Energy Plan, target to reach 100% renewable electricity by 2050.<br>• Costa Rica: Generation Expansion Plan 2022-2040 target for 1 775 MW of solar and wind capacity. |
| Australia and New Zealand | STEPS | • Australia: 82% renewable electricity generation by 2030. |
| Korea | STEPS | • Increase both nuclear and renewables in electricity generation to about 35%, and decrease coal-fired power by 2036 under the 10th Basic Plan for Long-term Electricity Supply and Demand. |
| | APS | • Power sector reduction target to 45.9% by 2030 from 2018 levels in the 2023 update of the National Basic Plans for Carbon Neutrality and Green Growth. |
| Southeast Asia | STEPS | • Viet Nam: Power Development Plan 8 targets for 2030 include: solar capacity to increase by 4 GW; onshore wind to reach 22 GW; offshore wind to reach 6 GW; hydropower to reach 29 GW; natural gas to reach 38 GW; and coal-fired capacity to peak at 30 GW.<br>• Cambodia: Power Development Plan 2022-2040 targets 3.1 GW of solar capacity and 3 GW of hydropower by 2040. |
| | APS | • Indonesia: Renewable energy accounts for half (21 GW) of total power capacity additions under the National Electricity Supply Business Plan 2019-2028.<br>• Indonesia adopted regulations for early retirement of coal-fired power plants and a moratorium on new coal plants after 2030. |

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. TWh = terawatt-hour; GW = gigawatt; MW = megawatt.

**Table B.8 ▷ Industry sector policies and measures as modelled by scenario for selected regions/countries**

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **All regions** | APS | • UN Resolution to end plastic pollution with a ban on single-use plastics. |
| **United States** | STEPS | • Inflation Reduction Act (2022): Clean manufacturing tax credits for CCUS.<br>• Carbon Utilization Procurement Grants: USD 100 million available to support states, local governments and public utilities for purchasing procurements of products derived from captured $CO_2$ emissions. |
| | APS | • Department of Energy Industrial Decarbonization Roadmap: 80% emissions reduction compared to 2015 from energy efficiency, CCUS and switching to low-emissions fuels.<br>• Federal Buy Clean Initiative: Public procurement of low-carbon construction materials. |
| **Canada** | STEPS | • Clean industry packages and provisions to promote clean industry, as part of Building Canada's Clean Industrial Advantage. |
| **Latin America and the Caribbean** | STEPS | • Brazil: Energy efficiency guarantee fund.<br>• Argentina: Industry 4.0 development plan to promote efficiency and high-tech industries.<br>• Colombia: 25% tax break on energy efficiency investments. |
| | APS | • Argentina, Brazil and Chile: Product Efficiency Call to Action initiative aims to double the efficiency of lighting, cooling and motors by 2030. |
| **European Union** | STEPS | • Emissions Trading System update: 2.2% annual reductions of emissions allowances.<br>• Innovation Fund support for renewables, energy-intensive industries, storage and CCUS.<br>• Sweden: Government credit guarantees for green investment.<br>• France 2030: EUR 5.6 billion for heavy industry decarbonisation. |
| | APS | • Net Zero Industry Act: Target to reach 40% of near zero emissions material production capacity in capacity additions in the European Union by 2030. |
| **Other Europe** | STEPS | • United Kingdom: Industrial Decarbonisation Challenge. Pilot funding for low-emissions industrial clusters, and Industrial Energy Transformation Fund funding for energy efficiency. UK emissions trading system. |
| | APS | • United Kingdom: Industrial Decarbonisation Strategy and Net Zero Strategy, including a target to capture and store 20-30 Mt $CO_2$ per year by 2030. |
| **Australia and New Zealand** | STEPS | • Australia: National Hydrogen Strategy to develop clean hydrogen. |
| **China** | STEPS | • Made in China 2025 targets for industrial energy intensity.<br>• Reduce comprehensive energy consumption per tonne of steel by 2% by 2025. |
| | APS | • Expansion of the emissions trading system coverage to industry.<br>• Made in China 2025: Raising domestic content of electronic and transportation industries core components and materials to 70% by 2025. |
| **India** | STEPS | • Perform, Achieve and Trade Scheme to trade energy saving credits.<br>• Make in India programme. Construction of 11 industrial corridors.<br>• Production Linked Incentives provide subsidies related to new manufacturing capacity for solar PV and modern batteries. |
| **Japan** | STEPS | • Green Innovation Fund provides R&D funding for innovative technology. |
| | APS | • Technology Roadmap for Transition Finance in the cement, pulp and paper branches. |
| **Korea** | STEPS | • Korean New Deal government investment in industrial energy efficiency by 2025. |

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; CCUS = carbon capture, utilisation and storage; R&D = research and development; UN = United Nations.

**Table B.9 ▷ Buildings sector policies and measures as modelled by scenario for selected regions/countries**

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **United States** | STEPS | • Inflation Reduction Act (2022): Tax rebates for heat pumps and energy efficiency upgrades in residential and commercial buildings.<br>• 2023 update to minimum energy performance standards (MEPS) for central air conditioners and heat pumps. |
| | APS | • State and local implementation of energy smart and zero energy building codes.<br>• Federal Building Performance Standard: Achieve net zero emissions in all federal buildings by 2045 with interim targets for electrification and decarbonisation. |
| **Canada** | STEPS | • Large-scale energy-efficient retrofits as part of the Canada Infrastructure Bank growth plan. Greener Homes Grant and interest-free loans for deep home retrofits.<br>• Updated National Energy Code of Canada for Buildings.<br>• Oil to Heat Pump Affordability Programme.<br>• Updated appliance efficiency standards. |
| | APS | • All new buildings meet zero-carbon-ready standards by 2030. |
| **Latin America and the Caribbean** | STEPS | • Argentina: Strengthened building energy codes and mandatory efficiency labelling for new social housing.<br>• Colombia: Support for efficient lighting, efficient refrigerators and substitution of firewood use with LPG or electric cooking stoves.<br>• MEPS for major residential appliances and equipment, including in: Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Mexico and Peru. |
| | APS | • Chile: Energy 2050 Strategy: All households to have access to low-emissions sources for heating and cooking by 2040; all new buildings to be net zero energy use by 2050.<br>• All national clean cooking targets are met. Three countries are already in compliance with the SDG 7, which aims to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. |
| **European Union** | STEPS | • Country-level government incentives and investment in energy efficiency in buildings and appliance upgrades, within the framework of the EU Recovery and Resilience Facility.<br>• Country-level building code upgrades.<br>• National and subnational bans and policies to limit the installation of certain fossil fuel boilers in buildings. |
| | APS | • Energy Performance of Buildings Directive: Objective to achieve a highly energy-efficient and decarbonised building stock by 2050. All new buildings to be net zero emissions by 2028. Retrofits required for existing buildings with lowest energy performance. Fossil fuel heating systems banned in new or renovated buildings.<br>• Renovation Wave: Objective to double the rate of building energy retrofits by 2030. |
| **Other Europe** | STEPS | • Norway: Ban on fossil fuel heating installations, financial incentives for heat pumps, minimum efficiency standards for heating.<br>• Türkiye: Minimum efficiency and renewable consumption standards for large buildings.<br>• United Kingdom: Low-Carbon Heat Support and Heat Networks Investment Project; 2023 Social Housing Decarbonisation Fund; Home Upgrade Grant allocations; and financial incentives to purchase clean household technologies. |
| | APS | • Switzerland: Annual renovation rate target of 3% of the building stock by 2035.<br>• National and subnational bans and policies to limit the installation of certain fossil fuel boilers in buildings. |

**Table B.9 ⊳ Buildings sector policies and measures as modelled by scenario for selected regions/countries** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **Africa** | STEPS | • Southern African Development Community: lighting standards.<br>• MEPS for major residential appliances and equipment, including in Algeria, Benin, Egypt, Ghana, Kenya, Morocco, Nigeria, Rwanda, South Africa and Tunisia. |
| | APS | • All national clean cooking targets met. Eight countries are already in compliance with the SDG 7. |
| **Australia and New Zealand** | STEPS | • Australia: Funding for energy efficiency measures, including energy rating labels and state funding for buildings retrofits. Energy efficiency standards for new homes upgraded in 2023.<br>• New Zealand: Replacement of all coal-fired boilers in schools with electric or renewable biomass alternatives by 2025. |
| **China** | STEPS | • Standard set for maximum energy consumption per square metre in buildings.<br>• Green and High-Efficiency Cooling Action Plan.<br>• MEPS and energy efficiency labelling for room air conditioners. |
| | APS | • 14th Five-Year Plan related to energy conservation in buildings: Target to reach solar PV capacity of 50 GW in new buildings by 2025. Geothermal energy for 100 million square metres of buildings floorspace.<br>• Carbon neutrality / peaking blueprint: Retrofit public buildings in key cities so that they are 20% more energy efficient by 2030. Increased use of low-carbon materials and re-use of construction waste. |
| **India** | STEPS | • Energy Conservation and Sustainable Building Code as part of the Energy Conservation Bill (amendment), comprising norms or energy efficiency and conservation, minimum use of renewable energy and other green building requirements.<br>• Cooling Action Plan. Standards and labelling for commercial air conditioners, freezers and light bulbs.<br>• Energy efficiency labelling for residential buildings. |
| | APS | • Smart Meter National Programme to facilitate demand-side reductions.<br>• AC @ 24 Campaign incentivising behavioural change to reduce cooling energy demand. |
| **Japan** | STEPS | • National Budget 2021: Allocation to decarbonise and promote resilience in buildings.<br>• Subsidies for highly efficient heat pumps. 2016 Buildings Energy Efficiency Act: Standards. |
| | APS | • New residential and services buildings collectively meet the net zero energy home or net zero energy buildings standards by 2030. |
| **Korea** | STEPS | • Rebate for purchase of appliances entitled to energy efficiency grade 1.<br>• Korean New Deal: Increased funding to improve the efficiency of schools, public housing, and recreational and healthcare facilities. |
| | APS | • Green Building Construction Support Act provides administrative and financial support to promote the creation of green buildings.<br>• All new buildings meet zero-carbon-ready standards starting in 2030. |
| **Southeast Asia** | STEPS | • Malaysia: MEPS and efficiency labelling for washing machines, refrigerators and air conditioners.<br>• Philippines: Minimum requirements for energy efficiency of new and retrofitted buildings.<br>• Singapore: Building codes for new buildings and the refurbishment of existing buildings.<br>• Viet Nam: MEPS and efficiency labelling for appliances and lighting in buildings. |

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; GW = gigawatt; LPG = liquefied petroleum gas; MEPS = minimum energy performance standards; SDG = Sustainable Development Goals.

**Table B.10 ▷ Transport sector policies and measures as modelled by scenario for selected regions/countries**

| Region/ country | Scenario | Assumptions |
|---|---|---|
| All regions | APS | • Zero Emissions Vehicles Declaration: Signed by 41 governments declares that all sales of new cars and vans are to be zero emissions globally by 2040, and by no later than 2035 in leading markets.<br>• Heavy-duty vehicles: Global MoU signed by 22 countries that targets 100% of new heavy-duty truck and bus sales to be zero emissions by 2040. |
| United States | STEPS | • Inflation Reduction Act (2022): Provides for tax credits for electric car purchases and investments in EV charging infrastructure to 2032. Tax credits for biofuels including sustainable aviation fuel.<br>• Target of 50% of all new passenger car sales to be zero emissions vehicles by 2030.<br>• Fuel economy standards to improve 8% per year for passenger cars and light trucks for model years 2024-2025 and baseline requirement of 10% for model year 2026 relative to 2021 levels. GHG emissions standards for model years 2023-2026 that require 5-10% emissions reductions per year.<br>• National Electric Vehicle Infrastructure Formula Programme: Funding for construction of EV charging infrastructure.<br>• California: Advanced Clean Cars II regulation aims to achieve 100% zero emissions passenger cars and light truck sales by 2035. In addition, Advanced Clean trucks and fleets regulations require an increase in sales of zero emissions medium-duty and heavy-duty trucks. Other states have announced similar actions. |
| | APS | • Announced multi-pollutant emissions standards for passenger cars and light-duty vehicles. Proposed Phase 3 of heavy-duty vehicles emissions standards.<br>• Sustainable Aviation Fuel Grand Challenge to scale up the production of at least 3 billion gallons per year by 2030, and sufficient sustainable aviation fuel to meet 100% of domestic aviation demand by 2050.<br>• 100% of medium-duty and heavy-duty truck sales to be zero emissions vehicles by 2040. |
| Canada | APS | • Emissions Reduction Plan: Target to achieve 100% zero emissions light-duty vehicles in new vehicle sales by 2035.<br>• 100% of new medium-duty and heavy-duty truck sales to be zero emissions vehicles by 2040.<br>• Target for 10% sustainable aviation fuel use by 2030. |
| Latin America and the Caribbean | STEPS | • Brazil: Biodiesel blending mandate to increase to 15% by 2026. |
| | APS | • Argentina: 35% of the vehicles sales are to be electric or hybrids by 2030.<br>• Colombia: 600 000 EVs on the road by 2030 (excluding two/three- wheelers).<br>• Chile: All light-duty vehicle and urban bus sales are to be zero emissions by 2035 and medium-duty and heavy-duty truck sales by 2040.<br>• Costa Rica: Target of 100% of new light-duty vehicles sales to be zero emissions vehicles from 2050.<br>• Mexico: All sales of new cars and vans to be zero emissions by 2040. |

**Table B.10 ▷ Transport sector policies and measures as modelled by scenario for selected regions/countries** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **European Union** | STEPS | • 100% $CO_2$ emissions reduction for both new cars and vans from 2035, emissions standards for heavy-duty vehicles and FuelEU maritime initiative.<br>• Alternative Fuels Infrastructure Regulation to accelerate EV recharging infrastructure deployment.<br>• Renewable Energy Directive II to supply a minimum of 14% of the energy consumed in road and rail transport from renewable energy by 2030. |
| | APS | • Emissions per km from new heavy-duty vehicles to decrease by 90% by 2040, relative to the reference period (mid-2019 – mid-2020).<br>• Revised Clean Vehicles Directive including minimum requirements for aggregate public procurement for zero emissions urban buses.<br>• ReFuelEU Aviation sets a 70% blending mandate of sustainable aviation fuels by 2050, with a sub-obligation for synthetic fuels.<br>• FuelEU Maritime initiative targets the reduction of average GHG intensity of energy used on-board by ships up to 75% by 2050 relative to 2020 levels. |
| **Other Europe** | STEPS | • United Kingdom: 10% ethanol blend mandate by 2032.<br>• Switzerland: 100% of new light-duty vehicle sales to be zero emissions by 2040. |
| | APS | • Türkiye: 100% of medium-duty and heavy-duty truck new sales to be zero emissions vehicles by 2040.<br>• Norway: Target for 30% sustainable aviation fuel target by 2030. |
| **Australia and New Zealand** | APS | • Australia: National Electric Vehicle Strategy includes details of state-level targets and incentives.<br>• New Zealand: 100% of new cars and van sales to be zero emissions by 2035. Targets zero emissions vehicles to make up 100% of urban bus sales by 2025 and 100% of stock by 2035. Increase zero emissions vehicles to 30% of the light-duty vehicle fleet by 2035. |
| **Japan** | STEPS | • Fuel economy standard for light-duty vehicles to improve fuel efficiency by 32% to 2030 relative to 2016 levels. |
| | APS | • Green Growth Strategy and 6th Strategic Energy Plan aims for sales of 100% EVs (including hybrids) for passenger cars by 2035 and for light commercial vehicles by 2040.<br>• Mandate for 10% sustainable aviation fuel use by 2030 for national airlines. |
| **Korea** | STEPS | • Grants available for the purchase of private and commercial light-duty electric vehicles and subsidies for electric buses.<br>• Subsidies for shifting from road freight to rail.<br>• Target of one-third of new passenger car sales to be EVs or fuel cell electric vehicles by 2030. |
| | APS | • Target for zero emissions vehicles by 2030: 50% of passenger car sales to be hybrid or plug-in hybrid vehicles; and 33% to be battery electric or fuel cell electric vehicles. |

**Table B.10 ▷ Transport sector policies and measures as modelled by scenario for selected regions/countries** (continued)

| Region/ country | Scenario | Assumptions |
|---|---|---|
| **China** | STEPS | • Corporate average fuel consumption target of 4.0 litres/100 km in 2025 and 3.2 litres/100 km in 2030.<br>• New Energy Automobile Industry Development Plan (2021-2035): Exceeds government targets of 20% new energy vehicle sales in 2025 and 40% new energy and clean energy-powered vehicles in 2030.<br>• China Society of Automotive Engineers target: EV car sales to reach more than half by 2035 including 1 million FCEVs.<br>• Extension of tax exemption for new energy vehicles to 2027.<br>• National railway investments. |
| | APS | • Installation of charging infrastructure for more than 20 million EVs by 2025. |
| **India** | STEPS | • New EV policy to support deployment of charging infrastructure, electric mobility in public transportation and purchases incentives.<br>• Urban and public transit investments.<br>• Partial implementation of 20% bioethanol blending target for gasoline and 5% biodiesel in 2025-2026.<br>• Extension of FAME II subsidies for EVs including support for 500 000 electric three-wheelers and 1 million electric two-wheelers. |
| | APS | • Aim to electrify all broad-gauge rail networks by the end of 2023.<br>• National railway target of net zero emissions by 2030. |
| **Southeast Asia** | STEPS | • Indonesia: B30 programme to increase biodiesel blends from 30% to 40% mandate by 2023. Subsidies to support deployment of battery electric vehicles. |
| | APS | • Indonesia: Government targets to have 2 million EVs in passenger light-duty vehicle stock and 13 million electric motorcycles in the fleet by 2030.<br>• Thailand: Target for 100% zero emissions vehicles in new sales from 2035.<br>• Viet Nam: Net zero GHG emissions in the transport sector by 2050, with a goal of 100% of road transport to use electricity and green energy.<br>• Singapore: Target to phase out passenger ICE vehicles by 2040. |
| **Other Asia** | APS | • Pakistan: Targets for new vehicle sales: 30% of passenger light-duty vehicle sales to be electric by 2030; 90% of truck sales to be electric vehicles by 2040; 90% of urban bus sales to be electric vehicles by 2040; and 50% of electric two/three-wheeler sales by 2030. |
| **Africa** | STEPS | • 28 countries have adopted the LDV Euro 3 or superior standard for second-hand vehicle imports, as well an upper age limit of eight years for imports. |
| | APS | • Ghana: 4%, 16% and 32% of cars and buses sold to be EVs in 2025, 2030 and 2050 respectively. |

Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. MoU = memorandum of understanding; GHG = greenhouse gases; km = kilometre; ICE = internal combustion engine; EVs = electric vehicles; FCEVs = fuel cell electric vehicle; CNG = compressed natural gas; LDV = light-duty vehicles. Light-duty vehicles include passenger cars and light commercial vehicles (gross weight <3.5 tonnes). Heavy-duty vehicles include both medium freight trucks (gross weight 3.5 to 15 tonnes) and heavy freight trucks (gross weight >15 tonnes).

**Table B.11 ▷ Industry-led initiatives and manufacturing targets by scenario**

| Initiatives | Type of pledge | Pledge | Achievement in: STEPS | Achievement in: APS |
|---|---|---|---|---|
| **Steel** | | | | |
| First Mover Coalition | Procurement | 10% of low-carbon steel by 2030. | Partially met | Fully met |
| Net Zero Initiative | Technology deployment | Bring zero-carbon primary steel production technologies to market by 2030. | Not met | Fully met |
| Glasgow Breakthrough | Procurement | Near zero emissions steel to be preferred for every member of the coalition (including European Union and United States). | Partially met | Fully met |
| **Cement** | | | | |
| Concrete Action for Climate | Emissions reduction | Achieve net zero carbon emissions from operations by 2050. | Not met | Partially met |
| **Shipping** | | | | |
| IMO Declaration on Zero Emissions Shipping by 2050 | Emissions reduction | Net zero emissions international shipping by 2050. | Not met | Fully met |
| **Aviation** | | | | |
| IATA Net Zero Initiative | Emissions reduction | Net zero emissions from international aviation by 2050. | Not met | Fully met |
| ICAO initiative | Emissions reduction | Offset $CO_2$ emissions above 2019 levels. | Partially met | Fully met |
| **Zero emissions vehicles** | | | | |
| Global MoU on Zero Emissions Medium-duty and Heavy-Duty Vehicles | Technology deployment | 100% of new MHDVs to be zero emissions by 2040. | Not met | Fully met |
| COP26 Declaration | Technology deployment | All sales of new light-duty vehicles to be zero emissions globally by 2040, and by no later than 2035 in leading markets. | Not met | Fully met |
| Car manufacturers corporate targets | Sales targets | EV share to reach 38-53% globally (IEA estimates). | Low-range met | Mid-range met |

Note: IMO = International Maritime Organization; IATA = International Air Transport Association; ICAO = International Civil Aviation Organization; MoU = memorandum of understanding; EV = electric vehicle; MHDVs = medium-duty and heavy-duty vehicles.

# Definitions

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

## Units

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

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

## General conversion factors for energy

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

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

## Currency conversions

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

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

## *Definitions*

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

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

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

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

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

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

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

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

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

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

**Biogases:** Include both biogas and biomethane.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

C

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

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

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

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

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

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

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

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

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

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

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

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

**Energy services:** See useful energy.

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

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

**Fossil fuels:** Include coal, natural gas and oil.

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

**Gases:** See gaseous fuels.

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

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

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

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

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

**Heavy industries:** Iron and steel, chemicals and cement.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Modern gaseous bioenergy:** See biogases.

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

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

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

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

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

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

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

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

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

**Non-energy-intensive industries:** See other industry.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Solar:** Includes both solar photovoltaics and concentrating solar power.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Unabated fossil fuel use:** Consumption of fossil fuels in facilities without CCUS.

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

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

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

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

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

## *Regional and country groupings*

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

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

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

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

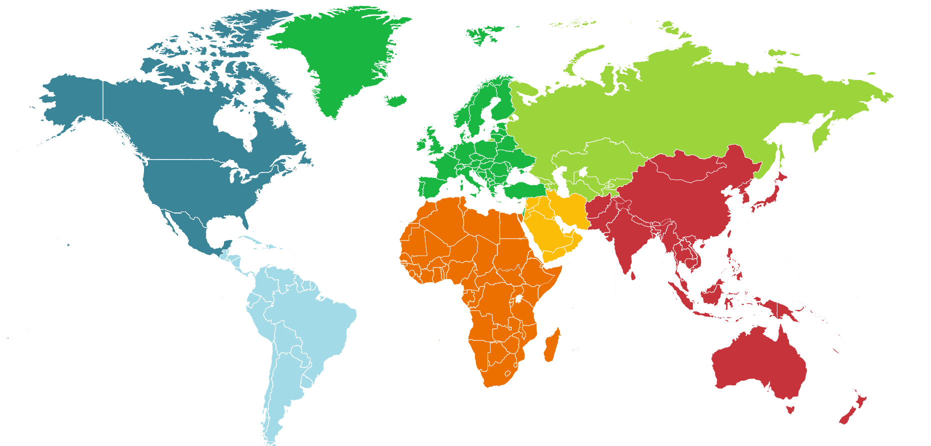
**Central and South America:** Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru,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

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

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

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

**Figure C.1 ▷ Main country groupings**




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

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

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

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

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

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

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

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

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

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

**North America:** Canada, Mexico and United States.

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

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

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

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

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

### *Country notes*

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

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

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

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

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

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

## *Abbreviations and acronyms*

| | |
|---|---|
| **AC** | alternating current |
| **AFOLU** | agriculture, forestry and other land use |
| **APEC** | Asia-Pacific Economic Cooperation |
| **APS** | Announced Pledges Scenario |
| **ASEAN** | Association of Southeast Asian Nations |
| **BECCS** | bioenergy equipped with CCUS |
| **BEV** | battery electric vehicles |
| **CAAGR** | compound average annual growth rate |
| **CAFE** | corporate average fuel economy standards (United States) |
| **CBM** | coalbed methane |
| **CCGT** | combined-cycle gas turbine |
| **CCUS** | carbon capture, utilisation and storage |
| **CDR** | carbon dioxide removal |
| **CEM** | Clean Energy Ministerial |
| **$CH_4$** | Methane |
| **CHP** | combined heat and power; the term co-generation is sometimes used |
| **CNG** | compressed natural gas |
| **CO** | carbon monoxide |
| **$CO_2$** | carbon dioxide |
| **$CO_2$-eq** | carbon-dioxide equivalent |
| **COP** | Conference of Parties (UNFCCC) |
| **CSP** | concentrating solar power |
| **CTG** | coal-to-gas |
| **CTL** | coal-to-liquids |
| **DAC** | direct air capture |
| **DACS** | direct air capture and storage |
| **DC** | direct current |
| **DER** | distributed energy resources |
| **DFI** | development finance institutions |
| **DRI** | direct reduced iron |
| **DSI** | demand-side integration |
| **DSO** | distribution system operator |
| **DSR** | demand-side response |
| **EHOB** | extra-heavy oil and bitumen |
| **EMDE** | emerging market and developing economies |
| **EOR** | enhanced oil recovery |
| **EPA** | Environmental Protection Agency (United States) |
| **ESG** | environmental, social and governance |
| **ETS** | emissions trading system |
| **EU** | European Union |
| **EU ETS** | European Union Emissions Trading System |
| **EV** | electric vehicle |

| | |
|---|---|
| **FAO** | Food and Agriculture Organization of the United Nations |
| **FCEV** | fuel cell electric vehicle |
| **FDI** | foreign direct investment |
| **FID** | final investment decision |
| **FiT** | feed-in tariff |
| **FOB** | free on board |
| **GEC** | Global Energy and Climate (model) |
| **GDP** | gross domestic product |
| **GHG** | greenhouse gases |
| **GTL** | gas-to-liquids |
| **$H_2$** | hydrogen |
| **HDV** | heavy-duty vehicle |
| **HEFA** | hydrogenated esters and fatty acids |
| **HFO** | heavy fuel oil |
| **HVDC** | high voltage direct current |
| **IAEA** | International Atomic Energy Agency |
| **ICE** | internal combustion engine |
| **ICT** | information and communication technologies |
| **IEA** | International Energy Agency |
| **IGCC** | integrated gasification combined-cycle |
| **IIASA** | International Institute for Applied Systems Analysis |
| **IMF** | International Monetary Fund |
| **IMO** | International Maritime Organization |
| **IOC** | international oil company |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPT** | independent power transmission |
| **LCOE** | levelised cost of electricity |
| **LCV** | light commercial vehicle |
| **LDV** | light-duty vehicle |
| **LED** | light-emitting diode |
| **LNG** | liquefied natural gas |
| **LPG** | liquefied petroleum gas |
| **LULUCF** | land use, land-use change and forestry |
| **MEPS** | minimum energy performance standards |
| **MER** | market exchange rate |
| **NDC** | Nationally Determined Contribution |
| **NEA** | Nuclear Energy Agency (an agency within the OECD) |
| **NGLs** | natural gas liquids |
| **NGV** | natural gas vehicle |
| **NOC** | national oil company |
| **NPV** | net present value |
| **$NO_X$** | nitrogen oxides |
| **$N_2O$** | nitrous oxide |
| **NZE** | Net Zero Emissions by 2050 Scenario |

C

| | |
|---|---|
| **OECD** | Organisation for Economic Co-operation and Development |
| **OPEC** | Organization of the Petroleum Exporting Countries |
| **PHEV** | plug-in hybrid electric vehicles |
| **PLDV** | passenger light-duty vehicle |
| **PM** | particulate matter |
| **$PM_{2.5}$** | fine particulate matter |
| **PPA** | power purchase agreement |
| **PPP** | purchasing power parity |
| **PV** | photovoltaics |
| **R&D** | research and development |
| **RD&D** | research, development and demonstration |
| **SAF** | sustainable aviation fuel |
| **SDG** | Sustainable Development Goals (United Nations) |
| **SHS** | solar home systems |
| **SME** | small and medium enterprises |
| **$SO_2$** | sulphur dioxide |
| **STEPS** | Stated Policies Scenario |
| **T&D** | transmission and distribution |
| **TES** | total energy supply |
| **TFC** | total final consumption |
| **TFEC** | total final energy consumption |
| **TPA** | tonne per annum |
| **TPED** | total primary energy demand |
| **TSO** | transmission system operator |
| **UAE** | United Arab Emirates |
| **UN** | United Nations |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environment Programme |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **US** | United States |
| **USGS** | United States Geological Survey |
| **VALCOE** | value-adjusted levelised cost of electricity |
| **VRE** | variable renewable energy |
| **WACC** | weighted average cost of capital |
| **WEO** | World Energy Outlook |
| **WHO** | World Health Organization |
| **ZEV** | zero emissions vehicle |
| **ZCRB** | zero carbon-ready building |

# References

## *Chapter 1: Overview and key findings*

BIS (Bank of International Settlements). (2023). Credit Statistics (database) accessed July 2023. https://www.bis.org/statistics/about_credit_stats.htm

Bordoff, J. and M. L. O'Sullivan (2023). The Age of Energy Insecurity: How the Fight for Resources Is Upending Geopolitics. https://www.foreignaffairs.com/world/energy-insecurity-climate-change-geopolitics-resources

IEA (International Energy Agency). (2023a). Building a Unified National Power Market System in China. https://www.iea.org/reports/building-a-unified-national-power-market-system-in-china

IEA. (2023b). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

IEA. (2023c). World Energy Investment 2023. https://www.iea.org/reports/world-energy-investment-2023

IEA. (2023d). Electricity Grids and Secure Energy Transitions. https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions

IEA. (2023e). Critical Minerals Market Review 2023. https://www.iea.org/reports/critical-minerals-market-review-2023

IEA. (2023f). Government Energy Spending Tracker: June 2023 update. https://www.iea.org/reports/government-energy-spending-tracker-2

IEA. (2023g). Energy Technology Perspectives 2023. https://www.iea.org/reports/energy-technology-perspectives-2023

IEA. (2022a). Solar PV Global Supply Chains. https://www.iea.org/reports/solar-pv-global-supply-chains

IEA. (2022b). The Future of Heat Pumps. https://www.iea.org/reports/the-future-of-heat-pumps

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

IEA. (2022d). World Energy Employment. https://www.iea.org/reports/world-energy-employment

IEA. (2021a). Financing Clean Energy Transitions in Emerging and Developing Economies. https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies

IEA. (2021b). The Role of Critical Minerals in Clean Energy Transitions. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

IEA. (2019). ASEAN Renewable Energy Integration Analysis. https://www.iea.org/reports/asean-renewable-energy-integration-analysis

IMF (International Monetary Fund). (2023). Climate Crossroads: Fiscal Policies in a Warming World. https://www.imf.org/en/Publications/FM/Issues/2023/10/10/fiscal-monitor-october-2023

NBSC (National Bureau of Statistics of China). (2023). (database) accessed July 2023. http://www.stats.gov.cn/english/

Oxford Economics. (2023). Oxford Economics Global Economic Model, accessed July 2023. https://www.oxfordeconomics.com/global-economic-model

UN DESA (United Nations Department of Economic and Social Affairs). (2022). https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

### *Chapter 2: Setting the scene*

Argus. (2023). Price data (database) accessed October 2023. https://direct.argusmedia.com/

IEA (International Energy Agency). (2023a). World Energy Investment 2023. https://www.iea.org/reports/world-energy-investment-2023

IEA. (2023b). The State of Clean Energy Manufacturing. https://www.iea.org/reports/the-state-of-clean-technology-manufacturing

IEA. (2023c). Tracking Clean Energy Progress 2023. https://www.iea.org/reports/tracking-clean-energy-progress-2023

IEA. (2023d). Electricity Grids and Secure Energy Transitions. https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions

IEA. (2023e). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

IEA. (2023f). Critical Minerals Market Review 2023. https://www.iea.org/reports/critical-minerals-market-review-2023

IMF (International Monetary Fund). (2023). World Economic Outlook: A Rocky Recovery. https://www.imf.org/en/Publications/WEO/weo-database/2023/April

McCloskey. (2023). Dashboard (database) accessed October 2023. https://mccloskey.opisnet.com/

Oxford Economics. (2023). Oxford Economics Global Economic Model, accessed July 2023. https://www.oxfordeconomics.com/global-economic-model

S&P Global. (2023). S&P Capital IQ Pro: Commodity Profile. (database) accessed July 2023. https://www.capitaliq.spglobal.com/

UN DESA (United Nations Department of Economic and Social Affairs). (2022). World Population Prospects. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

US EIA (United States Energy Information Agency). (2023). Petroleum & Other Liquids (database) accessed October 2023. https://www.eia.gov/dnav/pet/hist/RBRTED.htm

World Bank. (2023a). Global Economic Prospects. https://openknowledge.worldbank.org/handle/10986/39846

World Bank. (2023b). State and Trends of Carbon Pricing 2023. https://openknowledge.worldbank.org/handle/10986/39796

## *Chapter 3: Pathways for the energy mix*

Global Energy Monitor. (2022). Global Gas Infrastructure Tracker (database) accessed June 2023. https://globalenergymonitor.org/projects/global-gas-infrastructure-tracker/

IEA (International Energy Agency). (2023a). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

IEA. (2023b). Tracking Clean Energy Progress 2023. https://www.iea.org/reports/tracking-clean-energy-progress-2023

IEA. (2023c). Electricity Grids and Secure Energy Transitions. https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions

IEA. (2023d). Global Hydrogen Review 2023. https://www.iea.org/reports/global-hydrogen-review-2023

IEA. (2023e). Towards Hydrogen Definitions Based on Their Emissions Intensity. https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity

IEA. (2023f). Energy Technology Perspectives 2023. https://www.iea.org/reports/energy-technology-perspectives-2023

IEA. (2022a). Renewables 2022. https://www.iea.org/reports/renewables-2022

IEA. (2022b). The Future of Heat Pumps. https://www.iea.org/reports/the-future-of-heat-pumps

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

IEA. (2022d). Coal in Net Zero Transitions. https://www.iea.org/reports/coal-in-net-zero-transitions

NEA (Nuclear Energy Agency). (2022). Meeting Climate Change Targets: The Role of Nuclear Energy. https://www.oecd-nea.org/jcms/pl_69396/meeting-climate-change-targets-the-role-of-nuclear-energy

UN FAO (United Nations Food and Agriculture Organization). (2023). Global Agro-Ecological Zoning (GAEZ) (database, version 4) accessed July 2023. https://gaez.fao.org/

### *Chapter 4: Secure and people-centred energy transitions*

Benchmark Mineral Intelligence. (2023). Q3 Forecast. https://www.benchmarkminerals.com/forecasts/

China Ministry of Education. (2021). National Base Situation, accessed July 2023. http://en.moe.gov.cn/documents/statistics/2021/national/

Davis, L. (2023). The Economic Determinants of Heat Pump Adoption. https://www.nber.org/papers/w31344

First Movers Coalition. (2022). Steel commitment. https://www.weforum.org/first-movers-coalition/sectors

IEA (International Energy Agency). (2023a). Financing Reductions in Oil and Gas Methane Emissions. https://www.iea.org/reports/financing-reductions-in-oil-and-gas-methane-emissions

IEA. (2023b). Electricity Grids and Secure Energy Transitions. https://www.iea.org/reports/ electricity-grids-and-secure-energy-transitions

IEA. (2023c). Critical Minerals Market Review 2023. https://www.iea.org/reports/critical-minerals-market-review-2023

IEA. (2023d). Access to electricity improves slightly in 2023, but still far from the pace needed to meet SDG7. https://www.iea.org/commentaries/access-to-electricity-improves-slightly-in-2023-but-still-far-from-the-pace-needed-to-meet-sdg7

IEA. (2023e). A Vision for Clean Cooking Access. https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all

IEA. (2023f). Did affordability measures help tame energy price spikes for consumers in major economies? https://www.iea.org/commentaries/did-affordability-measures-help-tame-energy-price-spikes-for-consumers-in-major-economies

IEA. (2023g). The world’s top 1% of emitters produce over 1 000-times more $CO_2$ than the bottom 1%. https://www.iea.org/commentaries/the-world-s-top-1-of-emitters-produce-over-1000-times-more-co2-than-the-bottom-1

IEA. (2023h). Global EV Outlook 2023. https://www.iea.org/reports/global-ev-outlook-2023

IEA. (2023i). World Energy Investment 2023. https://www.iea.org/reports/world-energy-investment-2023

IEA. (2022). World Energy Outlook 2022.
https://www.iea.org/reports/world-energy-outlook-2022

IEA. (2021a). World Energy Outlook 2021.
https://www.iea.org/reports/world-energy-outlook-2021

IEA. (2021b). Financing Clean Energy Transitions in Emerging and Developing Economies.
https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies

IPCC (Intergovernmental Panel on Climate Change). (2021). IPCC Sixth Assessment Report, Climate Change 2021: The Physical Science Basis. https://www.ipcc.ch/report/ar6/wg1/

JATO Dynamics. (2021). Electric Vehicles: A Pricing Challenge.
https://info.jato.com/electric-vehicles-a-pricing-challenge

OECD (Organisation for Economic Co-operation and Development) (2023). Education at a Glance (database) accessed July 2023. https://stats.oecd.org/OECDStat_Metadata

S&P Global. (2023). Metals & Mining Properties Database, accessed June 2023.
https://www.spglobal.com/marketintelligence/en/

US National Center for Education Statistics. (2020). Digest of Education Statistics (database) accessed July 2023. https://nces.ed.gov/programs/digest/

UNEP (United Nations Environment Programme). (2021). Global Methane Assessment.
https://www.ccacoalition.org/resources/global-methane-assessment-full-report

Wood Mackenzie. (2023). Q2 Market Service Outlook (database) accessed July 2023.
https://www.woodmac.com/industry/metals-and-mining/

WHO (World Health Organisation). (2021). WHO Global Air Quality Guidelines: Particulate matter ($PM_{2.5}$ and $PM_{10}$), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide.
https://www.who.int/publications/i/item/9789240034228

World Bank. (2022). The Global Health Cost of $PM_{2.5}$ Air Pollution.
https://doi.org/10.1596/978-1-4648-1816-5

World Inequality Database. (2022). (database) accessed June 2023. https://wid.world/

### *Chapter 5: Regional insights*

Al-Masri, R. and J. Chenoweth. (2023). Desalination could give the Middle East water without damaging marine life. But it must be managed carefully.
https://phys.org/news/2023-01-desalination-middle-east-marine-life.html

Balza, L. et al. (2020). Traversing a slippery slope: Guyana's oil opportunity.
https://publications.iadb.org/en/traversing-a-slippery-slope-guyanas-oil-opportunity

Benchmark Minerals Intelligence. (2023). (database) accessed July 2023.
https://www.benchmarkminerals.com/

BNEF (Bloomberg New Energy Finance). (2023a). Solar PV Equipment Manufacturers (database) accessed July 2023. https://about.bnef.com/

BNEF. (2023b). Wind Manufacturers (database) accessed July 2023. https://about.bnef.com/

IEA (International Energy Agency). (2023a). Scaling Up Private Finance for Clean Energy in Emerging and Developing Economies. https://www.iea.org/reports/scaling-up-private-finance-for-clean-energy-in-emerging-and-developing-economies

IEA. (2023b). A Vision for Clean Cooking Access for All. https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all

IEA. (2023c). Cost of Capital Observatory. https://www.iea.org/reports/cost-of-capital-observatory

IEA. (2023d). Oman's huge renewable hydrogen potential can bring multiple benefits in its journey to net zero emissions. https://www.iea.org/news/oman-s-huge-renewable-hydrogen-potential-can-bring-multiple-benefits-in-its-journey-to-net-zero-emissions

IEA. (2023e). The State of Clean Technology Manufacturing. https://www.iea.org/reports/the-state-of-clean-technology-manufacturing

IEA. (2023f). Critical Minerals Market Review 2023. https://www.iea.org/reports/critical-minerals-market-review-2023

IEA. (2022a). Africa Energy Outlook 2022. https://www.iea.org/reports/africa-energy-outlook-2022

IEA. (2022b). Coal in Net Zero Transitions. https://www.iea.org/reports/coal-in-net-zero-transitions

IEA. (2022c). An Energy Sector Roadmap to Net Zero Emissions in Indonesia. https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia

IEA. (2021). World Energy Outlook 2021. https://www.iea.org/reports/world-energy-outlook-2021

IFRI (Institut Français des Relations Internationales/French Institute of International Relations). (2022). The Geopolitics of Seawater Desalination. https://www.ifri.org/en/publications/etudes-de-lifri/geopolitics-seawater-desalination

MCI (Ministry of Commerce and Industry, India). (2023). Import Commodity-wise HSCode 85414012. (database) accessed July 2023. https://tradestat.commerce.gov.in/

Ray, K. et al. (2021). An assessment of long-term changes in mortalities due to extreme weather events in India: A study of 50 years' data, 1970–2019. Weather and Climate Extremes, Volume 32. https://doi.org/10.1016/j.wace.2021.100315

SPV Market Research. (2023). (database) accessed July 2023. https://www.spvmarketresearch.com/

UNEP (United Nations Environment Programme). (2021). Used Vehicles and the Environment: Progress and Updates 2021. https://www.unep.org/resources/report/used-vehicles-and-environment-progress-and-updates-2021

US Department of Energy. (2023). (database) accessed July 2023. https://www.energy.gov/invest

Wood Mackenzie. (2023). (database) accessed July 2023. https://www.woodmac.com/industry/power-and-renewables/global-wind-service/

### *Annex B: Design of the scenarios*

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe/Federal Institute for Geosciences and Natural Resources). (2021). Energiestudie - Daten und Entwicklungen der deutschen und globalen Energieversorgung [Energy Study - Data and Developments in German and Global Energy Supply]. https://www.bgr.bund.de/DE/Themen/Energie/Downloads/energiestudie_2021.html

BNEF (Bloomberg New Energy Finance). (2022). Top 10 Energy Storage Trends in 2023. https://about.bnef.com

BP. (2022). Statistical Review of World Energy. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

CEDIGAZ. (2022). Country indicators (database) accessed July 2023. https://www.cedigaz.org/databases/

Cole, W., A. Will Frazier and C. Augustine. (2021). Cost Projections for Utility Scale Battery Storage: 2021 Update. https://www.nrel.gov/docs/fy21osti/79236.pdf

Financial Times. (2020). Electric car costs to remain higher than traditional engines. https://www.ft.com/content/a7e58ce7-4fab-424a-b1fa-f833ce948cb7

IEA (International Energy Agency). (2023). Cost of Capital Observatory. https://www.iea.org/reports/cost-of-capital-observatory

IEA. (2020). World Energy Outlook 2020. https://www.iea.org/reports/world-energy-outlook-2020

IEA. (2019). Offshore Wind Outlook 2019. https://www.iea.org/reports/offshore-wind-outlook-2019

IRENA (International Renewable Energy Agency). (2023). Renewable Power Generation Costs in 2022. https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

James, B. et al. (2018). Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2018 Update. https://www.energy.gov/sites/default/files/2020/02/f71/fcto-sa-2018-transportation-fuel-cell-cost-analysis-2.pdf

JATO. (2021). Electric Vehicles: A Pricing Challenge 2021. https://info.jato.com/electric-vehicles-a-pricing-challenge

OGJ (Oil and Gas Journal). (2022). Worldwide look at reserves and production. https://www.ogj.com/ogj-survey-downloads/worldwide-production/document/17299726/worldwide-look-at-reserves-and-production

Thompson, S. et al. (2018). Direct hydrogen fuel cell electric vehicle cost analysis: System and high-volume manufacturing description, validation, and outlook. Journal of Power Sources, 304-313. https://doi.org/10.1016/j.jpowsour.2018.07.100

Tsiropoulos, I., D. Tarvydas and N. Lebedeva. (2018). Li-ion batteries for mobility and stationary storage applications. https://publications.jrc.ec.europa.eu/repository/handle/JRC113360

UN DESA (United Nations Department of Economic and Social Affairs). (2022). World Population Prospects 2022. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

UN DESA. (2018). World Urbanisation Prospects 2018. https://population.un.org/wup/

US EIA (United States Energy Information Agency). (2023). Assumptions to the Annual Energy Outlook 2023: Oil and Gas Supply Module. https://www.eia.gov/outlooks/aeo/assumptions/pdf/OGSM_Assumptions.pdf

EIA. (2015). World Shale Resource Assessment. https://www.eia.gov/analysis/studies/worldshalegas

EIA. (2013). Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States. https://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf

USGS (United States Geological Survey). (2012a). An estimate of undiscovered conventional oil and gas resources of the world. https://pubs.er.usgs.gov/publication/fs20123042

USGS. (2012b). Assessment of potential additions to conventional oil and gas resources of the world (outside the United States) from reserve growth. https://pubs.er.usgs.gov/publication/fs20123052

World Bank. (2023a). World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2023b). State and Trends of Carbon Pricing 2023. https://openknowledge.worldbank.org/handle/10986/39796

# Inputs to the Global Energy and Climate Model

## General note

This annex includes references of databases and publications used to provide input data to the IEA Global Energy and Climate (GEC) Model. The IEA's own databases of energy and economic statistics provide much of the data used in the GEC Model. These include IEA statistics on energy supply, transformation, demand at detailed levels, carbon dioxide emissions from fuel combustion and energy efficiency indicators that form the bedrock of the *World Energy Outlook* modelling and analyses.

Supplemental data from a wide range of external sources are also used to complement IEA data and provide additional detail. This list of databases and publications is comprehensive, but not exhaustive.

## IEA databases and publications

IEA (International Energy Agency). (2023). Coal Information.
https://www.iea.org/data-and-statistics/data-product/coal-information-service

IEA. (2023). Emissions Factors 2023.
https://www.iea.org/data-and-statistics/data-product/emissions-factors-2023

IEA. (2023). Energy Efficiency Indicators.
https://www.iea.org/data-and-statistics/data-product/energy-efficiency-indicators

IEA. (2023). Energy Prices.
https://www.iea.org/data-and-statistics/data-product/energy-prices

IEA. (2023). Energy Technology RD&D Budgets. https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2

IEA. (2023). Global Energy Review 2023: $CO_2$ Emissions in 2022.
https://www.iea.org/reports/co2-emissions-in-2022

IEA. (2023). Greenhouse Gas Emissions from Energy. https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy

IEA. (2023). Methane Tracker Database 2023. https://www.iea.org/data-and-statistics/data-product/methane-tracker-database-2023

IEA. (2023). Monthly Electricity Statistics.
https://www.iea.org/data-and-statistics/data-product/monthly-electricity-statistics

IEA. (2023). Monthly Gas Data Service.
https://www.iea.org/data-and-statistics/data-product/monthly-gas-data-service-2

IEA. (2023). Monthly Oil Data Service Complete. https://www.iea.org/data-and-statistics/data-product/monthly-oil-data-service-mods-complete

IEA. (2023). Natural Gas Information.
https://www.iea.org/data-and-statistics/data-product/natural-gas-information

IEA. (2023). Real-Time Electricity Tracker.
https://www.iea.org/data-and-statistics/data-tools/real-time-electricity-tracker

IEA. (2023). Renewable Energy Market Update - June 2023.
https://www.iea.org/reports/renewable-energy-market-update-june-2023

IEA. (2023). SDG 7: Data and Projections.
https://www.iea.org/reports/sdg7-data-and-projections

IEA. (2023). Weather for Energy Tracker.
https://www.iea.org/data-and-statistics/data-product/weather-for-energy-tracker

IEA. (2023). World Energy Balances.
https://www.iea.org/data-and-statistics/data-product/world-energy-balances

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

IEA. (2022). Global Fuel Economy Initiative 2021 Data Explorer. https://www.iea.org/data-and-statistics/data-tools/global-fuel-economy-initiative-2021-data-explorer

IEA. (2022). Renewables 2022. https://www.iea.org/reports/renewables-2022

IEA. (n.d.). CCUS Projects Database.
https://www.iea.org/data-and-statistics/data-product/ccus-projects-database

IEA. (n.d.). ETP Clean Energy Technology Guide. https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide

IEA. (n.d.). Fossil Fuel Subsidies Database.
https://www.iea.org/data-and-statistics/data-product/fossil-fuel-subsidies-database

IEA. (n.d). Hydrogen Projects Database.
https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

IEA. (n.d.). Policies Database. https://www.iea.org/policies/

## External databases and publications

### Socio-economic variables

IMF (International Monetary Fund). (2023). World Economic Outlook: April 2023 Update.
https://www.imf.org/en/Publications/WEO/weo-database/2023/April

Oxford Economics. (2023). Oxford Economics Global Economic Model: July 2023 Update.
https://www.oxfordeconomics.com/global-economic-model

UN DESA (United Nations Department of Economic and Social Affairs). (2022). World Population Prospects 2022.
www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

UN DESA (2018). World Urbanisation Prospects 2018. https://population.un.org/wup/

World Bank. (20223). World Development Indicators.
https://data.worldbank.org/indicator/SP.POP.TOTL

### Power

ENTSO-E (European Network of Transmission System Operators for Electricity). (2023). Transparency Platform (database). https://transparency.entsoe.eu/

Global Transmission. (2020). Global Electricity Transmission Report and Database. 2020-29. https://www.globaltransmission.info/report_electricity-transmission-report-and-database-2020-29.php

IAEA (International Atomic Energy Agency). (2023). Power Reactor Information System (database). https://pris.iaea.org/pris/

NRG Expert (2019). Electricity Transmission and Distribution (database). https://www.nrgexpert.com/energy-market-research/electricity-transmission-and-distribution-database/

S&P Global (2023). World Electric Power Plants (database). S&P Market Intelligence Platform. https://www.spglobal.com/marketintelligence/

### Industry

European Union Joint Research Centre. EDGAR – Emissions Database for Global Atmospheric Research. https://edgar.jrc.ec.europa.eu/dataset_ghg70/

Fastmarkets RISI (n.d.). Pulp. Paper and Packaging.
https://www.risiinfo.com/industries/pulp-paper-packaging/

Global Cement. (2023). Global Cement Directory 2023. https://www.globalcement.com/

Global Cement and Concrete Association. (2023). GNR 2.0 – GCCA in Numbers.
https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/

Global Energy Monitor. (2023). Global Steel Plant Tracker.
https://globalenergymonitor.org/projects/global-steel-plant-tracker/

IHS Markit (n.d.). Chemical. https://ihsmarkit.com/industry/chemical.html

International Aluminium Institute. (2023). World Aluminium Statistics.
http://www.world-aluminium.org/statistics/

International Aluminium Institute. (2023). The Global Aluminium Cycle.
https://alucycle.international-aluminium.org/

IFA (International Fertilizer Association) (n.d.). IFASTAT (database).
https://www.ifastat.org/

METI (Ministry of Economy, Trade and Industry, Japan). (2023). METI Statistics Report.
https://www.meti.go.jp/english/statistics/index.html

MMSA (Methanol Market Services Asia) (n.d.). (database).
https://www.methanolmsa.com/

NBS (National Bureau of Statistics of China). (2023). Statistical Communiqué of The People's Republic of China on the 2022 National Economic and Social Development.
http://www.stats.gov.cn/english/PressRelease/202302/t20230227_1918979.html

OECD (Organisation for Economic Co-operation and Development). (2023). (database). The Global Plastics Outlook database.
https://www.oecd-ilibrary.org/environment/data/global-plastic-outlook_c0821f81-en

S&P Global. (2023). Platts Global Polyolefins Outlook.
https://plattsinfo.platts.com/GPO.html

UN DESA (United Nations Department of Economic and Social Affairs) (n.d.). UN Comtrade (database). https://comtrade.un.org/data/

UN FAO (United Nations Food and Agriculture Organisation of the United Nations) (n.d.). FAOSTAT Data (database). http://www.fao.org/faostat/en/#data

US EIA (United States Energy Information Administration). (2021). Manufacturing Energy Consumption Survey. https://www.eia.gov/consumption/manufacturing/data/2018/

USGS (United States Geological Survey). (2023). Commodity Statistics and Information. National Minerals Information Center. https://www.usgs.gov/centers/nmic

World Bureau of Metal Statistics (n.d). (database).
https://www.refinitiv.com/en/trading-solutions/world-bureau-metal-statistics

World Steel Association. (2023). World Steel in Figures 2023.
https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2023/

## Transport

AIM (Aviation Integrated Model). (2020). An Open-Source Model Developed by the University College London Energy Institute. www.ucl.ac.uk/energy-models/models/aim

Benchmark Mineral Intelligence (n.d.). Lithium ion Battery Gigafactory Assessment Report.
https://www.benchmarkminerals.com/market-assessments/gigafactory-assessment/

EV Volumes. (2023). Electric Vehicle World Sales (database). https://www.ev-volumes.com/

ICAO (International Civil Aviation Organization). (2023). Air Transport Monthly Monitor.
https://www.icao.int/sustainability/pages/air-traffic-monitor.aspx

IMO (International Maritime Organization). (2021). Fourth IMO GHG Study 2020. https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

Institute for Transportation and Development Policy. (2022). Rapid Transit Database. https://docs.google.com/spreadsheets/d/1uMuNG9rTGO52Vuuq6skyqmkH9U5yv1iSJDJYjH64MJM/

International Association of Public Transport. (2021). Metro World Statistics Database.

International Association of Public Transport. (2020). Light Rail Transit World Statistics Database.

International Union of Railways. (2022). High-Speed Lines in the World 2021. https://uic.org/passenger/highspeed/article/high-speed-data-and-atlas

International Union of Railways. (2022). Railisa UIC Statistics. https://uic-stats.uic.org/

Jato Dynamics (n.d.). https://www.jato.com/solutions/jato-analysis-reporting/

LMC Automotive (n.d.). LMC Automotive Forecasting. https://lmc-auto.com/

McD (n.d.). Motor Cycles Data. https://www.motorcyclesdata.com/

OAG (Official Aviation Guide) (n.d.). OAG (database). https://www.oag.com/

UNCTAD (United Nations Conference on Trade and Development). (2022). Review of Maritime Transport 2022. https://unctad.org/rmt2022

### Buildings and energy access

AHRI (Air Conditioning, Heating, and Refrigeration Institute). (2023). Statistics. https://www.ahrinet.org/analytics/statistics

CLASP (Collaborative Labeling and Appliance Standards Program). (2023). Mepsy: The Appliance & Equipment Climate Impact Calculator. https://www.clasp.ngo/tools/mepsy/

EHPA (European Heat Pump Association). (2023). Market Data. https://www.ehpa.org/market-data/

GOGLA (Global Association for the Off-grid Solar Energy Industry). (2023). Global Off-Grid Solar Market Report. https://www.gogla.org/global-off-grid-solar-market-report

IPCC WG1 (International Panel on Climate Change Working Group 1). (2023). IPCC WGI Interactive Atlas. https://interactive-atlas.ipcc.ch/

JRAIA (Japan Refrigeration and Air Conditioning Association). (2022). Estimates of World Air Conditioner Demand by Country. https://www.jraia.or.jp/english/statistics/file/World_AC_Demand.pdf

MEMR (Ministry of Energy and Mineral Resources, Indonesia). (2022). Handbook of Energy and Economic Statistics of Indonesia. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2021.pdf

National Bureau of Statistics China. (2023). China Statistical Yearbook 2022. http://www.stats.gov.cn/english/Statisticaldata/yearbook/

National Statistical Office (India) (2019). Drinking Water, Sanitation, Hygiene and Housing Conditions in India. https://www.mospi.gov.in/sites/default/files/publication_reports/Report_584_final_0.pdf

OLADE (Latin American Energy Organisation). (2023). Electricity Access (database). https://sielac.olade.org/default.aspx

US EIA (United States Energy Information Administration). (2023). 2020 RECS (Residential Energy Consumption Survey). https://www.eia.gov/consumption/residential/data/2020/

US EIA. (2023). 2018 CBECS (Commercial Buildings Energy Consumption Survey Data). https://www.eia.gov/consumption/commercial/

USAID (United States Agency for International Development) (n.d.). Demographic and Health Surveys (database). https://dhsprogram.com/Data/

WHO (World Health Organization). (2023). Household Air Pollution Data (database). https://www.who.int/data/gho/data/themes/air-pollution/household-air-pollution

World Bank. (2023). Regulatory Indicators for Sustainable Energy. https://rise.esmap.org/

### Energy supply and energy investment

Argus Media. (2023). (price database). https://direct.argusmedia.com/

BGR (Bundesanstalt fűr Geowissenschaften und Rohstoffe). (2021). (German Federal Institute for Geosciences and Natural Resources 2021). Energiestudie 2021. Daten und Entwicklungen der Deutschen und Globalen Energieversorgung. [Energy Study 2021. Data and Developments in German and Global Energy Supply]. https://www.bgr.bund.de/DE/Themen/Energie/Downloads/energiestudie_2021.pdf?__blob=publicationFile&v=4

Bloomberg Terminal (n.d.). https://www.bloomberg.com/professional/solution/bloomberg-terminal

BNEF (Bloomberg New Energy Finance). (2023). Sustainable Finance Database. https://about.bnef.com

BP. (2022). Statistical Review of World Energy 2022. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Cedigaz. (2023). Cedigaz (database). https://www.cedigaz.org/databases/

Clean Energy Pipeline. (2022). (database). https://cleanenergypipeline.com/

CRU (n.d.). Coal (database). https://www.crugroup.com/

IJ Global. (2023). Transaction (database). https://ijglobal.com/data/search-transactions

Kayrros. (2023). (data analytics). https://www.kayrros.com/

McCloskey by OPIS. a Dow Jones Company. (2022). Coal (database). https://www.opisnet.com/commodities/coal-metals-mining/

Oil & Gas Journal. (2022). Global Oil and Gas Reserves Increase in 2022. https://www.ogj.com/print/content/14286688

Refinitiv Eikon. (2023). Eikon (financial data platform). https://eikon.thomsonreuters.com/index.html

Rystad Energy. (2023). (database). https://www.rystadenergy.com

S&P Global. (2023). Capital IQ (financial data platform). https://www.spglobal.com/marketintelligence/en/solutions/sp-capital-iq-pro

US EIA (United States Energy Information Administration). (2022). (database). https://www.eia.gov/analysis/

US NASA (United States National Aeronautics and Space Administration) Langley Research Center (LaRC). (2022). Prediction of Worldwide Energy Resource Project. https://power.larc.nasa.gov/

World Bank. (2023). Public Participation in Infrastructure Database. (database). https://ppi.worldbank.org/en/ppi

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

Typeset in France by IEA - October 2023
Cover design: IEA
Photo credits: © Shutterstock

**World Energy Outlook 2023**

The *World Energy Outlook 2023* provides in-depth analysis and strategic insights into every aspect of the global energy system. Against a backdrop of geopolitical tensions and fragile energy markets, this year's report explores how structural shifts in economies and in energy use are shifting the way that the world meets rising demand for energy.

This *Outlook* assesses the evolving nature of energy security fifty years after the foundation of the IEA. It also examines what needs to happen at the COP28 climate conference in Dubai to keep the door open for the 1.5 °C goal. And, as it does every year, the *Outlook* examines the implications of today's energy trends in key areas including investment, trade flows, electrification and energy access.

This flagship publication of the International Energy Agency is the energy world's most authoritative source of analysis and projections. Published each year since 1998, its objective data and dispassionate analysis provide critical insights into global energy supply and demand in different scenarios and the implications for energy security, climate change goals and economic development.

iea