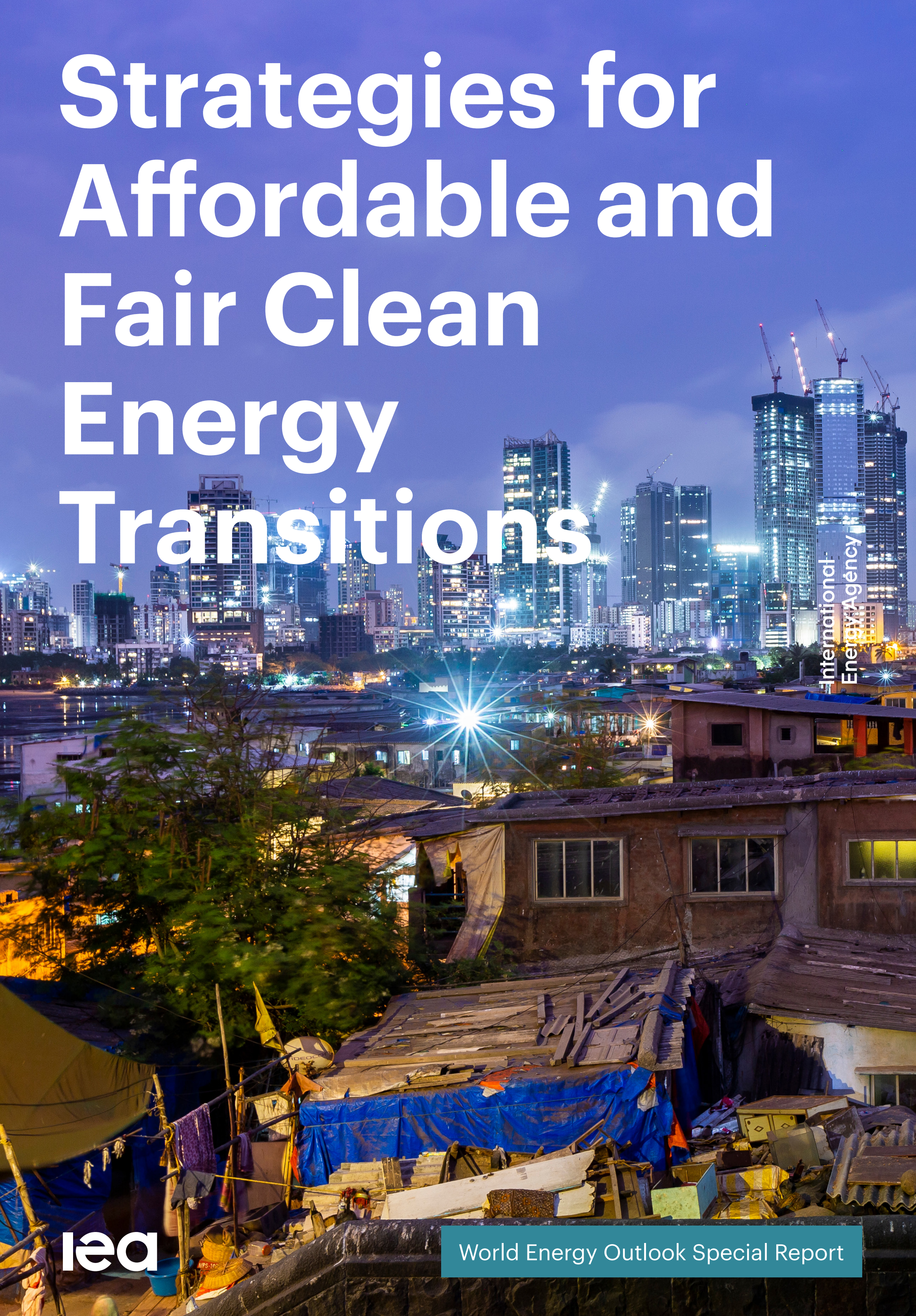
Strategies for Affordable and Fair Clean Energy Transitions



International Energy Agency

iea

World Energy Outlook Special Report

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

Revised version, June 2024
Information notice found at: www.iea.org/corrections

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

The last few years have been tough for many energy consumers around the world, with high energy prices putting a lot of pressure on the cost of living. The effects have been most severe for low-income countries and households. This has rightly put issues of affordability and fairness at the centre of the energy debate.

For an honest assessment of the situation, we need to be clear about where these pressures on the cost of living have come from. The global energy crisis that escalated in early 2022 was not caused by clean energy. Since the early days of the crisis, I have been speaking regularly with energy policy makers from around the world. None of them have complained of relying too much on clean energy. On the contrary, they wish they had more, because the result of investing in these technologies today is a more affordable energy system for consumers tomorrow – as well as less severe impacts from climate change, major improvements in air quality and greater energy security.

When people misleadingly blame clean energy and climate policies for the recent spikes in energy prices, they are, intentionally or not, moving the spotlight away from the main cause – the major cuts that Russia made to natural gas supply.

That said, there is still an important debate to be had about affordability and fairness in clean energy transitions – notably in terms of how the costs and benefits will be shared. And that is why we have produced this important new analysis. We wanted to provide an evidence base and actionable advice for policy makers as they consider their strategies for the future.

A key risk is that poorer households, communities and countries are excluded from the new clean energy economy that is emerging around the world because they cannot pay the upfront costs of the switch to a safer and more sustainable energy system. As a result, they remain vulnerable to swings in fuel prices, which already disproportionately affect their budgets and well-being compared with their wealthier counterparts.

Well-designed policies are essential to addressing this. This special report provides examples – from across advanced, emerging and developing economies – on ways to make clean energy technologies more accessible to all. This is an important and growing area of work for the International Energy Agency (IEA), as demonstrated by our longstanding work on energy access globally and, more recently, by our Global Summit on People-Centred Clean Energy Transitions in April 2024 and our Summit on Clean Cooking in Africa in May 2024, which mobilised USD 2.2 billion in new announcements from governments and private sources to increase clean cooking access in Africa. Both summits were firsts of their kind – but they won’t be the last as we continue to address these critical issues with stakeholders from around the world and work with them to drive progress.

As we consider the energy technology pathways available for communities and countries worldwide, it is essential to keep in mind that many of the clean and efficient choices are also the most cost-effective ones – typically because they require much lower day-to-day spending on fuels to operate. Putting the world on track to reach net zero emissions by 2050 requires additional investment but also reduces the operating costs of the global energy system by more than half over the next decade compared with a trajectory based on today's policy settings, this special report shows.

Pursuing such a path has considerable implications for economies across the globe, notably for fuel importers and exporters. This is why we have produced this special report to help all countries understand the costs, benefits, opportunities and challenges of moving rapidly towards a cleaner and more affordable energy system – and to offer strategies for doing so.

I would like to thank the team of IEA colleagues who worked on this first-of-its-kind analysis, including lead authors Peter Zeniewski and Siddharth Singh, under the expert guidance of Chief Energy Economist Tim Gould. I'm also grateful to Brian Motherway and Jane Cohen, who lead the IEA's work on inclusive energy transitions, for their valuable contributions. I'm confident that this report will provide an important foundation for productive and evidence-based discussions on ensuring that clean energy transitions benefit as many people as possible, and especially the poorest and most vulnerable.

Dr Fatih Birol
Executive Director
International Energy Agency

This study was prepared in close collaboration by various directorates of the International Energy Agency (IEA), led by the Office of the Chief Energy Economist in the Directorate of Sustainability, Technology and Outlooks (STO). The study was designed and directed by **Tim Gould**, Chief Energy Economist, and led by **Peter Zeniewski** and **Siddharth Singh**.

The Energy Efficiency and Inclusive Transitions (EEIT) Office led the analysis on policies promoting affordability and fairness in clean energy transitions among households, as detailed in chapter 3. **Jane Cohen** and **Lucas Boehlé** led this analysis with guidance from **Brian Motherway**, the Head of EEIT.

Key contributions from across the IEA were from:

Ilias Atigui, Blandine Barreau, Charlene Bisch, Tomás de Oliveira Bredariol, Eric Buisson, Federico Callioni, Elizabeth Connelly, Tanguy de Bienassis, Juliette Denis-Senez, Shobhan Dhir, Nouhoun Diarra, Jianlan Dou, Musa Erdogan, Eric Fabozzi, Caroline Fedrine, David Fischer, Roland Gladushenko, Emma Gordon, Ronan Graham, Paul Grimal, Jeanne-Marie Hays, Zoe Hemez, Dennis Hesseling, Jérôme Hilaire, Mathilde Huismans, Gyubin Hwang, Heeweon Hyun, Mine Isik, Tae-Yoon Kim, Martin Kueppers, Jinsun Lim, Jean-Baptiste Le Marois, Christophe McGlade, Yannick Monschauer, Emma Mooney, Vera O'Riordan, Mathieu Pierronne, Ryszard Pospiech, Luca Lo Re, Arthur Roge, Vida Rozite, Diana Perez Sanchez, Lucila Arboleya Sarazola, Max Schoenfisch, Jules Sery, Alessia Stedile, Jemima Storey, Jun Takashiro, Cecilia Tam, Gianluca Tonolo, Courtney Turich and Brent Wanner.

Eleni Tsoukala provided essential support.

Edmund Hosker was the editor and **Erin Crum** was the copy editor.

The report also benefited from valuable contributions and inputs provided by IEA colleagues, in particular Laura Cozzi, Keisuke Sadamori, Dan Dorner, Timur Guel, Jason Elliott, Nick Johnstone, Paolo Frankl, Rebecca Gaghen, Alessandro Blasi, Hiroyasu Sakagushi, Toril Bosoni, Araceli Fernandez Pales, Stéphanie Bouckaert, Eren Çam, Thomas Spencer, Simon Bennett, Daniel Wetzel and Roberta Quadrelli.

Additional thanks go to the IEA Communications and Digital Office (CDO) Division for their help producing the report and website materials, particularly to Jethro Mullen, Acting Head of CDO, Curtis Brainard, Astrid Dumond, Poeli Bojorquez, Clara Vallois, Jon Custer, Merve Erdil, Grace Gordon, Oliver Joy and Therese Walsh.

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:

Roberto Barrella	Comillas Pontifical University
Wiktoria Beckmann	Guidehouse
Mark Brownstein	Environmental Defense Fund

Nick Butler	King’s College London
Nina Campbell	Ministry of Business, Innovation and Employment of New Zealand
Russell Conklin	U.S. Department of Energy
Adnan Shihab Eldin	Oxford Institute for Energy Studies
Alessandro Federici	National Agency for New Technologies, Energy and Sustainable Economic Development
Francesco Fuso-Nerini	KTH Climate Action Centre
Dede Gafa	African School of Economics
Pedro Antonio Merino Garcia	Repsol
Francesca Gostinelli	Enel X
Sara Hastings-Simon	University of Calgary
Paola Velasco Herrejón	University of Oslo
Alexander Hijzen	Directorate for Employment, Labour and Social Affairs to the OECD
Gesche Huebner	University College London, Bartlett School of Environment, Energy and Resources
Abhishek Jain	Council on Energy, Environment and Water
Dave Jones	Ember
Ken Koyama	The Institute of Energy Economics, Japan
Pierre-Laurent Lucille	ENGIE
María María Ibañez Martín	Universidad Nacional del Sur
Prerana Misrahi	World Economic Forum
Shivika Mittal	CICERO
Peter Mulder	Netherlands Organisation for Applied Scientific Research (TNO)
Isabel Murray	Department of Natural Resources, Canada
Jessica Obeid	Middle East Institute
Cédric Philibert	Institut Français des Relations Internationales, Centre énergie et climat
Timo Ritonummi	Ministry of Economic Affairs and Employment
Baris Sanli	Permanent Delegation of Türkiye to the OECD
Aaron Sayne	Natural Resource Governance Institute
Clement Sefa-Nyarko	King's College London
Harsh Vijay Singh	World Economic Forum
Puree Sirasoontorn	Thammasat University
Wim Thomas	Expert Adviser

Nikos Tsafos	Office of the Prime Minister, Hellenic Republic
David Victor	UC San Diego School of Global Policy and Strategy
Tom Wilson	EPRI
Georg Zachmann	Bruegel
Peter Zapfel	European Commission
Christian Zinglersen	EU Agency for the Cooperation of Energy Regulators

The work reflects the views of the International Energy Agency Secretariat but does not necessarily reflect those of individual IEA member countries or of any particular funder, supporter or collaborator. None of the IEA or any funder, supporter or collaborator that contributed to this work makes any representation or warranty, express or implied, in respect of the work's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the work.

3 *Policies promoting affordability* *111*

4 *Price shocks and affordability* *151*

Annexes

The global energy crisis highlighted the importance of affordable energy

Affordability is always a concern for consumers and policy makers, but this has been heightened in recent years by price spikes for fossil fuels during the global energy crisis and resulting pressures on the cost of living. Consumers around the world spent nearly USD 10 trillion on energy in 2022 – an average of more than USD 1 200 per person – even after considering the subsidies and emergency support mobilised by governments. This is nearly 20% more than the average over the previous five years. Some countries and communities experienced a much greater shock, and high prices hit the poor and vulnerable hardest, in both developing and advanced economies. Almost one in ten people within the European Union – more than 40 million people – were unable to keep their homes adequately warm.

The spotlight is now on the affordability of energy transitions

Issues of affordability and fairness are central to clean energy transitions, with debate fuelled by two misperceptions. First, that today's pressures on the cost of living are related to clean energy, rather than the real cause – the gas supply crunch that followed the Russian Federation's cuts to deliveries to Europe. Second, the view that clean energy technologies are always more expensive than fossil fuel-based ones, which is not supported by the data. But there are nonetheless legitimate questions about risks to affordability that might arise during clean energy transitions, how transitions will be paid for, and how the costs and benefits of transitions will be shared. This special report provides, for the first time, an evidence base for the discussion and a pragmatic look at strategies and policy approaches that can safeguard affordability and fairness as transitions proceed.

Lower-income countries, communities and households are at the margins of today's energy system

The starting point for the analysis is an energy system characterised by multiple inequities, in which affordable energy is often out of reach. The most fundamental inequity is the 750 million people today who lack access to electricity and more than 2 billion people who do not have access to clean cooking technologies and fuels. There are also wide disparities in energy use and ability to pay across different income groups within societies. In advanced economies, the poorest 10% of households spend close to a quarter of their disposable income on residential energy and transport fuels, even though they consume about half as much of these fuels as the richest 10% (who spend 5% of their income on energy). There are even larger disparities across developing economies, with the poorest grouping consuming one-fourth that of the richest and often going without reliable, modern energy services. A key question for successful transitions is how policies can be designed in a way that ensures access to the clean energy economy for lower-income countries, communities and households.

Many clean energy technologies are already the most affordable ones, especially when lifetime costs are considered

Cost reductions for key clean technologies open a huge opportunity to chart a new course for the energy sector: clean, efficient choices are often now the most affordable ones, especially in terms of lifetime costs. Cost reductions have mainly been driven by a virtuous circle of innovation, accelerated deployment, economies of scale and policy support, with examples extending beyond renewable power to LED lighting in India and electric vehicles in the People's Republic of China (hereafter "China"). In 2023, more than 95% of new utility-scale solar photovoltaic (PV) installations and new onshore wind capacity had lower generation costs than new coal and natural gas plants. Where electric cars and two- and three-wheelers have higher upfront costs, which is not always the case, they typically result in substantial savings because of lower operating expenses. Efficient appliances, such as air-conditioning units, usually pay back any upfront premium with lower operating costs. Heat pumps can be more expensive than gas-fired boilers for heating alone, depending on the relative prices of electricity versus gas, but are typically competitive when considering both cooling and heating. Solar PV module prices are now exceptionally low – they declined by 30% in 2023 – creating affordable openings for everything from utility-scale projects to home solar systems, with their value enhanced by cheaper batteries.

A clean energy system is more efficient and cheaper to run

A more electrified, renewables-rich and efficient system brings important gains for affordability, alongside the clear environmental benefits. When all costs of delivering energy are considered (e.g. operating expenses, the need to pay back previous investments, financing costs) the Net Zero Emissions by 2050 (NZE) Scenario's 1.5 °C pathway is less costly on a global basis than the Stated Policies Scenario (STEPS), which is based on today's policy settings. This is because the running costs of a rapidly decarbonising energy system are much lower as the need to buy fuels reduces. Operating the energy system in the NZE Scenario in 2035 costs USD 2 per gigajoule (GJ) of energy in the NZE Scenario, less than half the USD 5/GJ in the STEPS. Electrification also brings important efficiency improvements: electric motors are more efficient than internal combustion engines. Likewise, heat pumps are more efficient than gas-fired boilers.

Today, around 50% of total consumer energy expenditure is on oil products, and another 35% is on electricity. In rapid energy transitions these swap places, making the price of electricity the key measure of affordability for most consumers. By 2035, in the NZE Scenario, the share of electricity in total spending on energy rises to 50% of the total, while oil falls to 25%. The average cost per unit of electricity is slightly higher in the near term in rapid energy transition scenarios, because of the need to pay for a surge in investments, but by the 2040s electricity prices in most regions are lower than in the STEPS. Retail electricity prices are typically less volatile than oil product prices, so consumers face more predictable energy costs as they move through transitions.

The costs of inaction are huge

Climate change is already affecting lives and livelihoods around the world, putting additional pressure on the cost of living, with poor and vulnerable communities ono the front line. This is raising awareness in many countries of the need to press ahead with action on emissions, as well as the benefits that this brings for a range of sustainable development goals. For example, the combination of increased clean electricity generation, electrified transport, phasing out of polluting fuels and progress with access to clean cooking fuels in the NZE Scenario leads to a significant improvement in health outcomes, particularly in developing economies, including 40% fewer deaths from air pollution by 2035 compared with the STEPS.

The destination is affordable, but how about the investment journey?

Realising the benefits of clean energy transitions hinges on unlocking the higher levels of upfront investment that are required. As things stand, around USD 3 trillion is invested each year into the energy sector, of which USD 1.9 trillion is in a range of clean energy technologies and infrastructure. By 2035, total investments need to rise to USD 5.3 trillion in the NZE Scenario, with USD 5 trillion going to clean energy. The required increases are particularly steep in emerging and developing economies outside China, whose 15% share of clean energy investment is far out of step with its two-thirds share of the global population, as well as its prospects for rapid growth in demand for energy.

Financing costs are a major issue, especially for developing economies

Financing costs for clean energy projects are a major additional hurdle, especially in emerging and developing economies that face a much higher cost of capital. Financiers and investors demand higher returns in these countries because investments tend to be – or are perceived to be – riskier than those in advanced economies. This issue has been exacerbated for relatively capital-intensive clean energy projects by the recent worldwide rise in borrowing costs. If financing costs remain high in developing economies, these countries risk being locked into polluting technologies that might initially be less expensive but end up incurring long-term fuel and environmental costs. Enhanced international efforts to increase the availability and lower the cost of capital for developing economies are a vital dimension of affordable transitions.

There are also distortions in today's system that favour the incumbent fuels

The need to keep energy affordable is a reason why many governments intervene to keep regulated fuel and electricity prices low. This also has the effect of introducing barriers to change, especially when the intervention keeps fossil fuel prices below their market value. Governments spent USD 620 billion in 2023 subsidising the use of fossil fuels, mostly in emerging and developing economies; many of these subsidies are poorly targeted and disproportionately benefit higher-income groups that use more of the subsidised fuel. This amount is significantly above the USD 70 billion that was spent in 2023 on support for consumer-facing clean energy investments, in the form of grants or rebates for electric vehicles, efficiency improvements or heat pumps. Innovative financial approaches are also required to facilitate the phase-out of the relatively young fleet of coal-fired power plants in many developing economies (mostly in Asia), which represent more than a trillion dollars of unrecovered capital.

What happens to energy bills?

The litmus test for affordability in energy transitions is what happens to consumer energy bills. Ultimately, consumers need to pay for the investments that are required to transform the energy system, whether directly through bills or indirectly through taxation or the cost of goods and services. However, the repayment of these investments is spread out over time, and the way that costs are allocated across different types of industrial and residential consumers is strongly affected by national circumstances and policies, making this a key decision point for policy makers. As it stands, some 10% of investment by consumers in clean energy is supported by governments in the form of grants or tax incentives.

Our projections highlight that rapid clean energy transitions result in lower consumer bills compared with a trajectory based on today's policy settings. In advanced economies, total energy expenditure in the NZE Scenario by 2035 is already 20% lower than in the STEPS. In emerging and developing economies, a key variable is the phase-out of fossil fuel subsidies: progress with energy transitions requires phasing out inefficient fossil fuel subsidies that do not address energy poverty as soon as possible, even if this pushes up energy expenses for some better-off households. This process needs to be accompanied by mechanisms to target support to those in need, while maximising private sector participation and keeping a watchful eye on public finances. The net effect in emerging and developing economies is that total consumer energy expenditure is higher in the NZE Scenario than in the STEPS – by 25% in aggregate over the next ten years – but by 2050 it is lower by nearly 20% compared with the STEPS.

Who should pay the upfront costs of fair and affordable transitions?

Who picks up the upfront costs of energy transitions is a political question for which countries will find a range of answers. Currently, around 45% of energy sector investments worldwide are made by private companies, around 35% by governments and state-owned enterprises, and 20% by households. Three-quarters of the financing for these investments comes from private and commercial sources. The remainder comes from states, with a small but important role for development finance institutions. Each of these actors face challenging starting conditions. Many governments are constrained in their ability to pick up a much larger share of the upfront costs of transitions because of fiscal limitations and indebtedness. Many large energy-intensive industrial consumers face intense international competition and thin margins, complicating efforts to invest in more innovative, cleaner technologies. Most investment in clean energy by households – such as efficiency improvements, solar panels, heat pumps or electric vehicles – are made by higher-income households. In the absence of policy interventions, the uptake of clean energy technologies by households will proceed much more slowly than is required for rapid energy transitions.

Solutions exist: many countries have implemented clean energy policies that benefit poorer communities and households

The analysis highlights examples of how well-designed policies can bring clean energy technologies to households and communities that would otherwise be underserved.

- **Alongside high standards for new construction, countries have adapted grant programmes for energy efficiency retrofits to make them more accessible to lower-income households.** Several countries, including France, Ireland and the United Kingdom, have focused these programmes on lower-income households that are often tenants rather than owners and more likely to live in homes with relatively poor energy performance.
- **Countries have used a range of policy tools to shift upfront expenditure away from poorer households**, for example by obliging energy utilities or suppliers to fund more efficient heating or cooling systems (over 30 countries have some form of energy efficiency obligation in place, although this is not always targeted at lower-income households), and through lease arrangements or pay-as-you-go schemes for solar panels or electric cars.
- **Governments have used minimum energy performance standards and top-up financing to make high-efficiency appliances more accessible**. Mexico's experience with performance standards shows that they can improve efficiency without pushing up costs, and policies in Senegal and Ghana illustrate how modest financial support can make best-in-class models competitive with less efficient ones.
- **Policies have focused on a range of affordable clean transport options**. Purchasing a new electric car is not an option for most low-income households, but there are policies that can make electrified transportation more widely accessible, with examples from China and India on support to the electrification of public transport and incentivising the purchase of electric two- and three-wheelers. Government support is now extending into second-hand electric vehicle markets in some countries.
- **There are good examples of countries replacing fossil fuel subsidies with targeted support for vulnerable households**. Subsidy reforms can be politically and socially difficult, but well-designed cash transfer schemes have proven to be effective in mitigating the impact of subsidy reforms on those in need, while freeing up resources for other social priorities such as health and education.
- **Where carbon pricing schemes are in place, there is an increasing body of experience on how the associated revenues can be used for social aspects of energy transitions**, following the examples of the European Union Social Climate Fund or California's Climate Credit.

Transitions mean huge shifts in energy-related revenue flows, which will have major implications for governments, especially today's producer economies

Taxes on energy production and use are important sources of revenue for governments around the world, and these will change profoundly as the world moves through

transitions. The situation varies widely by country, but at global level governments have seen a surfeit of energy revenues (USD 3.4 trillion) over energy expenditures (USD 1.1 trillion) in recent years. Taxes on energy production, mostly from oil, have averaged around USD 1.5 trillion in recent years. Governments also receive USD 1.8 trillion from taxes on energy use, again mostly from oil, and close to USD 100 billion from carbon pricing instruments. In rapid clean energy transitions, declining government revenue from taxes on fossil fuel production and use is partly offset by higher revenue from carbon pricing.

Net government income from the energy sector halves by 2035 in the NZE Scenario as fossil fuel-related revenues fall and support for clean energy picks up. Governments will need to formulate strategies to find alternative sources of revenue without penalising electricity use (which is already more heavily taxed than fuels in many countries), while managing the distributional implications. For example, expanding the scope of carbon pricing instruments to cover sectors such as transport and buildings could mean that lower-income households pay a larger proportion of overall CO_2 costs, if they cannot switch away from fossil fuels. There would be even larger implications at international level, with sharp reductions in fossil fuel rents payable to oil and gas exporters. How this plays out in practice depends on how fuel prices evolve, but the effect over time is to create severe strains on countries that are heavily dependent today on hydrocarbon revenues.

Energy transitions offer a path to cheaper energy, but governments, producers and consumers need to be wary of bumps along the way

Energy transitions are an opportunity to create an energy system that is cheaper as well as cleaner, but transitions are not immune from price shocks. Such shocks have been a regular feature of energy markets in the past and this will no doubt continue to be so in the future, even as the nature of the risks to affordability and exposure to them evolves. Geopolitical tensions and upheavals remain important potential drivers of volatility, both in traditional fuel markets and, in a more indirect way, in clean energy supply chains. But the shift to a more electrified energy system also brings a new set of hazards into play that are more local and regional, especially if investments in grids, flexibility and demand response fall behind. Many power systems are vulnerable to an increase in extreme weather events and cyberattacks, putting a premium on adequate investments in resilience and digital security.

And make sure that they're ready for disruptions when they come

Alongside preventative measures, governments need to be ready to react when price shocks come, including targeted measures to protect vulnerable segments of the population. During the recent global energy crisis, governments spent USD 900 billion to help consumers manage sky-high energy prices. Three-quarters of this support was not targeted to protect those most in need and was instead administered to all consumers. Readiness to manage risks in the future means prior design of support mechanisms that can be time-limited and targeted. The global energy crisis was a costly reminder of the frailties of today's energy system. It is time to move to one that is more affordable, and fair.

Guidance on incorporating considerations of fairness and affordability into strategies for clean energy transitions

1. **The transition to a clean energy system will not be complete unless all parts of society participate and benefit.** It is essential to generate sustained public support**.** The key measure of success for transitions is expanded access to clean and affordable energy for everyone.
2. **Affordable and fair transitions depend on policy design.** Fair distribution of the costs and benefits of clean energy technologies depends on intentional policy design. Assessing the distributional impacts of policies in advance and monitoring and evaluating their implementation are essential to positive outcomes.
3. **Make the most of clean technologies that are cost-competitive; bringing costs down and increasing access doesn't have to be expensive.** Many clean and efficient technologies are already cost-competitive with the alternatives, but they need to be widely available and their lifetime benefits recognised. There are tools available to policy makers, such as minimum energy performance standards, that can support clean energy goals without significant costs to either government or consumers.
4. **Recognise and value the wider benefits of clean energy transitions.** Successful energy transitions are not just about finding the cheapest pathway. Access to clean energy technologies can improve overall welfare through cleaner air, better-quality housing and improved health. Valuing such co-benefits can make an even stronger case for change.
5. **Know your consumers and their needs.** Nuanced policy and programme design can meet the needs of all different segments of society. Using trusted intermediaries and simple administrative procedures can help increase uptake of targeted technologies and programmes.
6. **Create the conditions for large-scale investment and finance from the private sector.** Investment needs for energy transitions are well beyond the capabilities of public sources, so affordable transitions require working with the private sector. Using public funds strategically will bring in much larger volumes of private finance and provide enhanced support to developing economies.
7. **Minimise the chances of adverse price shocks.** Policies for energy transitions need to be clear and well-sequenced, with adequate attention to infrastructure, power system flexibility, demand-side measures, and dialogue between consumers and producers, to minimise the risks of sudden market imbalances and price shocks.
8. **Be clear on long-term objectives, and vigilant on short-term risks.** Policy-making in energy transitions requires a long-term clarity of purpose to drive investment decisions alongside a readiness to respond to near-term threats to security and affordability. Emergency preparedness, market monitoring, supply chain diversity, and climate and cyber resilience are essential tools to limit the risk of disruptions.

Exploring affordable energy transitions

Setting the scene

SUMMARY

- Price spikes for natural gas and other fossil fuels during the global energy crisis in 2022 were a stark reminder of the importance of affordable energy. Consumers around the world spent USD 9.9 trillion on energy in 2022, which is nearly 20% more than the average over the previous five years. The fossil fuel price spikes affected lower-income households more than others.
- The crisis has raised awareness of risks that could arise in energy transitions, in particular if poorer households, communities and countries are excluded from the clean energy economy because they cannot pay the upfront costs of the switch to a cleaner and more affordable energy system. The benefits of energy transitions need to be widely felt if the process is to secure social acceptance.
- Cost reductions for clean energy technologies are making them an increasingly affordable choice, especially when lifetime costs are considered. Solar is the cheapest source of new generation; pairing it with storage adds costs but also brings value to power systems. In major markets, EVs – both cars and two-wheelers – are competitive with their fossil fuel counterparts, and heat pumps are increasingly competitive over their lifetime with gas boilers in key markets.
- However, there are various barriers that hinder greater adoption of clean energy technologies, including upfront investment costs and a regulatory landscape that often favours carbon-intensive technologies, including via large fossil fuel subsidies. Clean energy projects in many emerging and developing countries face particular barriers, notably a high cost of capital. For the moment, 85% of clean energy investment currently takes place in advanced economies and in China. Limiting the rise in global average temperatures to 1.5 °C requires a sixfold rise in clean energy investment in emerging and developing economies outside China by 2035.
- Capital investment is only one part of the picture. Running today’s energy system – including paying off investments and financing costs, and operating expenditure – costs over USD 7 trillion annually. These energy delivery costs rise in all scenarios to deliver energy services to a larger global economy and population, but costs are lower in the NZE Scenario than in the STEPS.
- Overall, our analysis finds that clean energy transitions deliver a lower-cost and more affordable energy system over time. However, in addition to the investments required, they also involve major reallocations in today’s energy-related capital flows away from fossil fuel producers, and they have distributional implications within countries as well. The changes involved have to be managed as fairly as possible.

1.1 Introduction

The past decade has seen the start of a transformative process for the energy sector with the rapid deployment of clean energy driven by supportive policies and steep cost declines. Solar and wind power generation, electric vehicle (EV) and heat pump sales, and battery energy storage have grown rapidly, and the number of countries with net zero targets have increased from 77 in 2019 to 145 in 2023. Governments are enacting policies to help reach these goals, but they do so against a backdrop of persistent inflation, high levels of government indebtedness and geopolitical tension. Cost-of-living pressures continue to loom large in both advanced and emerging economies. At the moment, the vast majority of investment in clean energy is taking place in advanced economies and the People's Republic of China (hereafter "China"), and within these countries, the switch to new technologies is often concentrated in wealthier households and businesses. This underlines the importance of making clean energy transitions affordable and fair for all.

Affordability has various dimensions beyond the mere cost-competitiveness of clean energy technologies over their lifetime. They include the scope for poorer and vulnerable households to adopt such technologies, the ability of industries to remain competitive, and the capacity for governments to target supportive measures towards those who most need them. For energy transitions to be affordable, they will need to be:

- Well-managed, avoiding unnecessary costs and bumps in the road.
- Equitable, ensuring opportunities for all countries and groups in society.
- Resilient, taking steps to prepare for possible disruptions and unexpected events.

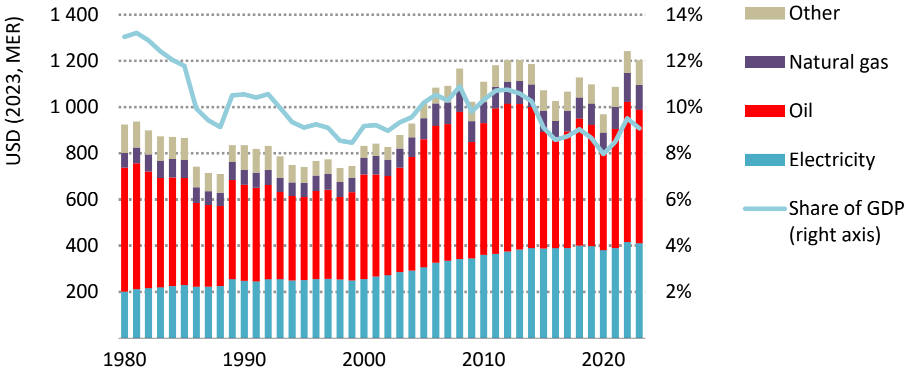
Whether or not clean energy transitions secure the support of a broad range of stakeholders depends on how well these criteria are addressed. Ultimately, for clean energy transitions to be well managed, equitable and resilient, technologies need to be affordable at the retail level and their socio-economic benefits need to be widely felt. Clean energy technologies become affordable not only due to technological advances and economies of scale but also through policies that provide a level playing field for clean energy, targeted measures that ensure the inclusion of the most vulnerable households and communities, and the availability of appropriate financing options for capital investment.

This report explores the various aspects of affordability. This opening chapter sets the context for the discussion on energy affordability by exploring the costs of the transition through the lens of investment, consumer energy bills, and the relative costs of clean energy and incumbent fossil fuel technologies. Box 1.1 contains a short discussion on the definitional issues of affordability. Chapter 2 explores the equity dimension of energy affordability, as well as the affordability implications for governments and industry. Chapter 3 discusses how governments around the world are addressing affordability concerns for households and communities, particularly those that relate to fairness and equity. Finally, Chapter 4 explores the consequences for affordability of sudden shocks to the system and considers lessons to be learned from the recent global energy crisis.

1.1.1 Why affordability matters

Energy represents a large part of annual consumer spending. On average, consumer spending on energy has been more than USD 1 000 per capita for the past decade (Figure 1.1). Oil (around 50%) and electricity (around 35%) currently account for 85% of consumer spending on energy. Oil price volatility has a major impact on consumer energy expenditure. The importance of electricity in consumer spending on energy is rising: electricity's share of total final energy consumption has almost doubled over the last four decades. Industry and transport each account for around a third of total energy expenditure, with the final third going to meet energy needs in buildings, including for heating, cooking, lighting and use of appliances.

Figure 1.1 ▹ Global energy bill per capita and as a share of GDP

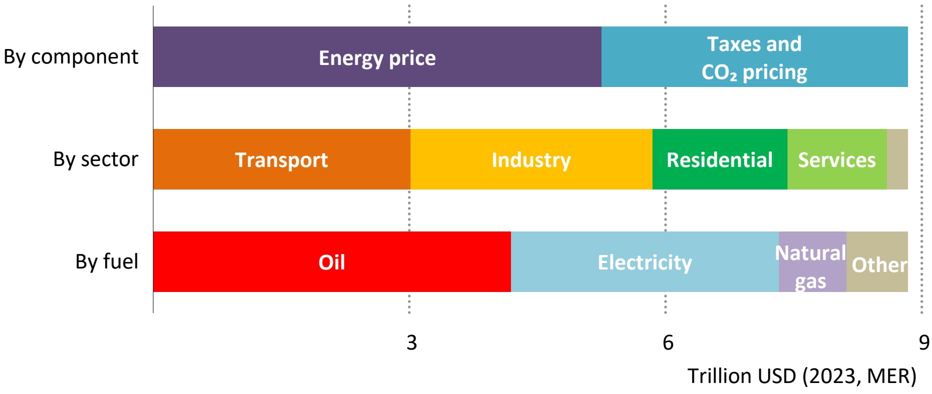


Consumer spending on energy made up around 8-10% of global GDP in recent years; oil price volatility has a significant impact on consumer energy bills

Notes: Other includes coal, modern bioenergy and district heat. The figure excludes traditional use of biomass.

The energy crisis in 2022 was a stark reminder of how much societies depend on reliable and affordable supplies of energy. Consumers around the world spent USD 9.9 trillion in aggregate in 2022 to meet their energy needs, equivalent to around 10% of global gross domestic product (GDP). This amount was almost 20% more than the average of the preceding five years. Government affordability support amounted to over USD 900 billion from the start of the energy crisis until April 2023. Taxes on energy production and consumption average around USD 3.1 trillion each year, accounting for around 40% of total consumer energy expenditure. This underlines the importance of energy consumption for government revenues (Figure 1.2). Government revenue from CO_2 pricing is a small but growing part of the total, reaching USD 100 billion in 2023.

Figure 1.2 ▹ Breakdown of annual average global energy bills, 2019-2023



IEA. CC BY 4.0.

Consumers pay, on average, around USD 9 trillion for energy each year, with roughly equal amounts spent on energy use in transport, industry and buildings (residential and services)

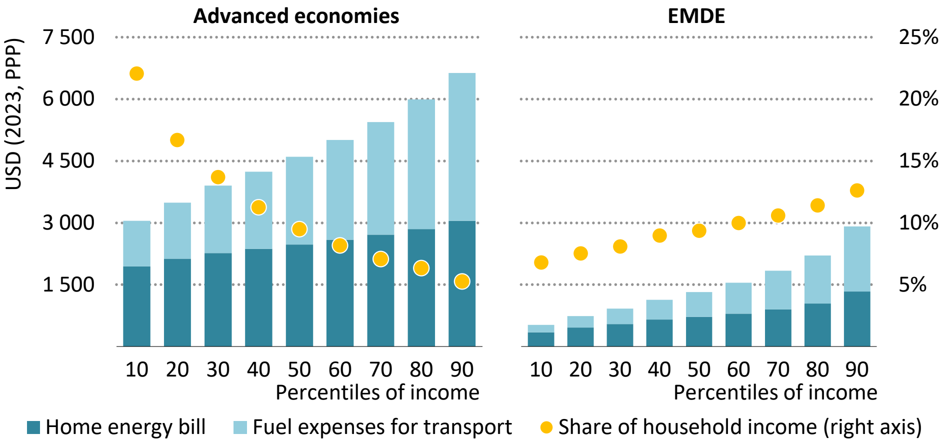
Notes: Taxes and CO_2 pricing include upstream royalties; fuel duties; and value-added, environmental and excise taxes, and are net of consumer subsidies. Oil, natural gas and other fuels used for power generation are included in electricity.

Energy consumption is characterised by inequities of various kinds. The most fundamental of these is that 750 million people today worldwide lack access to electricity and that more than 2 billion do not have access to clean cooking fuels. Eighty percent of those without access to electricity and around half of those without clean cooking solutions live in Africa, and most of the rest are in developing countries in Asia. Globally, a lack of clean cooking contributes to 3.7 million premature deaths annually, with women and children most at risk. Equally, without modern energy, households struggle to access education, earn a wage or start a business.

In advanced economies, energy poverty concerns are on the rise following the energy crisis in 2022 and the subsequent squeeze on the cost of living. The poorest 10% of households spend up to 22% of their disposable income on residential energy and transport fuels, even though they consume only about half as much of these fuels as the richest 10% (Figure 1.3). Some households face stark choices between heating their homes and meeting other basic necessities. To alleviate this burden, some governments provide targeted direct affordability support to low-income households.

In emerging market and developing economies (EMDE), the disparities between income groups are even wider, with the poorest consuming one-fourth that of the richest. In contrast to the situation in advanced economies, households in EMDE in lower income brackets spend *less* of their disposable income on energy than higher-income households. This is because these segments of the population often lack access to electricity and clean cooking options and have lower levels of ownership of energy-consuming equipment. Nearly 40% of residential energy demand in EMDE is met by the traditional use of biomass, which is not accounted for in expenditure metrics, and direct consumption of modern energy by households (the dominant forms being oil products, electricity and natural gas) is only a third of that in advanced economies. This leads to lower consumption and expenditure on energy in these households and a much higher share of their disposable income going to food, shelter and other basic necessities. More broadly, vehicle ownership is also significantly lower among households in EMDE than in advanced economies, and two-wheelers are much more common than passenger cars, leading to lower expenditure on transport. In addition, the energy prices paid by households for residential energy are on average lower in EMDE: this is at least in part because residential energy and transport fuels are often subsidised.

Figure 1.3 ▷ Annual household expenditure on residential energy and transport fuels by income decile, 2019-2023 average



IEA. CC BY 4.0.

Energy bills are a significant burden for low-income households in advanced economies, while in EMDE, poorer households typically lack access to modern energy, and have low ownership of appliances and vehicles that drive energy demand

Notes: EMDE = emerging market and developing economies; PPP = purchasing power parity. Income refers to household disposable income. Household disposable income deciles represent the weighted average of the deciles of each country grouping assessed. This analysis considers government subsidies that directly affect the energy prices paid by consumers such as energy price caps. It does not include direct payments to households such as energy assistance checks, which have accounted for a significant portion of disposable income for low-income households in certain countries in recent years.

As EMDE grow, the share of household income spent on energy in these countries will begin to catch up with that in advanced economies. There is, however, a long way to go: the richest 10% in EMDE today consume about as much energy as the poorest 10% in advanced economies.

Box 1.1 ▷ Understanding affordability

There is no universally accepted definition of affordability in the context of energy transitions, nor one that can be applicable in all contexts and geographies. Energy affordability is related to two similar but distinct concepts: energy access and energy poverty. Energy access occurs when a household gains access to sufficient clean cooking facilities and electricity to obtain a basic bundle of energy services. While there is no agreed threshold of energy poverty,* it generally refers to disadvantaged individuals, families or communities who are unable to afford some defined level of energy service.

In the context of energy transitions, affordability is a broader concept. It encompasses energy access and energy poverty and also applies to a wider range of stakeholders. Broadly, affordable energy transitions are those where the shift to clean energy technologies occurs without negatively impacting the cost of energy services or causing significant economic hardship to vulnerable consumers. At the same time, industries and businesses are able to reduce emissions without losing competitiveness, and governments can manage the changes in expenditure and revenue that accompany the shift from fossil fuels to clean energy. This report explores these various dimensions of affordable energy transitions.

* Discussed further in Chapter 2.

1.1.2 The macroeconomic and geopolitical contexts of affordability

In the 2010s, large parts of the world including the United States (US), the European Union (EU) and China witnessed rapid growth in clean energy deployment – particularly solar photovoltaic (PV), wind and EVs – in a period of relatively low interest rates, low inflation, and relative calm. In the wake of the Covid pandemic and the energy crisis resulting from Russian Federation’s (hereafter “Russia”) invasion of Ukraine, there is a new macroeconomic and geopolitical landscape. There are at least three significant macro trends which have particular importance for the affordability of clean energy. These are the changing monetary policy landscape, changing inflation fundamentals, and the growing influence of geopolitical considerations in energy and industrial policy.

The end of an era of accommodative monetary policies

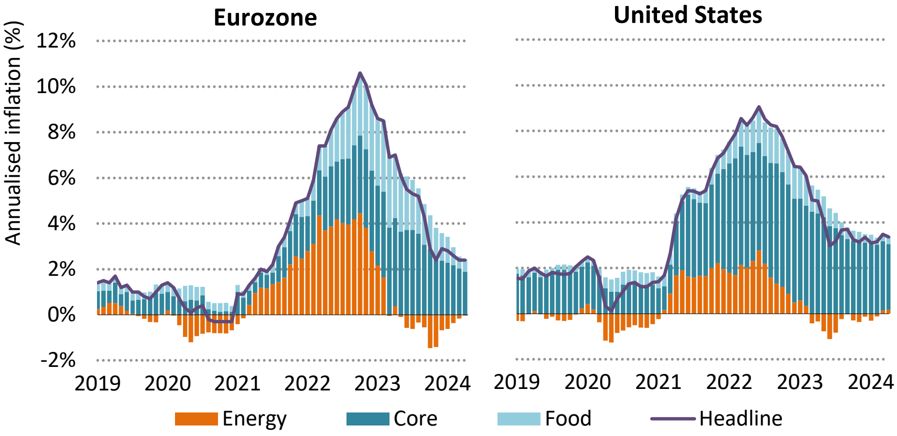
In the 2010s, low interest rates and easy access to capital were instrumental in fostering investment in renewable energy projects, but the era of accommodative monetary policies that enabled this growth in clean energy adoption now seems to be over. Central banks – particularly in the United States, European Union and United Kingdom – have moved towards more restrictive monetary policies, characterised by higher interest rates and reduced liquidity. As a result, the cost of capital for clean energy projects has risen. The United States, European Union and United Kingdom collectively constitute nearly 40% of global clean energy investment, and debt financing contributes to over four in ten US dollars invested in clean energy in this group of countries. Higher interest rates in these economies also have far-reaching impacts on EMDE, where USD, EUR and GBP dominate the lending instruments. For example, over 75% of all project finance[1] between 2015 and 2022 for clean power generation globally was denominated in USD, EUR and GBP.

An environment of higher interest rates could have an outsized impact on investment in clean energy projects because such projects typically involve relatively high upfront costs that are compensated over time by much lower operating expenses. In such an environment, future returns may look less attractive than more immediate gains from dividends or value-driven investing, and investors may allocate more of their funds to traditional energy sectors that are perceived to be less sensitive to interest rate fluctuations.

Rising inflation

Inflation and energy prices are closely linked, with energy price movements strongly influencing inflationary trends (Figure 1.4). Periods of high and rising energy prices tend to raise the rate of consumer price inflation, while falling energy prices have deflationary effects.

Figure 1.4 ▷ Inflation drivers in the Eurozone and United States, 2019-2024



IEA. CC BY 4.0.

After a decade of moderate headline inflation, it rose sharply since the onset of the global energy crisis in major advanced economies, with higher energy costs a major driver

Sources: IEA analysis based on Eurostat (2024) and FRED (2024)

The 2010s were a period of relatively low inflation in major advanced economies. For example, headline inflation in the United States through the 2010s averaged 2%, and in Germany, 1%. Since 2021, however, the headline rate has risen to 6% in the United States and 5% in Germany as inflation has surged in major economies. This surge is partly the result

---

[1] Approximately 20% of clean energy investment spending globally is in the form of project finance.

of energy price shocks. There is also a growing body of evidence that indicates that climate change has been threatening price stability. Higher temperatures have been increasing food and headline inflation; extreme summer heat in 2022 might have increased food inflation in Europe by 0.4-0.9 percentage points (Kotz et al., 2024). Periods of high and rising fossil fuel prices tend to increase the incentives to adopt clean energy technologies, while falling and low fuel prices tend to tip the scales the other way. High inflation in general reduces the capacity of households to spend on the capital or to service debt that is needed to purchase clean energy equipment.

Geopolitical risks to global trade and co-operation

Energy has always been bound up with geopolitics, and the experience of the global energy crisis has reinforced wariness about excessive reliance on supply from a limited number of countries, companies or trade routes. This applies not only to fossil fuels but also to aspects of the new clean energy economy. Opportunities to produce low-emissions energy are distributed widely around the world, but existing clean energy supply chains are currently highly concentrated.

Today, for example, over 80% of the production of several critical minerals (IEA, 2024a) and clean energy technologies are located in the top three refining and manufacturing regions respectively (IEA, 2024b). China has a notably strong position across the board. Its investments have helped make clean energy technologies more affordable, with multiple benefits for clean energy transitions. However, the high degree of concentration in energy supply chains is a concern, and there are justifiable reasons for countries to seek to increase the resilience and diversity of clean energy supply chains.

Recognising the risks associated with the current level of market concentration, many governments have brought forward measures to support clean energy manufacturing and encourage domestic critical mineral exploration and refining. These include the Inflation Reduction Act (IRA) in the United States, the Net Zero Industry Act (NZIA) and the Critical Raw Materials Act in the European Union, and the Production Linked Incentives (PLI) scheme in India. These measures have the potential to bring forward new suppliers and to make global supply chains more resilient over time. However, the risk in a low-trust world is that this process could tip over into more widespread barriers to trade, if countries prioritise autonomy over managed dependence. Doing so could delay the transition to clean energy by adding costs and complexity to the process of change.

1.2 How much do transitions cost?

The debate about the costs and affordability of clean energy transitions often focuses narrowly on the capital investment required to retool the global energy economy. Our analysis confirms the necessity of a large increase in capital flows to a wide range of clean energy projects, especially in emerging market and developing economies. As things stand, around USD 1.9 trillion is invested each year on clean energy, and this amount needs to more than double by the end of the decade to get on track with achieving net zero emissions by 2050. Investment needs to be financed, and rising financing costs make it more difficult for firms to maintain or increase investment plans.

But this does not tell the whole story, and a full account of the costs of clean energy transitions needs to consider several additional elements. In transitions, part of the higher investment in clean energy is offset in aggregate by lower investment in fossil fuels. Clean energy also tends to have lower ongoing costs than fossil fuels: this means that, once installed, clean energy technologies are much cheaper to run. Further, resource rents transferred to producers and exporters are far lower for clean energy than is the case for fossil fuels. Any considerations of the implications of clean energy transitions for the affordability of energy for consumers also needs to factor in the taxes, support mechanisms and subsidies for fossil fuels and clean energy that governments have in place today and how these might evolve in the future.

In this section, we start with an overview of the capital investment needs and financing costs across our different scenarios (Box 1.2), including new analysis on the sources of finance that are needed for clean energy transitions. As a key determinant of energy affordability, we then look at how prices for fossil fuels and electricity are formed in our scenarios. We next look at total system costs, which incorporate recovery of capital on upfront investments, financing costs, operating expenditure and the rents accrued to resource owners. We also consider taxes and subsidies to provide a full picture of consumer energy expenditure.

Box 1.2 ▹ Scenarios and definitions of key terms used in this report

International Energy Agency (IEA) analysis is based on scenarios that explore pathways based on various assumptions, which in turn lead to differing outcomes. Three scenarios are referenced in this report:

- **The Net Zero Emissions by 2050 (NZE) Scenario** sets out a pathway to the stabilisation of global average temperatures at 1.5° C above pre-industrial levels, showing what is needed for the global energy sector to achieve net zero carbon dioxide (CO_2) emissions by 2050. It also meets the key Sustainable Development Goals (SDGs) related to universal energy access and delivers major improvements in air quality.
- **The Announced Pledges Scenario (APS)** 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. The APS is associated with a temperature rise of 1.7° C in 2100.
- **The Stated Policies Scenario (STEPS)** explores the implications of today's policy settings, based on a detailed sector-by-sector assessment of what policies are actually in place or are under development by governments around the world. This scenario does not automatically assume that ambitious climate targets or SDGs such as universal clean cooking access are met. Emissions in the STEPS do not reach net

zero, and the rise in average temperatures associated with the STEPS is around 2.4° C in 2100.

There are key terms used through this report that help explain the contours and different dimensions of affordability. They include:

- **Energy investment** is capital expenditure on energy assets, including oil and gas fields, refineries, pipelines and grids, power plants, appliances, and vehicles. In the case of end use and efficiency, energy investment is the spending on electrification of processes, or the incremental spending to acquire more energy-efficient equipment.*
- **Capital recovery** is the spending over a defined period of time to recoup initial energy investment, and it includes the spending on assets built in preceding years. It is distinct from energy investment and excludes financing costs (this is discussed further in Box 1.4).
- **Financing cost** is the cost, interest and other charges involved in the borrowing of money to make an investment. It is determined by the cost of capital, which is the expected financial return, or the minimum required rate of return, to justify an investment in a company or project.
- **Operating costs** are the ongoing running costs involved in producing, transporting and delivering energy to end consumers.
- **Energy delivery cost** is the sum of capital recovery, financing cost, operating costs and fossil fuel rent.
- **Energy bills** are the amounts paid by households and businesses for modern fuels and electricity. They typically reflect the cost of producing and delivering energy to end consumers, plus applicable taxes and minus any subsidies. They do not include capital expenditure on end-use clean energy equipment such as EVs or heat pumps.
- **Total end-use energy expenditure**, also called total consumer expenditure on energy, is the sum of energy bills as well as capital recovery on end-use clean energy equipment.

***** For further details, please see World Energy Investment 2024: Methodology Annex (forthcoming).

1.2.1 Capital investment and sources of finance

Total investment flows to the energy sector globally reached USD 3 trillion in 2023, with USD 1.1 trillion invested in fossil fuels and USD 1.9 trillion going towards clean energy investment, which includes renewable power, nuclear, low-emissions fuels, electricity grids and storage, and investments in energy efficiency and electrification. Total energy investment has been growing rapidly since 2020, largely due to increased spending on clean power and electrification in advanced economies and in China, although there has also been a pickup in investment in fossil fuels after a slump during the pandemic. Investment needs to rise further in all of our scenarios, with all the increase in aggregate coming from clean energy. Investment in fossil fuel supply decreases to 2030 in the STEPS compared with current levels (Figure 1.5).

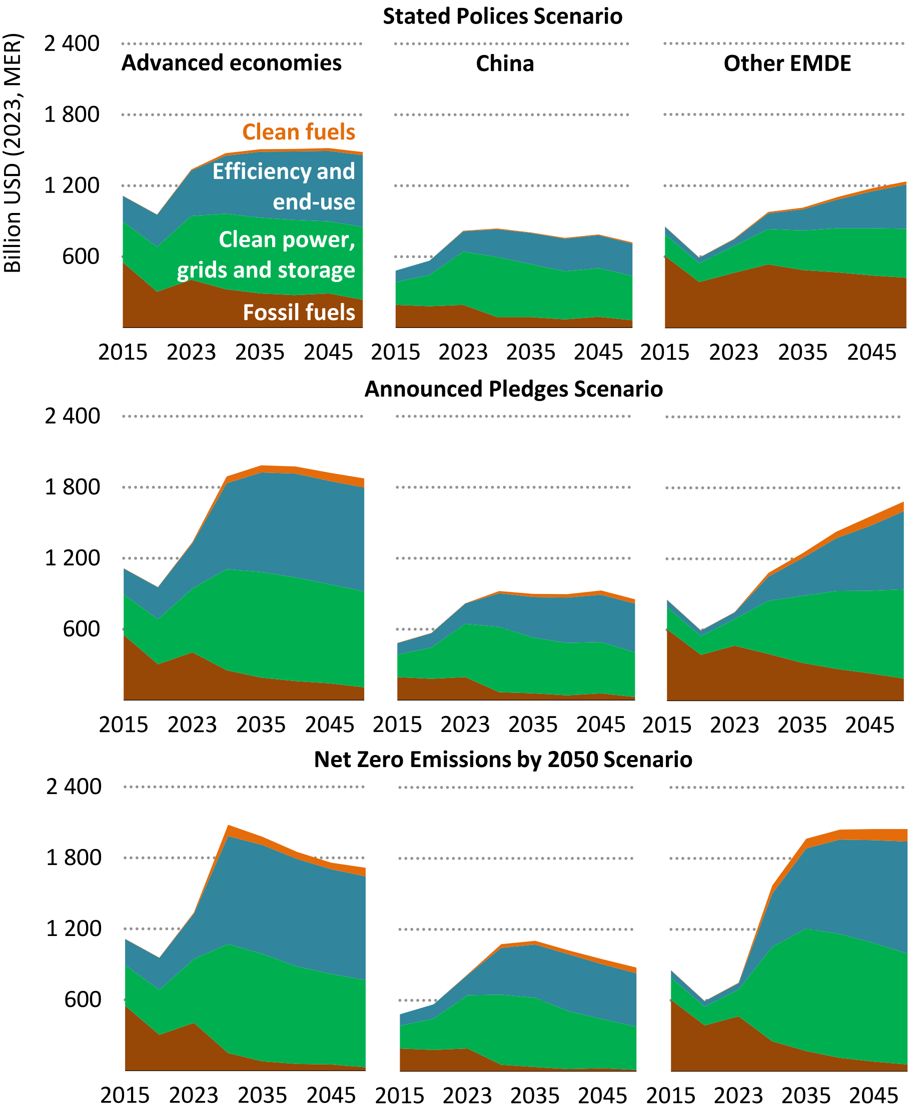
There are large country-by-country variations in investment flows, including a profound imbalance in spending on clean energy. At present, advanced economies and China account for about 85% of global clean energy investment. The 15% share of other EMDE is out of step with their two-thirds share of the global population and their one-third share of global GDP. This discrepancy is a warning sign for the future.

In the power sector, investment in low-cost renewables can improve affordability. In 2023, for example, more than 95% of new utility-scale solar PV installations and new onshore wind capacity had lower generation costs than new coal and natural gas plants. Solar PV module prices are very low – they declined by 30% in 2023 – and this offers a major opportunity to accelerate the deployment of cost-effective renewable energy. Manufacturing capacity is unlikely to be a constraint: if all manufacturing capacity currently under construction is completed, annual solar PV manufacturing capacity should reach 1 100 gigawatts (GW) by the end of 2024, which is two times the anticipated level of solar PV deployment. There are, however, several caveats.

- First, solar is highly concentrated in geographical terms, with China currently having an 80-95% share of global supply chains (depending on the manufacturing segment). Efforts to develop domestic PV manufacturing in other markets such as the United States, India and the European Union may help to diversify supply and create greater resilience but, at least in the near term, are likely to involve replacing cheaper imports with more expensive production.
- Second, solar needs supportive policies to facilitate investment, such as tenders or auctions for new utility-scale projects, and supportive regulations for the installation of rooftop solar for commercial or residential buildings. Further development of policies and regulatory regimes is needed in many countries.
- Third, large projects require grid infrastructure, and this is becoming a major bottleneck. IEA analysis of some of the largest markets for clean power suggests that 1 500 GW of new renewable capacity is at an advanced stage of development but is being held up by the lack of a transmission connection. Clean electricity systems depend on growing levels of investment in grids and storage: by 2035, in the APS and the NZE Scenario, the share of grids and storage in overall power investment rises to 50%, up from 30% today.

Looking to future investment requirements, energy efficiency and end-use sectors see the largest increases in investment from current levels in the APS and the NZE Scenario. These investments are mainly directed at producing more efficient buildings, appliances and industrial equipment, and at the electrification of transport and heat. Investment in more energy-efficient buildings and appliances is needed everywhere, but is particularly important

Figure 1.5 ▷ Investment in energy by region and scenario, 2015-2050



IEA. CC BY 4.0.

Clean energy investment in emerging market and developing economies excluding China accounts for only 15% of the total, and needs to scale up rapidly in the NZE Scenario

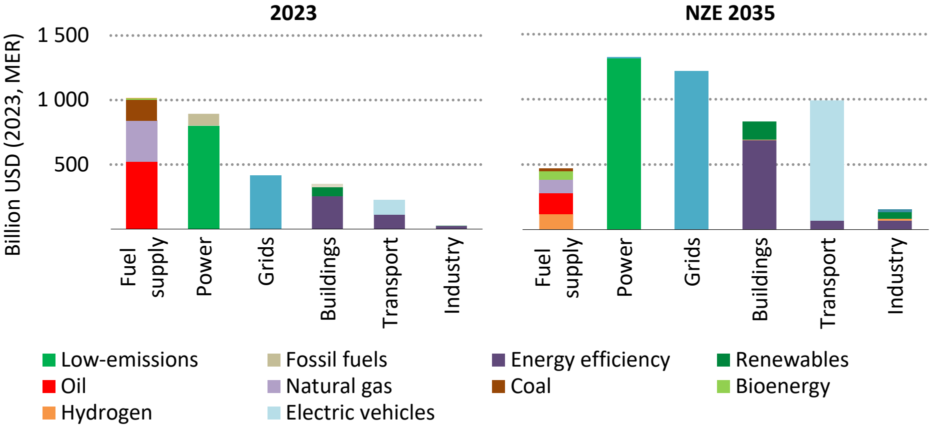
Notes: MER = market exchange rate. Fossil fuels here includes both fossil fuel supply and unabated fossil power generation. Direct air capture and power generation from non-renewable waste are excluded from this graph. Together, they constitute less than 2% of total annual energy investment globally in all scenarios through to 2050.

in rapidly urbanising EMDE. With notable exceptions such as India – where improvements in energy efficiency have been driven by building codes, appliance standards, and the innovative use of public procurement to drive down the costs of efficient lighting and cooling – spending in these areas in EMDE remains far below the levels seen in the APS and the NZE Scenario, and further policy support is needed to stimulate additional investment.

In aggregate, end-use investment rises from around USD 650 billion per year today to USD 2.2 trillion by 2035 in the NZE Scenario. This additional investment includes the purchase of equipment which improves efficiency in end uses such as electric vehicles, electrification of buildings and industrial processes, direct use of renewables, deployment of hydrogen and hydrogen-based fuels, and carbon capture, utilisation and storage (CCUS) in industry. In all cases, investment tracks the additional capital required in these clean energy technologies compared with fossil fuel-based technologies. For example, it tracks the cost of the battery pack in electric vehicles, which decreases over time, rather than the total vehicle cost.

Global energy investment in the NZE Scenario increases significantly over the next decade. Overall spending of USD 3 trillion in 2023 increases to USD 5.3 trillion by 2035. In the power sector, the NZE Scenario sees a rapid increase of investment in low-emissions sources of electricity generation (solar, wind, hydro, nuclear and geothermal) from nearly USD 800 billion in 2023 to over USD 1.1 trillion in 2035. Investment in grids and batteries triples, reaching USD 1.2 trillion in 2035. Electric vehicle investment increases eightfold. At the same time, fossil fuel investment decreases by three-quarters, while hydrogen and biofuel investments scale up (Figure 1.6).

Figure 1.6 ▷ Energy investment today and in the NZE Scenario in 2035



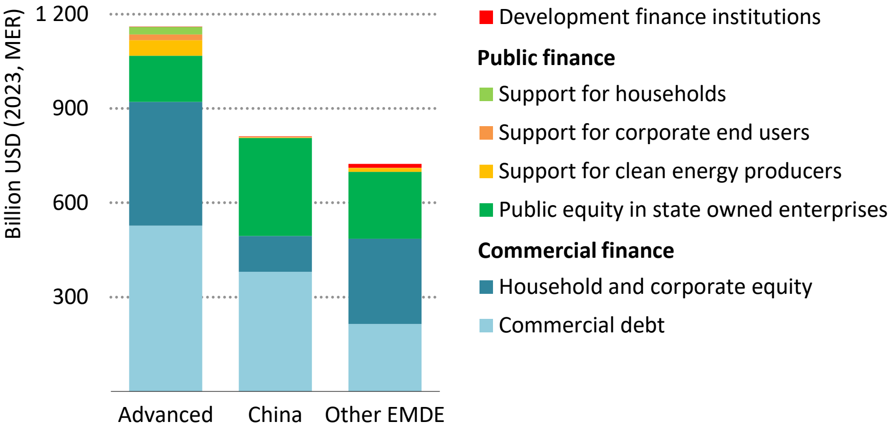
IEA. CC BY 4.0.

Total energy investment doubles in the NZE Scenario by 2035, led by a surge in clean electrification. For every dollar spent on fossil fuels in 2035, USD 18 is spent on clean energy

Sources of finance

Examining the sources of finance for energy projects helps to provide a better understanding of how they can be scaled to meet investment needs. Today, 75% of the available finance for investment in the energy sector is "commercial finance" (Figure 1.7). This includes equity investments made by private enterprises and households alongside debt from commercial banks and financial institutions. It also includes some finance from public financial institutions, such as national development banks, sovereign wealth funds and pension funds, some of which is in effect state-directed lending, especially in emerging economies with strong industrial policies.

Figure 1.7 ⊳ **Sources of finance for energy investment today**



Around 75% of overall finance for energy investment comes from commercial sources, mainly private commercial banks and financial institutions

Note: Advanced = advanced economies.

Another 25% of funding can be classed as "public finance", which includes public equity stakes in state-owned enterprises, public subsidies and tax incentives for energy consumers, and finance from some state-owned financial institutions such as export credit agencies as well as central banks. Less than 1% comes from development finance institutions (DFIs) that have an explicit development mandate. DFIs can be domestic (as in the case of BNDES in Brazil and PTSMI in Indonesia) or international, and in the latter case can be bilateral (such as the Agence Française de Développement, Germany's KfW and Japan International Cooperation Agency) or multilateral (such as the World Bank, the Asian Development Bank and the African Development Bank). DFI participation in a project either as an equity or debt holder, whether through grants or the provision of guarantees, typically strengthens project viability and helps to unlock higher amounts of private financing.

The shares of commercial finance and public finance vary among regions. In EMDE outside China, for example, public institutions accounted for 30% of all financing in the energy sector, with 2% financed by DFIs. But the bottom line is that financiers, in almost all cases, are seeking appropriate risk-adjusted returns. Where real or perceived risks are high, this can make capital unaffordable, especially for those considering investing in relatively capital-intensive clean technologies. The importance of the cost of capital, and the measures that can reduce it, are discussed in the next section.

Since investment in most clean energy technologies are supported today by commercial finance, these sources play a predominant role in scaling up the clean energy economy in our scenarios. There is, however, a distinct shift towards debt financing as technologies mature and domestic capital markets deepen in EMDE (Box 1.3). In the NZE Scenario, as investment in fossil fuels declines, so too does the relative share of public finance via state-owned enterprises. This is, however, preceded in EMDE by a significant step-up in DFI support, which triples between now and 2035.

Box 1.3 ▷ A transition powered by equity or by debt?

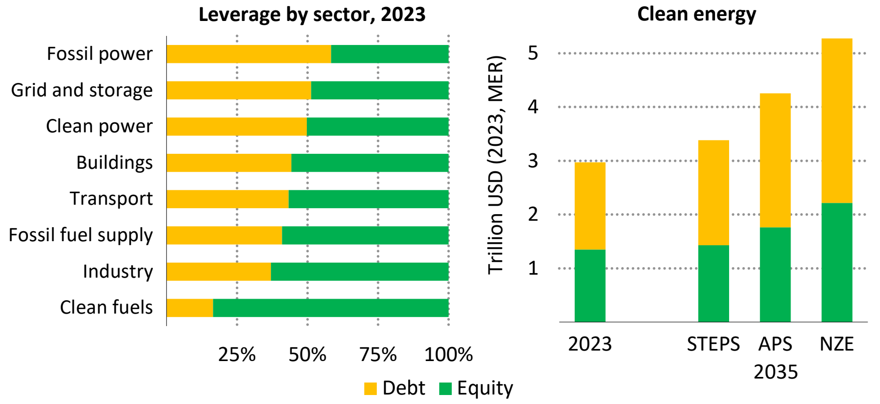
At present, we estimate that a slight majority of today's energy investments are financed via equity. This is in part because the traditional tendency of major oil and gas companies to rely relatively little on debt has been buttressed by record revenues and profits during the global energy crisis (Figure 1.8).

Most investment today in industry and buildings is financed via equity, the latter mostly from household savings. The current level of investment in clean fuels is relatively low, but the riskier nature of projects in such early-stage and emerging technologies means that equity financing is often the only way that such projects can move forward.

Debt financing tends to play a bigger part in investment of clean generation and grids. Many low-emissions power generation projects are backed by long-term power purchase agreements (PPAs), and in the case of grids by regulated tariffs. These provide for more predictable revenues, making debt financing easier to access and more affordable.

As clean energy transitions progress, we expect a gradual shift over time towards greater reliance on debt as a result of a ramping up of investment in clean generation and networks, a reduction in technology risks, greater experience with new business models in areas such as storage and clean fuels, opportunities to refinance operating projects once initial permitting and construction risks have diminished, and opportunities to tap into deeper local capital markets (and local currency financing) in EMDE. Debt is generally lower-cost than equity and so this shift could have positive implications for overall affordability. However, much depends on the broader context of debt levels and sustainability, especially in developing economies, and on the scaling up of concessional debt financing from DFIs.

Figure 1.8 ▷ Global financing structures by sector today and clean energy investment today and in 2035, by scenario



IEA. CC BY 4.0.

Investments in fuels have higher shares of equity relative to electricity

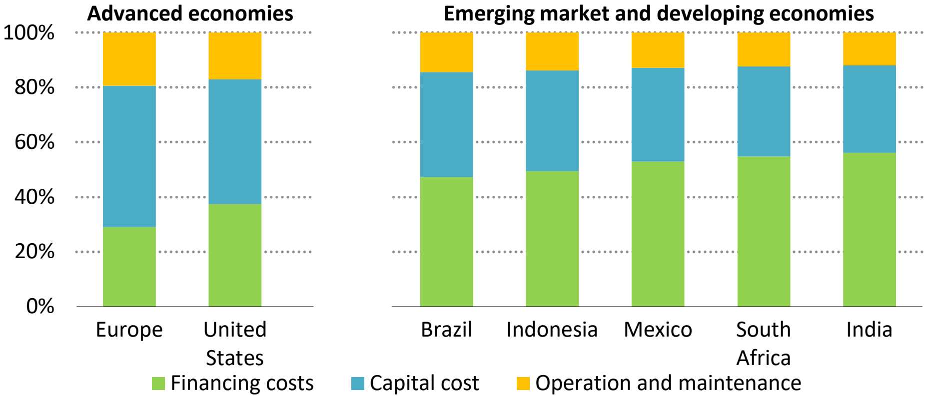
Financing costs

The affordability of finance for investing in energy transitions is critically important. Affordability centres on the cost of capital, which reflects the minimum return that a company requires to justify a decision to invest. This in turn reflects perceptions of risk: the riskier the project, the higher the rate of return that is required to justify investing. The cost of capital varies by country, subsector and technology. By and large, however, EMDE face a higher cost of capital because investments in these countries tend to be – or are perceived to be – riskier than those in advanced economies.

The latest survey data collected by the IEA through its Cost of Capital Observatory confirm that the cost of capital for utility-scale solar PV projects reaching a final investment decision in 2022 in a number of major EMDE (Brazil, India, Indonesia, Mexico and South Africa) was at least twice as high as that in advanced economies (the United States and various European countries) (Figure 1.9). This reflects a mix of broad country-related risks and macroeconomic factors together with energy-specific issues. Concerns about the reliability of revenues, the availability of necessary land and transmission infrastructure, and the way in which these issues are defined in contracts are among the factors that result in a higher cost of capital in EMDE than in advanced economies.

A high cost of capital pushes up financing costs and makes it much more difficult to generate attractive risk-adjusted returns, especially for relatively capital-intensive clean technologies. As a result, EMDE can end up paying more for clean energy projects or miss out on them altogether. Solar PV plants and other clean energy projects tend to involve a relatively high level of upfront expenditure. If countries cannot afford high upfront costs, they risk being locked into polluting technologies that might initially be less expensive but could end up costing more in the longer term because of their dependence on fossil fuels.

Figure 1.9 ⊳ **Composition of levelised cost for a utility-scale solar PV plant with final investment decision secured in 2022**



IEA. CC BY 4.0.

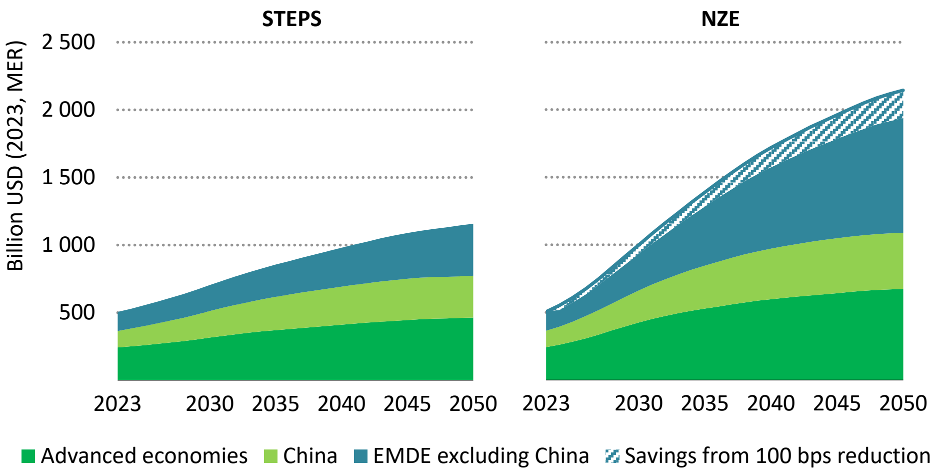
Financing costs accounts for around half of total levelised costs in EMDE, and significantly more than in advanced economies

In advanced economies, capital costs – e.g. for land, equipment, installation – are usually the largest single element in the total lifetime costs of a clean energy project. In EMDE excluding China, the largest element is often financing costs. Financing costs constituted around half or more of the total levelised cost of utility-scale solar PV projects in EMDE excluding China, reaching a final investment decision in 2022. In advanced economies, financing costs account for a much lower proportion of the overall costs.

Financing costs for the clean energy transition increase significantly in the NZE Scenario as a result of the large-scale deployment of capital-intensive clean energy technologies. Overall clean energy financing costs more than double by 2050 in the STEPS compared with today's USD 500 billion, but in the NZE Scenario they almost triple by 2035 and more than quadruple by 2050. The financing costs for clean energy technologies increase disproportionately fast in EMDE excluding China because of the higher costs of capital faced by EMDE and because of the scale of the clean energy investment needed to meet climate and energy access goals. Clean energy financing costs in EMDE excluding China increase sixfold in the NZE Scenario from USD 150 billion to almost USD 900 billion per year by 2050.

Efforts to push down the cost of capital closer to the levels in advanced economies are crucial to the overall attractiveness of clean energy investments in EMDE. For example, lowering the cost of capital in EMDE excluding China by 1 percentage point would reduce annual clean energy financing costs by 20% between 2024 and 2050 in the NZE Scenario (Figure 1.10).

Figure 1.10 ⊳ **Clean energy financing costs to 2050 by scenario, and effect of a reduction in the cost of capital in EMDE excluding China**



IEA. CC BY 4.0.

A reduction of the cost of capital by one percentage point (100 bps) would reduce their clean energy financing costs by 20% in EMDE excluding China

Note: bps = basis points.

There is no single way to reduce the cost of capital for clean energy projects, just as there is no simple categorisation of the risks affecting energy projects. Some risks – for example those arising from the lack of strong national institutions, high and persistent inflation, lack of financial sector development, and weaknesses in the rule of law — are beyond the realm of energy policy makers. However, there are some sector-specific interventions that would help to reduce the risks that contribute to a higher cost of capital for clean energy projects. As detailed in the special report Reducing the Cost of Capital (IEA, 2024d), a strategy to reduce the cost of capital would include:

- Laying out a clear long-term vision – and short-term implementation plans – for scaling up clean energy and raising investment, backed by reliable and timely data.
- Providing clarity and consistency in policy and regulation, together with action to address key regulatory risks identified by potential investors.
- Maximising the provision of international financial support, concessional loans and technical assistance for EMDE institutions, especially on regulation, contracts and data.
- Carrying out reforms to reduce revenue- and payment-related risks in EMDE, backed by payment guarantee mechanisms where necessary.

Strategies of this kind with targeted measures to address key barriers to increased investment could go a long way towards improving the risk profile of projects, reducing project financing costs and scaling up investment.

1.2.2 Energy prices

Prices are a key arbiter between supply and demand. Wholesale prices reflect fundamental forces of supply and demand and hold the system in equilibrium. But they vary over time, by geography, and by fuel, and they can be influenced by a wide range of geopolitical, commercial or natural events. Wholesale prices also differ markedly from the retail prices paid by end-use consumers, the level of which is affected among other things by taxes and subsidies. Here we look at the balance of these factors for oil, natural gas and electricity prices in our scenarios.

Oil and gas prices

Oil and gas prices in our scenarios are set by the cost of producing the most expensive barrel needed to meet demand. This cost includes exploration and development costs, operating costs, the cost of finance, transport costs, and any upstream royalties and taxes levied by the producing country. All these costs vary markedly among regions: to take just one example, the cost of producing a barrel of oil ranges from around USD 10/barrel in parts of the Middle East to more than USD 50/barrel in some parts of North America and Asia. The large differences in oil and gas costs and prices result in a substantial level of "rent" – the difference between the oil or gas price and production costs – that is shared between companies and host governments. In 2023, for example, oil production costs (excluding upstream taxes) averaged USD 26/barrel globally: with an average price of USD 82/barrel, around USD 55 upstream rent was generated globally for every barrel of oil produced.

Table 1.1 ▷ Wholesale oil and natural gas prices by scenario

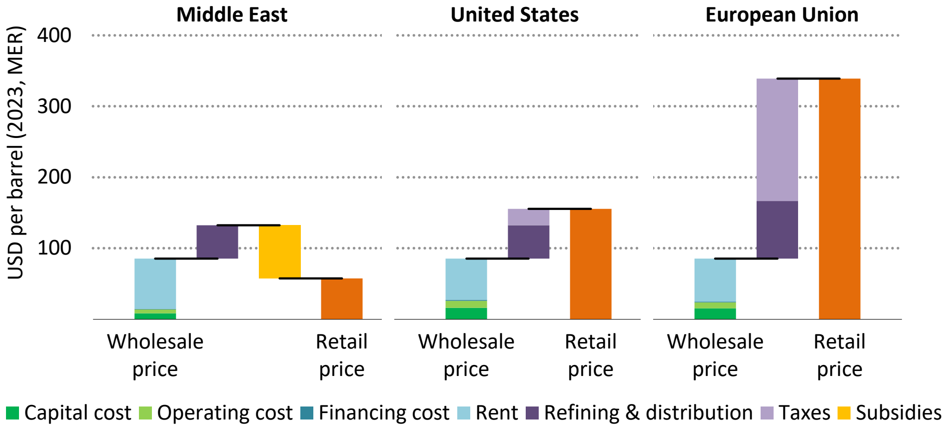
			STEPS		APS		NZE Scenario	
Real terms (USD 2023)	**2010**	**2022**	**2035**	**2050**	**2035**	**2050**	**2035**	**2050**
IEA crude oil (USD/barrel)	107	102	87	86	75	62	34	26
Natural gas (USD/MBtu)								
United States	6.0	5.3	4.2	4.5	3.1	2.3	2.5	2.1
European Union	10.2	33.5	7.1	7.4	6.4	5.6	4.3	4.3
China	9.1	14.2	8.2	8.0	7.4	6.5	5.7	5.5
Japan	15.0	16.5	8.9	8.0	7.6	6.5	5.5	5.5

Note: MBtu = million British thermal units.

Production costs vary over time and by scenario. Technology improvements reduce costs, while the need to develop more complex and less productive projects tends to increase average costs. In the NZE Scenario, sharp reductions in demand mean that there is no need to develop new long lead-time conventional upstream projects and so the marginal costs of production do not include the costs involved in developing such projects. Our scenarios also take account of the relationship between price levels and production costs. Increases in oil and gas prices are often accompanied by increases in the cost of the labour, drilling rigs and oilfield services required to develop and maintain projects. This results in a circular relationship whereby higher prices lead to higher costs, which in turn result in higher equilibrium price levels (and vice versa).

Prices in our scenarios are assumed to follow relatively smooth trajectories. We do not attempt to anticipate the fluctuations or price cycles that characterise commodity markets, but in reality, the potential for oil and gas price volatility is ever-present, and the profound changes that are needed to meet the world's climate goals may increase volatility. If producer economies chose to restrict production, this could lead to higher prices, while efforts on their part to gain market share could result in much lower prices. Higher and more volatile prices could also result if some large producers struggled to withstand the strains placed on their fiscal balances from lower oil and gas income.[2]

Figure 1.11 ⊳ Global average wholesale crude oil price and retail gasoline prices in selected regions in 2022



IEA. CC BY 4.0.

Retail prices vary markedly around the world, and differ significantly from wholesale prices as a result of consumption-based taxes and subsidies introduced by governments

Very few end-use consumers pay the wholesale price of oil and natural gas. The costs of transport, refining, marketing and distribution, customs duties, excise taxes, and value-added taxes contribute significantly to retail prices: in Europe, for example, taxes make up more than half of the retail price for gasoline (Figure 1.11). Equally, the fossil fuel subsidies

---

[2] See The Oil and Gas Industry in Net Zero Transitions (IEA, 2023d) for a discussion on what could cause volatility in wholesale prices in our scenarios.

that exist in a number of regions can result in much lower prices for consumers: in the Middle East, for example, the average retail price for gasoline in 2022 was around USD 55/barrel, one-third less than the wholesale crude oil price.

In our NZE Scenario, wholesale prices are much lower than today, and this risks feeding through into a rebound in oil and gas use that would jeopardise the overall goal of achieving net zero emissions by 2050. The NZE Scenario therefore incorporates policies both to achieve the initial cut in oil and gas demand and to prevent this rebound. For example, the introduction of a rising CO_2 price in advanced economies in the NZE Scenario means that retail gasoline prices in the STEPS and the NZE Scenario are broadly similar out to 2050, even though the wholesale price moves lower over time.

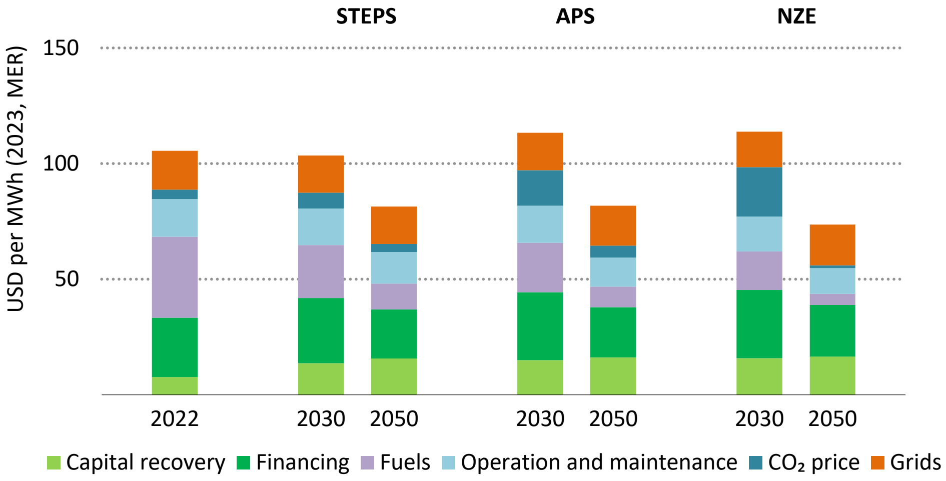
Electricity prices

In our scenarios, electricity prices reflect the cost of building and running existing power systems and networks together with the cost of current and planned projects. Total power plant costs cover capital recovery (the annuities paid over the economic lifetime of assets to recover their upfront investment), fuel costs, operation and maintenance, and CO_2 prices. Network costs mostly reflect the capital recovery of investment in grid expansions and replacements to deliver the electricity to end users.

Today, around 50% of electricity demand is in markets that have regulated prices based on average costs. Wholesale electricity prices exist in some markets – and China is also currently implementing power market liberalisation reforms – but only a fraction of electricity demand is usually exposed to these prices. Different end users tend to pay different prices within a region: industrial consumers, for example, often pay lower grid costs for their higher voltage connections and are generally charged a lower tariff than residential consumers; they also benefit in some regions from a policy of charging lower rates for high levels of consumption. There are also large differences in policies and taxes between regions; for example, taxes are much higher in the European Union (which on average applies a 20% value-added tax on electricity consumption) than in the United States.

The global average cost per unit of electricity remains stable through to 2030 in the STEPS. However, it increases by around 7-8% from 2022 levels in the APS and the NZE Scenario (Figure 1.12). These increases reflect higher capital recovery costs stemming from the widespread deployment of relatively capital-intensive low-emissions sources of generation, together with increased CO_2 prices that raise the cost of fossil fuel generation. These increases are partly offset by reductions in both fuel prices and fuel volumes. In the NZE Scenario, for example, coal-fired generation drops by 50% between 2022 and 2030, and natural gas generation drops by nearly 10%. In 2030, capital recovery is higher in all scenarios than in 2022. Higher costs to 2030 translate into higher residential and industry electricity prices in a number of regions, including the United States and China (Table 1.2), and prices rise more in the APS and the NZE Scenario than in the STEPS. In some regions, including the European Union, prices are nevertheless below the very high levels that were seen in 2022 after Russia's invasion of Ukraine.

Figure 1.12 ▷ **Global average cost per unit of electricity across scenarios, 2022-2050**



IEA. CC BY 4.0.

The average cost per unit of electricity rises to 2030 in the APS and the NZE Scenario, driven by investments to decarbonise the power sector. Costs fall after 2030 in all scenarios

Note: MWh = megawatt-hour.

Table 1.2 ▷ **Residential and industrial electricity prices by scenario**

			STEPS		APS		NZE	
Electricity prices (USD/kWh)	**2010**	**2022**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Residential								
United States	0.16	0.16	0.17	0.16	0.19	0.15	0.19	0.15
European Union	0.25	0.32	0.27	0.23	0.26	0.21	0.25	0.21
China	0.11	0.09	0.11	0.12	0.11	0.12	0.16	0.10
India	0.07	0.06	0.05	0.06	0.08	0.08	0.15	0.06
Industry								
United States	0.09	0.09	0.10	0.10	0.13	0.09	0.13	0.09
European Union	0.15	0.22	0.21	0.17	0.19	0.15	0.19	0.15
China	0.16	0.09	0.09	0.11	0.10	0.11	0.14	0.09
India	0.11	0.11	0.08	0.08	0.10	0.10	0.14	0.08

Note: kWh = kilowatt-hour.

After 2030, the average cost per unit of electricity falls in all scenarios. There are continued cost reductions in renewables, which benefit from policy support and lower investment risk, while reductions in fossil fuel generation bring falling fuel costs and CO_2 prices. In addition, the pace of renewables additions starts to subside in the 2040s in all scenarios and so the amount of capital recovery also starts to decrease. The largest reductions in the global average cost of electricity are seen in the NZE Scenario: by 2050, the global average cost of electricity is 30% lower in the NZE Scenario than in 2022. Following the reduction in costs, prices decline in all regions and scenarios; they decline fastest in the NZE Scenario, and prices in 2050 are lower in most regions in the NZE Scenario than in the STEPS.

Electricity makes up a growing share of consumers' total energy bills in all scenarios due to the increased electrification of end uses. In the NZE Scenario, for example, it accounts for 85% of average residential household bills in advanced economies in 2050, up from 30% in 2022. Tools to reduce revenue risk for power project developers such as contracts for difference and PPAs have been put in place in many regions, with the latter also serving to moderate the risk of rising electricity bills for consumers as the power sector undergoes a fundamental transformation.

1.2.3 Total energy delivery costs

The total cost of delivering energy to consumers includes paying back the cost of building and maintaining energy assets such as power plants, grids, and upstream oil and gas fields, as well as clean end-use equipment such as electric vehicles and heat pumps, efficient homes and industrial processes. We exclude from this domestic government interventions related to energy taxes, subsidies for clean energy or fossil fuels, and CO_2 pricing.

We estimate that the total global energy delivery cost was over USD 7 trillion in 2023. Just over half of this amount consists of monies paid by consumers for energy assets and equipment developed up to the end of 2023. These payments in effect repay some of the initial investment (capital recovery) and the cost of financing these investments (cost of capital), so some of the energy costs in 2023 are repaying loans or earning equity on assets that were built years – and sometimes decades – ago (Box 1.4). Capital recovery in 2023 (USD 2.2 trillion) is less than total capital investment in that year (USD 3 trillion), but the cumulative amounts paid to develop assets can be far greater than the amount of upfront capital investment. For example, if the capital investment for a power plant is financed with a 30-year loan at an 8% interest rate, consumers pay 2.5 times more than the initial cost over its lifetime.

Box 1.4 ⊳ The distinction between capital recovery and capital investment

Capital investment refers to the financial resources deployed to construct or upgrade physical energy assets with the expectation of generating future income or benefits. The investment is counted over the time period of construction, reflecting the real outlays in the economy that contribute to annual GDP.

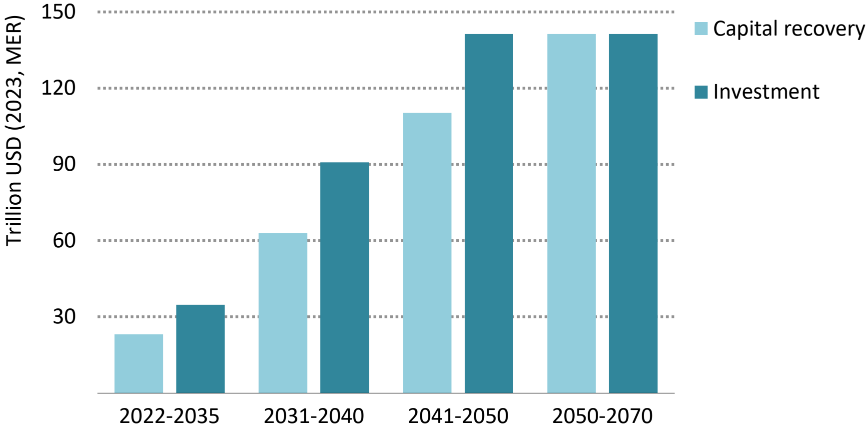
Capital recovery, on the other hand, involves recouping the initial investment made in a capital asset over its useful life, spreading the cost so that the investment is gradually recouped through the revenue generated by the asset. In this report, capital recovery does not include the cost of debt or equity involved in the capital investment (which is separately accounted for as financing cost).

In the NZE Scenario, annual investment in clean energy in 2035 is three times the average over the past five years. This requires an immediate and large-scale mobilisation of additional capital and resources. However, this large increase in investment will not immediately appear on consumer bills, but will be recovered gradually over the economic lifetimes of all energy-related assets.

Ultimately, the sum of capital recovery over the entire lifetime of all assets is equal to total investment in the NZE Scenario, but the former is measured over a different (and longer) time horizon than the latter. For example, USD 50 trillion of capital is spent on energy between 2031 and 2040 in the NZE Scenario, whereas USD 40 trillion is recovered through consumer bills over the same period, which includes the recovery of capital spent on assets built in preceding years.

The NZE Scenario therefore involves the twin challenges of raising finance for energy transition investments and of paying for these investments. Both are relevant to a discussion about affordability, but they play out in different ways and over different time frames.

Figure 1.13 ▹ Cumulative spending on energy in the NZE Scenario expressed as investment and capital recovery



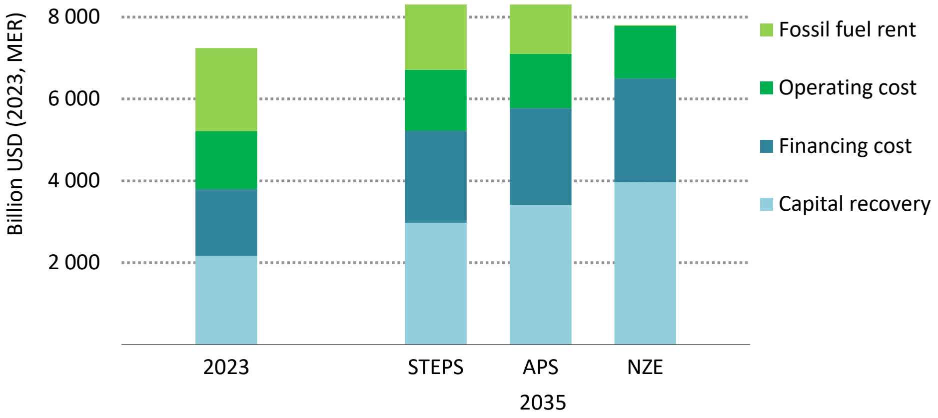
IEA. CC BY 4.0.

A huge increase in investment spending is required in the NZE Scenario; this capital is recovered gradually, imposing costs on consumers beyond 2050

Note: This figure shows investments made up to the year 2050. In practice, investment in any scenario will continue beyond the World Energy Outlook (WEO) modelling time horizon.

The remainder of total energy delivery costs in 2023 were operating costs (around 20% of the total) and fossil fuel rents (around a third of the total). Operating costs are the costs incurred to keep capital assets maintained and to ensure the continuing production, transport and storage of energy; they also include retail and marketing costs. Fossil fuel rents are the difference between fossil fuel prices and the full costs of production, and they mostly accrue to governments in the form of taxes, royalties or income from national oil and gas or mining companies. Fossil fuel rents are profits made after financing costs are met. They are distinct from profits made by renewable developers or utilities, which are fully captured in financing costs.

Figure 1.14 ▷ Total energy delivery costs by scenario



Total energy delivery costs rise in all scenarios to 2035, but the increase is smallest in the NZE Scenario as higher capital recovery and financing is offset by lower fossil fuel rent

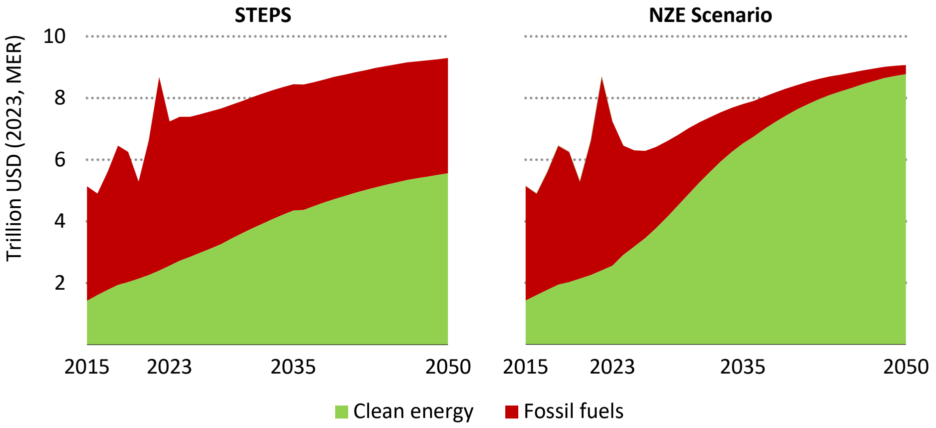
Notes: Financing costs are based on the weighted average cost of capital from the IEA's Cost of Capital Observatory, assuming capital recovery periods of 30 years for grids, 10 years for oil and gas, and 5 years, on average, for end-use technologies. Fossil fuel rent is net of financing costs.

In the STEPS, demand for energy continues to grow, and energy delivery costs increase by just under 20% to USD 8.2 trillion in 2035 (Figure 1.14). In the APS, the aggregate delivery cost is similar, although capital recovery and financing costs are slightly higher and operation costs and fossil fuel rents are slightly lower. In the NZE Scenario, the total energy delivery cost in 2035 is 8% lower than in the STEPS. There is a 70% increase in capital recovery and financing costs from 2023 to 2035, but a large portion of this increase is offset by a sharp reduction in oil and gas rent. The NZE Scenario tries to avoid generating a large level of stranded capital and so nearly all loans and financing costs are recovered in full, even as assets are retired before the end of their technical lifetimes. Because of low prices and falling demand, fossil fuel rents drop to zero in the mid-2030s, meaning resource holders are in some cases unable to cover capital and financing costs and operating expenditures. The global energy system in the NZE Scenario in 2035 also has much lower operating costs: more electrified and efficient energy systems mean that total system operating costs (including fossil fuel rent) are USD 2 per gigajoule (GJ) in 2035, compared with USD 5/GJ in the STEPS.

Around 15% of energy delivery costs in the NZE Scenario in 2035 are related to fossil fuels, compared with 65% today (Figure 1.15). Some of this covers past investments in fossil fuel assets, but it is also necessary to continue to invest in some traditional fossil fuel assets during transitions to avoid declines in supply outstripping declines in demand and creating a heightened risk of price spikes and market volatility. A key prerequisite for managing fossil fuel infrastructure is the reduction of scope 1 and 2 emissions; upfront investments totalling USD 600 billion would be required to halve the emissions intensity of oil and gas operations globally by 2030 (IEA, 2023a). Planning also needs to be carried out for the safe and responsible decommissioning of wells or pipelines when they are no longer needed to avoid negative environmental impacts.

Some fossil fuel assets and infrastructure also remain useful in net zero transitions: some gas-fired power plants, for example, need to be maintained in the NZE Scenario during the transition to net zero to provide flexibility and balancing services for electricity systems, though they operate much less frequently than now. Some gas pipelines or storage sites are also required and could in addition be repurposed to transport low-emissions gases. Retiring these assets prematurely could increase the cost of low-emissions alternatives and lead to delays in deploying them.

Figure 1.15 ▷ Total energy delivery costs of fossil fuels and clean energy by scenario



IEA. CC BY 4.0.

As clean energy is scaled up in the NZE Scenario, there is a decline in the costs of maintaining a fossil fuel-based energy system. Overall costs are similar to those in STEPS

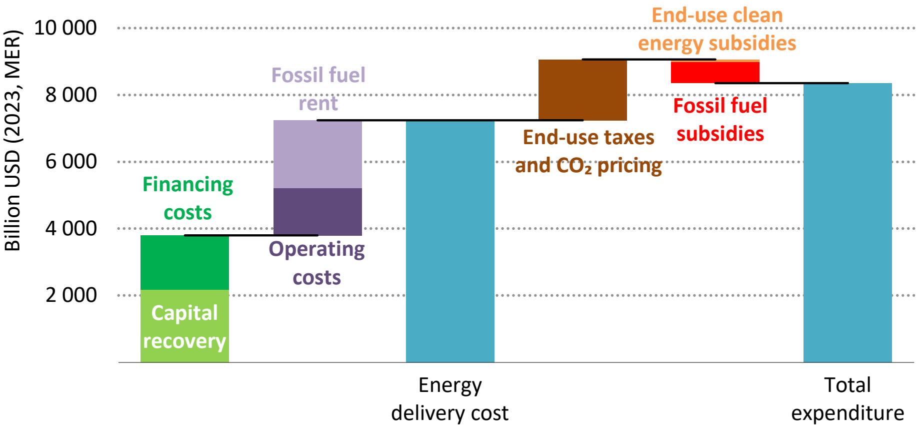
Energy delivery costs at the global level mask huge reallocations of costs among countries. Economies reliant on fossil fuel exports see a huge drop in income in the NZE Scenario. The advantages of today's producer economies in the energy sector do not disappear overnight in the NZE Scenario, but utilising the opportunities and advantages that exist is not simple and will require new types of collaboration both within countries and internationally.

1.2.4 Total consumer expenditure on energy

Energy delivery costs highlight how the overall cost of energy might evolve globally, but they are not the same as the energy bills paid by consumers, the cost of which is influenced by policy and market design through taxes, subsidies and other levies.

Energy taxes are a vital source of revenue for governments around the world. In 2023, we estimate that governments earned around USD 1.7 trillion from energy production, primarily through royalties and taxes on oil and gas extraction. A further USD 1.8 trillion was generated from energy consumption in the form of excise and value-added taxes, and a small additional amount (USD 100 billion) was raised through taxes and charges placed on CO_2 emissions.

Figure 1.16 ▷ Breakdown of global end-use energy expenditure, 2023



IEA. CC BY 4.0.

Expenditure on energy is nearly 10% of global GDP. Fossil fuel rents make up 25% of total delivery costs, and subsidies for fossil fuel use are far more generous than for clean energy

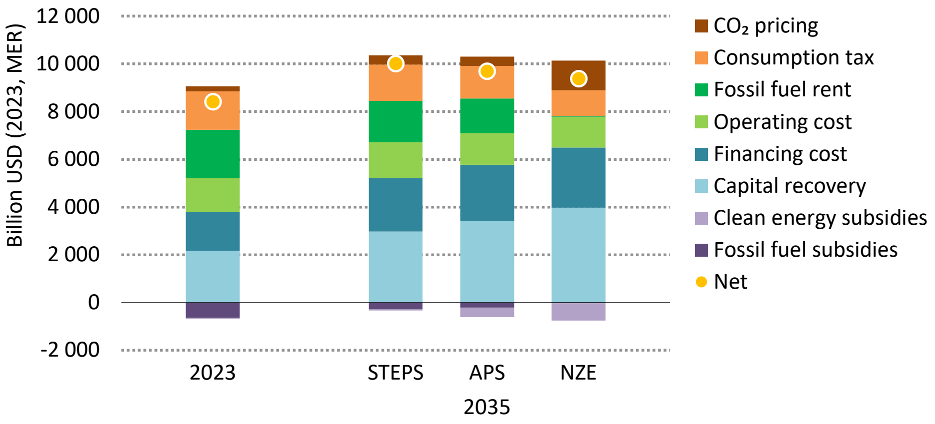
Over the past five years, governments spent on average around USD 500 billion each year subsidising the use of fossil fuels, mostly in EMDE. This is significantly more than governments spent on support for end-use clean energy investments, for example in the form of grants or rebates for electric vehicles, efficiency improvements or heat pumps. In 2023, this support for clean energy amounted to around USD 70 billion, covered around 10%

of total investment in end-use energy equipment and efficiency measures, and was overwhelmingly concentrated in advanced economies.

Taxes and total energy delivery costs minus subsidies together constitute total end-use expenditure on energy. This amounted to USD 8 trillion in 2023 (Figure 1.16), reflecting the total energy delivery costs paid for by households and industrial consumers (USD 7 trillion in 2023) plus additional taxes, net of fossil fuel and clean energy subsidies (USD 1.1 trillion).

In the STEPS, end-use energy expenditure rises to USD 10 trillion in 2035 (Figure 1.17). There is a modest increase in taxes raised from prices on CO_2 and a decrease in fossil fuel subsidies, but the main driver of increased capital expenditure is additional investment to meet growing energy demand.

Figure 1.17 ▹ Global end-use energy expenditure by scenario



IEA. CC BY 4.0.

Globally, expenditure on energy – including fuel and equipment costs – is lower in the NZE Scenario than in the STEPS, owing to lower delivery costs and more support for clean energy

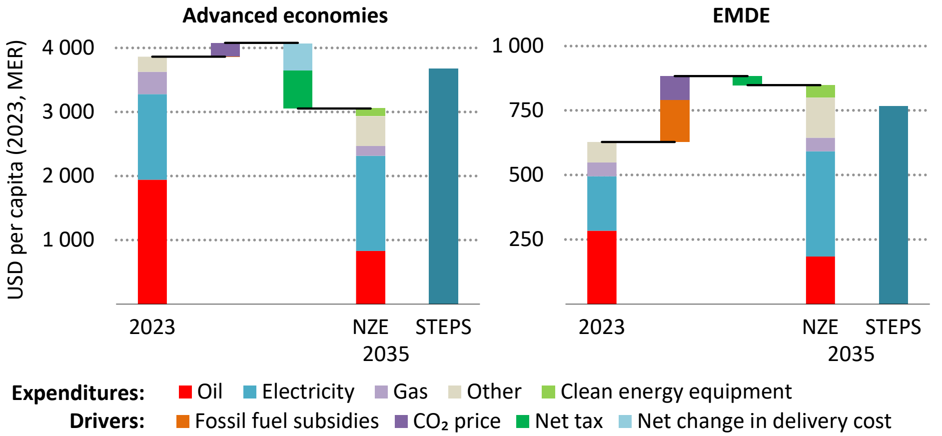
Note: "Clean energy subsidies" here refer to clean energy subsidies for end-consumers.

In the NZE Scenario, total energy expenditure in 2035 is USD 9.4 trillion – around 6% lower than in the STEPS. This is mainly because of lower total energy delivery costs: fossil fuel rent in the NZE Scenario is USD 1.7 trillion lower than in the STEPS, offsetting the larger capital recovery and financing costs, which are USD 1.3 trillion higher than in the STEPS. While end consumers around the world face higher expenditures from pricing CO_2 in the NZE Scenario compared to the STEPS (an additional USD 850 billion in 2035), this is likewise partially offset through lower energy consumption taxes (around USD 400 billion lower in 2035) and a USD 650 billion increase in subsidies for clean energy technologies. Fossil fuel subsidies are also assumed to be almost entirely phased out globally in the NZE Scenario by 2035.

These global results mask important differences in energy expenditure among countries. In advanced economies, increases in expenditure on electricity in the NZE Scenario are more than offset by falling fossil fuel costs, and per capita energy expenditure is lower than in the STEPS. In EMDE, on the other hand, per capita energy expenditure in EMDE is higher in the NZE Scenario than in the STEPS in the period to 2035. Modern energy consumption increases in both scenarios as incomes rise, but the additional efforts to provide universal access to modern energy in the NZE Scenario drives up spending on energy in the lowest income groups compared with the STEPS, in which 1.7 billion people still do not have access to clean cooking fuels in 2035 and 640 million remain without electricity. The overall increase in expenditure from populations gaining access is, however, modest, making up less than 5% of the total increase in spending in EMDE in the NZE Scenario over this period.

Spending on energy in the NZE Scenario in EMDE is higher than in the STEPS because of the gradual removal of fossil fuel subsidies and the introduction of CO_2 pricing. The result is that consumers in EMDE pay one-third more for energy in the NZE Scenario in 2035 than they do today, compared with 20% more in the STEPS (Figure 1.18).

Figure 1.18 ▷ Change in end-use energy expenditure per capita in the STEPS and the NZE Scenario



IEA. CC BY 4.0.

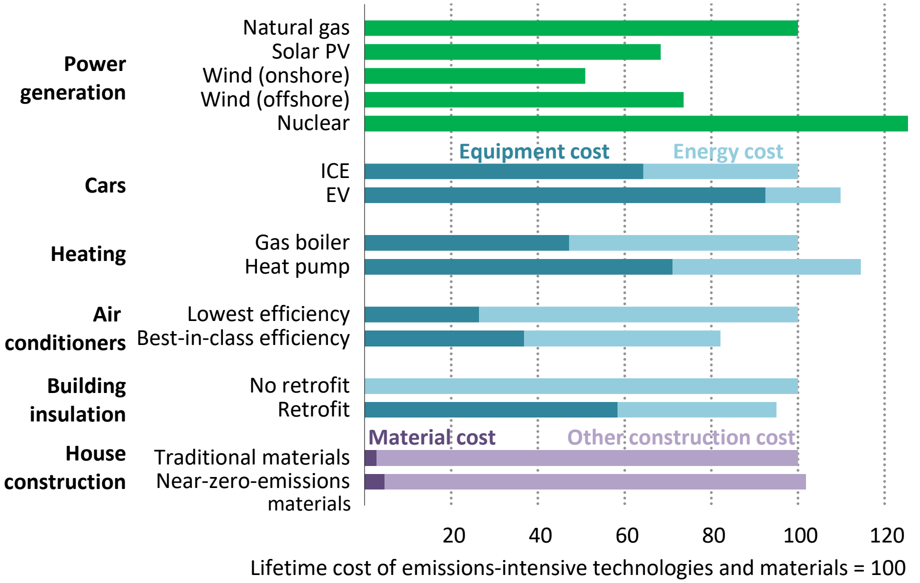
In advanced economies, expenditure on energy in the NZE Scenario in 2035 is lower than in the STEPS. In EMDE, it is higher due to CO_2 pricing and fossil fuel subsidy removal. The increase is partly offset by support for clean energy investment

Households in particular need to shoulder the upfront costs of clean energy equipment. In this respect, the relative affordability of cleaner options compared with incumbent fossil fuel-based technologies is a crucial factor in determining the overall affordability of energy transitions, a focus of the next section.

1.3 The competitiveness of clean energy technologies

An important aspect of the affordability of the clean energy transition is the relative evolution of costs of clean and emissions-intensive technologies. This section explores the costs of electricity generation, the lifetime costs of ownership of equipment and the costs of adopting low-emissions materials in construction. Figure 1.19 presents the summary findings in the form of an index of competitiveness of key energy technologies, equipment and materials in advanced economies. The costs of fuels, electricity, technologies and materials vary across countries depending on the policy landscape, market size, input costs and other factors, but our analysis shows that several key clean energy technologies are already competitive over the lifetime of their use.

Figure 1.19 ▷ Index of competitiveness of power generation, equipment and materials in advanced economies, 2022



IEA. CC BY 4.0.

Clean energy technologies, materials and power generation are competitive with emissions-intensive alternatives in advanced economies

Notes: Subsidy is not included. ICE = internal combustion engine. For power generation, costs considered are value-adjusted levelised costs of electricity. For equipment and insulation, costs considered are total costs of ownership. For house construction, costs considered are total costs. Heat pumps also provide space cooling, which is not considered in the analysis above. Lowest-efficiency air conditioners are the legal minimum efficiency equipment available in the market. Traditional materials are steel, aluminium and cement made using unabated fossil fuels and conventional production processes, while near-zero-emissions materials are steel, aluminium and cement made using near-zero-emissions processes. Other construction cost includes cost of labour, other materials, plumbing.

Taking advanced economies as an example, this index of competitiveness shows that the costs of electricity generation from solar PV and wind – adjusted for the value that they bring to the system – are lower than unabated natural gas-based generation. It shows that more efficient air conditioners have already become cost-competitive against lower-efficiency models, and the same is true for some other kinds of appliances, too. Electric cars in advanced economies on average are broadly competitive with ICE vehicles, even when unsubsidised. In many countries, they have lower lifetime ownership costs than their incumbent counterparts. Heat pumps require marginal support to ensure cost parity when compared with gas boilers. However, heat pumps also provide space cooling, and when deployed as a combined heating and cooling solution in mild and warm climates are less expensive than gas boilers and air conditioners deployed separately (IEA, 2022). Finally, while near-zero-emissions materials such as steel, cement and aluminium still cost nearly two-thirds more than they do when made by conventional processes, the impact of these extra costs on overall house construction costs is marginal. The cost-competitiveness of several of these technologies has benefited from the substantial cost reductions in the past decade in key technologies needed for clean electrification, including solar PV modules, wind turbines and batteries (Box 1.5).

While the increasing cost-competitiveness of clean energy technologies goes a long way towards making clean technologies an attractive alternative, it does not automatically imply rapid uptake. Despite competitive life-cycle costs, higher upfront costs remain a barrier for consumers, especially those in EMDE or in lower-income groups in advanced economies. There are several other barriers that impede the adoption of clean energy technologies despite their growing cost competitiveness, including:

- Existing market design and structures, and mature supply chains that favour the continued operations of legacy infrastructure or hinder the entry of new market players.
- The absence of financing and energy service models geared to the adoption of clean energy technologies that are typically associated with higher upfront costs.
- Unfamiliarity with clean energy technologies such as heat pumps on the part of consumers.
- The existence of large and inefficient fossil fuel subsidies that skew consumer demand.
- The lack of policy measures and fiscal support to de-risk clean energy technologies or provide incentives to adopt them, including measures geared specifically to the most vulnerable households and communities that are most at risk of missing out on greater access to clean energy and efficiency.

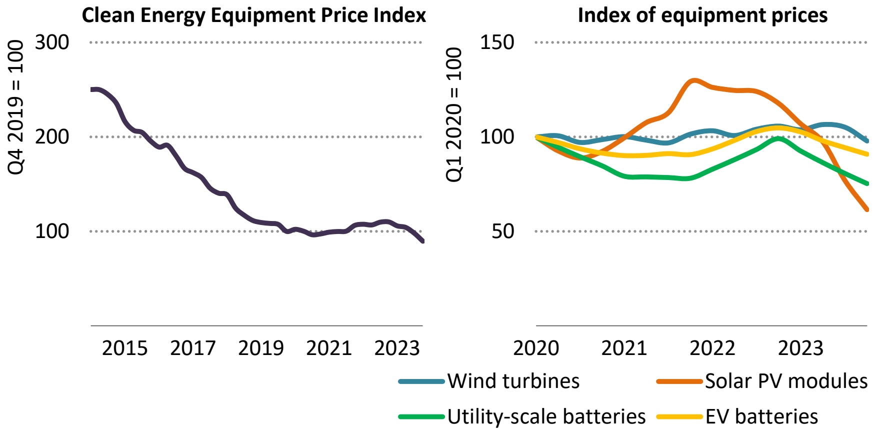
There is a need for policy to respond to these and other challenges to ensure that the clean energy transition is affordable to all sections of society. To help understand where the challenges lie, where each of the key technology options stands today in terms of costs, and how they might evolve in the near future, we analyse in this section the life-cycle costs of clean energy technologies and equipment that are at or near cost-competitiveness with incumbent fossil fuel-based options.

Box 1.5 ▻ Cost inflation in 2021-2022 temporarily reversed the long-term declines in clean energy equipment prices

There are a wide range of factors that influence the prices of clean energy equipment, which in turn impact project costs and retail prices. Technological advances and economies of scale push down clean energy equipment prices once commercial production begins, but there are also factors that can raise clean energy equipment prices. These include rising input costs, for example due to logistical bottlenecks, trade restrictions or an inability to increase the production in line with demand.

The IEA's Clean Energy Equipment Price Index (CEEPI) tracks price movements in a global basket of solar PV modules, wind turbines, lithium-ion batteries for EVs and energy storage that is weighted by shares of investment (Figure 1.20). Clean energy equipment prices, as measured by the CEEPI, fell by nearly 65% in the decade prior to 2024. However, there was then a period of cost inflation between late 2020 and late 2022. Solar PV modules prices increased by 40% over this period, and utility-scale lithium battery prices by 20%. These price increases were largely driven by rapid price rises in the cost of critical minerals such as lithium when mining and production were unable to keep up with increases in demand. Solar module and battery prices declined again in 2023, and the cost of solar PV modules is now back below pre-pandemic levels. The rise in component prices in 2020-2022 underlines the need for careful risk management to enable further gains to be made in the competitiveness of clean energy technologies.

Figure 1.20 ▻ IEA's Clean Energy Equipment Price Index (2014-2023) and clean energy equipment prices (2020-2023)



The price of key clean energy equipment increased in 2021 and 2022 after years of steady declines

1.3.1 Variable renewables versus fossil fuels in power generation

The share of renewables in electricity generation rises in all our scenarios. In the NZE Scenario, renewables provide 75% of electricity generation by 2035, and this increases to 90% by 2050. The growing share of generation taken by renewables across scenarios affects the relative affordability and value of all electricity-generating technologies, and this makes it vital to take account of the overall contribution that different technologies make to the electricity system as a whole.

While the levelised cost of electricity (LCOE) is a commonly used metric that brings together all costs directly associated with a given technology – including construction, financing, fuel and maintenance costs – it is an incomplete indicator of competitiveness, as it takes no account of impacts on and interactions with the overall power system. The IEA therefore uses the value-adjusted LCOE (VALCOE), a more complete metric of competitiveness. This combines the technology cost (LCOE) with the value of the technology, which is derived from detailed hourly modelling that estimates the value of three system services: energy, flexibility and capacity (IEA, 2020; IEA, 2023c).[3] The metric takes the perspective of system planners and is applicable in all regions, reflecting the differing and changing needs of power systems based on demand patterns, overall generation mix, and renewables penetration. For example, as higher shares of variable renewables lead to increased cannibalisation effects (see Box 2.3), variable renewables tend to be less competitive than the LCOE alone would suggest. However, the VALCOE does not attempt to be all-encompassing, and it does not account for network integration and other indirect costs, such as those related to pollution.

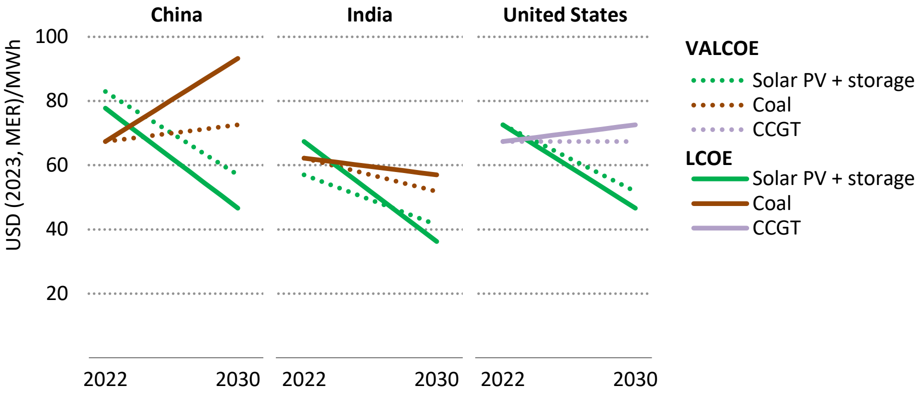
Between now and 2030, the LCOE and VALCOE evolve differently for different technologies in different regions (Figure 1.21). In general, solar PV and offshore wind become increasingly competitive in cost terms, but they offer lower value to the system in terms of capacity and flexibility compared with dispatchable technologies such as coal- and gas-fired generation, whose VALCOE are less than their LCOE in across key regions.

Between 2030 and 2050, higher shares of renewables continue to lead to lower electricity prices, and solar PV and wind show the lowest LCOEs across regions. Renewables are more capital-intensive than combined-cycle gas turbines (CCGTs) and coal, and more dependent on financing conditions and the availability of refinancing. However, the LCOE of CCGTs and coal depends on fuel prices and CO_2 prices, both of which are subject to frequent change, whereas renewables have no fuel costs, create no emissions, are therefore not required to pay CO_2 prices, and have on average lower operation and maintenance costs.

---

[3] The VALCOE is part of a family of competitiveness metrics that go beyond the LCOE. The VALCOE is most closely related to the System LCOE (Ueckerdt et al., 2013), which provides a comprehensive theoretical framework. It is also similar to the Levelised Avoided Cost of Electricity, used by the US Energy Information Administration (US EIA, 2022). These are all related to standard profitability metrics, such as net present value and internal rates of return, that consider the costs and revenues associated with different power technologies. Analysis of total power system costs for various power generation mixes are also closely related, though they do not necessarily provide a direct indicator of competitiveness for individual technologies.

Figure 1.21 ▷ **VALCOE and LCOE for key technologies and regions in the STEPS, 2022-2030**



IEA. CC BY 4.0.

Solar PV and wind become increasingly competitive with coal and gas to 2030 in the STEPS, with the VALCOE highlighting changing system needs in a decarbonised power sector

Source: IEA (2024e)

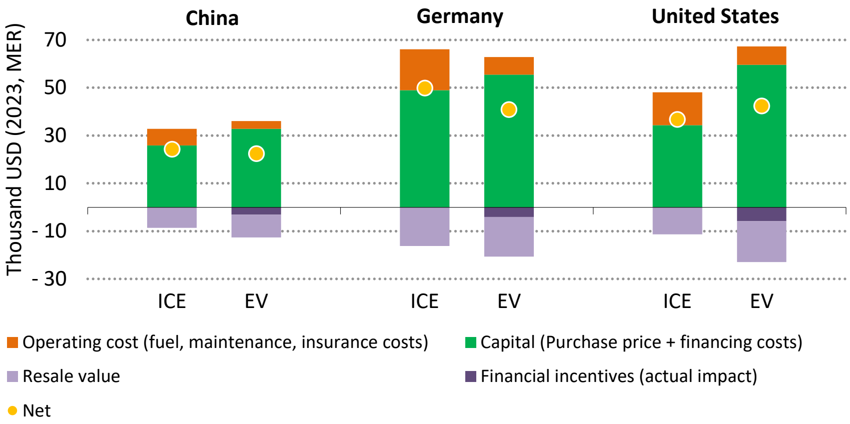
Higher shares of renewables also draw attention to system needs, where the capacity and flexibility of coal- and gas-fired generation count for more in a largely decarbonised power sector and are valued accordingly. While variable renewables remain VALCOE-competitive with coal and gas in the short term, the metric highlights the increasing need for variable renewables to be paired with battery storage. This is particularly the case for solar PV, whose generation hours are confined to daylight periods. Pairing solar PV-generated electricity with battery storage enables it to be utilised at other times of the day depending on demand, thereby increasing its capacity and flexibility value in the VALCOE. Without this pairing, solar PV risks suffering from decreased competitiveness due to the cannibalisation effect, which makes successive units of solar PV progressively less competitive.

1.3.2 Electric versus internal combustion engine vehicles

The cost differential between electric vehicles and internal combustion engine (ICE) counterparts has narrowed over the years thanks to policy support, scale economies and technological advances. Despite this, the unsubsidised sticker price of EVs remains higher in most markets than that of ICEs. However, the picture changes in some markets when looking at lifetime ownership costs, which include fuel and maintenance costs and also factor in subsidies, tax incentives and resale values (Figure 1.22). On this basis, EVs have already become cheaper than their ICE counterparts in markets such as China, Germany and Norway. In Norway, for example, a combination of generous EV subsidies and tax incentives means that electric cars in 2022 cost 15% less than ICEs on average, and 30% less in the case of medium-sized cars.

For EVs to be competitive with ICEs more widely, their purchase cost premiums have to reduce further. Innovation and a scaling up of manufacturing have a big part to play here. Independent analyses suggest that price parity between EVs and ICEs at the point of purchase even without subsidies could be achieved by 2030 for certain segments, marking a significant milestone in the affordability of electric vehicles (IEA, 2024c). In China, the world's largest electric car market, smaller models have already achieved price parity between EVs and ICEs, and indeed have gone beyond it in some market segments: small EVs are now more than 40% lower in total cost of ownership than their ICE counterparts. While luxury models push up the sales weighted average price of EVs sold in China, small models account for just over 20% of all EVs sold; the cheapest car available in 2023 was in fact a small city car with a 9 kWh battery EV which cost approximately USD 6 000 USD to buy new (JATO Dynamics, 2023).

Figure 1.22 ▷ Total cost of ownership of medium-sized electric and ICE cars purchased in select countries, 2023



IEA. CC BY 4.0.

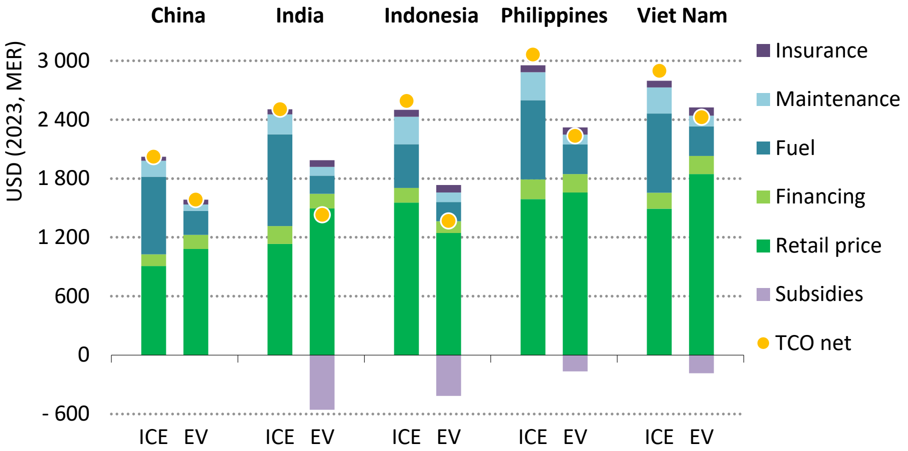
EVs have higher retail prices than their ICE counterparts, but offer a lower total lifetime cost of ownership in some key markets

Notes: First owner cumulative cost of ownership five years after purchase. Financial incentives include subsidies, vehicle purchase tax exemptions and tax credits.

Source: IEA (2024c).

While electric cars still have some way to go in many markets to match the lifetime competitiveness of their ICE counterparts, the balance is much more favourable in the case of electric two-wheelers (Figure 1.23). The total cost of ownership of electric two-wheelers in their top five markets – China, India, Indonesia, Philippines, and Viet Nam – is already between 16% and 47% lower on average than for ICE two-wheelers. The retail price of electric two-wheelers is higher, but lower fuel and maintenance costs mean a lower total cost of ownership over the lifetime of the two-wheeler.

Figure 1.23 ▷ Total cost of ownership of electric and ICE two-wheelers in select countries, 2023



IEA. CC BY 4.0.

Electric two-wheelers in leading markets have a lower total cost of ownership than their fossil fuel alternatives

Note: TCO = total cost of ownership. In this analysis, two-wheelers refer to vehicles with a top speed of at least 50 kilometres per hour and which fit the UNECE (United Nations Economic Commission for Europe) definition of L1 or L3 (UNECE, 2017). This excludes micromobility options such as electric-assisted. The total cost of ownership is calculated after five years of service for two-wheelers.

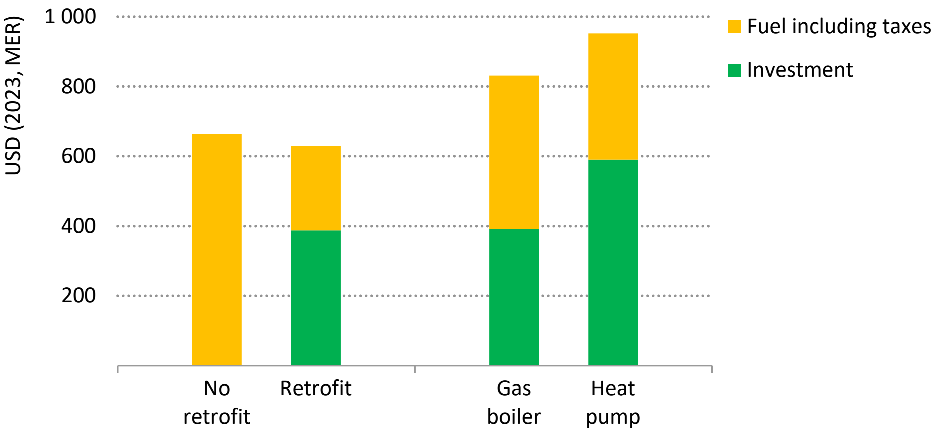
Sources: IEA analysis based on retail price data from MotorcyclesData.com (2024) and BNEF (2023), and fuel consumption data from BNEF in the case of auto-rickshaws (2023).

1.3.3 Efficient versus conventional buildings and appliances

Prices for construction materials, products and labour rose sharply between 2020 and 2023. The 2021 spike in prices was mostly the result of disruption to construction supply chains caused by the Covid-19 pandemic, rising commodity prices, and an increase in demand linked to government stimulus measures and people's desire to improve the spaces where they were now spending more time than ever before. The 2022 energy crisis only exacerbated the pressures. Construction and renovation markets across the globe have since stabilised, and in some cases have even entered recession, but the costs of insulation, glazing and heat pumps are not expected to return to their pre-Covid levels.

In major heating markets, higher costs have not substantially weakened the competitiveness of retrofit solutions and heat pumps on a life-cycle basis. Energy prices remain high in most countries, which reduces the payback periods for energy-efficient solutions, thereby countering some of the impact of rising upfront costs. Both retrofits and heat pumps remain broadly cost-competitive over their lifetime in the STEPS in advanced economies (Figure 1.24). Without incentives, under current policies the lifetime cost of heat pumps is 14% higher than that of gas boilers. However, the vast majority of governments in advanced economies have introduced subsidies far exceeding this additional cost. In milder climates, the scales tip strongly in favour of heat pumps, considering they provide space cooling as well. The IEA Future of Heat Pumps report (IEA, 2022) assessed the levelised cost of heating and cooling via an air-to-air heat pump compared with an air conditioner coupled with an electric heater or gas boiler in such climates. The results show that air-to-air heat pumps are cheaper over their lifetime, in part as a result of the avoided cost of purchasing two separate pieces of equipment.

Figure 1.24 ⊳ Costs of heat pumps and retrofits versus gas boilers and no retrofits in advanced economies in the STEPS



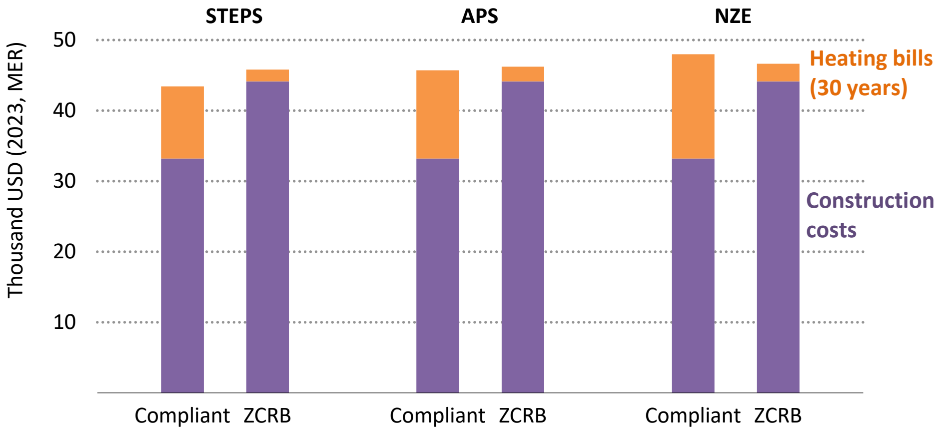
Building decarbonisation solutions are nearly cost competitive over their lifetime, even without subsidies

Notes: Values are annual and unsubsidised. Assumed lifetimes are 25 years for retrofits, 16 years for heat pumps and natural gas boilers/furnaces. Upfront costs and expenditure on space and water heating are based on a representative sample of households in Germany, Japan, the United Kingdom and the United States, with upfront costs financed at an interest rate of 5%, starting in 2024 for five years. Costs do not include subsidies.

In most advanced economies, rising construction costs are unlikely to have a significant impact on the quality of new buildings, given that energy performance of new buildings is primarily determined by mandatory building codes. In many emerging markets and developing economies, building codes do not include mandatory energy performance requirements, meaning that the energy performance levels of new buildings vary significantly. However, the United Nations Environment Programme (UNEP) and 28 signatories of the Buildings Breakthrough Agenda set a target at the 28th Conference of the Parties (COP28) to make near-zero-emission and resilient buildings the new normal by 2030, and most signatories represented EMDE that have not yet enshrined mandatory energy efficiency requirements in codes for new buildings. This underscores the vast potential of the Buildings Breakthrough Agenda, as well as the challenge posted by elevated construction costs.

A 30-year assessment comparing upfront costs and heating expenditure shows that zero-carbon-ready buildings are roughly cost-competitive in the STEPS and APS (Figure 1.25). In the NZE Scenario, they are cheaper than buildings with lower energy performance thanks to more favourable energy taxation and carbon pricing policies, among other factors. The analysis compares zero-carbon-ready buildings with "compliant buildings" which include only the most basic fabric efficiency measures that are generally expected by default in major heating markets, even when they are not mandated by law. The assessment of heating expenditure over the 30-year time frame assumes that both zero-carbon-ready buildings and compliant buildings are heated using an air source heat pump. The 30-year period assessed is considerably shorter than the average lifespan of new buildings in the regions concerned, and the cost-benefit assessment is even more favourable over a longer time frame.

Figure 1.25 ▷ Building construction and heating expenditure for new buildings in emerging markets and developing economies by scenario



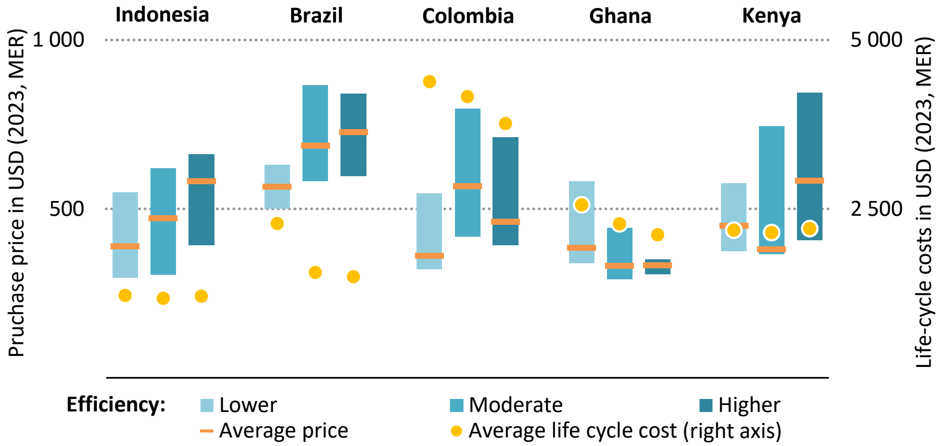
IEA. CC BY 4.0.

Higher construction costs of zero-carbon-ready buildings are balanced by lower heating bills over a 30-year period

Notes: ZCRB = zero-carbon-ready building. Compliant buildings use the most basic fabric efficiency measures available in the market, even when not mandated by law.

More efficient air conditioners generally come with lower life-cycle costs, though there is significant variation between countries as a result of differing electricity prices and climatic conditions (Figure 1.26). In some countries, a wide range of purchase costs reflects the availability of a large number of available models, functional features, sales channels and local supply chains. Some manufacturers focus entirely on specific market segments, and the presence of those manufacturers in a given country can have a major influence on the price of air conditioners of a certain efficiency class. In Ghana, for instance, the market for high-efficiency air conditioners is dominated by just one manufacturer offering products that are both highly efficient and yet relatively affordable, which explains the lower median and lower range of costs for high-efficiency air conditioners in that country. Meanwhile the market for high-efficiency air conditioners in Kenya offers a much wider range of models, including some with extensive features that push up the median price.

Figure 1.26 ▷ Life-cycle costs and purchase prices of air conditioners in selected countries, 2023



IEA. CC BY 4.0.

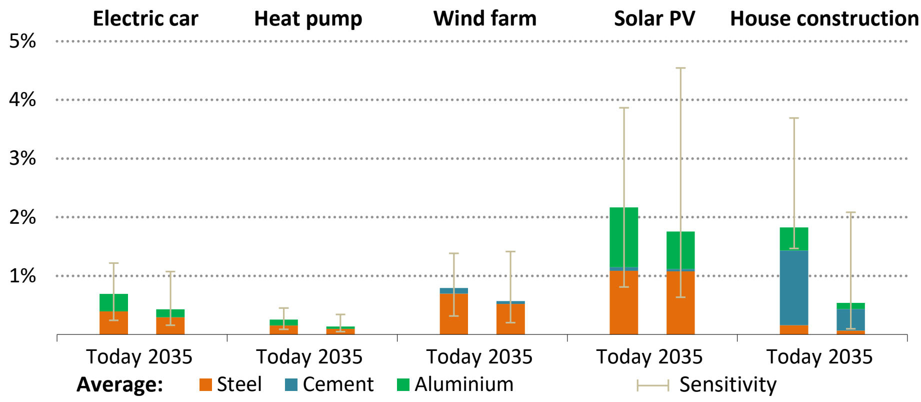
On a life-cycle basis, efficient air conditioners cost no more than those with lower efficiencies, and in some countries they cost less

Notes: Indonesia: lower, moderate and higher efficiency corresponds to seasonal energy efficiency ratio (SEER) below 12, SEER between 12-13.5, and SEER above 13.5; Brazil: efficiency below 5 W/W, between 5-6 W/W, and above 6 W/W; Colombia: ratings E/D, C, and B/A; Ghana: ratings 1 star, 2 stars, and 3 stars or above; Kenya: efficiency below 3.15 W/W, between 3.15-3.25 W/W, and above 3.25 W/W. The normalised purchase price represents the air conditioner price normalised with a cooling capacity of 12 000 British thermal units per hour. The analysis assumes a ten-year life-cycle for air conditioners and uses residential electricity tariffs from September 2023.

1.3.4 Near-zero-emissions versus conventional production of basic materials

Transitioning to near-zero-emissions production is challenging when producing materials such as aluminium, cement and steel where the technologies needed are not yet mature or involve a significant cost premium. The premium for near-zero-emissions production today is estimated at between 30% and 140% for these materials, depending on various factors including the cost of electricity and raw materials. Near-zero-emissions aluminium production is at the lower end of this range because production already involves a high degree of electrification, and near-zero-emissions cement production at the higher end because it depends on costly process modifications such as the addition of CO_2 capture.

Figure 1.27 ⊳ Additional capital costs from near-zero-emissions production for selected end uses, today and 2035 in the NZE Scenario



IEA. CC BY 4.0.

Premiums associated with near-zero-emissions material production impact final costs on average by around 1%; accelerated decarbonisation efforts could reduce this by up to half

Notes: Based on 2021 costs of typical products, which are USD 36 000 for an electric car, USD 11 000 for a heat pump, USD 2 860 per kilowatt (kW) for an offshore wind farm, USD 880/kW for solar PV and USD 300 000 for the construction of a single-family home. Costs in 2035 for clean technologies follow the reductions of the NZE Scenario (IEA, 2023c). The assumed material intensities are global averages and constant over time. The sensitivity considers lowest and highest premiums for all three materials.

Source: IEA (2023b).

While these cost premiums pose significant affordability challenges for the material producer and their direct customers, the knock-on effect on prices faced by the final consumer are generally small (Figure 1.27). In the case of four typical clean energy technologies that are essential for the energy transition (electric cars, heat pumps, wind farms, PV panels), the cost premium resulting from the use of near-zero-emissions materials is 0.2-3.9%. It is lowest (0.2%) in the case of heat pumps and highest (3.9%) in the case of solar PV panels (Figure 1.28). Basic materials usually account for a small share of the cost of these items, which means that the additional costs are diluted along the supply chain. The same is true for other important end uses. For example, a typical house with construction costs of around USD 300 000, where aluminium, cement and steel contribute less than 3% of the total costs combined, would cost an extra USD 5 500 if it were to be built using near-zero-emissions materials.

The average premium associated with near-zero-emissions material production relative to conventional production pathways shrinks over time in the NZE Scenario. The rapid deployment of these technologies leads to capital cost declines via learning effects, and continuing reductions in the cost of renewable electricity bring decreases in operational costs. At the same time, a policy environment that is conducive to large-scale production of near-zero-emissions materials increases the costs of material produced in ways that give rise to higher levels of emissions, for example through CO_2 pricing. As a result, the cost premiums for near-zero-emissions material production decrease from 30-140% on a global weighted average basis today to 10-30% by 2035, with aluminium remaining at the lower end of this range and cement at the upper end. This reduces the premium passed on to end-use technologies by a third on average, and by around 70% for a typical house. For houses, the biggest impact comes from the significant decrease of the premium for near-zero-emissions cement production. Material efficiency measures such as the use of different construction materials could reduce the premium even further.

On the material supply side, governments have begun putting in place specific policies to support the transition of energy-intensive industries, notably in advanced economies. Examples include the EU Innovation Fund, the EU Carbon Border Adjustment Mechanism, Germany's Carbon Contract for Differences and the US Industrial Demonstration Program. On the material demand side, cross-sectoral initiatives and individual companies are increasing momentum for near-zero-emission products. The First Mover Coalition (aluminium, cement and steel), SteelZero (steel) and ConcreteZero (cement and concrete) bring together companies from different sectors that pledge to procure a certain amount of material complying with ambitious standards. In parallel, the number of bilateral offtake agreements for low-emissions production has increased, securing revenue on the supply side and showing the willingness of some individual companies to pay a premium. Governments could strengthen the demand signal by making near-zero-emissions standards an integral part of public procurement processes and by considering their use in particular areas such as design standards.

Even when the total cost of ownership for clean energy equipment falls to the level of conventional alternatives, higher upfront costs and related adjustments often put that equipment out of reach for energy consumers with limited disposable incomes and constrained access to financing. Clean energy technology adoption hinges on finding ways to manage the higher upfront costs of clean energy technologies, especially in low-income households. Chapter 2 explores these challenges.

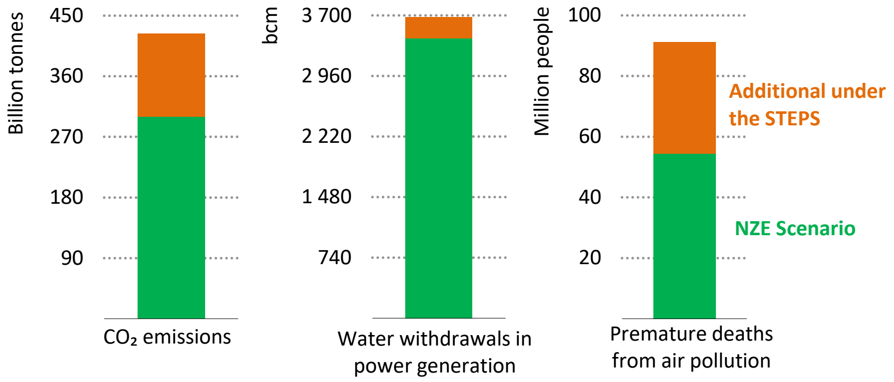
1.4 The costs of inaction

The notion that failure to take adequate action to address climate change now will lead to more significant costs in the future was emphasised almost 20 years ago in the Stern Review, which stressed the urgency of addressing climate change (Stern et al., 2022). The cost of inaction goes beyond direct losses in GDP; it also covers climate-related risks and impacts together with indirect costs including damage to health, biodiversity loss, forced migration and growing inequality.

Delayed action or inaction could have implications for affordability, notably by increasing costs or reducing the ability of the most vulnerable groups to pay for the energy and services they need. For example, the results of a 2023 bottom-up climate stress test by the European Central Bank (ECB, 2023) indicate that delayed transition to net zero scenarios would result in households experiencing large increases in total energy expenses compared with 2022, mainly because of continuing heavy dependence on fossil fuels and rising prices for those fuels.

While the IEA has not explicitly quantified the wider social and macroeconomic costs of inaction on climate, IEA scenarios provide some relevant insights. The STEPS, which is based on current policy settings, leads to 2.4 °C degrees of warming by 2100, while the NZE Scenario is a 1.5 °C aligned pathway. In the NZE Scenario, the combination of increased clean electricity generation, electrified transport, phasing out of polluting fuels and achieving universal clean cooking access leads to a reduction in cumulative deaths from air pollution. In the STEPS, cumulative premature deaths between 2024 and 2035 are 70% higher than they would be under the NZE Scenario. Water withdrawals for power generation are also nearly 10% lower in the NZE Scenario over the next decade (Figure 1.28).

Figure 1.28 ⊳ **Cumulative CO_2, air pollution and water metrics under the NZE Scenario and the STEPS, 2024-2035**



IEA. CC BY 4.0.

Under the STEPS, the world cumulatively adds three times today's annual CO_2 emissions by 2035 relative to the NZE Scenario. Premature deaths from air pollution are 70% higher.

Note: bcm = billion cubic metres.

Efforts to quantify monetary and non-monetary costs have been made by a number of regional and international organisations and institutions, though their figures vary due to differing assumptions and scenarios. For example, the Network for Greening the Financial System (NGFS) projected in 2022 up to 18% of GDP losses by 2100 under its current policies scenario (3° C warming). The International Monetary Fund (IMF) Climate Change Dashboard provides data on possible impacts, highlighting global and country-level economic indicators such as GDP losses (IMF, 2023).

Governments often adopt a cost-benefit analysis to internalise climate externalities, using the social cost of carbon – defined as the cost of damage from emitting an additional metric tonne of carbon dioxide emissions expressed in dollars – to guide regulatory decisions. This approach, which translates carbon emissions into dollar costs or savings, aims to align policies with climate objectives. For example, the United States federal government currently applies a social cost of carbon (SCC) value of USD 51 to evaluate policy proposals. However, estimates of the value of the SCC vary; much depends on underlying assumptions and on the discount rate used. A report from the Environmental Protection Agency (EPA, 2023) estimated that the SCC should be between USD 140 and USD 380 (in 2020 USD) in 2030, depending on the discount rate used.

Approaches such as target-consistent pricing offer an alternative to the use of the SCC by directly linking emissions reduction goals with pricing strategies. These approaches require policy makers to consider the annual cost of achieving emissions reductions and ensure that policies align with long-term climate objectives. The target-consistent pricing framework proposed by Stern and Stiglitz (Stern et al., 2022) focuses on achieving specific climate goals cost-effectively, aligning carbon pricing with temperature limits. These approaches provide a more focused analysis of specified technologies and time horizons and offer a framework for aligning policy decisions with climate objectives.

The inequality dimension of climate change is especially critical because the cost of inaction disproportionately affects low- and middle-income countries and vulnerable populations, including Indigenous Peoples. For instance, a 2022 study on flood exposure across 188 countries (Rentschler et al., 2022) showed that people in low- and middle-income countries accounted for 94% of those exposed to high flood risk in the 10 countries most at risk (1.15 billion out of 1.23 billion people). Analysis also showed that the vast majority of those at risk in low-income countries had very limited flood protection systems in place. Ignoring climate change and the unequal distribution of its impacts risks deepening existing global inequities, and climate policies designed for clean energy transitions must therefore ensure that they prioritise protecting the most vulnerable to ensure a just transition.

Across all economies, housing is increasingly exposed to risk from more frequent storms, fires, floods, subsidence and heat risk. The impacts of a more vulnerable housing stock could cascade through financial markets, and could also raise the costs of insurance. This puts the cost of climate mitigation into context. For example, the combined value of the real estate market in EU and North America was nearly USD 180 trillion at the end of 2022; by contrast, the cumulative costs of building retrofits to 2050 in the NZE Scenario would run to USD 8 trillion.

Investment and energy bills

Who pays, and how much?

SUMMARY

- All parts of society need to play their role in successful, affordable and fair energy transitions, but what capabilities and interests are in play? In this chapter we explore how governments, households and companies interact in different ways with the energy sector to understand what is at stake as energy transitions progress.
- Governments have unique capabilities to act and to set the rules of the game for others. Governments and state-owned companies account for around USD 1 trillion of investment each year (some 35% of total energy sector investment), largely into fossil fuels. Governments also subsidise the deployment of clean energy and the consumption of fossil fuels, with subsidies to fossil fuels being considerably larger.
- The situation varies widely by country, but overall annual government revenues from taxes on energy production (mostly from oil) have averaged around USD 1.5 trillion in recent years. Governments also receive USD 1.8 trillion from taxes on energy use, again mostly from oil, and over USD 100 billion from carbon pricing instruments. In clean energy transitions, declining government revenue from taxes on fossil fuel production and use is partly offset by increased revenue from carbon pricing. Reductions in expenditure on fossil fuel consumption subsidies are offset by a rise in support for clean energy. There are major differences between countries, with severe strains on those that are heavily dependent today on hydrocarbon revenues.
- Households make around 20% of the investments in energy today. These mainly come from higher-income households investing in efficiency improvements, rooftop solar, heat pumps or the additional upfront cost of an EV. Some 10% of this investment in clean energy is supported by governments in the form of grants or tax incentives.
- Household energy bills are a major concern worldwide. They are highly unequal: lower-income households consume less energy, but they spend a larger share of their income on it (up to 25% in advanced economies) or leave energy needs unmet. Energy transitions could lead to major reductions in household energy bills and accelerate progress towards universal energy access. But managing upfront costs for poorer and rural households – as well as ongoing costs – remains a key public policy challenge.
- The private sector makes up just under half of all investment in energy today. Energy transitions mean a shift in investment away from sectors with higher but more volatile returns on investment, such as oil and gas, to more regulated sectors such as power and networks. Energy-intensive sectors require particular attention; margins are thin, markets are often international, and low-emissions technologies for many processes are still under development or come with significantly higher costs.

2.1 Introduction

The speed and success of energy transitions hinges not only on technological advances and economic growth but also on the way that costs and benefits are distributed across different groups of stakeholders, both within countries and internationally. As discussed in Chapter 1, poorer households, firms, communities and countries could be shut out from the clean energy economy if they cannot pay the upfront costs of the switch to a more sustainable energy system. Conversely, companies that adopt some emerging clean technologies early could find themselves at a disadvantage compared with incumbent firms using technologies that rely on unabated fossil fuels.

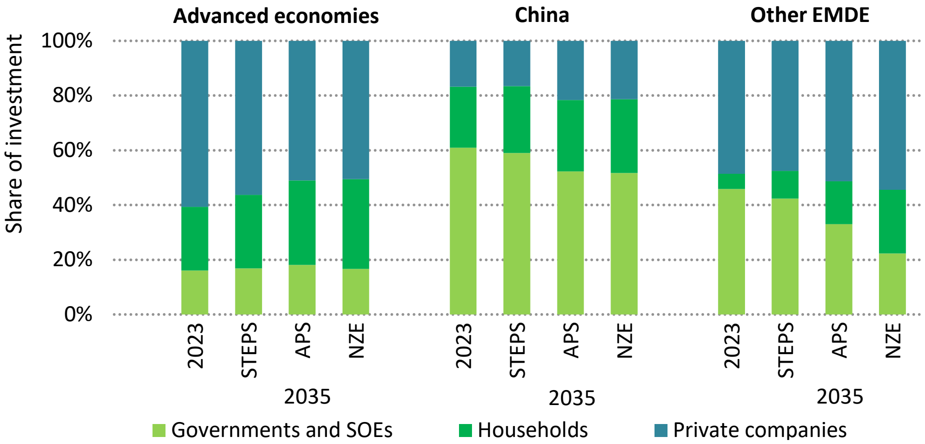
In this chapter, we start by continuing the investment discussion from Chapter 1, but this time considering the entity that is making the investment, whether governments, households or private companies. We then take each of these constituencies in turn, look at how they interact with the energy system as investors and also as market participants, regulators, consumers and producers, and examine their roles in making clean energy transitions affordable for all. In considering the role of governments, we recognise that they face competing calls on their resources as well as fiscal constraints, and that they need to balance their support for energy transitions with other priorities and with the risks of higher indebtedness, inflation and other macroeconomic imbalances.

Who is making energy investment decisions?

Total energy sector investment in 2023 amounted to around USD 3 trillion. Around 45% of this investment was made by private companies, and around 35% by governments and state-owned enterprises (SOEs). The share of overall investment made by governments and SOEs tends to be higher in emerging market and developing economies (EMDE) compared with advanced economies, especially those with large national oil companies and large state-owned utility companies. Households accounted for the remaining 20% of investment, most of which took the form of spending on energy efficiency measures such as building retrofits, the purchase of more efficient appliances, and the purchase of electric vehicles, rooftop solar panels and heat pumps. The share of investment made by households rises in all scenarios and is markedly higher in the Announced Pledges Scenario (APS) and Net Zero Emissions by 2050 (NZE) Scenario as households invest in more efficient equipment, homes, vehicles and rooftop solar (Figure 2.1).

These "sources of investment" need to be distinguished from the "sources of finance" discussed in Chapter 1. Sources of investment are the entities that make the investment decision, usually because they are – or will become – the asset owner (Figure 2.2). Sources of finance are the entity providing the finance for this investment. For example, a household that invests in rooftop solar could finance this through its own savings, borrowing from a financial institution or a public subsidy. The source of investment in all cases is the household, but the source of finance for borrowing is "commercial finance" and for subsidies is "public finance".

Figure 2.1 ⊳ Sources of investment in energy today and in 2035, by region

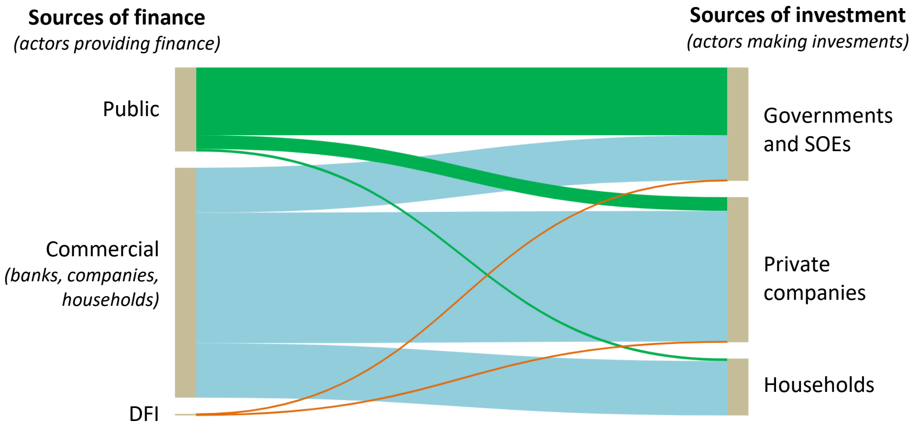


EA. CC BY 4.0.

Private companies dominate investment in all regions other than China, where governments and state-owned enterprises are the largest source of investment

Note: STEPS = Stated Policies Scenario. APS = Announced Pledges Scenario. NZE = Net Zero Emissions by 2050 Scenario. SOE = state-owned enterprises. EMDE = emerging market and developing economies.

Figure 2.2 ⊳ Sources of finance and investment, 2023



IEA. CC BY 4.0.

The entities providing finance are distinct from the entities making investment

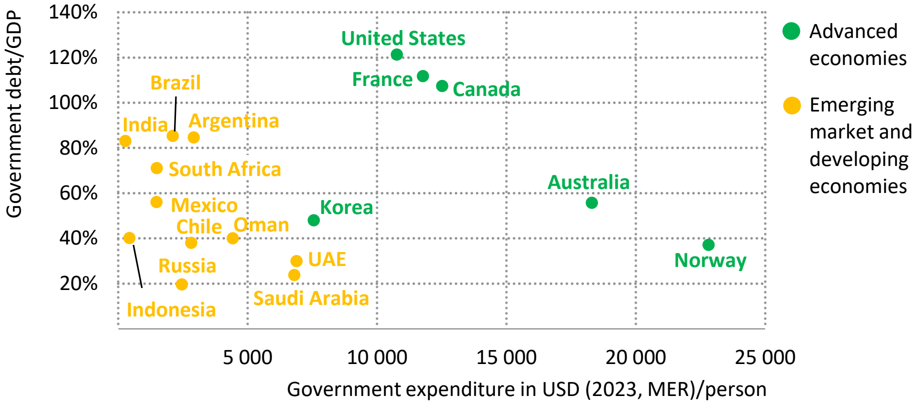
Notes: DFI = development finance institutions. SOE = state-owned enterprises. Public = equity shares of governments in companies and subsidies and tax incentives. Commercial = finance by private banks, private corporations, household savings and public entities with a commercial mandate (e.g. some public banks).

2.2 Governments

Governments have multiple roles in the energy sector, and can both take action themselves and guide the actions of others. They can lead the way in energy transitions by providing strategic vision, support for innovation, incentives for consumers, policy signals and public finance to catalyse private investment, and support for communities where livelihoods are affected by rapid change. They also have the responsibility of ensuring the security and affordability of supply.

Energy transitions have a major impact both on the revenue streams that governments receive from the energy sector and on public spending priorities. This section starts with a review of the different ways in which governments receive income from the energy sector, whether from energy production, consumption or carbon pricing, and how these might be affected by energy transitions. It then considers the direct and indirect roles of governments in energy investment, before analysing the support provided for consumers, including subsidies for fossil fuel consumption. It concludes by considering how government income and expenditure might evolve in energy transitions.

Figure 2.3 ▻ Government debt and government expenditure in selected economies, 2022



IEA. CC BY 4.0.

Some advanced economies have relatively high government debt burdens, but they also enjoy better access to debt than others, and are able access it at lower cost

Notes: GDP = gross domestic product; UAE = United Arab Emirates; MER = market exchange rate. "Government debt" = gross public debt.

Sources: World Development Indicators and IMF (2024a)

Different governments have very different scope to support affordable and fair transitions. The ability to raise funds, whether through taxation or borrowing, varies widely, as does the ability to disburse and spend these funds effectively in support of public policy objectives.

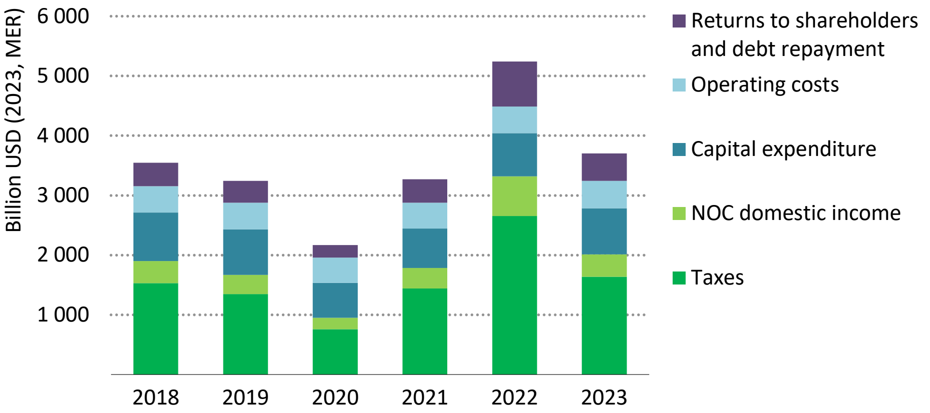
Indebtedness is a major constraint. Overall government debt burdens are relatively high in many advanced economies as a share of GDP, but governments in these countries have better access to debt than others, and are able to access it at lower cost to fund expenses. Governments of wealthier economies also tend to spend more per person, which gives them more scope to ensure that clean energy transitions are people-centred and inclusive by tackling some of the distributional risks that appear in energy transitions.

Many EMDE have lower debt-to-GDP ratios than advanced economies, in some cases because of macroeconomic prudence but mostly because investors will lend to them only within certain limits (Figure 2.3). Unlike most advanced economies, most EMDE are not rated "investment grade" by credit agencies. For example, in Latin America and the Caribbean, sovereign credit ratings vary from debt in default (Venezuela) to upper-medium grade (Chile), and fewer than 10 out of more than 30 countries are ranked investment grade. In Africa, only two countries are categorised as investment grade.

2.2.1 Government revenue from energy

Governments receive income from taxes on energy production and consumption, as well as from carbon pricing and other environmental or social surcharges. The ability of governments to change taxes and related measures gives them a great deal of power to influence investment and consumption decisions.

Figure 2.4 ▷ **Use of oil and gas revenue, 2018-2023**



IEA. CC BY 4.0.

The oil and gas industry has generated around USD 20 trillion of revenue since 2018. Half was paid to governments and 40% was spent developing and operating oil and gas assets

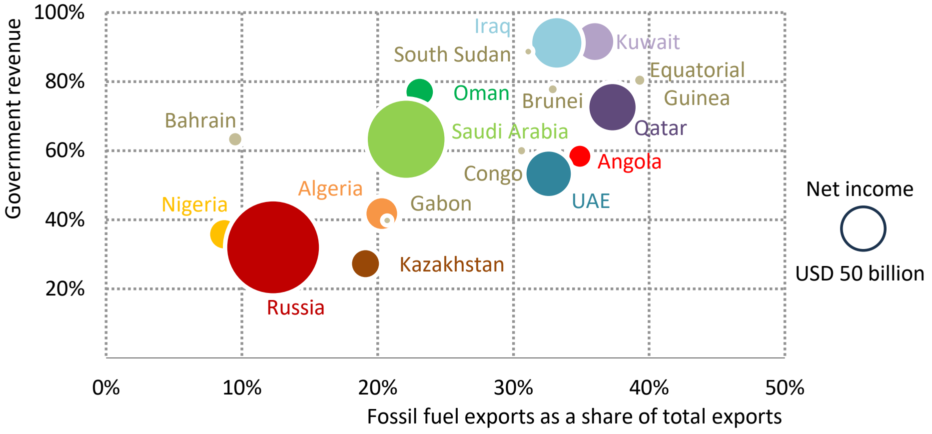
Note: NOC = national oil company.

Revenue from energy production

Taxes and royalties generated from energy production represent a significant source of income for many governments, and the majority comes from oil and gas. Since 2018, the annual revenues generated by the oil and gas industry have averaged close to USD 3.5 trillion. Around half of this has gone to governments. There is a high degree of year-on-year variation in this figure, with oil and gas revenues ranging from a low of USD 2.5 trillion in 2020 during the Covid-19 pandemic to a historic record high of more than USD 5 trillion in 2022 during the global energy crisis (Figure 2.4).

Revenues of this magnitude help governments in producer economies to finance public services and infrastructure development, but heavy reliance on oil and gas revenues comes with risks. Fiscal balances are vulnerable to changes in oil and gas prices, and this can mean that increases in government spending during boom years are followed by painful cutbacks when revenue falls. There is also a temptation for governments to expand public sector employment when revenues are rising, and this can sometimes come at the cost of private sector development and lower labour productivity.

Figure 2.5 ▷ Government revenue from fossil fuels and fossil fuel exports as a share of GDP for selected producer economies, 2018-2022



IEA. CC BY 4.0.

Many producer economies are heavily reliant on income from fossil fuel exports. This falls drastically in net zero transitions, bringing fiscal and other challenges for those economies

Note: IEA analysis based on IMF (2024b).

Net zero transitions will have profound implications for countries reliant on oil and gas revenues and trade (Figure 2.5). Our scenarios provide a sense of the magnitude of the changes that oil and gas producers face from falling demand and lower prices: in the NZE Scenario, income from taxes on fossil fuel production globally falls by USD 1.1 trillion to 2035 compared with the average level during 2018-2022. Rapid population growth in key producing countries means that the declines in income in those countries are even sharper when expressed on a per capita basis. This is the case for Angola, for example, which is set to double its population by 2050, and for Nigeria and Iraq, which are both expected to see a 70% increase in population by 2050. Across a group of established producer economies, net income per capita from oil and gas in the NZE Scenario is 70% lower by 2035 than the average level during 2018-2022. A drop in income of this size could well affect sovereign risk premiums, particularly in countries with large external debts.

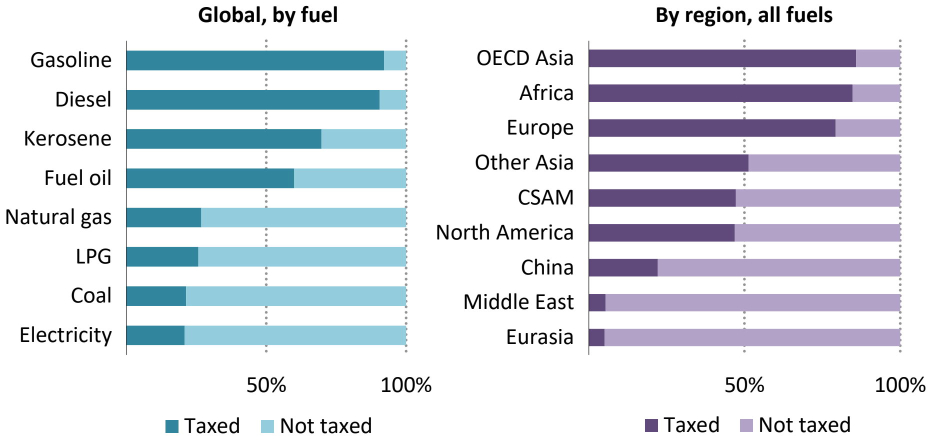
Major resource-holders tend to be among the world's least-cost suppliers, and this means that many of them could retain strong footholds in the markets, at least during the initial years of our projections. However, the trajectories mapped out in the APS and the NZE Scenario may in some ways understate the difficulties that lie ahead. These trajectories are relatively smooth, suggesting that they can be planned for. But that is not the way that markets and energy transitions are likely to work in practice. As explored in more detail in Chapter 4, transitions may well increase the likelihood of market imbalances, price shocks and volatility.

Revenue from energy consumption

Average annual government income from taxing energy consumption between 2018 and 2022 amounted to around USD 1.8 trillion, of which oil brought in USD 1.2 trillion, electricity USD 450 billion and other fuels around USD 150 billion. These taxes are not evenly distributed across countries or types of energy. In practice, more than half of final energy consumption is not subject to an excise or value-added tax. Transport fuels, notably gasoline and diesel, are the main source of tax revenues from energy consumption (Figure 2.6). Only 20% of coal consumption – which is mostly used in industry – is taxed, and liquefied petroleum gas (LPG) – which is crucial to residential cooking access – is also lightly taxed. Natural gas consumption is taxed to a similar extent as electricity consumption, and average tax rates for the gas consumption that is taxed (around USD 12 per megawatt-hour [MWh]) are around half of those for electricity (USD 25/MWh). Large energy-producing regions such as the Middle East and Eurasia do not apply any taxes at all to energy consumption. Europe and advanced economies in Asia – both major importing regions – apply taxes to a greater proportion of energy consumption than other regions and their tax rates on fuel consumption are also among the highest in the world.

In the NZE Scenario, annual consumption-related energy taxes fall by USD 700 billion, or two-thirds, to 2035 (compared with the annual average level between 2018 and 2022). This might pose major fiscal challenges for some countries; however, the drop in oil and gas import bills improves the overall trade balance for net-importing countries (Figure 2.7). In India, for example, the annual oil import bill in 2035 the NZE Scenario is USD 60 billion (or 50%) lower than the average of the past five years. Fiscal balances can also be shored up by increasing tax revenue in other parts of the energy sector, or by stepping up revenue from carbon pricing instruments.

Figure 2.6 ▻ Tax status of selected energy sources and total by region

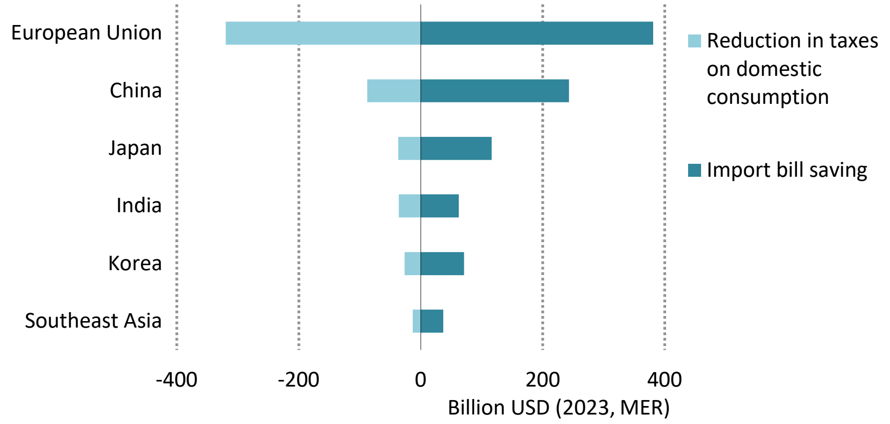


IEA. CC BY 4.0.

Over half of total final consumption is not subject to value-added or excise taxes

Notes: OECD Asia = Australia, Japan, Korea and New Zealand; CSAM = Central and South America. Sample includes over 70 countries for which the International Energy Agency (IEA) collects energy tax data (2024).

Figure 2.7 ▻ Reductions in taxes on oil and gas consumption and import bills in the NZE Scenario in 2035 compared with the annual average for the last five years



IEA. CC BY 4.0.

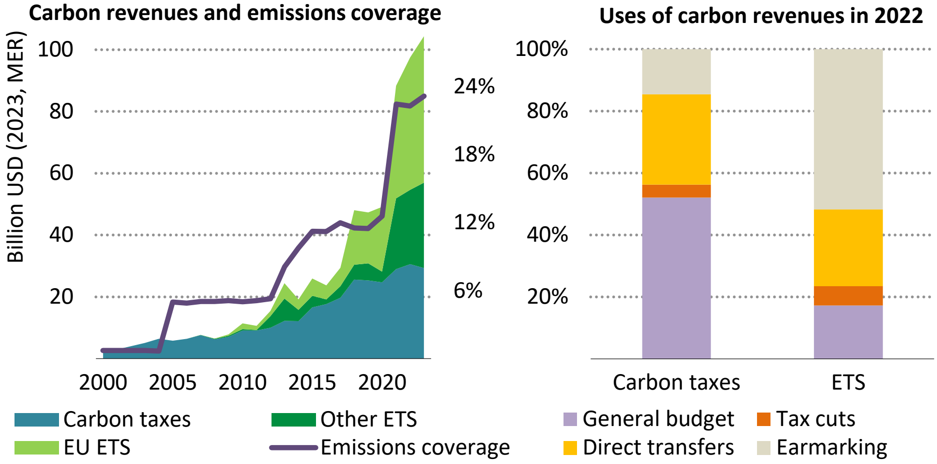
Income from taxing oil and gas consumption falls by USD 700 billion in the NZE Scenario by 2035 in major importing regions, but there is also a USD 1 trillion reduction in import bills

Revenue from carbon pricing instruments

Carbon pricing is one of the tools available to policy makers to bring down CO_2 emissions and scale up clean energy deployment, together with instruments such as standards, mandates and procurement strategies. It is particularly relevant to a discussion on affordability and fairness as it changes relative energy prices, raises revenue and can have significant distributional impacts.

Revenue generation is an important feature and benefit of compliance carbon pricing systems such as carbon taxes and emissions trading systems (ETSs). The level of revenues generated by carbon pricing instruments depends on the price set on carbon, the scope of emissions covered, and specific design features such as allowance allocation methods or rebate programmes. Revenues from carbon pricing instruments around the world have increased substantially in the last 15 years from less than USD 8 billion in 2007 to around USD 100 billion in 2023, with an increasing proportion of the revenue coming from ETSs. In 2022, over two-thirds of the revenues generated came from ETSs, and 44% from the European Union (EU ETS) alone (Figure 2.8).

Figure 2.8 ⊳ **Carbon revenues and emissions coverage, and uses of carbon revenues in 2022**



IEA. CC BY 4.0.

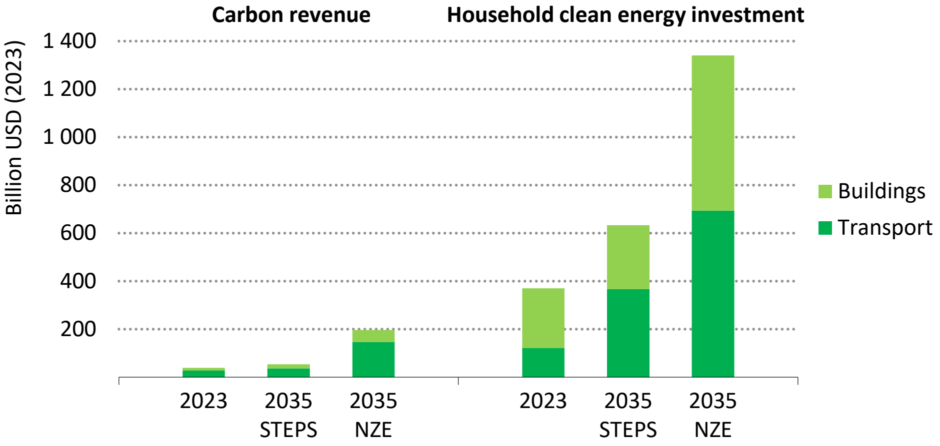
ETSs generated 70% of revenues from carbon pricing in 2022. Half of ETS revenue was earmarked for specific uses; the corresponding figure for carbon taxes was less than 20%

Sources: ETS = emissions trading system. IEA analysis based on World Bank (2024a) and I4CE (2023).

Targeted revenue recycling has the potential to help manage distributional and socio-economic challenges stemming from the application of a carbon price, but there is no single best practice for using the proceeds. Over half of the revenues from carbon taxes and one-third of the overall revenues from carbon pricing in 2022 went to general budgets without any specific allocation. Where legislation permits, revenues can be redistributed to households or companies, earmarked for projects contributing to the clean energy transition, or used to fund reductions in other taxes. In 2022, over half of the revenues from ETSs were earmarked to fund low-emissions projects, support technological innovation and mitigate carbon leakage risks.

In 2023, around USD 40 billion in annual revenues were generated from carbon pricing instruments that apply to fuels and electricity used in road, rail and air transport, as well as in residential buildings.[1] In the NZE Scenario, this rises to USD 200 billion in 2035 as more jurisdictions introduce carbon prices aimed at these sectors, carbon prices increase significantly to meet more ambitious decarbonisation targets, and the share of free allowances drops rapidly (Figure 2.9).

Figure 2.9 ▻ **Carbon revenues and household clean energy investment in buildings and transport in the Stated Policies and NZE Scenarios**



IEA. CC BY 4.0.

In 2035, carbon revenues could meet around 15% of global household clean energy investment needs in the NZE Scenario

Notes: Carbon revenue here is from carbon pricing instruments in road transport, aviation and rail, and residential buildings. Possible revenue from freight transport via road, rail and aviation is excluded.

As governments expand the scope of carbon pricing instruments to cover other sectors, notably transport and buildings, the distributional impacts are bound to increase. Lower-income

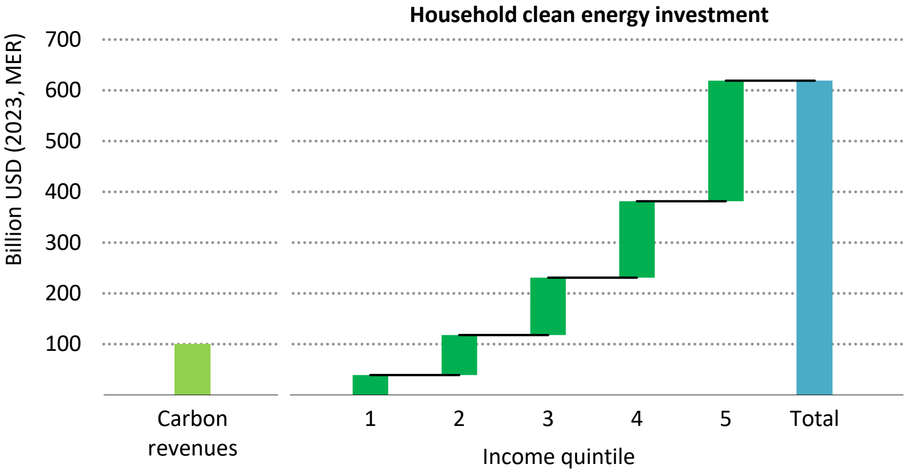
---

[1] In most cases, the revenue is not collected from carbon prices that are directly paid by households, but rather from carbon prices applied to refiners of fuels, electricity generators, or air and rail service providers who then pass through this carbon cost to customers in the form of higher fuel, electricity and ticket prices.

households are likely to pay a large proportion of overall CO_2 costs; they tend to live in buildings that are below average in terms of energy efficiency, where a large share of energy for heat and cooking is provided by fossil fuels, and they are likely to struggle to afford the upfront costs of switching to clean energy.

There is a strong case for addressing this problem by using a significant share of growing carbon pricing revenues to help those households that most need it. For example, the USD 100 billion raised from carbon revenues from buildings and transport in 2035 in the NZE Scenario would almost fully fund the required level of household clean energy investment in buildings and transport in the lowest two income quintiles, assuming that the income distribution in those economies remains as it is today (Figure 2.10). Recycling carbon revenues and targeting them in this way depends on effective and efficient revenue governance structures, but several jurisdictions with carbon pricing instruments such as the European Union (EU) and California provide examples of how it might be done (see Chapter 3).

Figure 2.10 ▻ Carbon revenues and household investment in transport and buildings in advanced economies in the NZE Scenario, 2035



IEA. CC BY 4.0.

Carbon revenues from transport and buildings could meet most of the additional household clean energy investment in advanced economies for the two lowest income quintiles

Note: Assumes that the proportion of spending on energy appliances and vehicles by income bracket in advanced economies in 2035 in the NZE Scenario remains the same as it was in 2022.

2.2.2 Government role in clean energy investment

Government actions play a central role in shaping investment flows to the energy sector. In some cases, governments act directly as investors, often through SOEs. In all cases, they determine the market and regulatory environment in which other actors make investment decisions. They can introduce regulatory requirements or deploy subsidies, grants, rebates, technical advice or loan guarantees to support innovation, early-stage deployment, public-private partnerships or specific projects.

Governments have devoted significant support to help scale up clean energy investment in recent years (Box 2.1). However, limited fiscal space and high levels of indebtedness have severely restricted the ability of most EMDE governments to provide such support directly, and more than 90% of clean energy investment support programmes since 2020 have been undertaken by advanced economy governments. DFIs clearly have a part to play here, and have sought to increase their lending for clean energy investment: they financed projects and corporations for less than USD 20 billion in 2023, mainly through debt products and guarantees focused in particular on middle-income countries.

Although most interventions to support projects involve the direct use of public funds, some focus instead on reducing or reallocating risk. For example, public-private partnerships often assume some of the risks faced by power projects in their early stages, such as those that stem from site selection, rights of way, environmental impact assessments or grid connection charges. This has helped to accelerate sector maturity and encourage private sector participation. Governments around the world are also increasingly concerned with broader questions concerning investment in energy value chains, including the manufacturing of clean energy technologies and components, inputs to these processes such as critical minerals, and the employment that goes with them.

One set of questions relates to supply chain diversity and resilience. For the moment the processes in question are highly concentrated, creating reliance on technologies produced in a limited number of countries, notably China. Increasing the resilience of clean energy supply chains requires policy support for more diversified manufacturing, but this can come – at least in the near term – with a cost premium (see Chapter 4).

Another set of questions relates to industrial competitiveness in the context of new and emerging technologies such as low-emissions steel or cement. These technologies are not yet competitive with traditional production processes, and governments are looking for ways to mitigate the risk that first movers in these areas are priced out of the market, or that policies promoting low-emissions production simply lead to industries relocating to jurisdictions with less stringent policies.

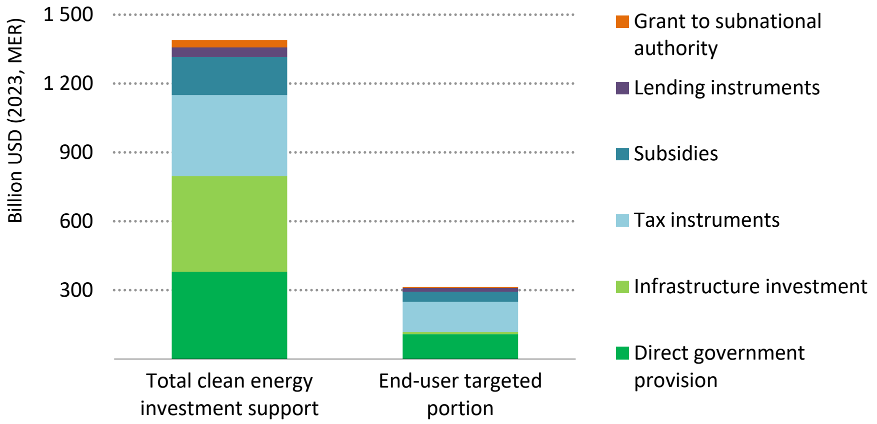
Box 2.1 ▻ Clean energy investment support

Over the last four years, governments have allocated over USD 1.3 trillion to clean energy investment support in their multi-annual budget frameworks, mostly in the context of Covid-19 related recovery plans (Figure 2.11). This spending – over 90% of which was committed in advanced economies – was earmarked for low-emissions electricity generation projects (USD 310 billion since 2020, mostly for renewable energy sources), mass and alternative transport infrastructure (almost USD 310 billion), and projects and schemes supporting energy efficiency improvement in buildings and industry (over

USD 260 billion). Some sectors, where government intervention would bring clear benefits, such as electricity grids (over USD 80 billion) or measures to mitigate the social and economic impacts of clean energy transitions, notably by training workers (USD 20 billion), have received less support.

The bulk of the earmarked spending has been for large infrastructure and technology innovation projects channelled through public and private operators or project grants and other direct government funding (both around 30% of the funds earmarked). Most of the rest takes the form of tax credit and tax reduction schemes to encourage clean energy investment notably in the transport and low-emissions power sectors (over 25%) and support for end users in the form of consumer-oriented support schemes encouraging the purchase of low-emissions equipment by energy-intensive companies or supporting improved home energy performances (over 10%). End-user support is mostly provided through tax instruments (over 40% of the funding earmarked), direct government investment (35%), subsidy schemes (almost 15%) and lending instruments, consisting either of loans provided by the state under preferential terms or public guarantees to bring down the cost of capital (5%).

Figure 2.11 ▻ Clean energy investment earmarked by governments, 2020-2023, by destination and policy instrument



IEA. CC BY 4.0.

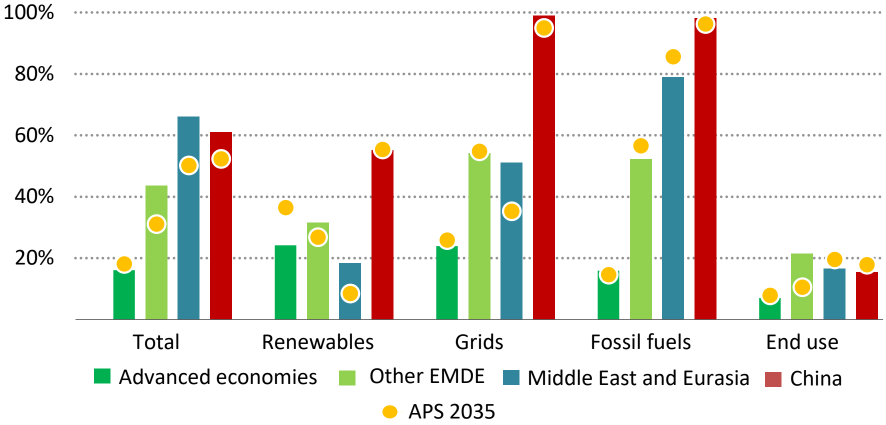
Government clean energy investment support often spans a decade or more, and mostly targets infrastructure and technology innovation

In both advanced economies and EMDE, governments have lately been seeking to favour domestic clean energy manufacturers. Grants that specifically target domestic producers, together with tax reductions and subsidy schemes that incorporate local content requirements, represented almost USD 90 billion of earmarked investment.

Investment by governments and state-owned enterprises

Investments in energy made by governments account for around 35% of the global total. Much of this investment takes place in China, where the government's share of total energy investment is around 60%, and in the Middle East and Eurasia, where 65% of energy investments come from the state and state-owned enterprises. In advanced economies, the share today averages around 16%, although some countries, such as France, Italy, Japan and Norway, have large energy sector SOEs. In the STEPS, these shares remain broadly constant, but in the APS, they gradually decline in most EMDE, though a bit less in China (Figure 2.12).

Figure 2.12 ▷ Share of state-owned energy investments by sector and country grouping in the Announced Pledges Scenario, 2023 and 2035



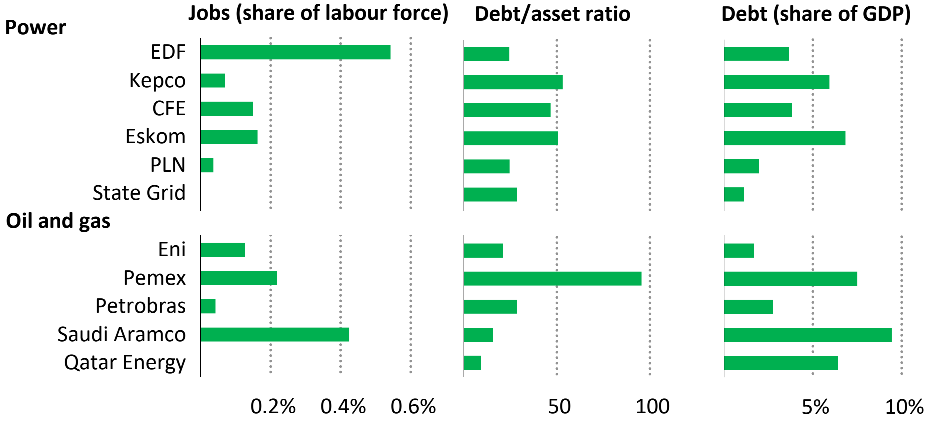
IEA. CC BY 4.0.

The respective roles of the state and the private sector vary widely by country and across different parts of the energy sector

The decline in the APS and the NZE Scenario reflects the fact that today's SOEs act mainly in traditional areas of the energy economy. National oil companies (NOCs) have a very strong position in global oil and gas supply, accounting for more than half of production and close to 60% of reserves. Power sector utilities with large coal-fired generation capacity also tend to be state-owned, as in the case of the major Chinese power companies, or PLN in Indonesia, Eskom in South Africa and NTPC in India. As things stand, the role of these enterprises is set to diminish as transitions gain momentum.

This assumes, however, that SOEs do not move at scale into new areas, and that the conditions are in place for the private sector to take on a larger role in the energy sector in the countries concerned. Existing SOEs could take on new roles in clean energy, particularly in clean technologies that are adjacent to existing areas of expertise. In the oil and gas sector, this includes areas such as offshore wind; geothermal energy; carbon capture, utilisation and storage (CCUS); biofuels; and low-emissions hydrogen. The Norwegian company Equinor is leading in this regard, with clean energy accounting for around 15% of its total capital investment in 2023. Countries could also look to create new national champions for clean energy. There are some examples already, including Masdar in the United Arab Emirates, which is owned by three other state entities.

Figure 2.13 ▷ Employment and debt levels of major energy SOEs



IEA. CC BY 4.0.

State-owned enterprises can be important sources of revenue and employment, but their debt levels can also have implications for their countries' fiscal positions

Notes: No employment data for State Grid and Qatar Energy. The debt-to-asset ratio is a measure of leverage and is calculated as total debt over total assets. Debt refers to short- and long-term debt. 2022 is the base year.

Source: IEA analysis based on Bloomberg (2024) and World Bank (2024b).

Governments may be tempted to allow NOCs to entrench their existing roles because of their importance as generators of revenue, but this would carry risks. If NOCs are under pressure to support government income and maintain employment, that could create institutional incentives to double down on spending on large oil and gas projects, which could then struggle to generate adequate returns in the APS and NZE Scenario. State-owned utilities often make losses, including some NOCs, and often around 25-50% of their energy assets are financed with debt. This is not intrinsically problematic, but could become so if the levels of debt become difficult to sustain. For example, the Mexican NOC Pemex is one of the world's most indebted oil companies (Figure 2.13). Its debt is equivalent to 7% of Mexico's GDP, and its situation was a contributing factor in a downgrade to Mexico's sovereign credit rating recently. Some countries also face increasing fiscal risks from sovereign guarantees extended by SOEs.

Government investment is by no means confined to SOEs in traditional areas of the energy economy. Investment in the transmission networks, in EMDE at least, is also typically restricted to state-owned companies. Privately financed models for grid investment have been tested in EMDE with some success, notably in Latin America, but they remain relatively rare.

2.2.3 Government support for consumer bills

Most governments have programmes and strategies in place to help vulnerable consumers who struggle to pay their energy bills (see also section 2.3). These programmes can intervene to set retail prices, via regulated, discounted or tiered end-user prices, or they can provide direct financial assistance. Broader strategies to address energy poverty include energy efficiency programmes, performance standards for buildings and appliances, and education and awareness programmes.

In this section we address two traditional approaches to affordability that have significant implications on energy transitions: fossil fuel consumption subsidies, and electricity tariffs that are kept below cost recovery levels.

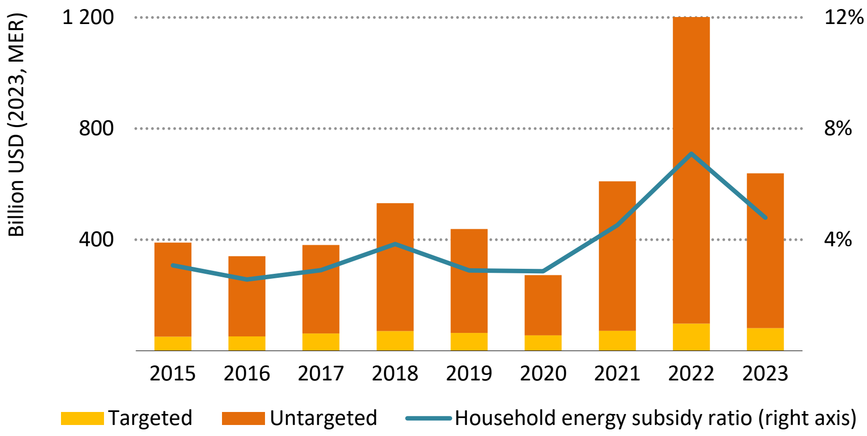
Fossil fuel consumption subsidies

Fossil fuel consumption subsidies come into being when consumer prices are held at levels that are lower than the market value of the products in question, based on reference prices that are adjusted as necessary for transport costs and value-added tax. While some of these subsidies can be justified as efficient in the sense that they help to achieve social and development policy objectives, notably when they improve access to clean cooking fuels, the majority simply incentivise often wasteful fossil fuel consumption. As such, they represent a major obstacle to progress on clean energy transitions.

We estimate that, after reaching an all-time high of over USD 1 trillion during the global energy crisis in 2022, fossil fuel consumption subsidies returned in 2023 to around USD 600 billion as benchmark prices eased, particularly for natural gas (Figure 2.14). As a result, the share of natural gas subsidies in total subsidies reverted to around 25% after having risen to one-third in 2022. Approximately USD 230 million of the USD 600 million total related to oil consumption, mainly for transport.

Only a small proportion of fossil fuel consumption subsidies benefit specific vulnerable groups. These include subsidies for LPG and kerosene in the residential sector, and some agricultural subsidies. On average over the last five years, such targeted subsidies have accounted for less than 15% of the total. Other untargeted subsidies tend to benefit wealthier segments of the population disproportionately because they consume more of the subsidised fuels. In Indonesia, for example, middle- and upper-income households account for about 20% of the population but consume 42-73% of the subsidised diesel and almost 30% of subsidised LPG. If these two subsidies were to be eliminated (saving 1% of GDP at 2022 prices) and replaced by targeted social transfers for the poor, vulnerable and aspiring middle class, the net fiscal gain would be 0.6% of GDP (World Bank, 2022).

Figure 2.14 ▷ Fossil fuel consumption subsidies, 2015-2023



IEA. CC BY 4.0.

The vast majority of fossil fuel consumption subsidies are untargeted and disproportionately benefit wealthier high-consumption segments of the population

Note: Targeted subsidies include agriculture and household (LPG and kerosene fuels only) sector subsidies. Household energy subsidy ratio is calculated by dividing household subsidies by total household energy expenditure.

Indonesia is an example of a fuel-importing country for which fossil fuel consumption subsidies are a substantial budgetary expenditure. However, most subsidies are found in resource-rich energy-exporting countries; in these countries, the consumption subsidy represents the opportunity cost of selling at below-market prices rather than a financial outlay.

Electricity tariffs that fail to recover costs

In many EMDE, revenues from electricity sales and services fail to cover the operating capital expenditures and debt service costs of utilities. This compromises the ability of these utilities to pay their bills and attract new investment, including in clean energy projects, and it leads to high debts, subsidies and service quality problems. Tariff levels are by no means the only issue, but retail prices that are kept unsustainably low in the interest of affordability are often one of the main reasons behind pervasive shortfalls in revenue.

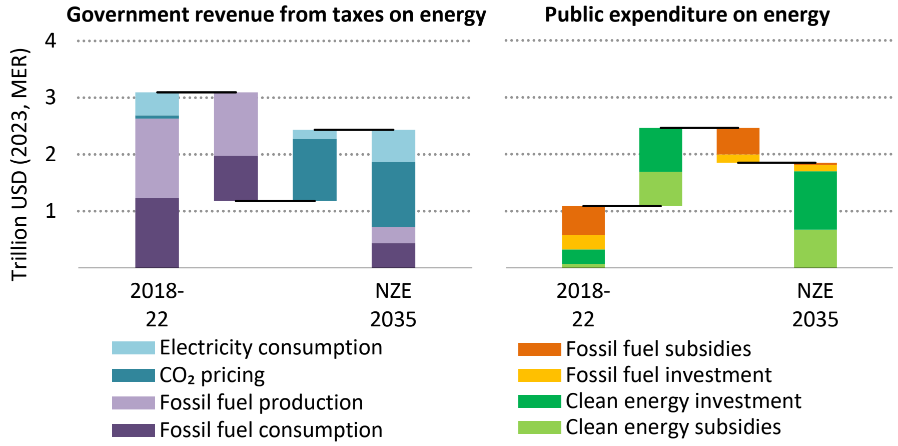
The situation has deteriorated in many countries since 2020 because of the Covid-19 pandemic and then because of the sharp escalation in fuel prices during the global energy crisis. In Africa, for example, much of the region's electricity supply infrastructure needs to be repaired and expanded, but progress has slowed on both fronts in recent years (IEA, 2022). The finances of most African utilities were hit by lower demand during the pandemic and by emergency measures that cancelled, reduced or deferred the payment of electricity bills by end users. Utilities in countries that import fuel for power generation were then hit by rising fuel costs after the Russian Federation's invasion of Ukraine, which led in many cases to the extension of emergency measures and prolonged operating losses.

A combination of limited government fiscal space, financially strained utilities, and consumers unable in many cases to afford higher power prices constitutes a triple affordability challenge for many developing economies, making it more difficult to bring relatively capital-intensive clean sources of electricity into the system. There are no simple solutions, and each country situation has its own specificities, but ingredients for success include a clear vision for clean energy transitions, policy and regulatory reforms that reduce barriers to entry for new clean sources of generation, efforts to modernise grids and tackle high network losses, improvements to metering and billing, and reforms to tariff design that preserve support for vulnerable groups while allowing for some cross-subsidisation from those most able to pay.

2.2.4 Changes in government income and expenditure in the NZE Scenario

In the NZE Scenario, overall public revenue from energy drops by USD 650 billion by 2035 compared with the annual average level between 2018 and 2022. Tax receipts from fossil fuel production drop by USD 1 100 billion, and tax receipts from fossil fuel consumption fall by USD 800 billion. This is partly offset by a USD 1 100 billion rise in public income from CO_2 pricing schemes and a rise of USD 150 billion in electricity taxes as the electrification of end uses continues to grow.

Figure 2.15 ▷ Government revenue from taxes on energy and public expenditure on energy in the Net Zero by 2050 Scenario



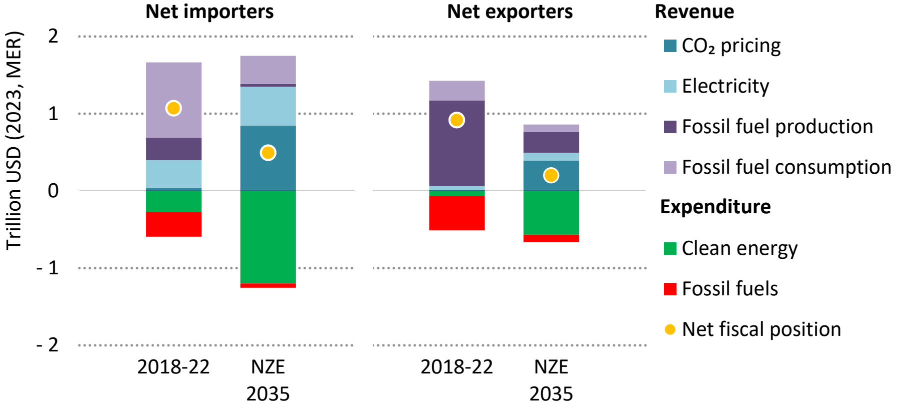
IEA. CC BY 4.0.

Government revenue from fossil fuel taxation falls but this is partly offset by higher CO_2 income. More is spent to support clean energy and less on fossil fuel consumption subsidies

Overall public expenditure on energy, meanwhile, rises by more than USD 750 billion in the NZE Scenario in 2035 compared with average between 2018 and 2022. Public investment in fossil fuels falls by USD 150 billion – a 60% drop – and fossil fuel subsidies worth around USD 500 billion per year are mostly phased out, while public investment in clean energy, mostly through investments made by state-owned enterprises, increases by almost USD 800 billion (Figure 2.15). Governments also scale up support to end-use consumers in the form of grants, subsidies and tax instruments. Around USD 170 billion of public money was earmarked to energy producers to support scaling up clean energy supply, and to consumers – households and industries – in recent years to support their purchases of clean energy equipment such as electric vehicles (EVs) and heat pumps or to fund efficiency measures. In the NZE Scenario, government subsidies increase to cover more of the required spending, resulting in a USD 600 billion increase in annual public expenditure by 2035. If this increase were entirely funded by additional public debt, it would not raise any country's debt-to-GDP ratio by more than 5 percentage points in 2035, all else being equal.

These global changes mask some major differences between countries. Net exporters of oil and gas face severe strain on their fiscal balances at a time when the need for economic diversification brings pressure for public spending increases. For this group, income from upstream oil and gas production is around USD 900 billion lower in 2035 than the annual average between 2018 and 2022, a drop of around 80%. Eliminating fossil fuel subsidies avoids some expenditure, but the reduction in income from taxing oil and gas production is the main reason their fiscal balances are around USD 700 billion worse in 2035 than the average seen in recent years. The fiscal balances of net importers are also affected by a similar magnitude (Figure 2.16).

Figure 2.16 ▷ Public revenue and expenditure for net oil and gas importing and exporting regions in the NZE Scenario



IEA. CC BY 4.0.

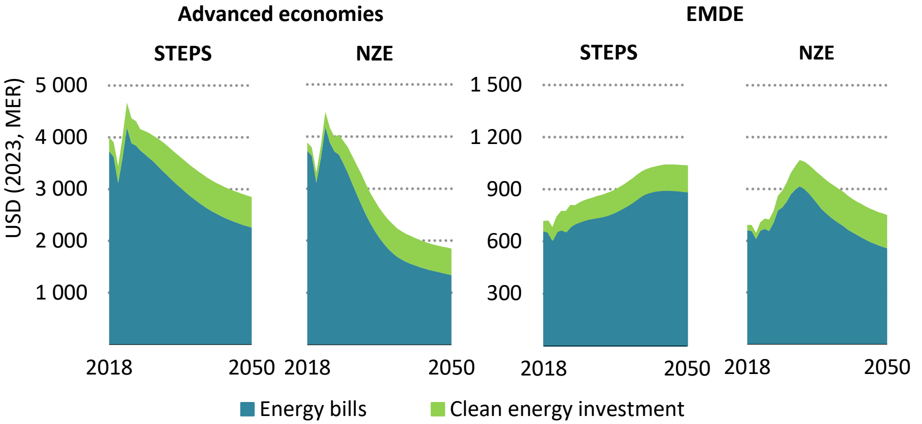
Government revenue from oil and gas production and consumption falls in the NZE Scenario; this has a larger impact on net exporting regions

2.3 Households

Energy transitions are about improving outcomes for people, so the way that they affect households is naturally central to the prospects for successful change. Today, total household expenditure on energy – including residential energy and transport fuels – averages nearly USD 4 000 per year in advanced economies and around USD 700 per year in EMDE. In the NZE Scenario, households in advanced economies start to see lower energy bills than in the STEPS, following on from a wave of investment into heat pumps, EVs and building retrofits that pay dividends relatively quickly.

In EMDE the process of change is less linear: even as energy expenditure rises partly due to increased consumption of modern energy in all scenarios, households face an initial period of higher bills in the NZE Scenario relative to the STEPS as fossil fuel subsidies are gradually removed and CO_2 pricing is introduced to encourage investment in electrification of end uses. While households face higher bills in the near term, they also witness multiple benefits of this transition in the NZE Scenario, including better air quality and increased insulation from the volatility of oil and gas prices. In parallel, there is a need to better target subsidies even as they are gradually phased out, and ensure a corresponding ramp-up in government support for clean technologies, such as grants for electric two-wheelers and cars, efficiency retrofits, and efficient air conditioning. International support can further unlock less expensive transitions that could be reflected in household energy bills in EMDE. Nonetheless, despite the rise in energy expenditure in the near term, household energy expenditure in EMDE in the NZE Scenario drops 20% below STEPS levels by 2050, and is 30% lower in advanced economies (Figure 2.17).

Figure 2.17 ▷ Average annual household energy expenditure by scenario



IEA. CC BY 4.0.

Households in EMDE face an initial period of higher bills in the NZE Scenario compared with the STEPS, largely due to subsidy phase-out, but by 2050 their expenditure is 20% lower

This section focuses on investment and energy bills from the perspective of different income groups. A final section looks at the challenge of providing universal access to modern energy from an affordability lens.

2.3.1 Investment

Many of the changes required to move to a net zero emissions system require active buy-in from households. Upgrading the energy performance of buildings and appliances, electrifying end uses where possible, and investing in rooftop solar, electric mobility and technologies such as heat pumps will not be possible without broad public support. It will also not be possible without upfront spending, which many households are not able to afford. This section defines the contours of this challenge, while Chapter 3 explores the policy solutions.

About 20% of the upfront investments made today in the energy sector are made by households, although this share is only about 5% in EMDE. In the STEPS, this share remains roughly the same in 2035, albeit with a slight increase in EMDE. However, in rapid energy transitions of the sort modelled in the APS and the NZE Scenario, the share increases to about 25% by 2035, with a particularly large increase in EMDE which reflects their lower starting point. In the NZE Scenario, households in advanced economies spend an extra USD 350 billion on clean energy equipment in 2035, more than double today's level.

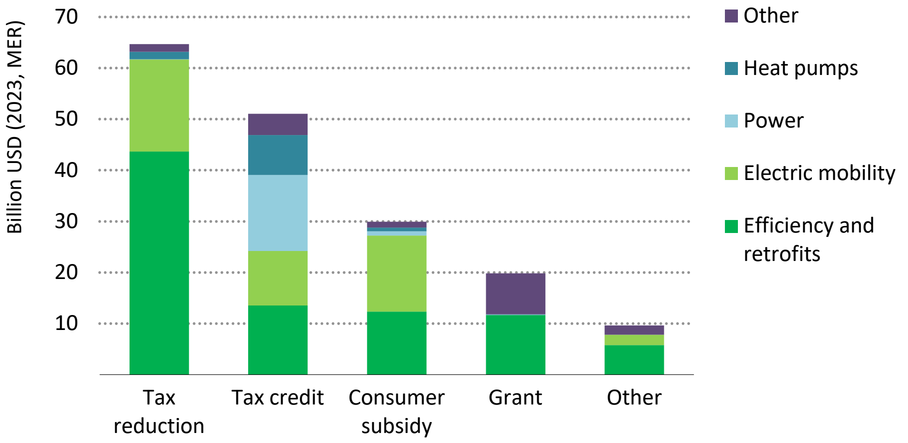
Many of the investments required in more efficient equipment or in the electrification of mobility make good economic sense because the additional upfront investment and long payback period are offset by lower energy costs over time. But the initial investment that is needed remains a major impediment, especially for poorer households. For example, the annualised cost (the investment split over the lifetime of the assets) of a heat pump, a deep home energy efficiency retrofit and an electric vehicle would amount to over 2% of the annual income of households in the top 20% of earners in the United States (20th percentile). For households in the lowest 20% income bracket, these costs would represent about 15% of annual household income. Purchasing conventional alternatives would represent less than 2% of income for the top 20% of households and 10% for the lowest 20%. In EMDE, the annualised upfront costs of a clean investment package would raise the same issues in a more acute form, and would simply be unaffordable for many in the lowest-income countries. Many households do not have the savings to pay for the upfront costs required and might not be able or willing to access alternative sources of finance.

In practice, it follows from this that – in the absence of policy interventions – the uptake of clean energy technologies by households will proceed more slowly than is needed for rapid energy transitions, and will be skewed heavily towards wealthier countries and to the wealthier segments of the population in those countries.

Some policy interventions are now taking place. Since 2020, governments in advanced economies have earmarked around USD 175 billion in financial support to households that make investments in clean energy (Figure 2.18). Spanning over 100 specific policies in

70 countries, the majority of support comes in the form of tax reductions or tax credits (65%) and grants and consumer subsidies (30%). Almost half is for measures to improve energy efficiency, with most of the remainder helping to cover electric vehicle purchases. This will help speed up progress. However, very little such support is available in EMDE. Moreover, although they are growing, the amounts of money involved are still relatively small compared with the more than USD 900 billion in near-term affordability support disbursed by governments since the onset of the global energy crisis in 2022, on top of USD 500 billion worth of fossil fuel subsidies.

Figure 2.18 ▷ Government financial support in advanced economies for household clean energy investment by policy type, 2020-2023



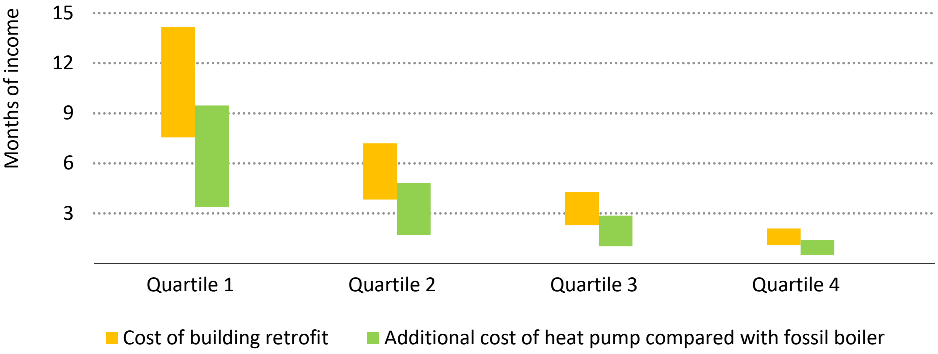
IEA. CC BY 4.0.

Governments have made nearly USD 175 billion of support available for households to undertake clean energy investment, mostly for efficiency, retrofits and electric mobility

Even when governments provide support, it is challenging to make elements such as deep efficiency retrofits and heat pumps accessible to all citizens. For example, although low-income households are more likely to have smaller houses or apartments, they are also more likely to inhabit the worst-performing buildings in terms of energy efficiency, increasing the complexity and cost of carrying out deep retrofits and heat pump installations. House ownership is another factor: lower-income households tend to rent more, and thus have limited incentives to invest in building efficiency, while landlords will typically invest only if they can be sure they can transfer the cost to rent, or if obliged to do so by regulation (as they currently are in only a few countries globally).

Against this background, an argument could be made that transition costs should be shouldered initially by wealthier households, especially since they consume proportionally more energy than others. If the highest-earning 20% of households in advanced economies were to fully adopt clean energy technologies over the period to 2035 – purchasing heat pumps and electric vehicles and undertaking efficiency retrofits – this alone would meet over 40% of the emissions reductions in residential energy consumption and passenger vehicles required in the NZE Scenario. This rapid uptake of clean energy technologies would help drive down costs to the benefit of groups further down the income bracket, who could transition at a later date.

Figure 2.19 ▻ Upfront cost premium of retrofits and heat pumps expressed as months of household income in advanced economies, 2023



IEA. CC BY 4.0.

While affordable for most households in advanced economies, building decarbonisation can cost well over a year's worth of income for the bottom 25% of income earners

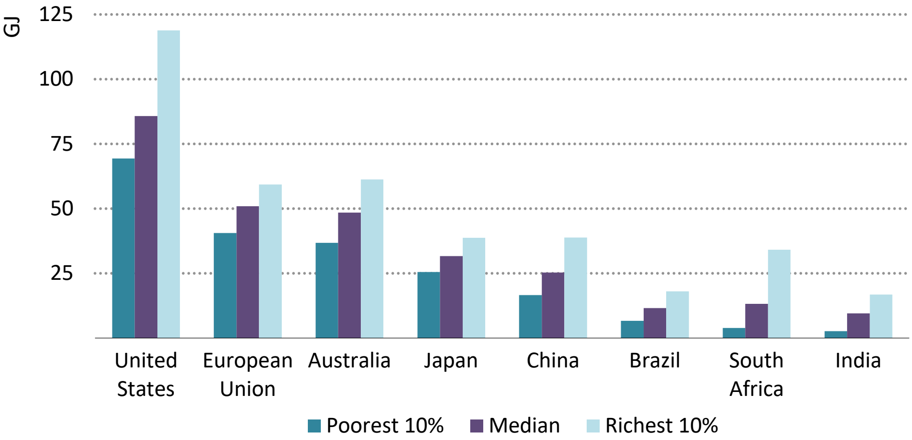
However, this sequencing is problematic in practice. It risks creating new dividing lines between those that have made the switch to cleaner energy and those that struggle with the upfront costs. And insofar as richer households receive support for their investments in solar panels, retrofits or electric vehicles, this could even imply an element of cross-subsidisation from poorer to wealthier households.

This all adds up to a strong case for targeted measures to balance the scales, a theme taken up in detail in Chapter 3. Since 2020, 12 advanced economies have put in place means-tested grant schemes for retrofits and heat pumps to provide targeted support to low-income households. While some of these schemes are well established, most were introduced in response to the 2022 global energy crisis and are therefore relatively new. Subsidy schemes require several years to develop to the point where there is significant uptake, and typically five to ten years are needed before a long-lasting, structural change in the renovation market can be secured. Ensuring the stability and longevity of these new initiatives will be a key test for an inclusive energy transition.

2.3.2 Residential energy bills

There is no universally accepted definition or indicator of household energy affordability. Conceptually, it is closely related to energy poverty, which has also been a difficult concept to define and measure (see Spotlight below). Various criteria have been explored, from the cost of energy as a share of disposable income to survey-based assessments of the share of households which are able to keep their homes adequately warm. Such indicators are unlikely to capture all the nuances of energy affordability and fuel poverty, but if used consistently they can help to determine the relative magnitude of the problem and the required scale of targeted energy affordability measures. We have conducted an extensive analysis of national survey data to derive estimates of residential energy consumption and energy bills by income deciles. As this indicator is sensitive to changes in fuel prices, seasonal energy usage and income levels, we have used averages over the past five years for our analysis. The disparities between the richest 10% and the poorest 10% are significant in all countries examined, but are largest in EMDE (Figure 2.20).

Figure 2.20 ▻ Residential energy consumption per household, 2023



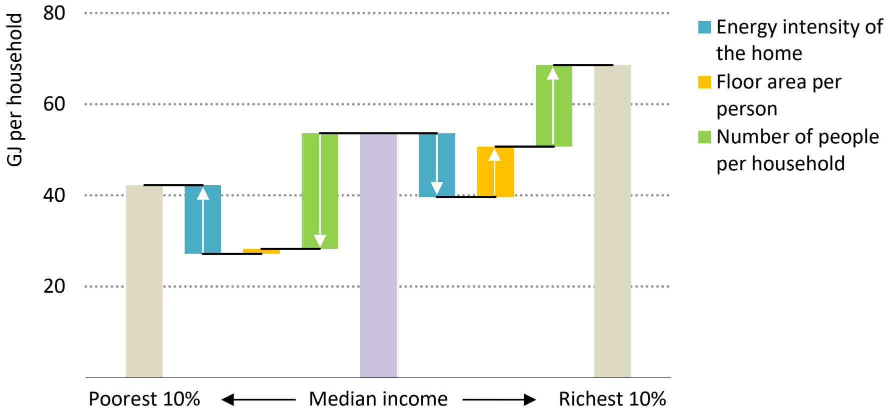
IEA. CC BY 4.0.

On average, the poorest 10% of households consume around half as much energy as the richest 10%. The disparities are wider in emerging market and developing economies

Note: GJ = gigajoules. Poorest 10% and richest 10% refer respectively to the residential energy consumption per household in the 10th and 90th percentiles.

In advanced economies, more than two-thirds of household energy use is for water heating and space heating and cooling, with the remainder used for cooking, lighting and appliances. The cost of thermal comfort therefore accounts for the majority of household energy bills, and this cost is linked to two key factors. The first is size. In the United States, for example, dwellings are on average twice as large for the richest 10% of households as they are for the poorest 10%. The second is the level of insulation. Buildings tend to be relatively poorly insulated in low-income areas; owner-occupiers and landlords are less likely to invest in upgrading their properties.

Figure 2.21 ▷ Key drivers influencing residential energy consumption disparities across income groups in advanced economies, 2023



IEA. CC BY 4.0.

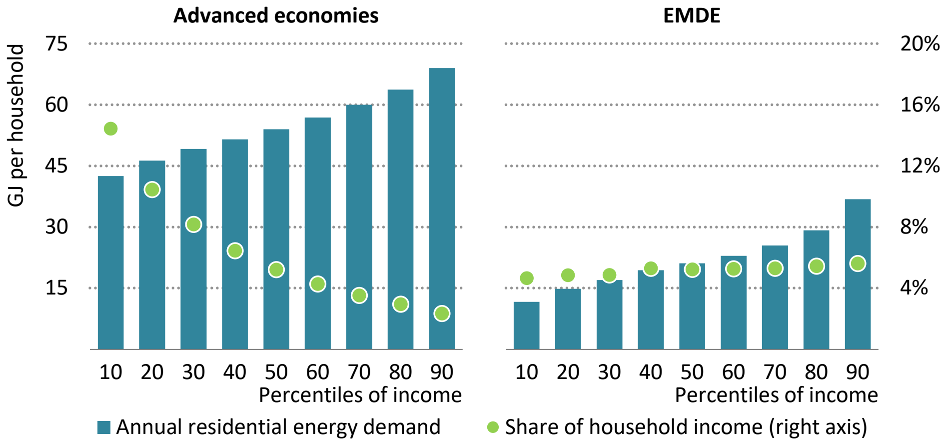
Richer households tend to have more efficient homes than poorer ones, but they are larger and have more inhabitants, driving up overall energy consumption

Note: The energy intensity of a home is calculated as the total energy consumed by the building over the course of one year, divided by the floor area of the building. Poorest 10% and richest 10% refer respectively to the residential energy consumption per household in the 10th and 90th percentiles.

There are also effects related to the composition of households: in most advanced economies, poorer households contain on average fewer people (the opposite is generally the case in EMDE). The net effect is that the poorest 10% of households in advanced economies use around 40% less energy in their homes than the richest 10% of households, with household composition being the largest driver explaining the difference between them (Figure 2.21).

Despite a higher number of people per dwelling, residential energy demand in EMDE households is significantly lower than in advanced economies, with the richest 10% of households in EMDE using about the same amount of energy as the poorest 10% in advanced economies. This reflects major income-driven differences in appliance ownership, size of living space, lifestyle and cultural factors, and levels of comfort. In EMDE, there is also a much greater gap in energy consumption between the poorest 10% and the richest 10% than in advanced economies. Although lower-income households consume less energy than better-off households in advanced economies, they spend a larger share of their disposable income on it. We estimate that around 20% of households in advanced economies spend more than 10% of their income on energy bills (Figure 2.22).

Figure 2.22 ▹ Annual residential modern energy consumption by income bracket and spending as a share of households income, 2019-23

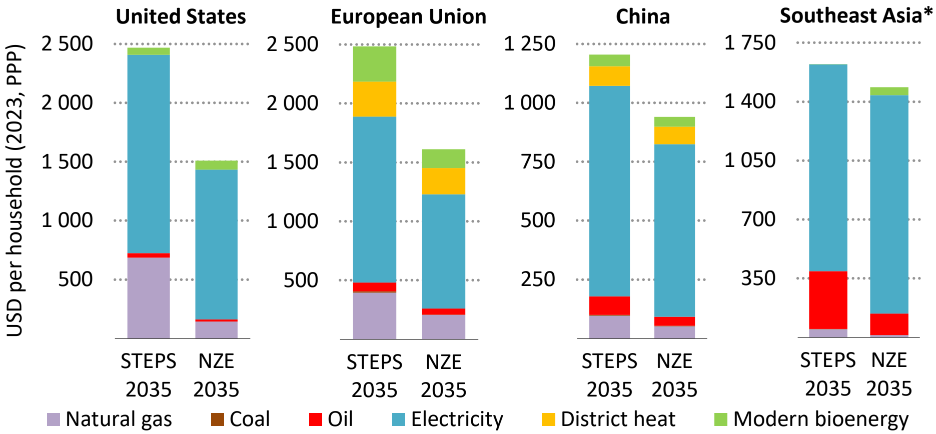


In advanced economies, the poorest 20% of households spend over 10% of their income on their residential energy needs. In EMDE, lack of access and equipment among poor households leads to lower spending

Notes: Modern energy excludes the traditional use of biomass. Income refers to household disposable income. Household disposable income deciles represent the weighted average of the deciles of each country grouping assessed. This analysis considers government subsidies that directly affect the energy prices paid by consumers such as energy price caps. It does not include direct payments to households such as energy assistance checks, which have accounted for a significant portion of disposable income for low-income households in certain countries in recent years.

The picture in EMDE is, however, different in some important respects. First, the share of disposable income spent on energy by the bottom 50% of income earners in EMDE is lower than in advanced economies. Second, the share of income spent on energy in EMDE is largely flat across all income deciles. End-user prices for modern energy in the residential sector are approximately 50% lower in EMDE than in advanced economies, and most EMDE have temperate climates that do not require space heating, while ownership rates of air-conditioning units to keep cool are currently very low. But the key point here is that almost 40% of energy demand in the residential sector in EMDE is met through traditional use of biomass, which typically carries no monetary costs (even though it has significant implications for labour – especially women – and significant negative health impacts). In EMDE, 750 million people still lack access to electricity, while more than 2 billion people lack access to clean cooking solutions. This means that a very large number of households without access in the lower income deciles do not spend any of their income on energy, while others with access may be spending a relatively high share of their income on it.

Figure 2.23 ▹ **Median residential energy bills by fuel in the STEPS and the NZE Scenario across selected regions, 2035**



An inclusive and equitable energy transition has the potential to significantly reduce household home energy expenses

* Excludes Indonesia.

An inclusive and equitable energy transition has the potential to significantly reduce ongoing household home energy expenses (Figure 2.23). In the NZE Scenario, households in the European Union see a reduction of almost 35% in home energy bills in 2035 compared with the STEPS, thanks to investments in improved insulation, more efficient heating and cooling systems, and lower wholesale fuel costs as a result of lower demand. This trend holds true across regions. For example, households in China and Southeast Asia see reductions of 20% and 10% respectively in their residential energy bills in the NZE Scenario in 2035 compared with the STEPS. Realising these gains, especially for low-income households, will, however, require support for the investment needed for efficiency improvements and low-emissions heating systems.

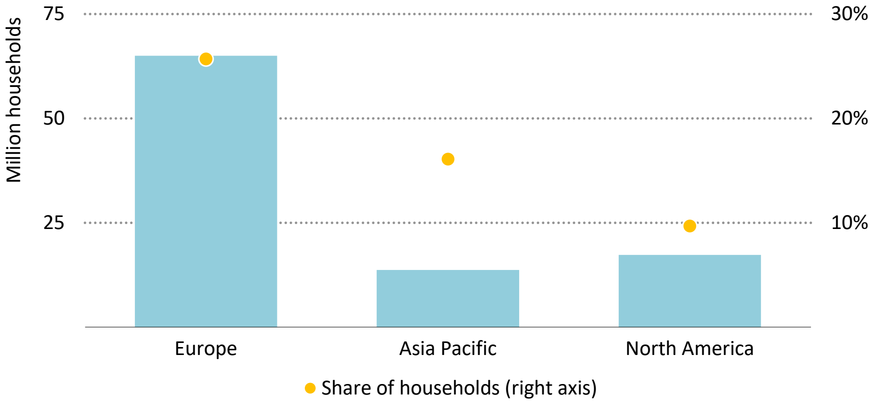
SPOTLIGHT

Understanding energy poverty

Energy poverty refers to cases where households experience inadequate levels of essential energy services in the home, such as heating, cooling, lighting or cooking. This is a multifaceted problem with no single definition or framework. Its effects go well beyond energy services and can include poor health and socio-economic deprivation. Energy poverty is distinct from the concept of energy access, which refers to populations who experience a lack of reliable access to modern energy services due to their lack of connection to the grid or off-grid electricity sources.

Energy poverty is difficult to measure, requiring consideration of a range of household and external factors, such as income, household composition, building efficiency, and the type and quality of energy supplied. In advanced economies, a range of indicators have been used, which are usually self-reported and/or expenditure based. Self-reported metrics are collected in surveys; they record a household's perceived indoor thermal comfort and housing conditions and the degree of difficulty it faces in paying utility bills. Expenditure-based metrics look at energy costs and household income; some advanced economies classify households as energy poor if they spend more than 10% of their income on residential energy. If applied across all advanced economies, a 10% threshold would capture around 100 million households, or around 20% of the total (Figure 2.24). However, this metric does not capture cases where households deny themselves energy services due to affordability concerns, and may therefore underestimate the number of energy-poor households.

Figure 2.24 ⊳ **Number and share of households in advanced economies that spend above 10% of their income on residential energy bills, 2019-23**



IEA. CC BY 4.0.

Around 20% of households in advanced economies spend more than 10% of their income on energy, a common – but incomplete – indicator of energy poverty

Note: Income refers to household disposable income.

Because of such complexities, some studies and organisations call for the use of multidimensional frameworks for measuring energy poverty, combining expenditure-based and self-reported measures. For example, the European Commission recommends the use of 13 indicators to capture three main dimensions of energy poverty: low income, high share of energy in spending and low energy efficiency. The Multidimensional Energy Poverty Index, which is more applicable to EMDE, takes a similarly broad approach: it focuses on the deprivation of access to modern energy services, and aims to capture both the incidence and intensity of energy poverty.

Energy poverty is a pervasive issue across the world, though its dimensions vary from one region to another, with implications for how it is defined. In Europe, for example, energy poverty measurement has focused on keeping homes warm, while data on cooling poverty or "summer energy poverty" have remained scarce. Another area of interest is transport poverty, which considers vehicle ownership in different income groups and the accessibility and convenience of different modes of public and private transport. A further area of interest is the energy poverty gap, which is concerned with the fact that some households are more energy poor than others. Energy vulnerability is a related concept which is concerned with the risk of becoming energy poor.

Tackling energy poverty has many benefits. In addition to improving the indoor comfort and personal well-being of households, it can lead to reduced government spending on health, higher levels of educational attainment, economic development, and a reduction in carbon emissions through energy efficiency improvements. Understanding and measuring energy poverty is essential for programmes targeting those most vulnerable.

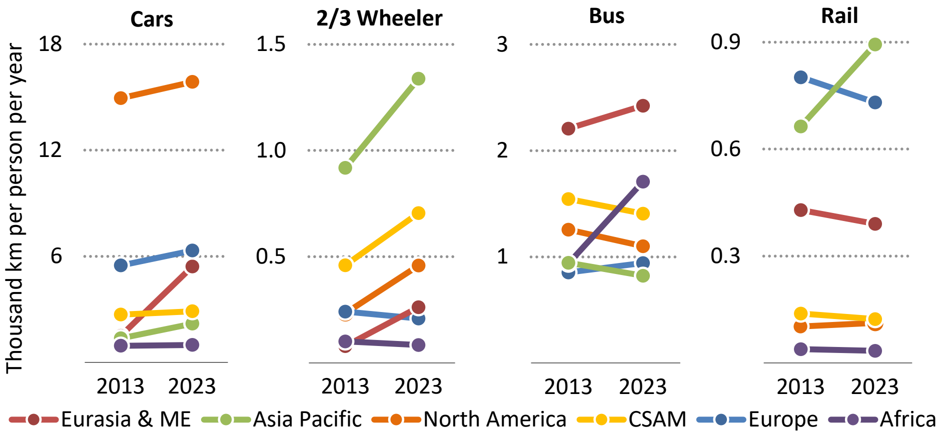
2.3.3 Transport costs

There are major disparities in transport use across regions which reflect infrastructure, policy choices and income levels. Passenger light-duty vehicles (PLDVs) have the highest passenger kilometre demand (pkm) globally;[2] their level of use in North America (16 000 km per person in 2023) is, however, more than quadruple that in other parts of the world. Car ownership per capita is more than five times lower in EMDE than in advanced economies and this is a large reason for the major difference between PLDV use in advanced economies (9 600 km per capita in person) and EMDE (2 000 km per person) (Figure 2.25). Countries in Asia Pacific lead the use of two- and three-wheelers, which have seen very rapid growth over the last ten years; bus transport is particularly important in Eurasia. The use of railways is correlated with the availability of rail infrastructure: high in Europe, Eurasia, China and India, and much lower in North America, the Middle East and Africa. The relationship between density of population and mass transit infrastructure is bidirectional: densification of populations can justify investment in transport infrastructure, and access to high-quality transport infrastructure can in turn establish conditions for further densification in a virtuous cycle of development.

---

[2] Passenger kilometre demand represents the total number of kilometres a typical person travels in a year in PLDVs, bus, rail, and two- and three-wheelers.

Figure 2.25 ▷ Passenger kilometres per capita by transport mode across regions, 2013-2023

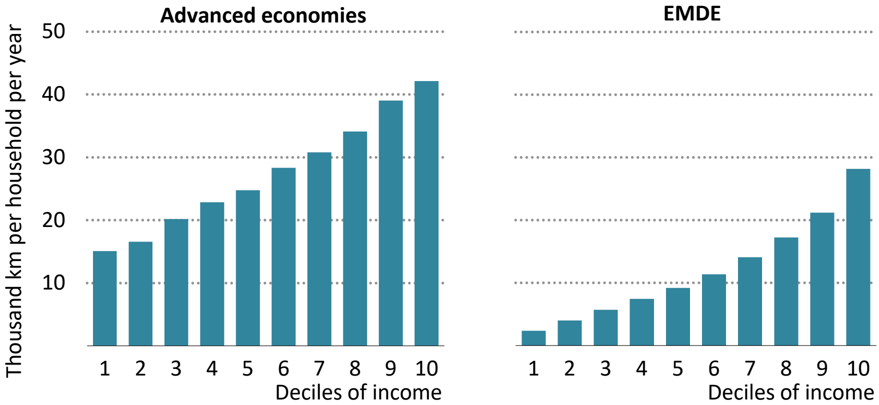


IEA. CC BY 4.0.

North America has the highest PLDV per capita demand whereas two-/three-wheelers are much more popular in Asia Pacific, and bus transport in Eurasia, the Middle East and Africa

Note: ME = Middle East; CSAM = Central and South America.

Figure 2.26 ▷ Distance travelled per household per year via road private motorised transport by income decile in 2023



IEA. CC BY 4.0.

Households in advanced economies in the lowest decile travel more than the 70% of households in the lowest income deciles in EMDE via private motorised transport

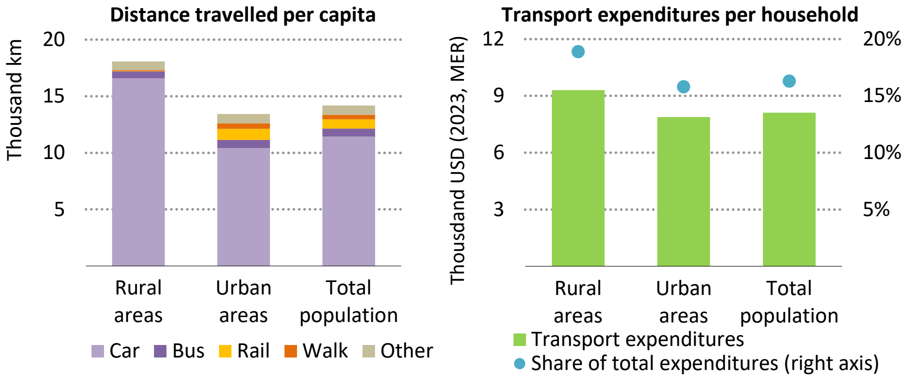
Note: Income refers to household disposable income. For each household disposable income decile, the reported value is the median. Therefore, 1 corresponds to the 5th percentile, 2 to the 15th percentile, and so on. Household disposable income deciles represent the weighted average of the deciles of each country grouping assessed.

These variations in transport activity produce highly unequal patterns in transport fuel use across countries and income brackets and between urban and rural areas (Box 2.2). Road private motorised passenger kilometres are significantly higher in advanced economies and in higher income deciles (Figure 2.26). Differences are particularly stark between income deciles in EMDE, with those in the lowest decile travelling 92% less than their highest decile counterparts.

Box 2.2 ▻ Urban versus rural transport inequalities in advanced economies

While income significantly influences household spending on transport, location also plays a pivotal role, with rural households in advanced economies allocating around 20% more of their budget to transport compared with households in urban areas. Overall, rural households in advanced economies spend 20% of their total annual expenditures on transport compared with 15% for urban households (Figure 2.27).

Figure 2.27 ▻ **Annual distance travelled per rural and urban households and associated expenditures in advanced economies**



IEA. CC BY 4.0.

In advanced economies, rural households travel 35% more kilometres than their urban counterparts, resulting in additional expenditure of USD 1 400 per year

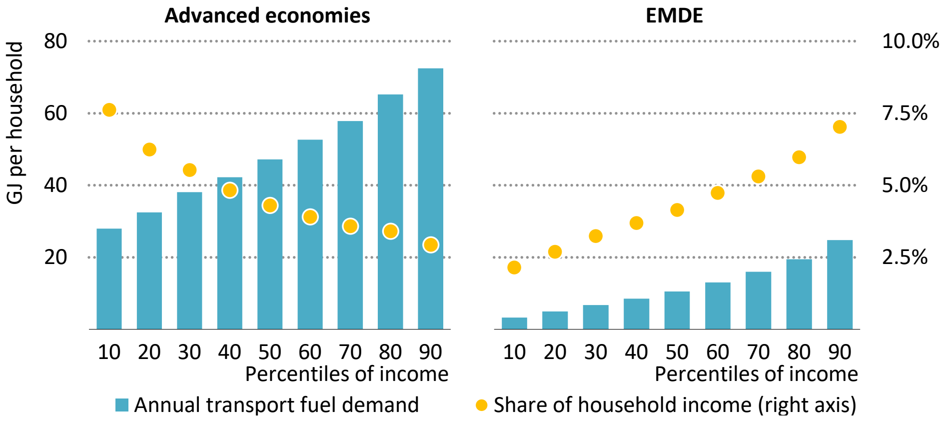
Notes: Per capita travel distances are determined using data from 2017 and 2021, varying by region. Expenditure data pertains to the year 2022.

Sources: IEA analysis based on Department for Environment Food & Rural Affairs (2024), Miotti (2023), Department for Transport (2022) and US Department of Transportation (2022).

This disparity stems from two factors. First, residents in rural areas must travel longer distances to reach local and regional services. In the European Union, for instance, the average distance per person to the nearest local facilities such as schools, small health care facilities, childcare services and small markets is four times higher in rural areas than in urban areas (8 kilometres [km] versus 2 km) (Kompil et al., 2019). The discrepancy widens further for regional facilities — including specialised centres, large cultural venues and governmental organisations — with European urban dwellers travelling an average of 12 km compared with 48 km for their rural counterparts (Kompil et al., 2019). Overall, rural residents in advanced economies travel 35% farther in a year than their urban counterparts.

Another defining aspect of the rural-urban gap is accessible public transport. Given the limited availability of public transport, households in rural areas are more likely to own a car than their urban counterparts, even when their income is low. For instance, in the United Kingdom in 2021, 25% of urban households had no car, compared with 10% of rural households (Department for Transport, 2022).

Figure 2.28 ▷ Annual private transport fuel demand by income bracket and spending as a share of household income, 2019-23



IEA. CC BY 4.0.

Fuel consumption for private transport is unequal across income brackets. In advanced economies, the poorest 10% of households allocate 7.5% of their income to it

Note: Income refers to household disposable income. Household disposable income deciles represent the weighted average of the deciles of each country grouping assessed. This analysis considers government subsidies that directly affect the energy prices paid by consumers such as energy price caps. It does not include direct payments to households such as energy assistance checks, which have accounted for a significant portion of disposable income for low-income households in certain countries in recent years.

In advanced economies, households in the highest income decile consume nearly three times more transport vehicle fuel than households in the lowest income decile (Figure 2.28). The gap is still wider in EMDE, where high-income households consume almost 8 times more energy for private transport than their low-income counterparts. This high level of transport fuel demand inequality in EMDE can be attributed to several factors. Lower-income households typically have fewer vehicles than others, or may not own a vehicle at all, and those that do possess vehicles often rely on two-wheelers rather than cars, which consume less fuel and are generally used for shorter distances.

Even though low-income households in advanced economies consume less fuel for transport than their higher-income counterparts, their spending on these fuels constitutes a much larger portion of their income. Households in the highest income decile spend less than 3% of their income on transport fuels, but the corresponding figure for those in the lowest income decile is 7.5%. Low-income households often live in places that are not well connected by public transit to employment hubs. This makes it difficult for them to avoid having to own and use a private vehicle, especially since low-income jobs typically require physical presence at the worksite.

EVs are currently mostly owned by the wealthiest households. Addressing the upfront cost barrier for low-income households to access electric mobility is a critical policy imperative to ensure an equitable and resilient transition. Action on this front would promote fairness in the transition process and alleviate some of the financial burden on low-income families in terms of transport energy expenditure.

In the NZE Scenario, increasing use of clean energy technologies is combined with policies to provide equitable access to these technologies for low-income households and with enhanced public transport services. As a result, households in the lowest income decile in advanced economies are projected to spend less than 3.5% of their income on transport fuels in 2035. In the STEPS, these households still dedicate 6.5% of their annual income to transport fuels.

Public transport plays a significant role in the transition to sustainable mobility, and the NZE Scenario sees rapid growth in bus and rail transport in both advanced economies and EMDE. This helps to alleviate the transport cost burden on low-income households.

The second-hand market for electric vehicles

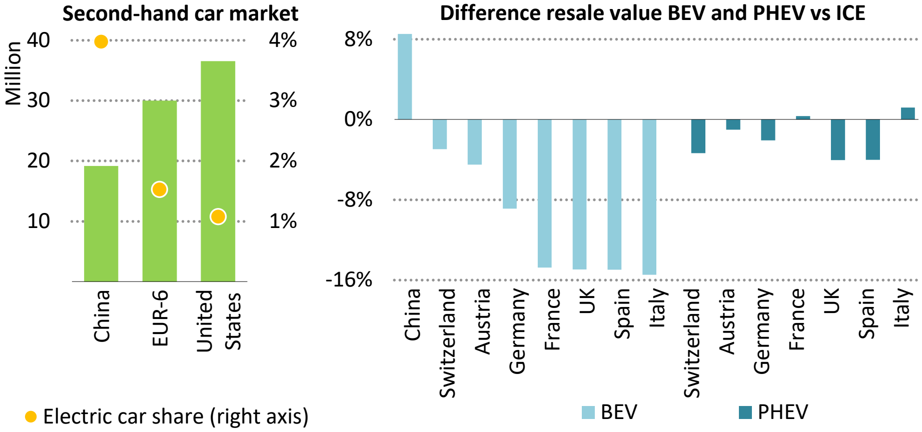
The development of second-hand markets has been critical for the affordability and mass-adoption of conventional internal combustion engine (ICE) vehicles, and it will be the same for EVs. Currently, eight out of ten EU citizens purchase their car second-hand (Transport and Environment, 2023), and this rises to nine out of ten among low- and middle-income groups. The same is true in the United States, where seven out of ten vehicles sold are second-hand and only 17% of lower-income households purchase a new car. This underlines the point that second-hand markets for EVs are essential to significantly increase the accessibility of EVs to the wider population, particularly as new EVs remain relatively expensive in most markets.

With the rapid deployment of EVs, a growing number of used electric cars are becoming available for resale. Total second-hand electric car sales were approximately equal to new electric car sales in the United States in 2023. Annual second-hand electric cars sales are estimated at nearly 800 000 in China, 400 000 in the United States and 450 000 for France, Germany, Italy, Spain, the Netherlands and the United Kingdom combined (Figure 2.29). These numbers are still small compared with the conventional ICE market, but are growing:

electric cars already account for 4% of the total second-hand car sales in China, 1% in the United States, and around 2% in the grouping of France, Germany, Italy, Spain, the Netherlands and the United Kingdom.

For buyers of second-hand cars, affordable second-hand EVs are proving to be an attractive option, able to compete with used ICE equivalents. In the United States, over half of second-hand electric cars are already priced below USD 30 000, and at USD 25 000, they become eligible for the federal used car rebate of USD 4 000, making them competitive with best-selling new and used ICE options. The price of a second-hand Tesla in the United States dropped from over USD 50 000 in early 2023 to just above USD 33 000 in early 2024, making it competitive with a second-hand ICE sport utility vehicle (SUV) and many new models as well. In Europe, second-hand battery-electric cars are available for between USD 16 000 and USD 27 000, and second-hand plug-in hybrids for around USD 32 000. Several European countries also offer subsidies for second-hand electric cars: in the Netherlands, for example, the subsidy for new electric cars has been steadily declining since 2020, while that for used electric cars remains constant at EUR 2 000, and a similar subsidy of EUR 1 000 is available in France. In China, used electric cars are significantly cheaper than in other major markets: they cost around USD 11 000 on average in 2023.

Figure 2.29 ⊳ Second-hand electric car market size and difference between resale value of BEVs and PHEVs compared to ICEs, 2023



IEA. CC BY 4.0.

Second-hand electric cars have considerably greater discounts on offer than ICE equivalents in Europe

Notes: BEV = battery electric vehicle; PHEV = plugin hybrid electric vehicle. EUR-6 includes France, Germany, Italy, Spain, the Netherlands and the United Kingdom.

The likely price of EVs in the second-hand market is clearly an important consideration for potential buyers of new EVs. A significant reduction in the resale value implies a significant loss in original value, which is bad news for new buyers, although it greatly increases the accessibility and affordability of vehicles in second-hand markets. In all regions except China, the resale value of battery electric vehicles is currently up to 16% lower than it is for ICEs. The difference is much smaller for plug-in hybrids – just a few percent in most countries considered. However, the resale value of battery electric cars has steadily increased since 2017 in Europe and China as a result of improving battery technology and increasing demand for second-hand electric cars. Over time, the advantage that ICEs enjoy in the second-hand market is likely to reduce, and EVs may well come to have greater retained value than ICEs, as is already the case in China.

2.3.4 Energy access

Worldwide today, 750 million people lack access to electricity and more than 2 billion do not have access to clean cooking solutions. Eighty percent of those without access to electricity and around half of those without clean cooking solutions live in Africa, and most of the rest in developing Asia. In sub-Saharan Africa, roughly one-third of the population lives in extreme poverty, and most of the households without access to modern energy fall within this group (World Bank, 2023). Both upfront and recurring costs for energy services can prove prohibitively expensive for these groups.

In the case of electricity access,[3] households may need to pay grid or mini-grid connection charges or purchase a standalone system such as an SHS, wire their house, and purchase appliances to use this electricity. Although prices vary by country, an SHS – often the option with the highest upfront cost – can cost the equivalent of up to 18 months of the income of a household in extreme poverty (Figure 2.30). Since these costs are prohibitive, targeted policies and business models have emerged which spread them over time. Pay-as-you-go (PayGo) models, based on a rent-to-own or leasing agreement, have become widespread, bringing upfront costs down and increasing adoption. However, even with a PayGo model in place, poorer households often still need additional support to gain access to a fuller range of energy services. Some utilities and regulators provide micro-financing solutions or subsidise the cost of connecting households to the main grids – as in Cote d'Ivoire, Ghana, Kenya, Mozambique and Rwanda – and recover the cost over a longer period.

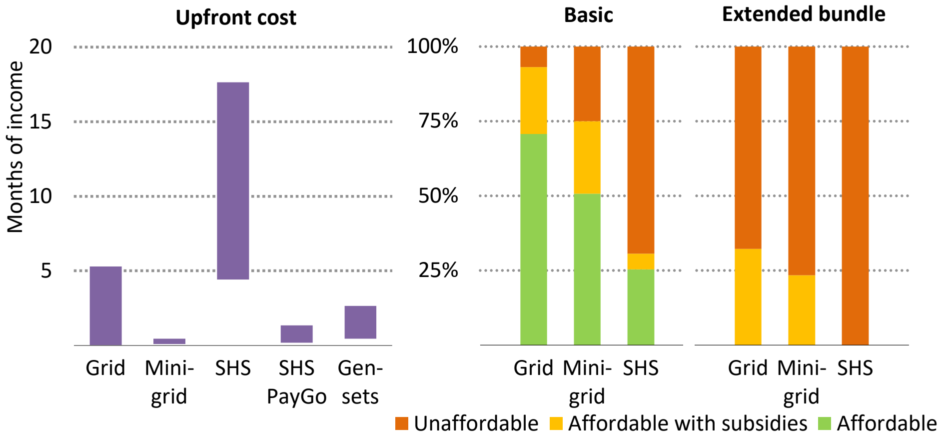
Upfront costs are not the only issue. Even after that challenge has been overcome, paying for electricity services can take an unsustainable share of household income. Based on subsidy regimes currently in place across sub-Saharan Africa, grid-based electricity is the most affordable for many households, thanks to the use of low social tariffs in many

---

[3] The IEA defines access as a household benefiting from an active connection to the grid or to off-grid electricity sources large enough to provide a defined minimum level of energy services and able to increase over time. This minimum is the basic bundle referring to a range of consumption around 50-75 kilowatt-hours (kWh) per household per year or 10 watt-peak (Wp) in case of solar home systems (SHS). The IEA also defines the essential bundle – corresponding to roughly 500 kWh per household per year or 50 Wp and above for SHS, and the extended bundle for a consumption of 1 250 kWh per household per year or a SHS more than 100 Wp.

countries. A basic bundle of services can be afforded by 70% of households without access today, but a package of essential or extended services is generally not affordable. Even households that do currently have access to electricity often consume only a low level of electricity and are unable to afford an expansion of services. Although the targets under Sustainable Development Goal 7 do not stipulate the level of access to be universally available by 2030, larger systems will be necessary to support socio-economic development, and that implies an expansion of grid services.

Figure 2.30 ▻ Electricity access costs and affordability in sub-Saharan Africa



IEA. CC BY 4.0.

Upfront costs and ongoing electricity costs often prove prohibitive for households without subsidy support, particularly for larger systems

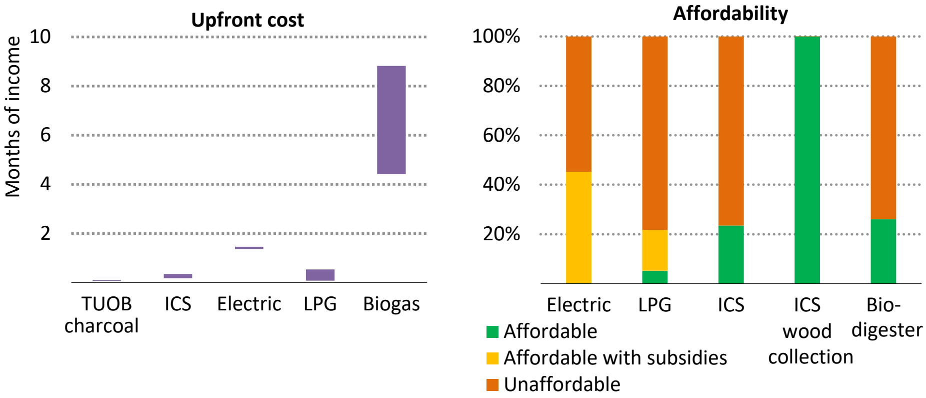
Notes: Analysis is based on existing subsidy regimes. A solution is considered affordable if it accounts for less than 5% of household income. The basic bundle refers to a range of consumption around 50-75 kWh per household per year or 10 Wp in case of SHS. The extended bundle refers to a range for a consumption of 1 250 kWh per household per year or a SHS more than 100 Wp.

Sources: IEA (2022; 2023b).

Clean cooking solutions present a similar mix of challenges related to upfront costs associated with the purchase of a new device and ongoing costs for fuel. Based on current technology, the costs of clean cooking solutions range from an average of one-third of monthly income (improved charcoal cooking stoves) to six times monthly income (biogas and digesters) for a low-income household in sub-Saharan Africa (Figure 2.31). PayGo models – especially for LPG-based cooking – have been used to support households to manage these costs, particularly in East Africa where these models are widely deployed for electricity access, so the technology ecosystem is well developed. However, while financing initiatives have emphasised the provision of free or reduced-price stoves, the need to provide training on utilising new stoves has emerged as an important issue, with many programmes reporting that this should be regarded as a necessary element of cookstove roll-outs.

Modern cookstoves could pay back their upfront costs over their lifetime in many urban contexts through improved energy efficiency or reduced fuel purchasing costs, but the switch to paid fuels means increased costs for vulnerable households in rural areas that gather solid bioenergy fuels. When factoring in the opportunity cost associated with the saved time, modern energy cooking options are a better option than traditional biomass. However, access to clean cooking solutions does not directly translate into better household income, meaning there is often still a need for external subsidies or other interventions that support job creation. Given that fuel price volatility also poses a major risk, governments in some countries opt to subsidise clean cooking fuels, particularly LPG, although these subsidies do not always support the most vulnerable households and can lead to increased burdens on public finances. For the poorest households, transitional solutions based on improved biomass cookstoves will be key to address the affordability issue as they do not require a change in fuel use and their upfront costs are relatively low.

Figure 2.31 ▷ Clean cooking costs and affordability in sub-Saharan Africa



IEA. CC BY 4.0.

Most clean cooking options except for improved cookstoves are unaffordable with or without subsidies for the majority of the households

Notes: TUOB = traditional use of biomass; ICS = improved cookstove. Analysis is based on existing subsidy regimes. A solution is considered affordable if it accounts for less than 5% of household income.

Source: IEA (2022; 2023b).

Even with current incentives for devices and fuels, clean cooking solutions still represent a significant outlay for many households. For example, more than half of households yet to gain access in sub-Saharan Africa are likely to spend more than 5% of their income on clean cooking solutions, even once incentives are included. Bringing down the cost for clean cooking fuels to levels consistent with 5% of income for all households gaining access would require USD 40 billion to USD 55 billion per year of additional incentives (IEA, 2023a). While some of this can be managed through cross-subsidisation between low-income and high-income consumers, it is also likely to require a significant outlay in terms of direct consumer support, including from grant capital provided by donors. Carbon markets also represent an important opportunity for reducing the costs of clean cooking stoves for end users. However, concerns about their credibility have slowed the development of these markets, and further efforts are needed to strengthen methodologies so as to improve both the quality of the credits and the confidence of buyers.

Affordability poses a major challenge not just for households but also for those who provide finance for energy access projects. Few private sector companies have been able to achieve profitability in access projects outside urban and peri-urban areas, with limits on what end users can afford and relatively low levels of demand acting as breaks on revenue. In order to achieve universal energy access by 2030, investment of USD 38 billion is needed each year – USD 32 billion for electricity access and USD 6 billion for clean cooking. This would represent a rapid and dramatic increase from historic levels. Funding from multiple sources will be necessary, with concessional finance providers making grants available for the most vulnerable households and for the creation of bankable projects, as well as providing other de-risking capital to allow the private sector to take a more active role.

Financing vehicles for both electricity and clean cooking already exist, including blended finance funds, but many of these vehicles are held back by the lack of investable opportunities. Policy makers can help drive the creation of bankable opportunities by developing detailed access plans which are integrated with wider energy and industry planning to support demand stimulation and economic growth, and by putting in place clear policies and regulations which include targeted incentives. Concessional finance providers can utilise grants and equity capital in parallel to help companies with early-stage financing. Even with these steps in place, public finance from governments and development agencies will need to play a significant role in ensuring that access is affordable for the most vulnerable households.

2.4 Private companies

Private companies account for about 46% of total energy investment. They range from large energy companies that operate in fossil fuel and clean energy markets through to companies in energy-intensive industries such as cement or steel and to small and medium-sized enterprises (SME) in different sectors of the economy.

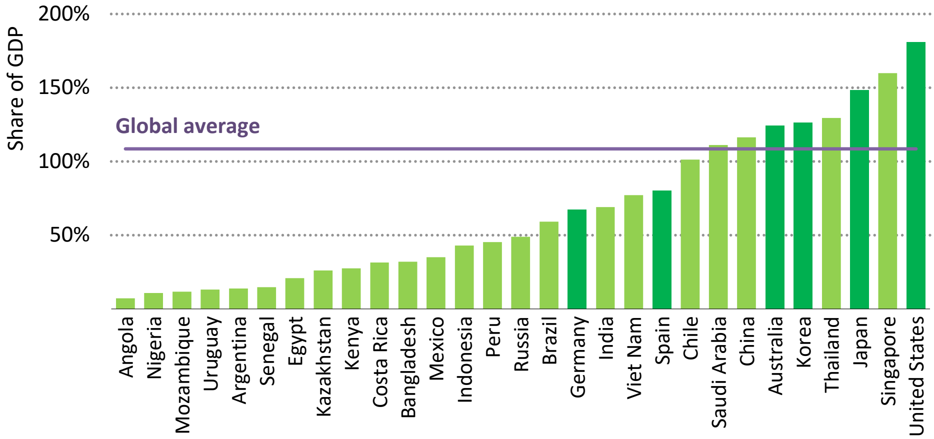
These companies have widely different abilities to invest and to raise capital. For example, oil and gas companies may have robust balance sheets and can tap into international capital markets to raise large amounts of debt or equity at attractive rates. Large utilities or energy-intensive firms may also have such access and abilities, especially in advanced economies. Heavy industry can be exposed to cyclical trends and downward pricing in periods of overcapacity, making it harder to raise financing for capital investments. SME are generally more capital constrained, and their equity structure and debt profiles influence their ability to raise capital, particularly in EMDE.

Table 2.1 ⊳ Characteristics of private companies by type

	Energy producers		Energy consumers	
	Oil and gas	**Utilities and clean energy companies**	**Energy-intensive industries**	**SMEs**
Average company size	Large	Medium to large	Large	Small to medium
Access to capital markets	Mostly yes (in advanced economies or major EMDE) Mostly no (in most EMDE)			Mostly no

Reaching net zero goals includes replacing old technologies with new low-emissions industrial processes, necessitating major capital investment. Without a suitably high global carbon price or policies that prevent carbon leakage, companies will find it challenging to justify investments in low-emissions processes, particularly for bulk materials such as steel, aluminium and chemicals where extensive international trading creates pressure on margins.

Figure 2.32 ⊳ Financial system development indicator for selected countries, as share of GDP, 2017-2022



Most emerging market and developing economies have capital markets and banking sectors that are less well developed than the global average

Notes: Financial system development indicator shows the average of the share of private credit to GDP and the share of stock market capitalisation to GDP over the most recent five years. Global average is weighted by GDP. Dark green = advanced economies; light green = emerging market and developing economies

Source: IEA analysis based on IMF (2023) and World Bank (2024c)

Geography also influences the ability of companies to raise capital. In EMDE, capital markets tend to be underdeveloped (Figure 2.32) and not particularly liquid. The availability of domestic credit – measured as a share of GDP – is lower than in advanced economies, and risk profiles tend to be higher. High demand for capital with limited supply may also push up financing costs or lead to only the least risky projects receiving the necessary capital. Local banks sometimes also lack the ability to undertake risk analysis, especially in connection with new technologies required in the clean energy transition.

2.4.1 Oil and gas companies

Oil and gas companies face some stark choices and pressures in net zero transitions. From 2018 to 2022, annual oil and gas industry revenue averaged close to USD 3.5 trillion. This falls sharply in rapid energy transitions, and revenues could fluctuate significantly from year to year as they decline, making oil and gas a riskier business. Faced with the possibility of a shrinking market as the world transitions away from fossil fuels, some companies may choose to diversify into clean energy and develop alternative sources of revenue. Others may decide to remain focused on their core business, even as demand falls over time.

There is no single blueprint for change. However, one objective that can and should be in all company transition strategies is to reduce emissions from the oil and gas industry's own operations, which resulted around 5.1 gigatonnes of carbon dioxide equivalent emissions in 2022. These emissions are cut by more than 60% by 2030 in the NZE Scenario by tackling methane leaks, reducing flaring, electrifying facilities, using low-emissions hydrogen and equipping facilities with CCUS. For facilities implementing this entire suite of measures, the average cost of producing oil and gas would increase by less than USD 2 barrels of oil equivalent.

Several low-emissions fuels and technologies could benefit from the skills and resources of the oil and gas industry. Technologies such as hydrogen and hydrogen-based fuels, CCUS, bioenergy, and geothermal could make use of the industry's technical and operational knowledge in handling liquids and gases, subsurface conditions, and executing and managing multibillion-dollar projects. If oil and gas companies choose not to be involved in the deployment of these technologies, this does not mean that they will not be successfully deployed, but it may take much longer for them to reach the level of maturity where they can be supplied cost-competitively, and it may also significantly increase the overall cost of transitions.

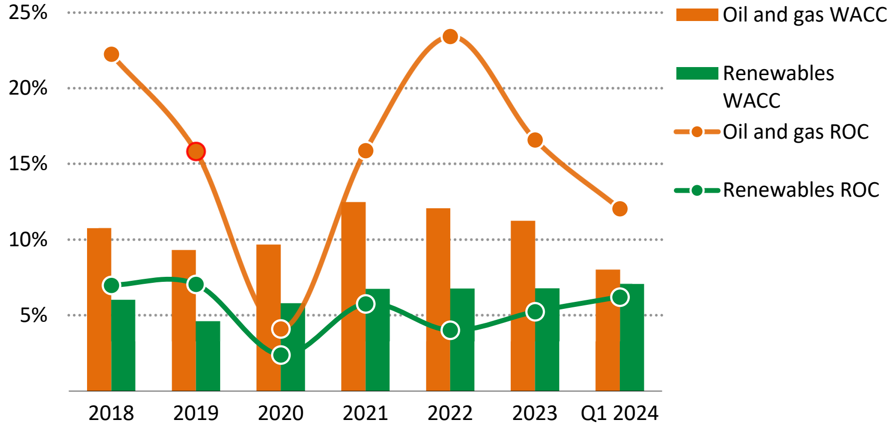
2.4.2 Power utilities, generation companies and manufacturers

Private power utilities are generally medium to large companies, but their business varies by country; some are vertically integrated and cover generation, transmission and distribution, while others only operate in some segments. Their geographical reach can also vary; some companies operate in just one country, while others such as Iberdrola or Enel invest across the world.

These companies operate in sectors that are highly regulated, such as transmission or distribution, or that are in effect regulated by contract, such as renewable generation, where large portions of revenues are defined upfront under long-term contracts. In advanced economies, where power wholesale markets are more developed, power utilities may take responsibility for some risk on levels of demand, but 15-, 20- or 25-year contracts are quite common, even if they are tending to shorten. Companies are also highly dependent on governments' power expansion plans, since it is the state that defines and issues tenders for major infrastructure, even in countries with lots of private sector participation.

The top 25 largest renewable-heavy utilities have a combined market capitalisation of USD 895 billion. They include international companies such as Iberdrola, which has over 42 000 employees, USD 150 billion euros in assets and investment plans of over USD 13 billion per year (Iberdrola, 2024). Utilities are likely to continue growing in importance as the world moves towards greater electrification. However, they do not have balance sheets as large as those of oil and gas companies, which were instrumental in financing the energy sector through the second half of the 20th century. The market capitalisation of the top 25 renewable utilities is only 20% of that of the top 25 oil and gas companies. The nature of the businesses is also different: oil and gas companies sell a USD-denominated internationally traded commodity, while utilities sell electricity in local currency and are subject to domestic demand. This is reflected in their returns: the top oil and gas firms have shown higher, but volatile, returns on investment over recent years, while those of the top renewable power companies returns have been steadier but lower, reflecting the more regulated nature of the business.

Figure 2.33 ▷ ROC and WACC in oil and gas versus renewable power companies



IEA. CC BY 4.0.

Large oil and gas companies have had higher but more volatile returns than renewable power companies over the last years

Notes: ROC = return on capital; WACC = weighted average cost of capital. Calculation based on the top 25 companies in each sector, according to production capacity.

Sources: IEA analysis based on Bloomberg (2024) and S&P Global (2024).

In addition to power utilities and generation companies, clean energy equipment manufacturers are also important players in the clean energy supply chain. Clean energy supply chains remain highly concentrated, with the top three countries – and China in particular – accounting for around 80% of global manufacturing capacity of equipment such as solar photovoltaic (PV) and wind turbines, though a number of regions are now attempting to develop their own domestic capacity in order to reduce import dependence. The profitability of these manufacturers – Chinese and others – has been under strain in recent years. Chinese exports of cells and modules have risen over 300% since 2019 and reached a record 255 gigawatts in 2023, but the USD value of sales was lower than the previous year for the first time since 2017. Despite high demand, oversupply of manufacturing capacity is affecting profitability and hitting solar stocks. In the wind turbine industry, both European and Chinese firms have also been under financial strain in recent years.

Energy service companies (ESCOs) are also included in this grouping. These companies provide a range of services such as energy audits, the operation and maintenance of energy assets, and the delivery of energy efficiency and renewable projects to help their customers – companies and households– save energy and reduce energy expenses. There are some key differences between ESCOS and traditional energy consultants or energy equipment providers: ESCOs also help their customers to finance these projects, and their remuneration is linked, in full or in part, to the savings provided to the customers. These contracts are known as energy performance contracts. The size of the global ESCO market has been growing, though at USD 33 billion in 2020 it still represents a small portion of total investment in energy efficiency – about two-thirds of total annual capital spending of Saudi Aramco in 2023, a large NOC.

Box 2.3 ▹ What are the risks of decreasing profitability of renewables?

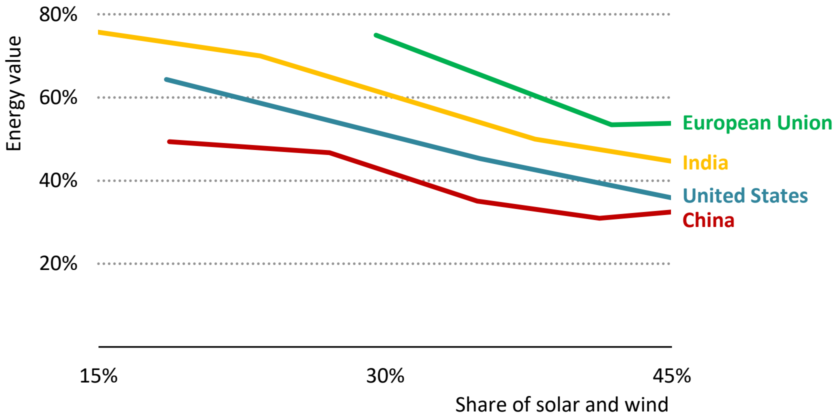
Renewable energy projects that are exposed to market risk may see declining profitability as their share of generation continues to increase across regions. This phenomenon, which is known as the cannibalisation effect, is a result of the way in which the output from renewables bring about lower wholesale market prices. As renewables such as solar PV and wind ramp up, the price of the marginal unit of electricity sold in the market is driven down by the abundance of available solar PV and wind in the system and their lower operating costs (Figure 2.34).

As this marginal unit becomes the price setter for all participating generating units in the market for that given time period, lower prices can translate to lower revenues earned by each generating unit, unless offsetting measures are taken to hedge this risk. As installed capacities of solar PV and wind continue to increase, they may be able to fully meet demand and set the price more frequently, potentially decreasing revenues for every unit with each additional unit that is installed.

For renewable project owners and developers, the cannibalisation effect can present a significant risk for profitability where they are exposed to wholesale market prices. To reduce or eliminate this risk, long-term contracts have emerged as the preferred and most common arrangement to facilitate investment in variable renewables. Managing project costs, from construction to operation and maintenance, then become directly linked to the profitability of renewable projects. Because of this, consideration is now being given to protecting developers against cost inflation that is outside their control in order to help solidify the profitability of projects.

From the consumer affordability perspective, the cannibalisation effect can signal the potential benefits of enhanced power system flexibility or a more diversified portfolio of low-emissions sources of electricity. Greater flexibility, such as from power plants, demand response or storage technologies like batteries, can make better use of the available supply from wind and solar PV and reduce the cannibalisation effect. In turn, this can reduce the need for other sources, translating into lower overall electricity system costs and potentially prices to consumers.

Figure 2.34 ▻ Energy value of solar PV in select regions in the STEPS



IEA. CC BY 4.0.

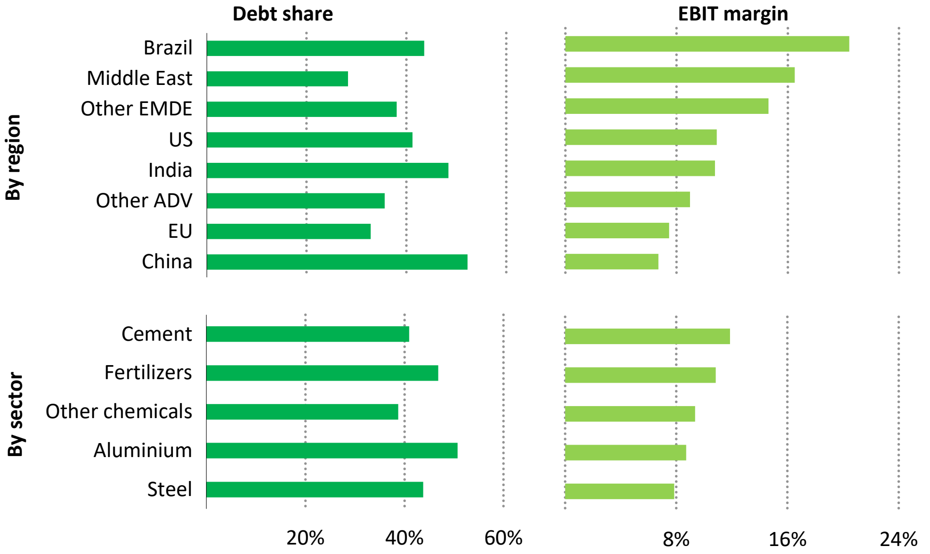
In the STEPS, the energy value of stand-alone solar PV tends to decrease with increasing shares of variable renewables due to cannibalisation

Note: Energy value for a technology represents the average price received for output over a given period based on least-cost merit order dispatch. Values are shown in percentage terms relative to the average wholesale electricity price.

2.4.3 Energy-intensive industries

For energy-intensive industries, adopting clean energy technologies while maintaining competitiveness is one of the defining challenges of the energy transition. Many of the clean energy technologies needed by heavy industries such as steel, cement or chemicals involve a high degree of risk because they are still at the demonstration stage. Switching to these technologies also requires significant upfront capital expenditure. These difficulties are exacerbated by the fact that steel and chemicals in particular are traded internationally in competitive markets with margins that are too slim to absorb higher production costs or to encourage first movers to adopt new technologies. This means that companies in these sectors may simply move to another jurisdiction if environmental regulations or energy prices put them at a competitive disadvantage. Such moves risk causing damage to the industrial competitiveness of the country that loses the companies concerned without achieving any reduction in global emissions.

Figure 2.35 ▹ Debt share and profitability of listed energy-intensive industries by region and sector, average 2015-2023



IEA. CC BY 4.0

Energy-intensive industries in most regions have low debt-to-equity levels, indicating some room for growth in debt. However, profit margins are low

Notes: EBIT = Earnings before interest and taxes. ADV = advanced economies.

Data on energy-intensive industries show a financially constrained environment with very little room to absorb higher operating and financing costs. In these industries, earnings before interest and tax are at relatively low levels, ranging from 7-15% in most countries: Brazil stands out at a high of 20%, although this value is skewed by the strong performance of a single firm and by the relatively small sample size for the country (Figure 2.35). Excess capacity in the steel sector has also led to falling utilisation rates over the last two years, and these rates are expected to decline further in the future. In 2023, the gap between global steel capacity and production widened to 600 million tonnes; this is similar to the size of the gap in 2014 that marked the start of the last steel crisis (OECD, 2024). While average debt-to-equity levels of energy-intensive industries tend to be below 40%, current low margins point to potential difficulty in servicing higher debt levels. This is particularly true for sectors such as steel where replacing existing capacity with low-emissions processes would typically require investment of around USD 2 million per tonne for a single plant.

Total cumulative investment needs for energy-intensive industries under the NZE scenario reach USD 890 billion to 2035. Meanwhile, the total market capitalisation of these sectors amounts to around USD 4.6 trillion (S&P Global, 2024), highlighting the potential challenges these sectors face in raising adequate finance for decarbonisation investments and the need for stronger government support and policy to drive investment decisions. Shareholders of these firms look to maximise returns and will not approve large outlays for capital investments unless they enhance overall returns.

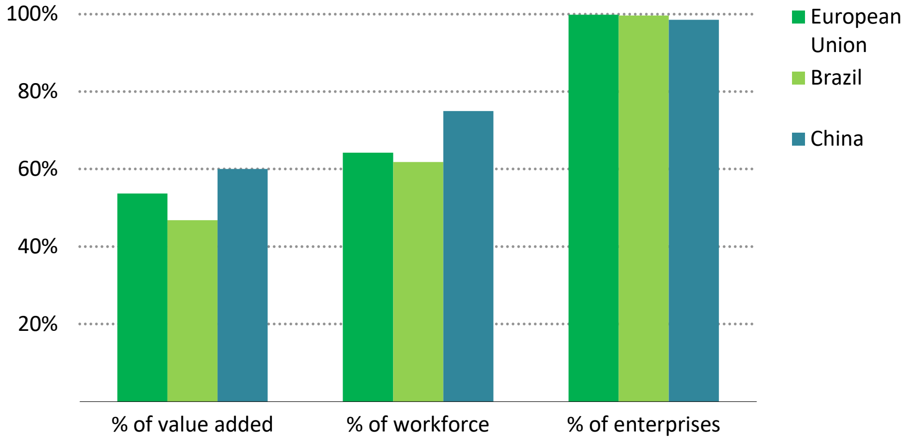
Accelerating the uptake of decarbonisation technologies for energy-intensive industry will therefore require strong policy intervention, incentives and more favourable market conditions to justify investments. In the NZE Scenario, efforts to implement carbon border adjustment measures and similar pricing schemes help level the playing field and maintain the competitiveness of companies and sectors that adopt decarbonising measures. Revenue from such measures could be recycled to help manage the higher material input costs to businesses, which eventually reach the end consumer through higher prices (although the price rises involved are likely to be relatively modest, as explored in Chapter 1).

2.4.4 Small and medium-sized enterprises

The Organisation for Economic Co-operation and Development (OECD) defines SMEs as firms of less than 250 employees. SMEs represent a substantial share of global GDP, and they account for around two-thirds of all employees and a huge proportion of the total number of firms in all countries. In the European Union, for example, SMEs account for about 53% of GDP and employ 64% of the workforce. In Brazil, the GDP figure is lower at 47%, but the SMEs share of the workforce is similar at 62% (Figure 2.36). The numbers in Brazil would probably be higher still if informal SMEs were to be included, since they are often an important part of the economy in EMDE.

SMEs are often well-suited to meeting the specific needs of their local communities and critical to the clean energy transition, but their relatively small size means that SMEs are generally more financially vulnerable than larger firms to the consequences of climate change. Their resources tend to be limited, and larger firms generally have lower financing costs and better access to the banking sector, capital markets and insurance products. SMEs in EMDE also tend to face higher financing costs than those in advanced economies. For instance, average interest rates for loans to Brazilian SMEs are six times the rate of those in the European Union. At an aggregate level, SMEs represent a considerable portion of the global carbon footprint. The efforts made by SMEs to improve energy efficiency or reduce carbon intensity therefore have the potential to substantially reduce global emissions. Financial decisions taken by SMEs can also have a large impact on environmental and social outcomes, though SMEs have less access to resources on how to transition and fewer capabilities to produce data on sustainability performance.

Figure 2.36 ▻ **SMEs contribution to GDP, share of jobs in the workforce, and proportion in total number of enterprises in the European Union, Brazil and China, 2020**



IEA. CC BY 4.0.

SMEs generally account for a substantial portion of a country's GDP and represent about two-thirds of their workforce and the majority of their enterprises

Sources: IEA analysis based on OECD (2022; 2023) and European Commission (2023).

Policies promoting affordability

Pursuing fair outcomes for households

SUMMARY

- Policies influence how the costs and benefits of clean energy transitions are distributed. Good policy design considers the distributional aspects and wider social impacts of a policy and ensures that everyone has access to affordable clean energy technologies. This chapter explores clean energy policies that attempt to do this.
- Appliance ownership growth underlines the need for efforts to promote efficient and affordable appliances. Policies in Senegal and Ghana show how financial support can make best-in-class models competitive with less efficient models, while Mexico's policies on minimum energy performance standards show how such standards can drive up efficiency without damaging affordability.
- Many homes require retrofits to make them energy-efficient, but lower-income households can often not afford the upfront costs. Examples in Ireland, France and the United Kingdom show how policies can be designed to provide targeted support to vulnerable households, resulting in wider social benefits.
- Electric vehicles are central to clean energy transitions, but their upfront costs can make them unaffordable for lower-income households. Policies in India and China show how a focus on the electrification of public transport and on incentives for electric two- and three-wheelers can promote affordable clean transport for all.
- Energy bills lie at the heart of concerns around affordability, and energy market design inevitably influences the structure and cost of bills. Experiences in Indonesia, Nigeria and Egypt show the challenges of reforming fossil fuel subsidies while promoting affordable clean energy consumption.
- Carbon pricing will disproportionately affect poorer households if they do not gain access to clean energy technologies as quickly as others, and there is a strong case for recycling revenues from these instruments to mitigate the cost impacts for these households in particular. The European Union and California provide examples of how this can be done.
- Household renewable energy production reduces the need to buy electricity from the grid and usually pays for itself quickly, but upfront investment costs and unreliable grid connections make participation difficult for low-income households in rural areas in particular. Policies in Bangladesh, China and Nigeria show how good policy design can roll out affordable solar systems to increase access to electricity.
- The case studies in this chapter show the power of policy design. The social impacts of policies should be identified and taken into account by policy makers. Only then can clean energy technologies be affordable and accessible for all.

3.1 Introduction

This chapter gets into the details of how governments can integrate considerations of affordability and fairness into their approaches to energy transitions. Transitions bring tangible benefits that go well beyond reductions in risks from climate change, including cleaner air, better health and new opportunities for employment, but these benefits need to be accessible and felt widely across societies for the process to enjoy sustained buy-in and support. Policies need to be intentionally designed with affordability and fairness in mind; they are not automatically part of the process of change.

That said, circumstances vary widely from country to country and there are no one-size-fits-all solutions. Much depends on available energy resources and infrastructure, institutional capacity, and demographics. Approaches vary depending on the stage of a country's development and how emissions reductions are integrated with other national social and economic priorities, the financial resources available to support energy and climate policies, and the groups and technologies prioritised for this support. This chapter does not attempt to provide a single blueprint for these complex and inherently political choices. The aim is rather to map out the landscape for policy makers by highlighting examples from different countries and contexts and by identifying best practices and approaches that have worked.

There are different types of intervention in play. For affordability, where clean technologies are already cost-competitive with carbon-intensive options, the challenge is to ensure that the advantages of clean choices are visible to consumers. Where clean technologies and services are not yet cost-competitive, the challenge is to adopt policies that bring down their costs or reduce the risks associated with their deployment to enable them to become cost-competitive. In relation to fairness, the main goal should be to adopt policies that will ensure that those least able to pay are able to manage the upfront costs of clean energy technologies and thereby gain a stake in the clean energy economy.

Earlier chapters provided the big picture and some broad macro framing on issues of affordability and fairness in energy transitions. The perspective in this chapter is more bottom-up, exploring how well-designed policies can meet the energy needs of households and communities. It considers issues of access, distributed clean energy production and energy bills. A particular focus is on the distributional impacts of clean energy transitions and illustrates, using a number of country case studies, how policies can provide support to different income groups or vulnerable segments of the population. There are a number of policies and regulatory instruments in force around the world that attempt to address the various dimensions of affordability and fairness for households: Table 3.1 provides a summary of areas that are discussed in greater detail in subsequent sections.

Table 3.1 ⊳ Key policies to improve affordability of clean energy for households

Regulation and sector-wide interventions	Incentives for consumers
Efficient appliances	
• Minimum energy performance standards for appliances. • Bulk procurement of efficient appliances and devices such as LED bulbs to drive down costs. • On-bill or on-wage financing mechanisms to spread out the upfront investment costs over time or cover costs with energy savings.	• Targeted or income-based subsidies for more efficient devices such as refrigerators, air conditioners and washing machines. • Rebates on the purchase of efficient appliances, often in exchange for scrappage of old and inefficient ones.
Efficient buildings	
• Minimum energy performance standards for new buildings. • Energy efficiency obligations that mandate energy utilities and suppliers to scale up efficiency among low-income households or other vulnerable consumers, shifting a part of the burden of household efficiency onto companies. • Energy services companies that can provide affordable financing options alongside implementation of efficiency in buildings.	• Targeted or means-tested grants and subsidies for energy efficiency retrofits. • Low-interest loans for energy efficiency investments in buildings. • Grants and subsidies for clean heating systems to replace fossil fuels, such as heat pumps or biomass boilers.
Clean transport	
• Public transport policies that lay out guidelines and offer financial support for cities and towns to establish and expand mass transit and non-motorised transport infrastructure. • Encouraging public charging infrastructure with a wider geographical reach.	• Vouchers for public transport. • Targeted subsidies and trade-in bonuses for new and second-hand electric vehicles (EVs). • Affordable EV leasing or car-sharing options for low-income households. • Grants and incentives to install EV charging infrastructure in low-income households.
Energy bill reforms	
• Time-of-use tariffs that help shift electricity consumption to periods when it is less expensive. • Net metering that factors in system costs, or credits self-generation added to the grid. • Recycling revenues from carbon pricing to support households to encourage clean energy adoption.	• Targeted support for low-income households during times of high energy prices. • Fossil fuel subsidy reform that includes provision for continued support to the most vulnerable populations and a reallocation of resources to promote cleaner options.

(Continued…)

Regulation and sector-wide interventions	Incentives for consumers
Distributed clean energy production	
• Setting up financial institutions that can provide concessional loans to households and small and medium enterprises to scale up distributed clean energy production and efficiency. • Improve know-how and provide guidelines to existing banks and financial institutions. • Instruments such as on-bill financing or pay-as-you-go programmes operated by utilities that help moderate or remove upfront costs. • Community solar and solar for social housing programmes.	• Targeted or income-based subsidies, discounts, rebates, tax credits and concessional loans for scaling up solar systems. • Grants targeted at low-income households and other vulnerable communities for off-grid renewable energy systems.
Clean energy access	
• Clearly laid out national and regional universal energy access goals and implementation plans that factor in local constraints and the availability of resources. • International financial and technical support for infrastructure and supply-chain creation to ensure universal access. • Financing mechanisms that reduce upfront costs or costs associated with services or fuel purchases, such as results-based financing, grants, cash transfers.	• Social tariffs, micro-financing solutions and/or subsidised connection charges for households that currently lack access to electricity or are below certain income thresholds. • For the poorest households, carefully designed and targeted subsidies to support both electricity and clean cooking solutions.

3.2 Efficient appliances

Efficient appliances use less electricity and emit less carbon dioxide (CO_2) than their inefficient counterparts and are often less expensive for consumers over their lifetimes, with higher upfront costs outweighed by lower operating costs, as illustrated in chapter 1. Rapid growth in the use of appliances, especially in emerging market and developing economies, underlines the case for action to promote efficiency. This section discusses a few key policies that have been promoting the uptake of efficient appliances, in part by reducing upfront investment costs.

3.2.1 Minimum energy performance standards

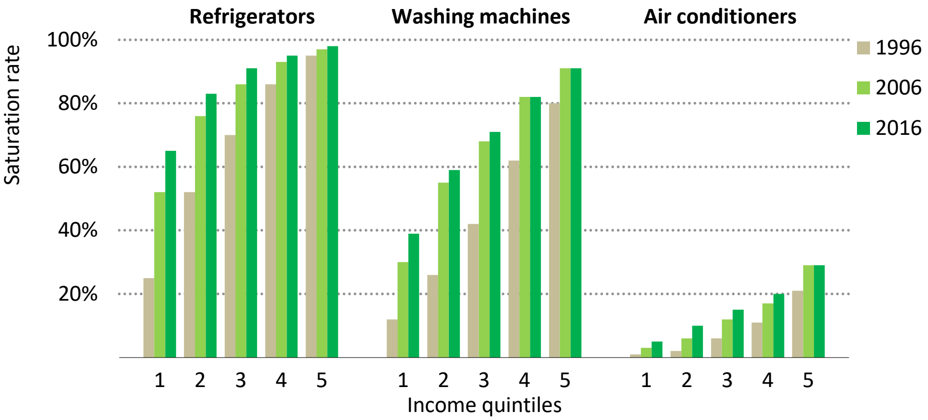
Minimum energy performance standards (MEPS) remove inefficient products from the market. They are often used in conjunction with energy efficiency labels. Currently, over 110 countries have introduced MEPS for new appliances placed on the market, particularly for air conditioners and refrigerators, covering almost 90% of their global energy consumption. Fewer MEPS are currently in place for other end uses such as cooking stoves and space and water heating appliances.

The number of MEPS has been steadily increasing for the last 20 years, but coverage still varies across regions. International co-operation and regional harmonisation can play an important role in aligning standards across countries, decreasing compliance costs for industry and reducing government expenditure for compliance testing. The impact of MEPS depends to a large extent on their level of stringency and the capacity of governments to monitor and enforce their compliance. They work best when governments signal ahead and give manufacturers a window in which to adapt and supply more efficient models to the market. MEPS are a key tool for policy makers, as experience from multiple countries demonstrates that they can bring about significant improvements in energy efficiency without increasing prices.

Mexico

Mexico has put in place several labelling schemes with maximum energy consumption limits for appliances, starting in 1995 with refrigerators and air conditioners and moving on in subsequent years to water heaters and washing machines. In 2003, only eight years after the implementation of the first standard, an updated regulation significantly lowered maximum energy consumption limits, with a reduction of up to 53% for new refrigerator-freezers and 20% on average for new washing machines, depending on the model classification.

Figure 3.1 ▹ Appliance ownership per household by income quintile and year, Mexico

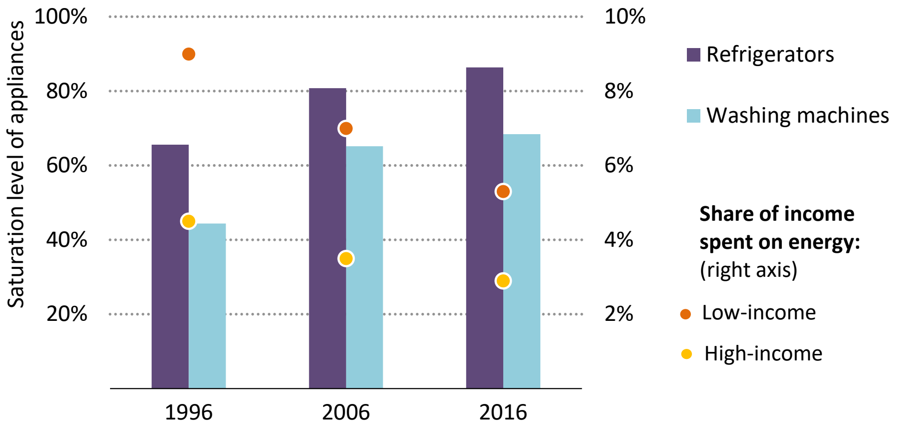


IEA. CC BY 4.0.

Ownership of appliances increased across all income quintiles from 1996 to 2016 in Mexico

When the first standards were implemented, only 66% of the population owned a refrigerator, and only 44% a washing machine. These numbers were much lower for low-income households, 25% of which owned a refrigerator and 12% a washing machine (Figure 3.1). Over a 20-year period, the overall ownership of refrigerators and washing machines increased more than 30%, while the average household electricity consumption went down by at least 20%, with a similar trend being observed for per capita residential energy consumption. Ownership in low-income households rose faster than the average over this period as improvements in energy efficiency brought down monthly electricity costs, allowing low-income households to access more energy services (Figure 3.2). These changes were brought about by a continuous improvement in the energy efficiency of products in the market which was underpinned by the policies put in place and the development of technology (Secretaría de Energía, 2018).

Figure 3.2 ▻ Saturation level of appliances and share of income to cover energy expenses per household, Mexico, 1996-2016



IEA. CC BY 4.0.

While ownership of appliances has increased in Mexico, the share of income that households dedicate to energy has decreased, partly as a result of MEPS

3.2.2 Financial support

A common way to increase the affordability of best-in-class products on the market is to make available purchase rebates for specific high-efficiency models. Government programmes to fund rebates can increase sales of efficient appliances and lead to energy savings, especially when combined with a replacement programme for inefficient appliances.

In Hungary, the Warmth of Homes scheme which was in place between 2015 and 2020 provided a rebate of up to 50% of the retail price of appliances such as washing machines and refrigerators in exchange for scrapping old, inefficient appliances. Only the highest energy efficiency classes were eligible. In total, almost 82 000 appliances were replaced, saving more than 20 000 tonnes of CO_2 per year between 2015 and 2020. Appliance rebate programmes in Austria and Croatia showed similar results, with increased uptake of more efficient devices. (Buettner et al., 2021).

In Malaysia, the Sustainability Achieved Via Energy Efficiency (SAVE) 4.0 programme provides a rebate of up to USD 85 to households that purchase energy-efficient air conditioners and refrigerators with 4-star or 5-star energy efficiency labels. In Singapore, the Climate Friendly Households Programme offered rebates of around USD 110 for the purchase of new refrigerators with at least 3 ticks on the energy label. In Australia, the Victorian Energy Upgrade programme supports households that install more efficient appliances through discounts and rebates, for example by providing around USD 45 towards the cost of an efficient refrigerator or clothes dryer.

Other countries are providing credit at low or zero interest rates to reduce the burden of high upfront costs of appliances. In countries with low access to credit, governments are collaborating with banks and utilities. In West Africa, the United Nations ECOFRIDGES Initiative facilitates the purchase of energy-efficient air conditioners and refrigerators through bank loan products designed to address short- to medium-term financing needs. In Senegal, on-bill financing gives consumers the option to finance the purchase of efficient appliances through monthly payments on their electric utility bills. This option comes with the offer of a credit facility providing loans of up to USD 1 500 with 0% interest over 12 months. Customers can also get can get a discount voucher by trading in their old appliances. In Ghana, on-wage financing allows employees to pay for the purchase of best-in-class energy-efficient refrigerators and air conditioning units through monthly salary deductions. By April 2023, the programme had led to USD 1.4 million of spending on more than 3 000 new refrigerators and air conditioners. This is estimated to have reduced lifetime energy demand by over 25 gigawatt-hours and CO_2 emissions by 20 000 tonnes (BASE, 2023).

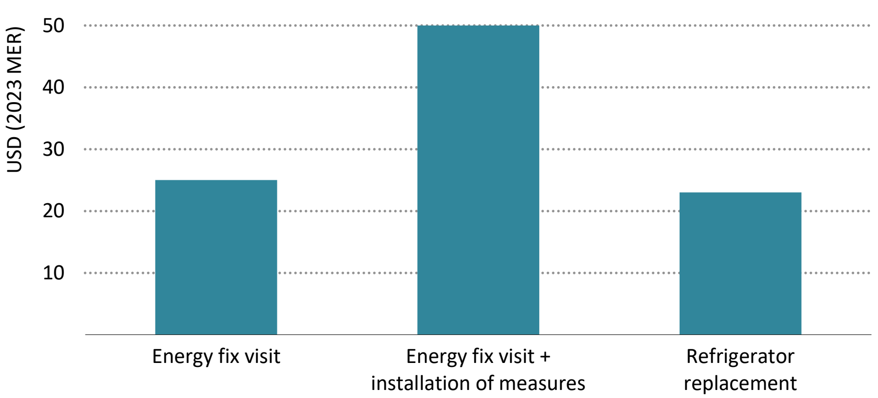
Box 3.1 ▹ Energy fixers in the Netherlands

At the height of the 2022/23 energy crisis in the Netherlands, consumers faced rapidly rising energy bills. Some households applied for subsidies to help them with the cost of insulation measures and heat pumps under schemes such as the Sustainable Energy Investment Subsidy (ISDE), which saw applications more than double from 2021 to 2022. However, there were also households that could not afford energy efficiency investments, even with the grant.

Local initiatives were set up to address immediate energy affordability concerns during the crisis. Several “energy fix teams” were created to go door-to-door to vulnerable households and install quick energy-saving measures such as draught strips, LED lighting and radiator reflectors. These short-term measures directly contributed to lowering household energy bills (Figure 3.3). The programme also sought to engage hard-to-reach communities and build trust, for example by recruiting members of the energy fix teams from those communities. In 2023, the Dutch national government allocated USD 200 million for municipalities to scale up these energy fix teams and to fund other energy poverty-alleviating initiatives such as free appliance replacement schemes.

Similar programmes are in place in other countries, such as the Support for Energy Education in Communities programme in New Zealand.

Figure 3.3 ▷ **Average reduction in monthly energy bills of energy fix teams in the Netherlands by measure in USD**



IEA. CC BY 4.0.

Advice and simple energy-savings measures led to average reductions of USD 25 on monthly energy bills, increasing to USD 50 if combined with more thorough measures

Source: IEA analysis based on Netherlands Organization for Applied Scientific Research (TNO, 2023)

Note: Simple measures include radiator reflector foil and draught stirps. More thorough measures include the replacement of doorposts, sills and frame profiles.

3.3 Efficient buildings

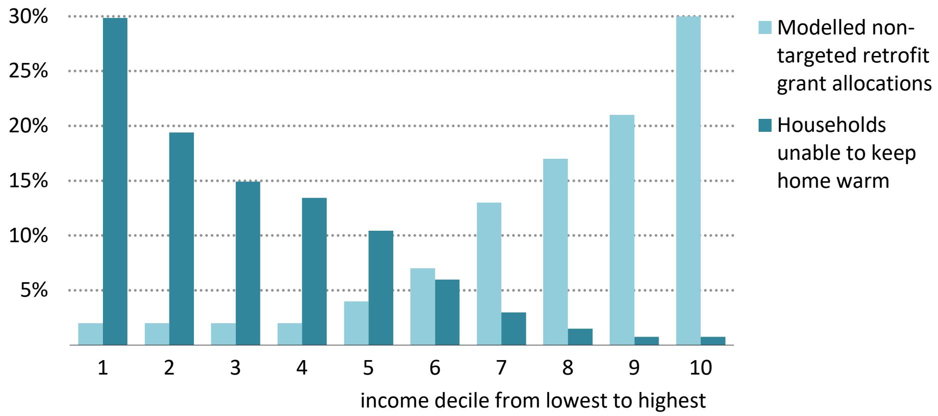
Clean energy technologies in buildings such as efficient heating and cooling as well as insulation contribute to affordability. Efficient homes reduce energy consumption and can decrease energy bills, and the costs of making a building more efficient are typically much lower than the benefits that such measures bring over their lifetime. However, access to efficiency improvements in buildings can be limited by affordability and ownership issues. Energy retrofits require significant upfront investment costs which not all households can afford, and low-income families often live in poorly insulated, energy-inefficient homes that are difficult to sufficiently warm in cold weather or cool in hot weather.

For people who need access to efficient housing the most, the upfront investment cost can be prohibitively expensive. Costs can range from a few thousand dollars for relatively simple measures such as the replacement of windows to tens of thousands of dollars for deep building renovations. Policies can increase the affordability of energy retrofits by lowering the upfront costs through subsidies, tax benefits, grants and market-based instruments, and can be targeted in particular at lower-income households.

3.3.1 *Direct grants*

Direct retrofit grants provide applicants with funding to cover part or all of the investment costs of implementing efficiency measures. The simplest grant covers a fixed percentage of the total costs for all applicants, with the rest of the costs to be covered by the applicant. However, for low-income households, these upfront costs often represent a large part of their annual income, and they are often tenants rather than owners, potentially excluding them from this kind of scheme (Figure 3.4). Several countries have therefore adapted the design of retrofit grants to make them more accessible to low-income households.

Figure 3.4 ⊳ Distributions of a modelled non-targeted retrofit grant and households unable to warm their home, per income decile, European Union



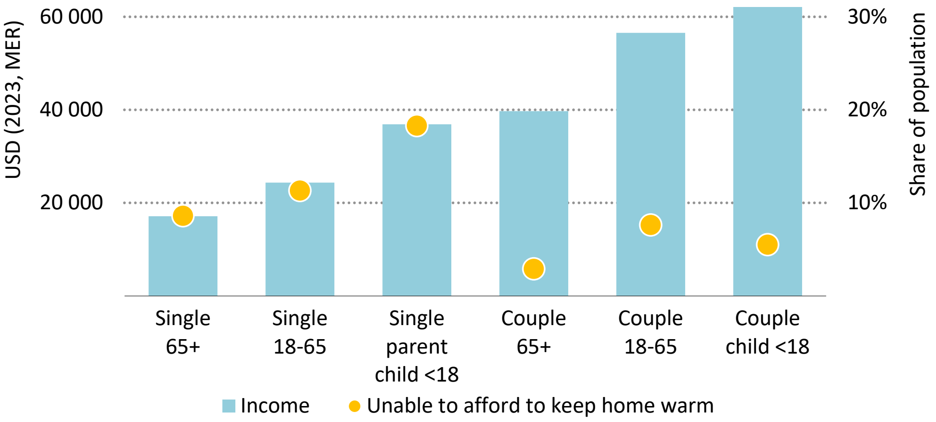
An untargeted, fixed-rate retrofit grant risks leaving behind households unable to afford the upfront costs and disproportionately benefiting the highest-income groups

Sources: IEA analysis based on Odyssee-Mure (2021), OECD (2022) and World Bank (2023b).

Case study: Ireland

Vulnerable groups in Ireland are more likely than other groups to live in homes with relatively poor energy performance (Figure 3.5). Certain vulnerable groups are disproportionately affected. For example, 41% of single parents lived in a building with an energy performance rating of D or lower in 2016, and 18.3% of single parents were unable to keep their home adequately warm in 2022. One of the most effective ways to decrease their energy bills and increase the comfort of their home would be an energy retrofit. However, without targeted support, the high cost of deep-energy retrofits can make this option unaffordable for many households.

Figure 3.5 ▷ Average income and ability to afford to keep the home adequately warm for selected groups, Ireland, 2022



IEA. CC BY 4.0.

Households that need retrofits the most – those who cannot pay for the energy to keep their home adequately warm – are also the ones least able to afford a retrofit

Note: MER = market exchange rate.

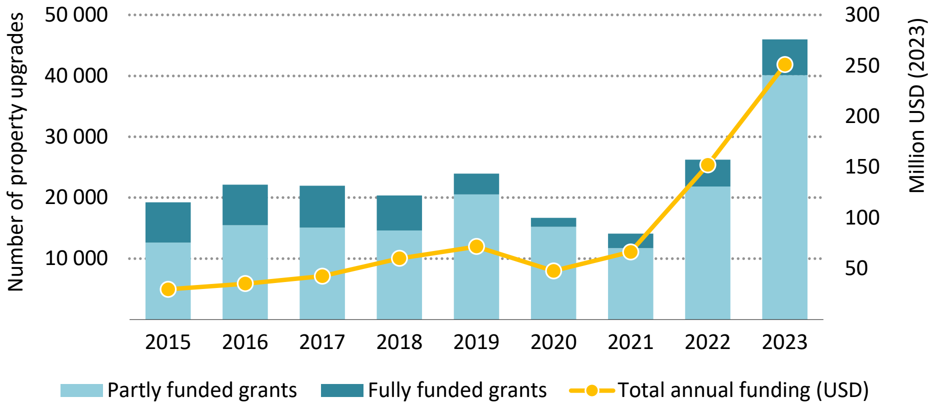
Source: IEA analysis based on Central Statistics Office (2016)

As a part of the national retrofitting scheme, the Sustainable Energy Authority of Ireland (SEAI) offers grants for partially funded and fully funded home energy upgrades (Warmer Homes Scheme, Warmth and Wellbeing Scheme) to address the problem of fuel poverty in low-income homes. These schemes aim to improve the energy efficiency and comfort of homes occupied by low-income households, and to establish systems to increase Ireland’s capacity to install such measures.

Eligibility for the Better Energy Warmer Homes Scheme is limited to owner-occupied households in homes built before 2006 that are receiving benefits from at least one of six social welfare programmes aimed at low-income households. The Warmth and Wellbeing Scheme, which fully funds energy efficiency retrofits, targets a specific group of people. The scheme aims to enhance the quality of life for applicants who are suffering from chronic respiratory conditions and are aged 0 to 12 or 55 and over. SEAI determines what specific energy efficiency retrofit measures are needed (including attic insulation, cavity wall insulation, external wall insulation, internal wall insulation; secondary work such as lagging jackets, draughtproofing and energy-efficient lighting) and provides the funding for them. It provided more than 10 000 fully funded property upgrades in 2022-2023 at a cost of around USD 220 million (Figure 3.6).

There was a slowdown in funded retrofits during the Covid-19 pandemic due to construction sector closures and restrictions on home visits. However, activity picked up again from 2022, and the average spend per home is now close to USD 24 000. The total number of grants for partial and full energy retrofits (both fully funded and partly funded) more than tripled from 2021 to 2023 and overall scheme expenditure almost quadrupled. The 2024 budget allocated a record level of funding to the scheme of around USD 225 million.

Figure 3.6 ▹ Partly funded and fully funded energy retrofits, Ireland, 2015-2023



IEA. CC BY 4.0.

The number of grants for energy retrofits more than tripled and the total amount funded almost quadrupled from 2021 to 2023

Source: IEA analysis based on Sustainable Energy Authority of Ireland (2024)

Other countries are putting similar policies in place. For example, the Greener Homes Initiative in Canada provides grants and loans for energy upgrades. In addition, the government announced in 2024 that they will launch a new Canada Greener Homes Affordability Program that specifically targets low- to median-income households. The government announced almost USD 600 million in funding for energy efficiency retrofits in these households. It also provides grants and loans for community and affordable housing providers for social housing retrofits where occupants are primarily renters.

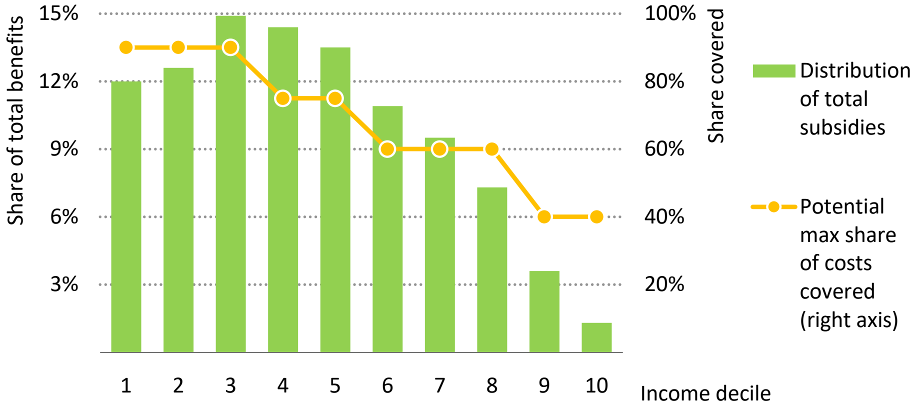
France

In 2020, France introduced MaPrimeRénov', a new consumer subsidy designed to cover a proportion of renovation costs based on multiple criteria, including household income. The scheme was aimed at low-income groups and was intended to complement pre-existing retrofit grants, tax credits and state loans which targeted energy-intensive dwellings but left a significant share of expenses to be shouldered by households.

MaPrimeRénov' initially targeted only the poorest households on the basis that other schemes, notably tax credits, were available for middle-income categories. It was revised in 2021 to include four income categories; applicants with the lowest incomes were eligible to receive up to 90% of total renovation expenses, depending on what retrofits were planned, while those in the highest income category were limited to less than 40%. Moreover, the grant was made available to all properties that were built at least 15 years ago, including rented ones. Additional incentives for "deep renovations" combining several retrofitting measures were also included.

Between 2020 and 2022, the programme succeeded in targeting older buildings and in prioritising low- and middle-income households, with those below the median income receiving nearly 70% of the allocations, and high-income groups receiving less than 5% (Figure 3.7). Over this period, low-income beneficiaries received on average over 40% of their total retrofit costs from the MaPrimeRénov' scheme: when combined with other subsidies, the share of their costs covered rose on average to around 60%. Most applicants claim they wouldn't have carried out the renovations without the subsidy scheme.

Figure 3.7 ▻ **Distribution of allocations of MaPrimeRénov' grant and maximum share of retrofit costs covered, 2020-2022, France**



IEA. CC BY 4.0.

Careful design of policy has led to a fairer and more equal distribution of the benefits of retrofit grants across income groups in France

Note: Income deciles are based on available income at household level, including social benefits (INSEE definition).

Source: IEA analysis based on Ministère de la Transition Ecologique et de la Cohésion des Territoires (2023)

Most of the measures subsidised were heating system upgrades in the form of heat pump installations, hot water system replacement and interior insulation. Deep renovations accounted for only around 0.3% of total projects supported, indicating that most households still struggled to afford the high upfront costs that they involve, even when incentives were available. In the context of government efforts to restrain overall spending, a lower-than expected uptake also led policy makers to decrease the planned budget allocation for the scheme.

In order to increase the number of deep renovations, the French government further reformed MaPrimeRénov’ in 2024 by introducing two sub-schemes. The first provides subsidies for a limited number of interventions, such as the installation of insulation and the replacement of heating systems, and is aimed at low- and middle-income households (MaPrimeRénov’ Efficacité); the second provides subsidies for deep renovations, with technical support from a professional throughout the whole process (MaPrimeRénov’ Performance). Only deep-renovation supports are now provided for buildings classified as least energy-efficient (class F or G), while homeowners of other buildings can opt for either of the two sub-schemes. Simplified processes and criteria were also implemented together with provisions for lower-income households to combine existing benefits with MaPrimeRénov’ in order to receive subsidy support of up to 70% upfront.

Box 3.2 ▻ Greece's Save and Renovate for Young People programme

The Save and Renovate for Young People programme in Greece is an initiative to increase access to affordable, efficient housing for young people, particularly those facing financial constraints. The programme promotes energy efficiency upgrades alongside homeownership by offering low -or zero-interest loans to people born between 1984 and 2005 to encourage sustainable living and alleviate energy poverty among young people. By combining financial support for homeownership with incentives for energy-saving renovations, it not only empowers young individuals to secure affordable housing but also contributes to environmental sustainability and economic resilience. It is supported by the Recovery and Resilience Fund, with a total budget of EUR 300 million.

The programme has two aims. The first is to help young people to buy their own homes. About 70% of those aged 18-34 live in their parental homes, primarily due to financial constraints and limited alternatives. The average age at which Greeks leave their parental homes is 30.7 years, which is well above the European Union (EU) average of 26.4 years (Eurostat, 2024).

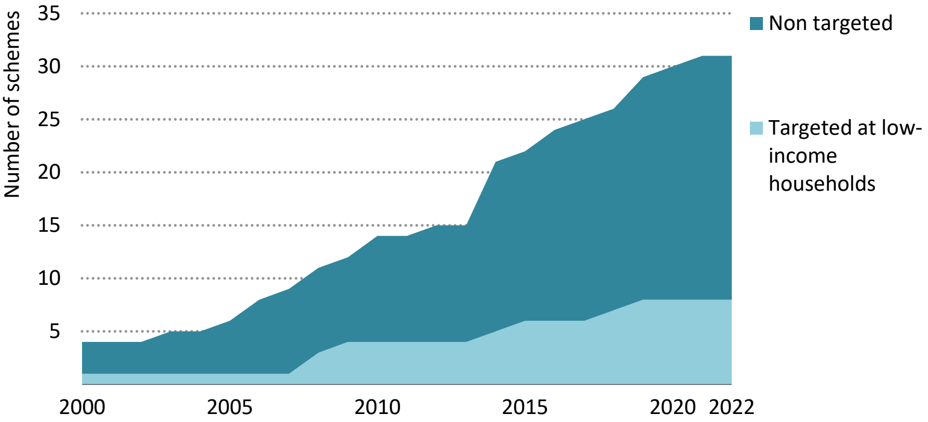
The second is to promote energy-saving in the homes that young people buy through financial incentives for energy-saving interventions and home renovations. Eligibility criteria include age restrictions (18-39 years), income thresholds and property ownership requirements. The "Save" component focuses on improving energy efficiency through measures such as thermal insulation, heating system upgrades, and renewable energy installations. The programme aims to achieve significant energy savings (213 kilotonnes of oil equivalent per year) by contributing to the renovation of over 105 000 homes by 2025 (UK Ministry of Environment and Energy, 2024). By promoting energy-efficient housing, the initiative seeks to reduce energy consumption and lower utility bills.

3.3.2 Energy efficiency obligation schemes

Energy efficiency obligation (EEO) schemes require obligated parties - usually energy utilities or suppliers – to achieve energy savings by improving energy efficiency, for example by funding the installation of more efficient heating systems and insulation measures in the homes of their end-use consumers. Energy efficiency investment grants are a direct cost for the government, but an EEO shifts the costs to the obligated companies, which in effect spreads them over the energy bills of all households. They can accordingly be particularly useful to countries with limited fiscal space for investment grants.

Over 30 countries had some form of EEO in place in 2022, but the majority of EEO policies tracked by the International Energy Agency (IEA) do not provide targeted obligations (Figure 3.8). As a result, the uptake of efficiency measures may end up concentrated in higher income brackets. As the costs of EEOs are often socialised through the energy bills of all households, this could mean lower-income households contribute to the costs without receiving a proportionate share of the benefits. This can be overcome by requiring a certain percentage of total savings to be achieved in particular income groups, and many schemes do exactly this. A frequently targeted subgroup in EEOs is low-income households. While EEOs can be effective in targeting lower-income groups, policy design should ensure adequate outreach to these groups to ensure that they are able to fully take advantage of what is on offer.

Figure 3.8 ▹ Number of targeted and non-targeted energy efficiency obligations schemes worldwide, 2000-2022



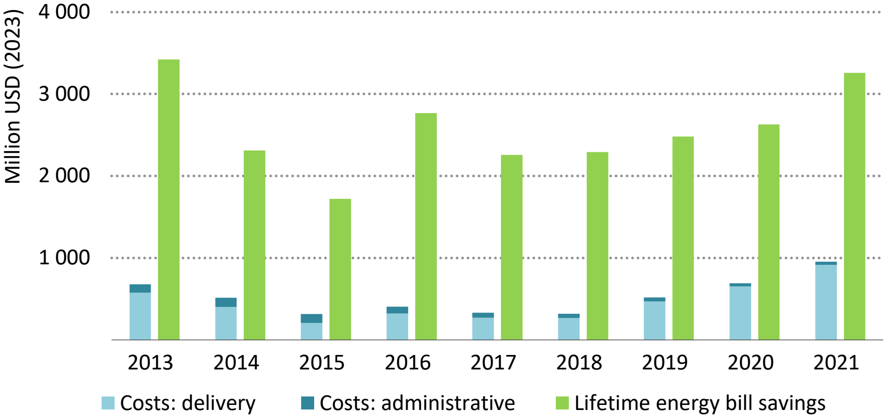
IEA. CC BY 4.0.

Despite increases over the last decade, energy efficiency obligation schemes targeted at low-income households remain a small proportion of the total

United Kingdom

In the United Kingdom, the Energy Company Obligation requires energy suppliers to promote energy efficiency in low-income households by contracting installers to implement energy efficiency measures in homes. Each energy supplier is given targets for energy bill savings, and fines are imposed if the targets are not met. As part of the obligation, they are also required to monitor and report the costs of delivering an energy efficiency measure in a home and its impact on energy bill savings. Since the start of the scheme, every year, the estimated lifetime energy savings of the installed measures have been at least three times higher than their costs. The costs are recovered and socialised through the energy bills of all consumers (Figure 3.9).

Figure 3.9 ▹ Costs and estimated savings of the Home Heating Cost Reduction Obligation in the United Kingdom, 2013-2021



IEA. CC BY 4.0.

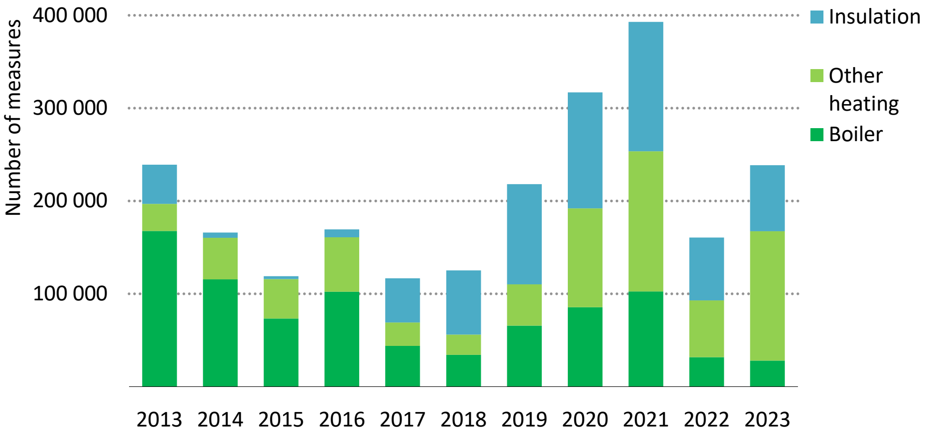
Every year, the benefits of the UK EEO scheme have been at least three times higher than the costs

Source: IEA analysis based on Department for Energy Security and Net Zero (2024)

The first and second phases of the programme ran from 2013-2017 and consisted of three separate obligations: the Carbon Emissions Reduction Obligation, the Carbon Saving Community Obligation and the Home Heating Cost Reduction Obligation (HHCRO). Low-income households were specifically targeted under the HHCRO. During the third phase of the scheme from 2018-2022, the programme (called ECO3) was solely focused on the HHCRO obligation and support for low-income households. In ECO3, every pound spent by energy suppliers on energy efficiency measures resulted on average in almost four pounds of estimated lifetime energy bill savings for low-income households. These savings do not take into account other potential savings in health costs or increased productivity.

In total, the HHCRO has led to the installation of 2.2 million energy efficiency measures, split roughly in equal parts among more efficient boilers, other heating-related measures such as heating controls, and insulation measures such as cavity walls, and loft and solid wall insulation (Figure 3.10). ECO3 alone is estimated to have achieved lifetime bill savings of more than USD 10 billion.

Figure 3.10 ⊳ **Installed energy efficiency measures under the Home Heating Cost Reduction Obligation in the United Kingdom, 2013-2023**



IEA. CC BY 4.0.

Focusing the UK EEO scheme on low-income households since 2018 has helped to increase the uptake of energy efficiency measures in this group

Source: IEA analysis based on Department for Energy Security and Net Zero (2024)

Box 3.3 ⊳ Multiple benefits of energy retrofits

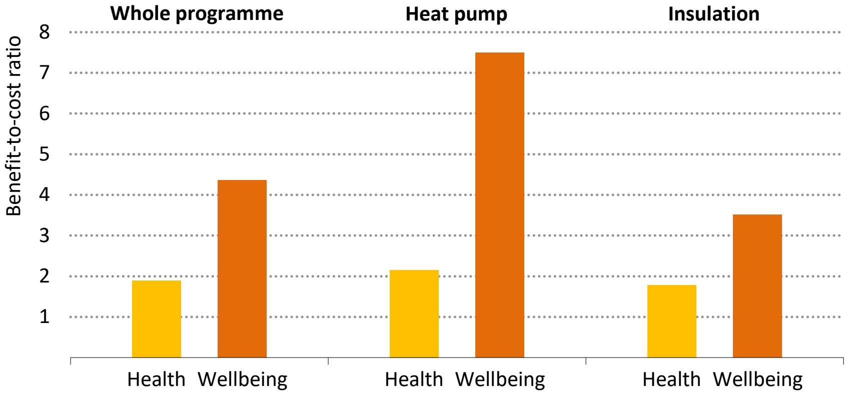
Living in a poorly insulated home leads to higher energy bills, decreases comfort and well-being levels, and can lead to a range of adverse health outcomes. One study suggests that dampness or mould in homes can result in a 30-50% increase in respiratory issues for inhabitants, especially children, while a survey of 699 low-income households in 2010 showed that half of the people living in cold homes reported increased anxiety and depression symptoms (Anderson et al., 2010; CA-EED, 2024). Two other studies found that extensive renovations and energy efficiency improvements can lead to a 20% decrease in days of school absence for children with asthma, and reduce by more than 30% the mortality risk for those over 65 with a history of cardiovascular hospitalisation.

Healthcare-related costs have an important bearing on the case for investing in energy retrofits. For example, estimates from the European Union indicate that the economic cost of inadequate housing is around EUR 190 billion every year, while the total costs for retrofits in the European Union could be funded by a one-time investment of around

EUR 300 billion. This suggests that the payback period for full retrofitting in the European Union would be a lot lower if wider health and social costs were to be factored in.

Some governments are starting to adopt policy measures that recognise and seek to measure these wider benefits (mental well-being, energy and carbon savings, direct and indirect health benefits). For instance, an analysis of the Warmer Kiwi Homes scheme in New Zealand, which provides heat pumps and insulation in low-income homes, uses two alternative societal approaches to calculate benefit-to-cost ratios (BCRs); well-being/energy BCR emphasises house warmth and energy savings, while the health/energy BCR includes health benefits alongside energy savings. Under the well-being/energy BCR approach, the Warmer Kiwi Homes scheme is estimated to have resulted in benefits that were on average more than four times higher than costs, while the heat pumps component resulted in a ratio above seven (Figure 3.11).

Figure 3.11 ▷ Benefit-to-cost ratio of the Warmer Kiwi Homes Programme, New Zealand, 2022



IEA. CC BY 4.0.

The Warmer Kiwi Homes programme in New Zealand resulted in energy, health and well-being benefits that were seven times higher than the costs

Source: IEA analysis based on Motu Economic and Public Policy Research (2022).

3.3.3 Affordable loans

Affordable credit fulfils several critical functions in the renovation market. It enables low-income households to leverage available grants by providing a way of funding the non-subsidised costs of renovation work. It allows governments to encourage renovation activity among middle- and high-income households – including private landlords – without depleting public budgets. Finally, it helps renovation projects of multifamily buildings to get buy-in from all residents when only some of them are eligible to receive grants. In emerging market and developing economies, green mortgages can be especially helpful in triggering the switch to zero-carbon-ready buildings by offering home buyers cheaper mortgages when they opt to purchase such houses.

Lithuania

Over the past two decades, Lithuanian authorities have pioneered the development of public-private partnerships that use public funds provided by the government and the EU Regional Development Fund to unlock private investment in retrofits of multi-apartment buildings. Operated by the European Investment Bank, Lithuania's Fund for Multi-Apartment Building Modernisation (JESSICA I and II) has triggered more than EUR 1.2 billion worth of renovations with only a fraction of that investment coming from public funds. During the second instalment of the programme (JESSICA II, 2014-2020), every euro of public funds invested unlocked five euros' worth of renovation activity. Over 83 000 households have benefitted from the scheme, saving 65% of building energy consumption on average.

The model uses public grants to subsidise interest rates and to provide technical assistance as well as a capital rebate to repay some of the loaned amount upon achievement of certain energy-saving objectives. The grants also serve as a first-loss guarantee in order to attract commercial banks that have been traditionally wary of lending to associations of apartment owners. Loans – issued at a fixed 3% interest rate for a period of 20 years – can be combined with subsidies as part of the same administrative process. In certain municipalities, local authorities have stepped in to cover the loan repayments of low-income households.

3.4 Clean transport

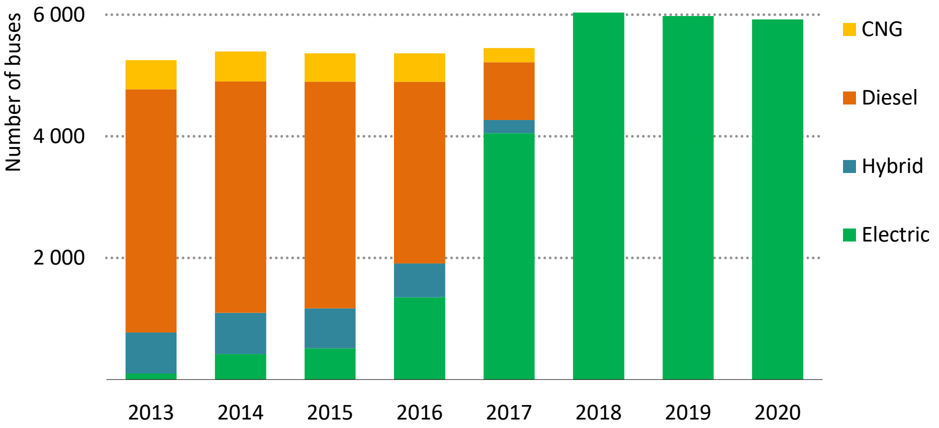
As explored in Chapter 2, household spending on transport is highly uneven across income groups. The purchase of an electric vehicle is often out of reach for lower-income households, because of high upfront costs or lease payments. Well-designed policies to promote affordable electric mobility therefore include a focus on public and shared transport, which is disproportionally used by low-income households, and provide financial support for more affordable forms of electric transport, including two- and three-wheelers. Financial incentives for EVs can be geared to those who need them most, for example by covering more of the upfront costs for low-income groups than for others, and to the most efficient EVs, for example by setting caps based on the weight of the vehicles that are eligible for subsidy support.

3.4.1 Public transport

Public transport – which includes buses, trams and light rail – is the cornerstone of affordable mobility, especially for low-income households and vulnerable groups such as the elderly. Access to affordable public transport increases mobility and leads to improved social and economic outcomes. When governments introduce policies promoting affordable electric mobility, public transport needs to be at the forefront of their thinking.

The People's Republic of China (hereafter "China") has been the world leader in this regard. In 2022, it was responsible for around 80% of global electric bus sales. According to China's Ministry of Transport, around two-thirds of urban buses and trams in the country are already electric. This was driven by ambitious policy, including financial incentives in the "ten cities and thousand vehicles" programme. The policy resulted in significant changes in the composition of the bus fleet in selected cities. Shenzhen, for example, electrified its entire bus fleet in just five years (Figure 3.12).

Figure 3.12 ▷ Bus composition by fuel in the Shenzhen Bus Group fleet, China, 2013-2020



IEA. CC BY 4.0.

Ambitious policy measures can accelerate the electrification of public transport

Note: CNG = compressed natural gas.

Source: IEA analysis based on World Bank (2021)

Other countries are also taking action to encourage the use of electric buses. The United States provides funding for zero-emission buses under the Inflation Reduction Act and has put in place new emissions standards in 2024 for heavy-duty vehicles that will come into force from 2027. The European Union is considering legislation to require all new city buses to be zero-emission by 2030. Emerging market and developing economies are also increasingly implementing electric bus policies as cost-effective and equitable transport solutions. Ghana, for example, has set a target for 16% of bus sales to be electric by 2030; Panama has set a target of 33% for the same date; and Viet Nam is encouraging new and existing bus stations to accommodate electrification by 2030.

Public procurement can play an important part in supporting the use of electric buses. For example, India announced a scheme in 2023 which aims to set up a public-private partnership to procure 10 000 electric buses for cities that currently lack adequate public transportation. The scale of this procurement should enable manufacturers to drive down costs. Increasing the availability of public and non-motorised transport provides a range of social benefits. For example, 84% of trips taken by women for work are in some form of public, intermediate public transport and non-motorised transport (World Bank, 2022).

As well as increasing the supply of affordable clean public transport, governments are implementing policies on the demand side to encourage a modal shift from private vehicles to public transport, notably in Europe. In Brussels, for example, the municipality provides residents with a voucher of up to EUR 1 010 for a public transport subscription, the purchase of a bicycle, or a bike-sharing service subscription in exchange for scrapping an old vehicle. In the German city of Heidelberg, residents are allowed a free public transport subscription for a year in exchange for scrapping their old car. Using the global energy crisis as a catalyst, Germany and Spain have lowered the costs of public transport, incentivising a move away from private car use to public mobility options.

3.4.2 Electric vehicle grants

For many consumers in the lower income deciles, the price gap between internal combustion engines (ICEs) and EVs is very significant. As a result, the upfront investment cost of electric vehicles is still often out of reach for these consumers. Aiming grants at lower-income households and at the modes of transport most frequently used by those households, such as electric two- and three-wheelers, can help to make clean personal transportation options more accessible.

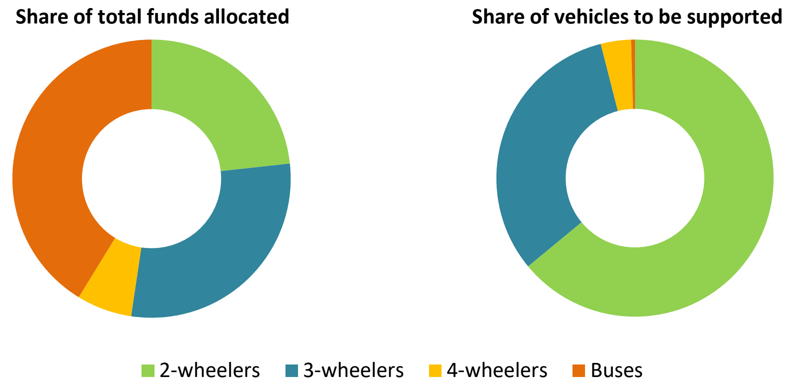
India

The Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme was launched in April 2015 under India's National Electric Mobility Mission to provide financial support for the purchase of electric and hybrid vehicles and to stimulate domestic production of electric vehicles (Ministry of Heavy Industries, 2019). The scheme supported the purchase of electric three-wheelers, four-wheelers and buses used for public and commercial transport; the only privately owned vehicles that were eligible for grant support were electric two-wheelers. It was designed to ensure that the most affordable vehicles got most of the allocated funding, and that a larger proportion of their purchase price was subsidised. Both of these design choices were intended to promote affordable and accessible electric transport. In addition, the scheme included a localisation rule which required the electric vehicles sold under the scheme to be made in India, stimulating the domestic manufacturing of electric vehicles.

The first phase (2015-2019) focused on four areas: demand creation, pilot projects, technological development and charging infrastructure. The second phase (FAME II) was initially a three-year programme from 2019 until 2022 but was subsequently extended until March 2024. It focused on supporting the electrification of public, shared and private transportation by providing grants for electric vehicles and rolling out charging infrastructure. The programme had a budget of USD 1.2 billion in total, 86% of which was spent on demand incentives for electric vehicles and 10% on developing charging infrastructure.

The programme focused on electric two -and three-wheelers and electric buses. The funds were allocated in such a way to stimulate the purchase of around 7 000 electric and hybrid buses, 1 million electric two-wheelers, 500 000 electric three-wheelers, and 55 000 electric and hybrid four-wheel passenger cars. Only 6% of the budget was spent on electric and hybrid four-wheelers, while two-wheelers accounted for 23%, three-wheelers for 29% and buses for 41% (Figure 3.13). The programme also financed charging infrastructure, and 532 charging stations had been installed by July 2022.

Figure 3.13 ▷ Share of funds allocated to EV categories (left) and share of supported vehicle categories (right), FAME II India, 2019-2024



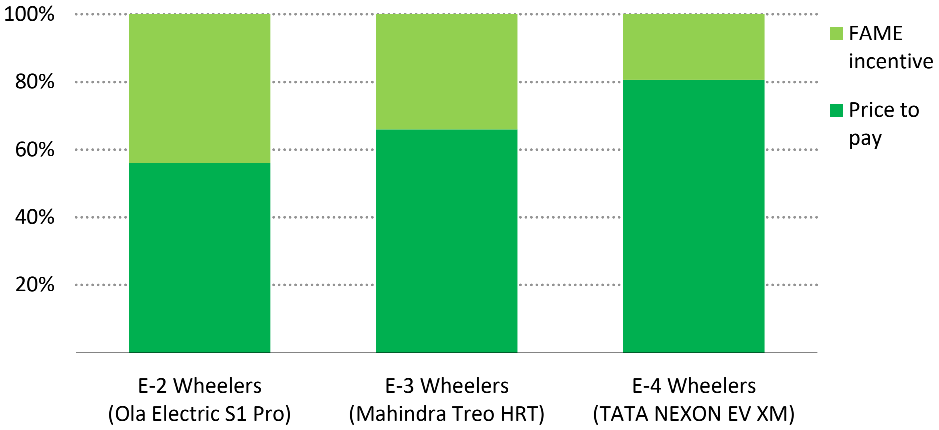
India allocates a larger share of funds towards more affordable forms of electric mobility, such as electric two-wheelers, three-wheelers and buses

Source: IEA analysis based on Ministry of Heavy Industries (2019)

In addition to allocating a large proportion of funds for electric two -and three-wheelers, the scheme provided a higher percentage of subsidy for purchases of these vehicles than for an electric four-wheeler, even though the size of the subsidy itself was higher for a four-wheeler. The price of a typical electric two-wheeler in India is around USD 1 600 (Ola S1 Pro), and the FAME II scheme subsidy covered around USD 700, which amounts to approximately 45% of the cost. For electric three-wheelers, with a typical model priced at around USD 2 400 (Treo Yaari), the subsidy was a little over USD 800 on average, giving a benefit of around 35%. For electric four-wheelers, the price of a typical model (Tata Nexon EV) was much higher at around USD 17 500, and the subsidised amount was a bit above USD 3 300. This means the benefit of the incentive covered approximately 19% of the price (Figure 3.14).

Sales data from electric vehicles in India show that the scheme has had the intended effect. In 2018, before the introduction of FAME II, a total of 129 110 electric vehicles were sold in India, 17 067 of which were electric two-wheelers – a mere 13%. By 2023, the total number of electric vehicle sales in India had increased to over 1.5 million units, and more than half of these were electric two-wheelers (Figure 3.15).

Figure 3.14 ⊳ **Average benefit from incentives under the FAME II scheme, per electric vehicle category**

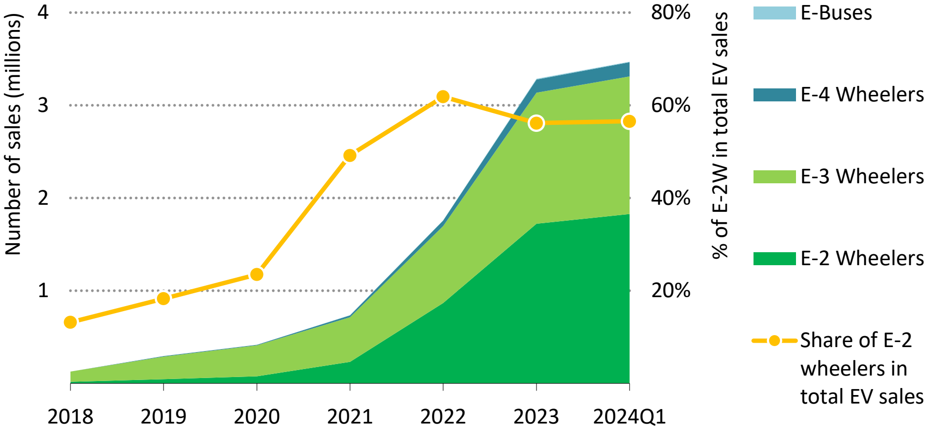


IEA. CC BY 4.0.

In India, the average benefit from incentives is proportionally greatest for two-wheeler and three-wheeler vehicles, which are on average less expensive than electric cars

Source: IEA analysis based on Ministry of Heavy Industries (2022).

Figure 3.15 ⊳ **Sales of electric vehicles per category and share of electric 2-wheeler sales in total EV sales, India, 2018-2024Q1**



IEA. CC BY 4.0.

Well-designed policy can lead to a rise in sales of more affordable forms of electric vehicles

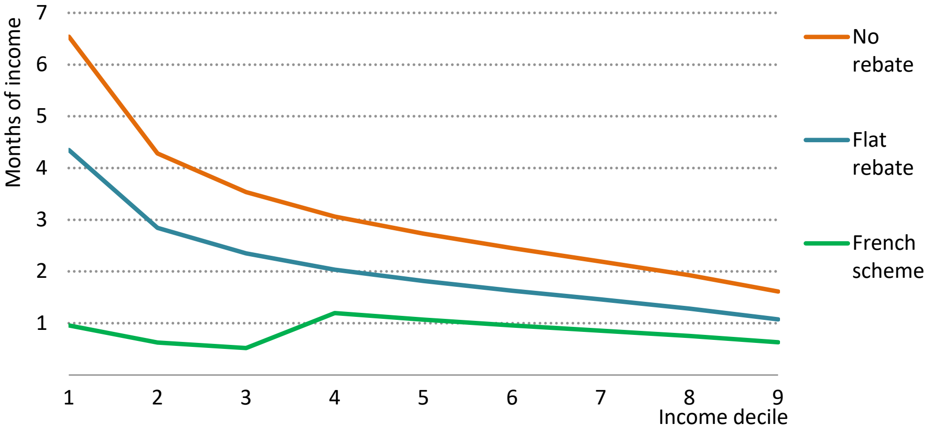
Source: IEA analysis based on Society of Manufacturers of Electric Vehicles (2024)

Overall electric vehicle sales have risen more than ten-fold in five years, and this growth has primarily come from electric two- and three-wheelers. In 2023, the Government of India announced the subsidy amount for electric two-wheelers would be decreased from around 40% of the sale price to just 15%, but this has not dented sales: 725 000 electric two-wheelers were sold in the first ten months of the financial year 2023/24, compared with 728 000 in the total financial year 2022/23, indicating a robust and resilient electric vehicle market.

Europe

Several countries in Europe have redesigned their EV incentives in recent years to integrate distributional considerations. For example, Germany and Spain have introduced price caps for the eligibility of grants to incentivise the development and adoption of lower-price EV models, while Italy and France are providing higher grant amounts if applicants earn below a certain income threshold in order to help lower-income households meet the upfront investment cost of an electric vehicle (Figure 3.16).

Figure 3.16 ▹ Purchase cost premium for EVs in months of average household income in France after applying benefits/grants existing in selected countries



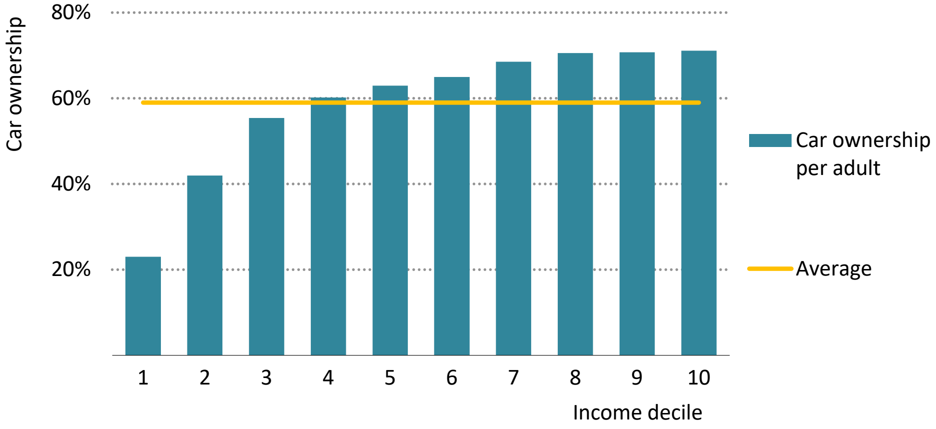
IEA. CC BY 4.0.

Redesigning EV subsidies with fairness in mind can decrease the purchase cost premium of EVs for low-income households, leading to more equitable access

EV subsidies are nevertheless still likely to favour wealthier households. This is partly because car ownership in general is much lower among low-income households: in the United Kingdom, only around 60% of the households in the lowest income quintile have access to a car, compared with over 90% for those in the highest income quintile; many wealthy households also own more than one vehicle. In addition, data from France suggest that new cars are more often purchased by those in the highest income quintile, while low-income households are more likely to buy second-hand cars or older models, which means that it takes time for them to be able to access new technologies (Ministère de la Transition Écologique, 2020). Low-income households buy as many as three used cars for each new one, while this proportion falls to about one to one in the highest income deciles. In Norway, for example, nearly 70% of new cars are bought by households with incomes in the top three deciles, while those earning less than the median income buy only around 15% of all new cars, reflected in their car ownership levels (Figure 3.17).

A number of governments are now adopting policy measures designed to encourage affordable EV use for all income groups. For instance, Spain allows EV grants to be used to purchase one-year-old used cars, and France offered grants of EUR 1 000 for the purchase of a used EV. A similar policy is in place in Malta, where grants are available for used electric vehicles up to five years old, with benefits decreasing based on vehicle age (PwC, 2023).

Figure 3.17 ▷ Car ownership per adult in Norway by income decile



IEA. CC BY 4.0.

Since low-income households have lower levels of car ownership, EV subsidies are more likely to benefit relatively richer households

Source: IEA analysis based on Statistics Norway (2020).

Vehicles are often leased rather than bought in many countries, and some governments support low-income households in leasing EVs. For example, France has implemented a programme called My Electric Leasing which is aimed at people living in low-income households who need a vehicle for professional activities. The programme allows applicants to lease an EV for less than EUR 150 per month, depending on the model. After its implementation in December 2023, the programme received more than 80 000 applications in about three weeks, significantly oversubscribing the originally foreseen 25 000 vehicles.

Box 3.4 ▹ The unequal distribution of public EV charging infrastructure

Most EV charging demand is currently met by home charging, but public chargers are increasingly needed to provide the same accessibility as for refuelling conventional vehicles. In cities, where access to home charging is more limited, public charging infrastructure is essential for a rapid increase in EV ownership. At the end of 2022, there were 2.7 million public charging points in the world, more than 900 000 of which were installed in 2022. However, this charging infrastructure is not equally distributed. In the United States, for instance, seven out of ten public EV charging points are in the richest counties, while more than half of all counties without charging infrastructure fall in the lowest income group. The United States has allocated around USD 600 million to install public EV charging points, with 70% of the budget allocated for projects in disadvantaged communities. Other governments may need to consider whether they should also take action to ensure a more equal distribution of public EV charging points.

3.5 Energy bill reforms

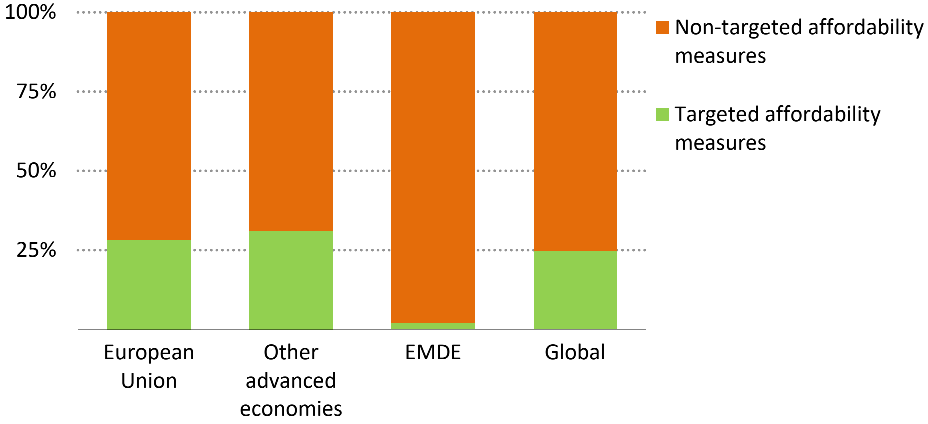
There are many ways in which government policy can influence how much consumers pay for energy. Subsidies can change fuel choices and consumption rates, while smart tariff design can target specific sets of consumers or change the timing of their consumption. Adding CO_2 charges to energy bills or designing carbon markets can similarly change consumer behaviour. All require a careful balancing of different goals and the interests of different stakeholders. The recent global energy crisis led to a worldwide surge in measures to help keep energy prices affordable, underlining the importance and difficulty of carrying out these balancing acts (Figure 3.18). This section explores policy instruments that could enable governments to better direct the affordability support they provide towards the most vulnerable consumers.

3.5.1 Time-of-use tariffs

Time-of-use tariffs are made possible by the deployment of smart meters, and help to make electricity more affordable in at least two ways: they allow consumers to shift their consumption to periods when electricity is less expensive, and at the same time they provide incentives for demand behaviour to align with the broader needs of the energy system, reducing total system costs. As the importance of time-of-use tariffs is increasingly recognised, some existing policy measures such as net metering for rooftop solar photovoltaic (PV) need to be revised to reflect costs more completely and to make the growth of distributed renewables more sustainable (Box 3.5).

From the perspective of affordability, it is important to note that not all demand is flexible, particularly for the most vulnerable consumers. Nonetheless, there are ways in which time-of-use tariffs can be implemented without negatively affecting these consumers. One option could be to implement a block tariff structure where electricity is priced differently depending on the quantity consumed. This would allow for a base amount to be priced at a flat rate, facilitating access and affordability of basic services, while enabling additional blocks to be priced at time-of-use rates.

Figure 3.18 ▷ **Government emergency energy affordability spending earmarked in response to the global energy price crisis by destination, 2021-2023**



IEA. CC BY 4.0.

In advanced economies, government affordability spending mostly sought to compensate electricity and heating costs while EMDE governments focused on transport fuel subsidies

Note: EMDE = emerging market and developing economies

Determining the price level of time-of-use tariffs is important to ensure that customers are not exposed to undue price risk while still maintaining incentives for efficient behaviour and allowing for cost savings by shifting consumption. Introducing time-of-use tariffs that reflect spot prices, for example, creates strong signals for behaviour change, but at the same time exposes household customers to high levels of risk with no tools to manage their inflexible energy demand.

Another option for improving affordability as more services are electrified could be to allocate multiple meters to a single customer, each of which could have a separate tariff structure. This would allow certain flexible loads, such as electric vehicles or water heaters, to be placed on time-of-use tariffs, without exposing inflexible basic services such as cooking, heating or lighting to the same variable tariff. The ability to use time-of-use tariffs to shift load and reduce energy costs for consumers can be significantly increased by utilising enabling technology (such as EV chargers or water heaters that can respond to price signals or time slots).

Box 3.5 ▹ Does net metering for solar PV make electricity more affordable?

Net metering schemes have been successful in many markets in supporting the deployment of rooftop solar PV, bringing in additional private capital and benefiting consumers. For many years, annual net metering with retail pricing – where credits valued at the retail price are earned for solar PV output that can be applied to a bill over a year – was the main policy incentivising distributed solar PV (IEA, 2019). However, net metering does not reflect the actual value of output, which time-of-use tariffs make transparent, because it pays a single fixed price for all solar PV output. As a result, net metering risks creating higher system costs and shifting costs from higher-income households to lower-income households.

Regardless of the structure of end-user electricity bills, which vary by region, the cost of providing electricity includes both fixed and variable costs. Fixed costs include those related to physical infrastructure, such as the grid connection, while variable costs cover actual electricity consumption from the grid. In most cases, adding rooftop solar PV to existing households reduces only the variable costs, roughly equal to the wholesale electricity price (IEA, 2016). When new households that integrate rooftop solar PV are thereby able to reduce their grid connection charge, the fixed costs they pay decrease. Since the overall fixed costs of the system do not decrease, this reduction in grid connection charges for households with rooftop solar must be funded from elsewhere.

In instances where funding for net metering comes entirely from within the electricity customer base, giving a value to rooftop solar PV that is higher than the avoided costs creates a deficit that needs to be made good by consumers without solar PV or through lower profitability for electricity providers. Given the upfront cost, wealthier households have been the primary adopters of rooftop solar PV, including in the United States (LBNL, 2023). In some instances, the way that rooftop solar PV is valued through net metering has shifted costs from wealthier households with rooftop solar PV to lower-income households that could not afford solar PV. In this situation, as the share of homes with rooftop solar PV increases, so does the extent of the cost shifting. To avoid this, electricity generated by rooftop solar PV should be valued in line with the avoided costs.

There are other ways in which the uptake of solar PV can be supported to avoid the problem of cost shifting. These include setting up sustainable support mechanisms that can scale up to support a high share of households with rooftop solar PV, and making financial support available from outside the consumer base, as in the Inflation Reduction Act passed in 2022 in the United States, which included federal funding for rooftop solar PV. Such funding should, however, be weighed against other options for its use, including the provision of support for utility-scale solar PV in regions where there is potential for this; utility-scale typically has lower installed costs and higher performance than rooftop solar PV. Where net metering schemes continue, they should be reconciled in the shortest time frame possible – ideally hourly or even more frequently.

3.5.2 Reforming fossil fuel subsidies

In some countries, regulated end-user prices for fossil fuels and for electricity are set lower than their market value. While such policies are intended to keep energy prices affordable, they encourage wasteful consumption, distort investment incentives across the economy and also push up emissions. Moreover, when they are untargeted, as is often the case, households which consume more energy – which in general are higher-income households – receive a greater share of the subsidies.

There are many reasons governments might decide to reform fossil fuel subsidies. Such subsidies can create fiscal burdens, raise environmental concerns, introduce economic inefficiencies and – if untargeted – be at odds with social equity goals. However, subsidy reform is politically sensitive and requires careful planning and stakeholder engagement to manage its potential short-term economic and industrial impacts as well as its effects on households, especially those with lower incomes. International commitments have been made at various fora, including the World Trade Organization (WTO), Group of 20 (G20) and Group of Seven (G7), to advance the phase-out of “inefficient” fossil fuel subsidies which do not address energy poverty or just transitions and encourage wasteful consumption. However, only 16 of the nationally determined contributions (NDCs) submitted under the Paris Agreement to date have included a commitment to implement subsidy reform.

While there are many successful and unsuccessful examples of reform, past examples suggest that pricing reform needs to be embedded in a broader suite of policies that includes efficiency measures and a social safety net for vulnerable groups (IEA, 2024b).

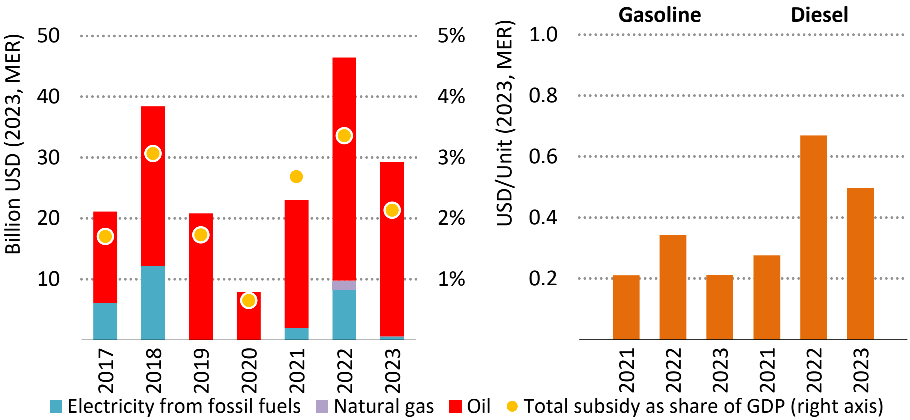
Indonesia

Fossil fuel subsidies has been a longstanding issue in Indonesia and have been one of the central fiscal policy challenges. Energy subsidies in Indonesia cover electricity, fuel (diesel and gasoline), and liquefied petroleum gas (LPG) and have typically benefited higher-income households more than poorer ones. In 2019, for example, the top 20% of households enjoyed nearly half of fuel subsidies while the bottom 40% received less than one-fifth. In September 2022, Indonesia made a renewed effort to switch from subsidies to more targeted support, after government spending on fossil fuel subsidies rose to over USD 30 billion, or more than three times the original budget. The reforms resulted in a 30% increase in prices (Figure 3.19) and were accompanied by the implementation of direct cash transfers to low-income households and increased support for public transport.

Egypt

Over the past decade, Egypt has gradually implemented subsidy reforms to manage its fiscal deficit, discourage wasteful consumption and improve the reliability of electricity networks. As a result, the prices of gasoline, residential LPG and electricity have gradually been increasing. To cushion the impacts on vulnerable households, Egypt introduced a targeted cash transfer programme in 2015, the amounts of which have declined from a peak in 2018. The value of subsidies jumped in 2022 as the effects of the global energy crisis jolted fuel and electricity markets. The Egyptian government allocated over USD 25 billion to petroleum product subsidies in 2022, contributing to an increase in the overall budget deficit, and the total subsidy burden reached 14% of gross domestic product (GDP) (Figure 3.20).

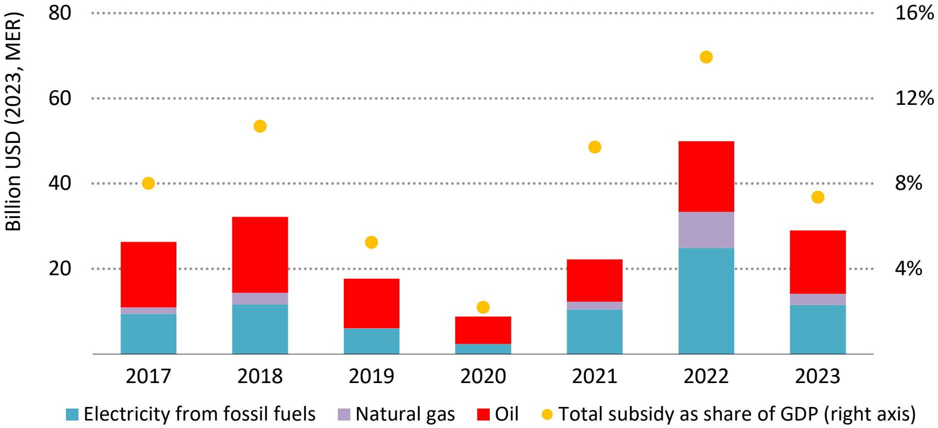
Figure 3.19 ▻ Fossil fuel consumption subsidies (left) and gap between benchmark price and end-user price (right) in Indonesia



IEA. CC BY 4.0.

Oil subsidies, which account for the majority of fossil fuel consumption subsidies in Indonesia, reached a record level in 2022; this triggered policy reforms

Figure 3.20 ▻ Value of fossil fuel consumption subsidies in Egypt, 2017-2023



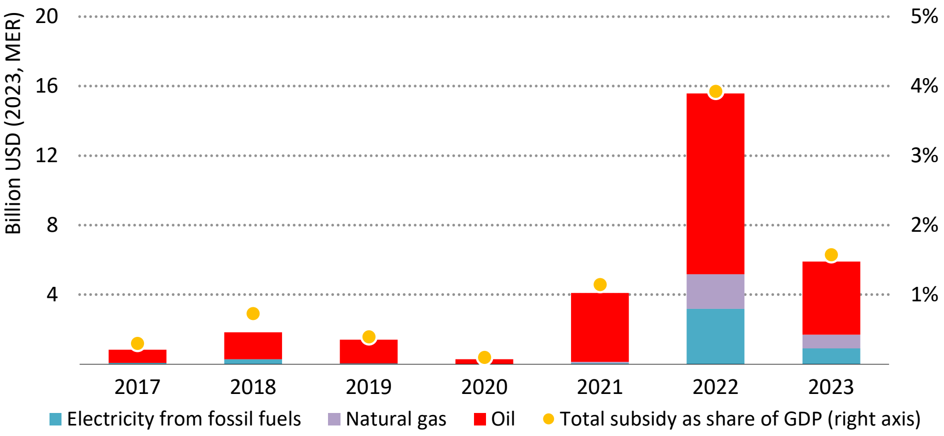
IEA. CC BY 4.0.

After significant falls in recent years, fossil fuel consumption subsidies in Egypt increased significantly in 2022 in response to the global energy crisis, but have come down since

Nigeria

After a major rise in the cost of fossil fuel subsidies in 2022, the Nigerian government introduced two major policy changes in May and June 2023. These changes reduced the level of fossil fuel subsidies and brought about a change to a market-reflective exchange rate system (Figure 3.21). They led to a 160% increase in premium gasoline prices and to inflation reaching 27% year-on-year in October 2023. To protect consumers, the government provided direct cash transfers to 15 million poor households for three months, starting in October 2023. These cash transfers were extended in February 2024, and the government has also promised additional support for households, including social security schemes for unemployed youth and graduates and consumer credit schemes.

Figure 3.21 ▹ Value of fossil fuel consumption subsidies in Nigeria, 2017-2023



IEA. CC BY 4.0.

Historically high fossil fuel consumption subsidies in Nigeria have forced the government to undertake rapid reforms

3.5.3 Recycling revenues from carbon pricing

Another way to increase the affordability of the clean energy transition is by recycling revenues from carbon pricing instruments. The distribution of revenues and costs from an emissions trading system (ETS) depends on the design and implementation of the specific programme. Governments normally generate revenue by auctioning emission allowances or selling them directly. In some cases, allowances may be initially distributed for free to certain industries, with firms in those industries being given the option to sell surplus allowances later. When allowances are auctioned, the government usually has the authority to decide how to allocate the revenue generated.

This revenue can be used for various purposes, such as funding clean energy projects, supporting climate adaptation measures or promoting industrial competitiveness.

Governments may also choose to recycle the revenue back into the economy by implementing measures such as tax cuts or rebates, or by investing in renewables and energy efficiency projects.

Table 3.2 ▷ Main uses of carbon revenues in selected emissions trading systems and carbon taxes

	General budget	GHG mitigation support	R&D support	Climate adaptation	Energy system modern-isation	Household support	Industry support
EU ETS	●	●	●	●	●	●	●
Korea ETS		●	●	●	●	●	
California cap-and-trade		●				●	●
US Regional Greenhouse Gas Initiative ETS	●	●			●	●	
Canada ETS and levy		●		●		●	●
New Zealand ETS		●				●	
Ireland carbon tax	●	●				●	
Switzerland CO_2 levy		●				●	

Notes: GHG mitigation support includes the use of carbon revenues to fund clean energy deployment (e.g. low-emissions transport or renewable energy) as well as energy efficiency programmes. Energy system modernisation includes support for the modernisation of energy networks and energy storage. For the US Regional Greenhouse Gas Initiative, this includes "beneficial electrification" which is the displacement of direct fossil fuel use with electric power. Canada requires all federal territories and provinces to implement their own carbon pricing system or adopt the federal one, which includes a levy on fossil fuels and an ETS for large industrial emitters.

European Union

As the European Union gears up to create a new, separate emissions trading system for emissions from fuel combustion in buildings and road transport and some additional smaller industries (ETS 2), it has adopted a so-called Social Climate Fund which will pool the revenues generated from the auctioning of allowances in ETS 2 (European Union, 2023).

Boosted by a 25% mandatory contribution by EU member states, this fund is expected to mobilise almost USD 100 billion between 2026 and 2032. With these resources, it will support vulnerable households, transport users and microenterprises by funding building renovations and affordable energy-efficient housing and by improving access to zero- and low-emissions vehicles and incentivising the use of affordable public transport. It will also be able to provide temporary direct income support to vulnerable households and transport users affected by higher fuel prices as a result of ETS 2.

California

Since 2012, California has been implementing a cap-and-trade system. Through its consignment auction system – whereby allowances are auctioned, and the revenues returned to utilities under certain conditions – the state requires investor-owned utilities (which make up 75% of the market) to distribute all their auction proceeds to industrial, small business and residential customers.

Between 2013 and 2021, some 80% or around USD 6 billion of these revenues were returned to households through lump-sum rebates (California Climate Credit), with the rest distributed to industrial and small businesses or invested in clean energy and energy efficiency programmes (California Air Resources Board, 2023).

The benefit of using lump-sum payments is that it preserves the cost pass-through of the carbon price signal to consumers, and thus maintains the incentive to reduce electricity demand, while still returning money to vulnerable households. Meanwhile, state-owned utilities must transfer their auction proceeds to the Greenhouse Gas Reduction Fund, which supports state programmes in clean transportation, sustainable communities, clean energy, energy efficiency and waste management. California mandates that 35% of these funds must go to support disadvantaged and low-income communities (California Climate Investments, 2022).

3.6 Distributed clean energy production

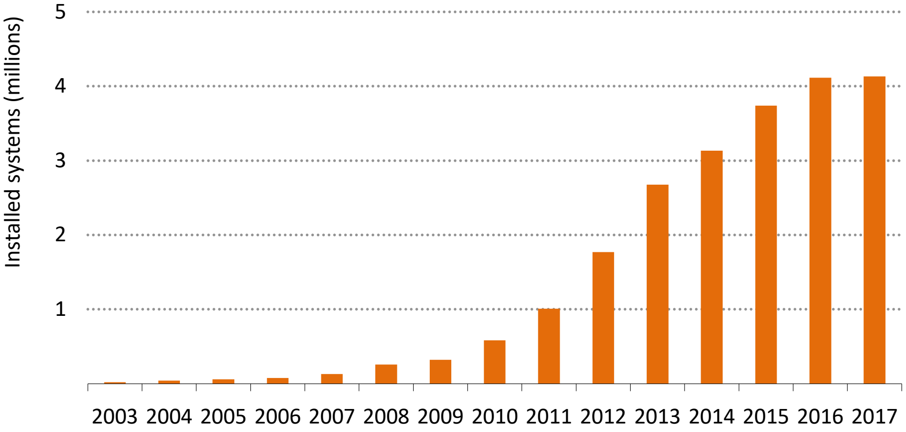
Residential energy production has grown rapidly in recent years. Rooftop solar PV in particular has become more prevalent across the world: 25 million households had solar PV rooftop installations in place by 2022. Household energy production can significantly lower energy bills because it reduces the need to buy electricity from the grid, and the investment often pays for itself in under ten years. However, the upfront investment costs involved and limited or unreliable grid connections can form barriers to access, especially for low-income households in rural areas. Policy design can make it easier to access affordable clean energy production. For example, countries could purchase solar systems in bulk and install them in rural low-income communities, if they have the fiscal space to do so, or provide microloans to be paid back through energy bill savings.

Bangladesh

In 1997, Bangladesh founded the Infrastructure Development Company Limited (IDCOL) to serve as a non-bank financial institution to help the country's development, including by providing access to electricity. In the early 2000s, only 27% of the rural population in Bangladesh had access to electricity (World Bank, 2023a). In 2003, IDCOL started the solar home systems (SHS) scheme with the aim of installing SHS to meet the basic electricity requirements of people in rural areas not connected to the grid. IDCOL initially received credit and grant support from the World Bank and Global Environment Facility to fund the programme. In total, IDCOL has provided more than USD 500 million of credit finance and almost USD 100 million in grants since the programme started (IDCOL, 2023).

The SHS programme is one of the largest off-grid electrification programmes in the world. More than 4 million SHS have been installed since 2003 (Figure 3.22), bringing solar electricity to 18 million people, or around 12% of the country's total population, most of whom previously used kerosene lamps for lighting purposes. Thanks in part to the programme, electricity is available today to almost the entire population of Bangladesh. From 2015 onwards, the programme was gradually replaced as the rural grid expanded and solar energy systems were provided through other support schemes.

Figure 3.22 ▷ Cumulative solar home systems, Bangladesh, 2003-2017



IEA. CC BY 4.0.

Solar home systems grew rapidly under the Bangladesh programme

China

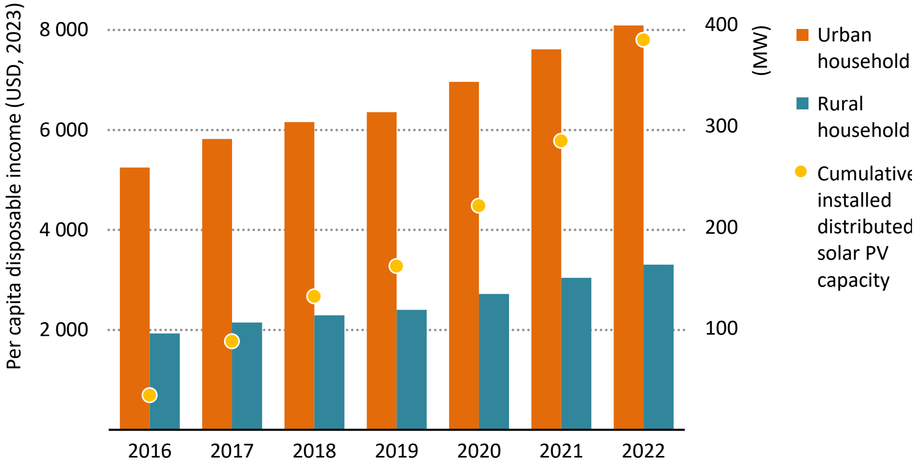
in 2014, the Solar Energy Poverty Alleviation Programme (SEPAP) was launched by the Chinese government as part of its broader strategy to alleviate energy poverty and promote renewable energy. The National Energy Administration (NEA) and the State Council jointly issued a work plan to implement the programme in order to tackle energy poverty in remote regions where there is limited or unreliable grid infrastructure. The six-year initiative targeted the installation of over 10 gigawatts (GW) of capacity with the objective of benefiting over 2 million low-income households nationwide by 2020.

Under the SEPAP umbrella, the government funded in full four main types of solar projects in rural regions:

- village-level solar PV power stations, with the income generated by these stations shared among all low-income households within the village
- multi-village joint construction arrays
- distributed rooftop installations targeting poor households
- centralised, large-scale PV power stations for villages that are owned by villagers and run by government-appointed local officials and that serve as centralised sources of electricity for rural communities.

According to the Chinese NEA, the implementation of SEPAP resulted in the generation of 26 GW of electricity, producing an annual economic profit of around USD 2.5 billion and creating 1.25 million jobs (NEA, 2023). The programme also increased the annual income of the 2 million households involved by around 7% per household, narrowing the income gap between urban and rural areas (Zhang et al., 2020) (Figure 3.23).

Figure 3.23 ▷ Change in cumulative solar PV capacity and rural/urban household income, China, 2016-2022



IEA. CC BY 4.0.

Installed distributed solar PV capacity has steadily increased in China

Note: MW = megawatt.

Sources: IEA analysis based on National Bureau of Statistics of China (2023) and IEA (2024a).

Box 3.6 ▻ Financing mechanisms for solar PV

Distributed solar PV has the potential to increase access to affordable energy, particularly for low-income and rural households. However, the upfront costs of solar installations often pose a significant barrier to its use. Various financing instruments and incentives have emerged to address this issue.

Subsidies, grants, discounts, rebates and tax credits can help to make solar PV financially viable for low-income households. These incentives serve either to lower the initial cost or enhance the overall value of solar installations. In the United States, a Low-Income Communities Bonus Credit Program under the Inflation Reduction Act provides for an increase to the energy investment credit for solar projects if low-income communities stand to directly benefit from them.

Community solar programmes allow multiple households to share the benefits of a single solar installation. This can be beneficial for low-income households who do not have suitable roofs for solar panels or who cannot afford individual installations. Participants sign up for a portion of the solar energy generated by the project and receive credits on their electricity bills. In the United States, community solar programmes aim to power around 5 million households by 2025, generating USD 1 billion in electricity bill savings.

There are also some programmes specifically aimed at **solar PV for social housing**. For example, Brazil has announced a 2 GW solar plan to deploy PV systems on a large scale in social housing with the aim of reducing electricity bills for families by up to 70%. This initiative involves building 2 million new social housing units by 2026, each equipped with two solar modules that provide 1 kilowatt of power per dwelling. New Zealand has a similar programme called the Māori and Public Housing Renewable Energy Fund.

Low- or zero-interest solar loans help to cover upfront costs. For example, the Massachusetts Solar Loan Support Program reduces the loan principal by up to 30%, lowers interest rates by up to 1.5%, and offers loan loss guarantees for residents with poor credit.

Other types of instruments include **on-bill repayment, on-bill financing and pay-as-you-go programmes** which empower utilities to fund solar upgrades for low- to moderate-income households. Under these programmes, utilities provide the initial capital for solar installations and customers repay this through a tariff integrated into their electricity bill.

Solar leases provide an alternative to ownership of solar PV systems, enabling households to benefit from solar energy without any need to pay upfront costs. With solar leasing, homeowners instead pay a fixed rate determined by the leasing company for the installation and use of solar panels.

3.7 Clean energy access

Access to modern energy is crucial for households to earn a wage, start a business or gain access to education. In sub-Saharan Africa, around 40% of the population lives in extreme poverty, and most of the households without access to modern energy fall within this group (IEA, 2022). Affordability constraints prevent these households from gaining and maintaining electricity access, and these same constraints also imply that many energy access projects will not be commercially viable for profit-driven financiers. In this context, public sector intervention through targeted policies can be effective in lowering the barriers to access and scaling up the adoption of cleaner energy sources. The public sector has a key role as a direct financier for energy access projects, and it can also use policy tools to help crowd in private sector investment.

Nigeria

In Nigeria, in 2021 (latest available data) around 40% of the population does not have access to electricity; in rural areas, this increases to more than 70% (World Bank, 2023b). In 2021, around 40% of Nigeria's electricity needs were met with diesel generators, increasing the country's emissions and exposing users to price volatility (IEA, 2023). The government and private sector have identified mini-grids as a cost-effective solution to increase electricity access and to reduce reliance on diesel and gasoline generators (Figure 3.24). While the case for mini-grids is clear, attracting investment can still prove challenging. Private mini-grid developers face high initial capital costs, and there are strict limits on what the end users with whom they are working can afford. As a result, developers are still heavily reliant on external forms of support such as grants.

Nigeria has put in place strong policies to drive the expansion of the country's mini-grid sector, and the Nigerian Electricity Regulatory Commission regulatory framework for mini-grids set out clear guidance in 2016 for mini-grid development. Its regulations covered procedures for licensing, tariff setting and compensation mechanisms; they also included safety measures, contract templates and quality standards. The predictable and straightforward processes that were put in place paved the way for the launch of the 2019 Nigeria Electrification Project (NEP), which aims to provide electricity access to more than 500 000 people by 2025 while simultaneously avoiding 1.7 million tonnes of CO_2 emissions (AFDB, 2024). The NEP has so far installed over 63 000 electricity connections through mini-grids, providing electricity to 3.8 million people, far exceeding its initial expectations (REA, 2024).

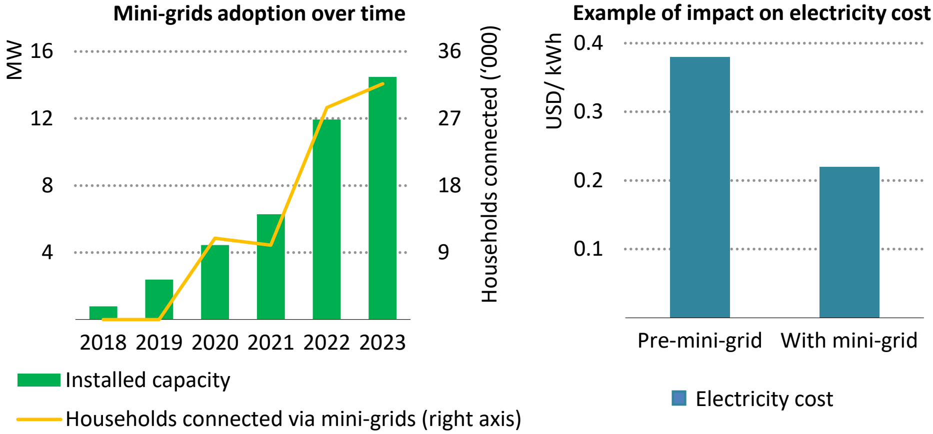
The NEP includes access to grants via two results-based financing mechanisms under which grants are distributed after mini-grids are built and households connected to the Rural Electrification Agency's (REA's) satisfaction. There are two schemes ("windows") that developers can apply to:

- **Minimum Subsidy Tender window**: the REA provides data on nearly 350 priority sites that were selected based on geospatial analysis and surveys on customer segmentation and estimated consumption. Developers compete for projects, with proposals being selected based on the minimum subsidy requested per connection.

- **Performance-Based Grant window**: developers carry out their own due diligence and submit offers to the REA to receive a grant per new connection. Grants are allocated on a first-come-first-served basis, with a minimum fixed grant amount per connection.

The clear policy environment and strategic access planning established by the government has helped to mobilise significant investment, and the NEP has secured investment of USD 350 million from the World Bank and USD 200 million from the African Development Bank (GIZ, 2023). The government has also worked closely with concessional finance providers and the private sector to ensure that blended finance schemes are as effective as possible. It has in addition responded to feedback from the private sector and made its schemes more flexible by adjusting the grant amount and delivery schedule to take account of risks and high initial costs. Despite this, the economics of many projects remain challenging, and private investors are still dependent on mobilising additional grant funding. As a result, the pace of implementation dropped significantly in 2023 after grant funding had been fully disbursed (World Bank, 2024b).

Figure 3.24 ▷ Mini-grid capacity and costs in Nigeria



IEA. CC BY 4.0.

Government policies have supported a growth in mini-gird construction, often resulting in cheaper power for the end user, but many projects are still reliant on grant funding

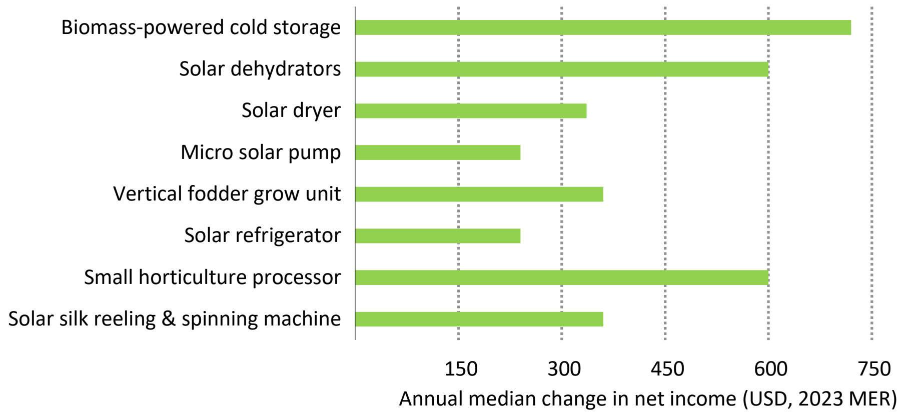
Notes: MW = megawatt. kWh = kilowatt-hour. The case study in the right-hand side is based on Wuse market in Abuja. In 2019, before the arrival of the mini-grid, customers were reliant on generators and grid power. The costs were significantly lower when a mini-grid was introduced in 2022.

Sources: IEA analysis based on Nigeria SE4All (2024) and World Bank (2024a; 2024b).

Box 3.7 ⊳ Socio-economic impacts of affordable clean energy

In addition to improving health outcomes and reducing emissions, gaining access to affordable clean energy can have socio-economic benefits that include increased productivity and employment, higher incomes or savings, and improved gender and other welfare outcomes. One example of programmes aiming to capture those additional benefits is the Powering Livelihoods programme in India, jointly led by public policy think tank Council on Energy, Environment and Water (CEEW) and social enterprise incubator Villgro. This multimillion programme aims to promote the commercial scaling up of affordable clean energy through support focused on capacity building in local enterprises and has enabled the deployment of around 13 000 clean technologies by nearly 20 000 people in rural communities. It has more than doubled the annual revenue of the enterprises involved in three years and attracted around USD 7 million in follow-on capital from investors (Figure 3.25).

Figure 3.25 ⊳ **Median increase in net annual income due to the deployment of clean energy through the Powering Livelihoods programme, June 2020-December 2022**



The Powering Livelihoods programme has led to a rise in annual household incomes

Notes: Net income increase is dependent on productivity (output), additional revenue streams, savings on fuel/electricity, input costs and loan repayment. This case study was developed with the inputs of CEEW (2023).

Data on the socio-economic impact on the end users show that the usage of clean energy technologies has also led to positive social impacts such as higher self-confidence, skills development and better access to credit/institutions. Recognising the potential of productive use of renewable energy, the Indian government set up in 2022 a policy framework for the Promotion of Decentralised Renewable Energy Livelihood applications.

3.8 Policy design for affordable and fair energy transitions

Policies promoting clean energy can take many forms, but the existence of a policy is often not enough to ensure its affordability and uptake. This chapter has explored how strategic design of clean energy policies can make these technologies more widely available to societies, particularly for lower-income communities, setting out examples of how policy design affects distributional outcomes and the co-benefits felt by consumers. Although circumstances vary widely among countries, the analysis reveals several core considerations for governments when designing policy for more affordable, equitable outcomes.

- **Make the most of clean energy technologies that are already cost-competitive:** affordability should be a baseline goal for energy transitions, but this does not mean that all interventions promoting affordability are expensive. Many clean and efficient technologies are already cost-competitive with the alternatives, and the task for governments is to ensure that they are widely available and that their benefits are recognised.
- **Incentivise continued cost reductions alongside greater local benefits**: governments have multiple levers at their disposal to help bring down costs for clean technologies. For example, bulk public procurement is a powerful instrument for achieving economies of scale while encouraging local manufacturing.
- **Reduce upfront costs where possible, particularly for low-income groups**: high upfront cost can be a major barrier for low-income households to access clean energy technologies and programme benefits. Minimising upfront costs can reduce the risk that the most vulnerable households will be excluded from clean energy transitions.
- **Use scarce public resources carefully to scale up investment and impacts:** public finances are under strain in many countries and cannot cover all needs, so policy design should seek to “crowd in” private finance where possible and should encourage business models that allow private companies to contribute a larger share of the investment.
- **Think through the distributional impacts of policies in advance:** engaging in an inclusive way with a diverse group of stakeholders on the potential consequences of a policy beforehand can limit affordability risks and unintended consequences.
- **Know the groups that you are targeting**: information is key to good policy making, so mapping out the needs and preferences of key groups is essential. This includes issues such as language diversity and access to information technologies.
- **Make administrative procedures as clear and simple as possible**: time-consuming or excessively bureaucratic processes can act as a major disincentive for low-income and rural populations in particular. Keeping things simple, using plain language, translating important documents as necessary and offering support during the application process all matter in this context.
- **Communicate early and often:** lack of consumer awareness is often a key barrier in scaling up clean energy technologies, even when they are cost-competitive. Well-targeted information campaigns raise awareness of preferential funding opportunities

and provide clear advice on how to access them. They are most successful when based on behavioural insights and when they involve trusted, local intermediaries.

- **Monitor, evaluate and adapt:** structural data collection, analysis and dissemination, including information on where the benefits and costs of a measure accrue, is essential to evaluating programmes on the basis of key performance indicators or benchmarks for success. Designing a framework that can easily be adapted in the light of feedback allows policy makers to improve the policy over time, based on the analysis of such metrics.

Chapter 4

Price shocks and affordability

Preparing for the unexpected

SUMMARY

- This chapter addresses risks to affordability from sudden shocks to the energy system, considers how the causes of such price shocks might evolve as the world moves through energy transitions, and asks what lessons on policy responses can be drawn from the recent global energy crisis.
- Energy history has been marked by sporadic oil price shocks. Since 1973 there have been 13 episodes of sharp or sustained oil price rises, with their incidence increasing slightly since 2000. Rapid demand growth, disruptions to supply or geopolitical events can quickly lead to price escalation if spare capacity is thin.
- European gas markets have been considerably more volatile than oil markets over the last ten years. High transportation costs mean that global gas markets are more regionally fragmented than in the case of oil, even if they are increasingly linked by LNG. As recent years have shown, gas markets are prone to geopolitical disruption. They are also sensitive to weather and closely tied to electricity markets.
- The transition to a more electrified, efficient, renewables-rich energy system will reduce overall exposure to fossil fuel price volatility. Risks remain, however, and will increasingly fall on emerging and developing economies, which are set to account for a higher share of global oil and gas use. Lower revenues for major producers meanwhile increase the possibility of geopolitical instability affecting supply.
- The transformation of the power sector brings multiple benefits, but there are risks if the process of change is poorly sequenced, especially if investments in grids, flexibility, demand response and resilience fall behind. Many power systems are vulnerable to an increase in extreme weather events and cyberattacks.
- Pressures on clean energy supply chains could push up inflation and the overall cost of transitions. Mineral prices are falling, but if they had remained at the high levels seen in 2022, EV battery pack costs in 2023 would have been 13% higher. The risk of future spikes points to the need for action to build diverse, resilient supply chains.
- During the recent global energy crisis, governments spent USD 900 billion to help consumers manage sky-high energy prices. Three-quarters of this support consisted of retail price interventions benefiting all consumers that, while quick to administer, were an inefficient and costly way to protect the vulnerable, and that also muted or distorted demand responses.
- Alongside measures to promote orderly transitions, governments need to increase their readiness for future price shocks by designing emergency support mechanisms that can be time-limited and targeted towards consumers that most need assistance, and by stepping up investments in climate and cyber resilience.

4.1 Introduction

The preceding chapters addressed a series of broad questions about the affordability of transitions and how policies can make clean energy technologies more widely accessible. This chapter approaches the issue of affordability from a different perspective: what about the risk of sudden shocks to the system? Price spikes for different fuels and for electricity can occur for a variety of reasons, but one thing they have in common is that the impacts fall disproportionately on poorer segments of the population. An ability to anticipate, avoid and mitigate the risks associated with such price shocks is an important element of a comprehensive approach to affordability. The discussion is divided into three parts:

- The first section explores the frequency and impact of past energy price shocks. It covers oil, gas and coal markets as well as electricity.
- The second section then considers the future and assesses how the causes of price shocks might evolve as the world moves through energy transitions, and what new risks might emerge.
- A final section considers the implications of price shocks for consumers and considers the case for policy interventions to mitigate risks. It draws on the experience of the recent global energy crisis to come up with a menu of best practices for policy makers to minimise the risk of price spikes and to respond to them when they happen.

4.2 Past price shocks

4.2.1 Oil

The global economy has become steadily less dependent on oil over recent decades, but it remains the most valuable traded commodity in the world. The oil price remains the most watched of the energy indicators. It is a bellwether of the state of the global economy and its increasingly complex geopolitics as well as an indicator of the balance of oil demand and supply.

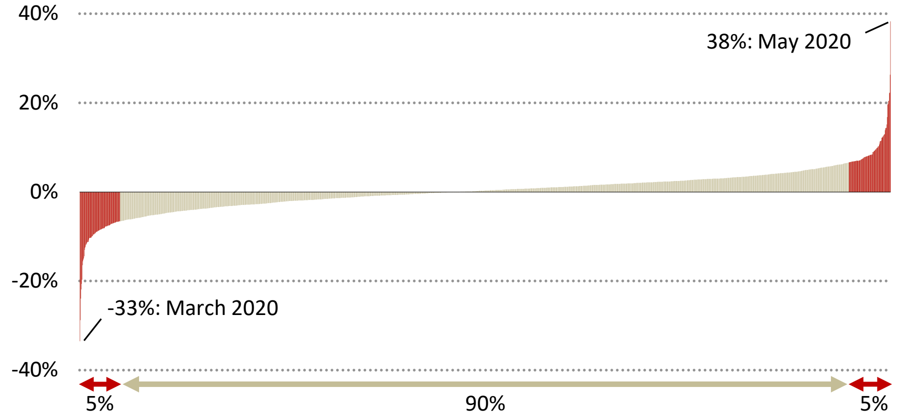
The first oil shock of the 1970s was a watershed moment for oil markets, shifting the balance of market power towards large producers in the Middle East while also prompting a series of policy responses from oil-importing countries, which sought both to diversify away from oil and to secure more reliable sources of supply. Since then, the oil market has evolved to become more competitive and integrated, especially as technological advances (and periods of high prices) have brought new resources into play, including deepwater and tight oil from shale formations.

Well-functioning markets, alongside the spare capacity held by members of the Organization of the Petroleum Exporting Countries (OPEC), have helped countries respond to shifts in supply and demand. The International Energy Agency (IEA) co-ordinated system of oil stocks, which was created in response to the first oil shock of 1973, has also provided a buffer against disruptions. But the history of oil markets has nonetheless been one of volatility.

The way that changes in global oil prices are passed through to consumers varies substantially from country to country. The link between global and domestic fuel prices is weakest in countries that have fixed, heavily subsidised retail prices, as many Middle East oil and gas producers do. Pass-through is much more immediate in advanced economies. In all countries, government interventions through taxes and subsidies alter price signals and can exacerbate situations of both high and low prices.

Although most short-term oil price movements at the daily or weekly level are relatively small, prices do occasionally plummet or surge (Figure 4.1). Since 1973, there have been multiple episodes of sharp or sustained oil price increases (Figure 4.2).[1] While these price episodes have occurred at irregular intervals, they have become slightly more frequent since 2000.

Figure 4.1 ⊳ **Distribution of week-over-week percentage changes in the price of Brent crude oil, 1987-2024**



IEA. CC BY 4.0.

Ninety percent of the weekly changes in the price of Brent crude oil are within ±7%; the largest since 1987 were the crash and recovery in 2020 in the early weeks of the pandemic

Source: IEA analysis based on US Energy Information Administration (2024a).

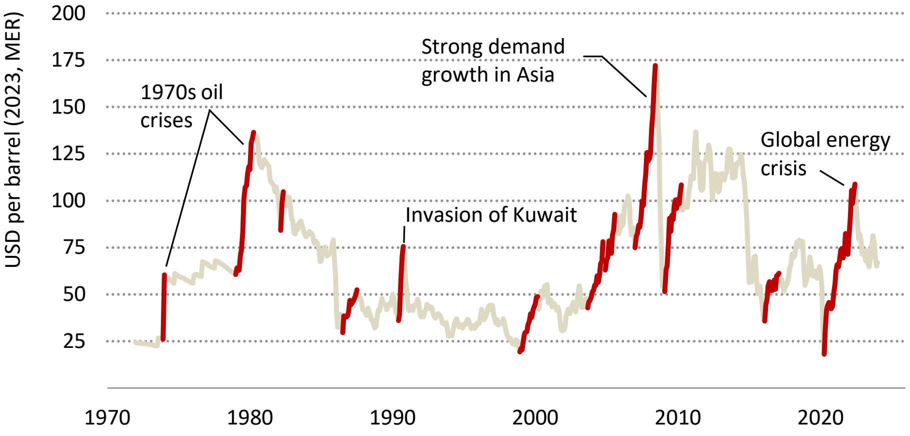
Oil price shocks have been influenced by a variety of factors including economic conditions, business cycles, market dynamics, geopolitical risks and events (especially those involving major resource-holders and exports, or affecting major chokepoints for trade such as the Strait of Hormuz), and natural disasters and weather-related incidents. In many cases, buffers have been in place to absorb these shocks. When spare capacity is thin, however,

---

[1] Sharp is defined as a monthly price rise or successive monthly price rises that average at least 10%. Sustained is defined as a series of monthly price rises that average between 5% and 10% over a period of at least six months.

robust demand and/or tight supply can result in rapid upward pressure on prices, since both demand and supply respond relatively slowly to changes in price.

Figure 4.2 ▹ **WTI real price of crude oil and selected major oil price shocks, 1972-2024**



IEA. CC BY 4.0.

Crude oil prices have fluctuated significantly over the past 50 years, and fluctuations have sometimes led to major price shocks

Note: WTI = West Texas Intermediate; MER = market exchange rate.

Source: IEA analysis based on US Energy Information Administration (2024a).

The shale revolution in the United States (US), enabled in part by the extraordinary rise in oil prices in the early 2000s, has had a massive impact on oil and gas markets and politics. There are many examples of a country switching from being a net energy exporter to a net importer; it is very rare to see the opposite, especially when the country in question is one of the world's largest importers of oil. Nor has this simply been a question of an increase in supply: the short investment cycle of tight oil and shale gas, compared with conventional production, also had major implications for market and security dynamics because it allowed for a relatively rapid supply response to price signals. This responsiveness remains an important feature of oil markets, although it has diminished somewhat as investors and shale companies have started to prioritise capital discipline over output growth.

Case study: The run-up in oil prices in 2008

Many past oil price shocks were the result of a growing misalignment between supply and demand rather than a sudden physical disruption. The run-up in oil prices in 2008 is a case in point. In essence, the People's Republic of China (hereafter "China") led a strong increase in oil demand; the supply of oil was unable to keep pace; and over time the mismatch led to a significant increase in oil prices, which peaked at a record USD 147 per barrel in July 2008 (in nominal terms). This price shock brought higher energy costs for households and businesses and contributed to broad inflationary pressures in the global economy. It also provided the spur for efficiency gains, precipitated other demand-side effects (for example, the automobile industry was hit by declining car sales as consumers became more cautious about buying new vehicles) and incentivised technological innovation on the supply side, notably the combination of hydraulic fracturing and horizontal drilling that produced the US shale revolution.

4.2.2 Natural gas

The dynamics of price shocks for natural gas differ from those in oil markets. The high cost of building gas infrastructure for gas transported through pipelines or as liquefied natural gas (LNG) means that natural gas markets are more regionally fragmented. The combination of high costs and market fragmentation diminishes the incentive to build spare supply capacity; any new facilities capable of moving gas over long distances need guaranteed high rates of utilisation to be financially viable.

As a result, price and volume risks were carefully negotiated for decades as part of strong, long-term bilateral ties between buyers and sellers. Prices were typically indexed to the oil price, and contracts included both take-or-pay clauses (the buyer takes defined volumes of gas or pays a penalty) and destination clauses (restricting the right of the buyer to resell the gas). The initial rise of LNG trade followed this model, despite its inherently different nature. But the rigidities of this model were loosened by the expiry of the first wave of Asian LNG contracts, the creation of the European single market, and the rise of the United States first as a gas importer and then, even more importantly, as an exporter after the shale revolution.

These developments accelerated the transformation of a gas market that used to be mostly bilateral into an increasingly well-connected and liquid global market, in which price formation is based on competition among different sources of gas supply. However, even with these connections among markets, gas prices still vary significantly from one region to another in a way that crude oil prices do not. Different pricing mechanisms and contractual models co-exist, and persistent inter-market spreads and volatility highlight a strong degree of segmentation.

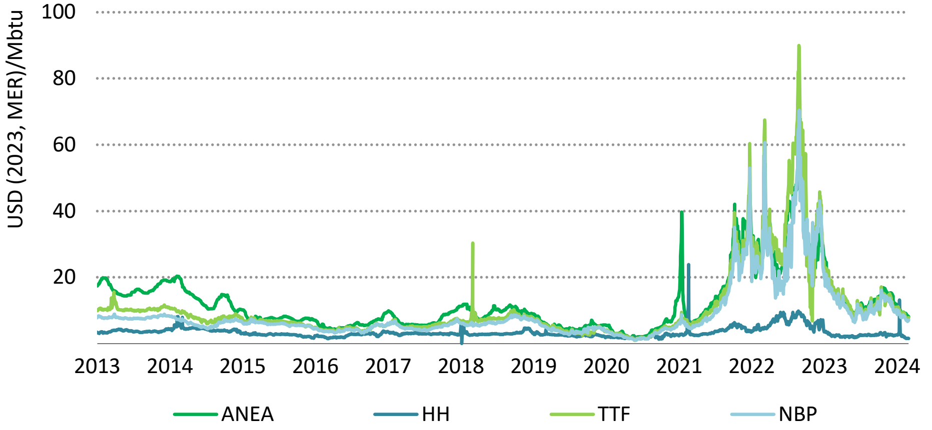
The global energy crisis[2] that followed the Russian Federation's (hereafter "Russia") invasion of Ukraine was largely a gas supply crisis. The 80 billion cubic metre (bcm) cut in pipeline supplies from Russia was the primary cause of market turbulence, both in Europe and further afield, but it was not the only one. Changes in Russian behaviour in gas markets began well before its invasion of Ukraine: Gazprom was much slower than usual to refill its European gas storage in the third quarter of 2021, leaving Europe much more vulnerable during that winter. In addition, the call on the tight gas market was exacerbated by a very poor year for both hydropower and nuclear output in Europe. The implications of the crisis for prices were

---

[2] The implications of the global energy crisis are examined in detail in section 4.4.

profound, but not universally felt (Figure 4.3). Price levels in the United States were much less affected than those elsewhere, and the price of deliveries indexed to oil followed a different path.

Figure 4.3 ▹ Natural gas prices at selected hubs and regions, 2013-2024



IEA. CC BY 4.0.

The level and volatility of natural gas prices vary significantly among regions

Note: MBtu = million British thermal units; ANEA = LNG des Northeast Asia (Japan, Korea and China); HH = Henry Hub (United States); TTF = Title Transfer Facility (European Union), NBP = National Balancing Point (United Kingdom).

Sources: IEA analysis based on Argus Media (2024), US Energy Information Administration (2024b).

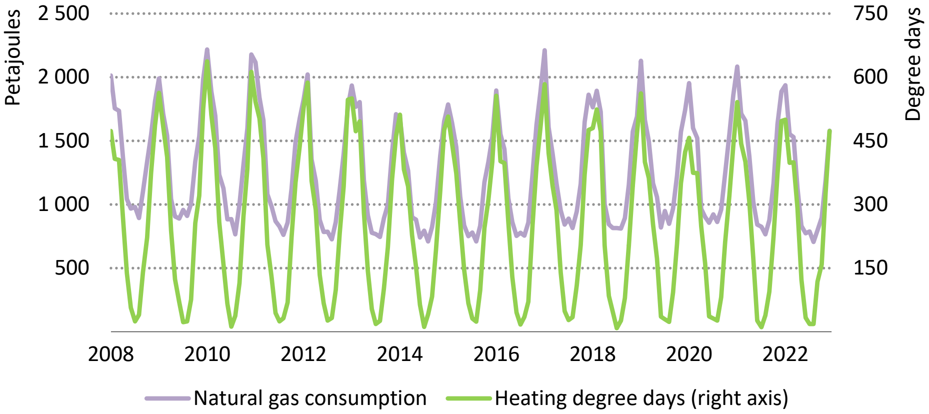
Risks to gas market stability go beyond geopolitics. The main uses of gas make it prone to rapid changes in demand that can affect prices. Most gas is used to provide heat, notably in the residential sector, and to generate electricity. In the power sector, gas is often the marginal source of generation, meaning that it needs to step in if other sources of generation such as wind and solar photovoltaic (PV) are unavailable (Figure 4.4). In markets where gas is required to heat buildings, demand is strongly seasonal and requires large amounts of storage: in many European markets, peak gas demand in the winter can be more than twice as large as peak gas demand in the summer. The upshot is that gas demand is much more sensitive to temperature and weather than other energy commodities, especially in temperate climates. As a result of these structural and consumption-based factors, the average annualised volatility in the European TTF gas market was 127% higher than volatility in the Brent crude market between 2013 and 2023.

Case study: Extreme cold in north Asia in January 2021

After spot prices for LNG bottomed out due to weak demand during the Covid-19 pandemic, an extreme cold event in early January 2021 sent them soaring to unprecedented heights in Japan, Korea and China. Temperatures in northern and western Japan were 2-4 degrees lower than the seasonal average. In Seoul, temperatures dropped to -18.6° C, the lowest in 35 years. In North China, more than 50 cities reached or broke temperature records; Beijing recorded a temperature of -19.6° C on 7 January, making it the coldest day there since 1966. Demand for additional LNG cargoes pushed the average spot LNG import price to a (then) record high.

As is often the case with price shocks, the cold snap took place against a backdrop of other factors that exacerbated the pressure on prices. The LNG market at the time had limited liquidity; supply issues in Australia, Qatar and Malaysia led to reduced export availability; and the route from the US Gulf Coast to east Asian regasification facilities faced logistical barriers due to bottlenecks at the Panama Canal. Available US LNG spot cargoes and some rerouting of Qatari volumes from Western Europe to Asia did, however, succeed in bringing a measure of relief to gas consumers in North Asia.

Figure 4.4 ▷ **Natural gas consumption and heating degree days in the European Union, 2008-2022**



IEA. CC BY 4.0.

The use of gas for heating means that demand patterns vary much more than is the case for other fuels or electricity

Sources: IEA analysis based on Eurostat (2024)

4.2.3 Coal

Coal consumption is much more concentrated than is the case for oil and gas. China is the giant of global coal consumption, accounting for over half of global coal demand; its power sector alone accounts for one-third of the total. India accounts for a further 11% of global consumption, and the overall share of emerging market and developing economies in global coal consumption exceeds 80%, up from half in 2000. Most coal consumers rely mainly on domestic production, meaning that coal is a less widely traded global commodity than the other fossil fuels. These factors together create the potential for significant swings in internationally traded prices: a relatively small shift in the supply-demand balance, notably in China, can have an outsized effect on the traded market. However, coal is also relatively easy and cheap to store, which typically helps to provide a buffer against volatility.

The last few years have seen unusually high price swings for coal. After falling to 14-year lows in 2020, thermal coal prices rebounded strongly in 2021 as demand for electricity picked up sharply after the first wave of lockdowns. In early 2022, spot thermal coal prices rose further when the Indonesian government decided to suspend exports in response to domestic supply shortages, and then shot up precipitously following Russia's invasion of Ukraine as consumers looked for alternatives to gas. This led to the extremely uncommon situation in late 2022 where thermal coal (for use in power generation) was more valuable than metallurgical coal (a higher-quality grade used in steel making).

The ability for some power systems to alternate between coal and natural gas for electricity generation, based on price and availability, is an important feature of price formation for both fuels. As seen in 2022, when natural gas prices surge, coal becomes more economically attractive, and power producers with the ability to do so tend to switch to using more coal. Conversely, when coal prices increase, they can switch back to natural gas. This flexibility acts as a "safety valve" for both markets, helping to balance supply, demand and prices. As a result, the prospective decline of coal in the electricity system has significant implications for both energy security and market stability. As coal-gas switching declines, energy markets may become more vulnerable to price volatility and supply disruptions, particularly during periods of high demand or constrained production of natural gas or renewables. This is, however, not a reason to try to arrest the decline of coal in electricity markets, given the environmental and human health impacts associated with coal-fired generation.

4.2.4 Electricity

The nature of electricity systems makes storage of electricity over longer time periods extremely difficult and requires instantaneous balance between supply and demand, so most of the buffers in the power system are financial in nature and not physical. This means that the market structure and regulatory framework of any given electricity market has a significant impact on how the changes in prices of electricity and fuels used for producing electricity are passed on to final consumers.

One central distinction is whether the electricity market is liberalised or regulated. In the case of regulated markets, system costs should in theory be passed on to consumers through predefined tariff or payment structures. In liberalised markets, there will be a regulatory framework setting the rules, but within that framework there will typically be a series of markets across different time horizons over which electricity will be traded by various agents, each of which can have a different price formation mechanism. The way that price pressures and volatility are managed will vary substantially across these markets.

In regulated markets, since prices are often fixed or subject to strong regulatory oversight, volatility tends to be relatively low. In theory, keeping electricity prices affordable is a matter of keeping overall system costs in check while maintaining the adequacy of investments and the revenue necessary to fund them. In practice, as discussed in Chapter 2, it is easy to get this balance wrong, with guaranteed returns leading in some cases to inefficient investment, and regulated end-user tariffs in other cases being set too low to cover system costs, leading to subsidies, indebtedness and poor service quality. Low-cost renewables can be a major asset for affordability in such markets, but can also face barriers to entry.

In liberalised markets, there are several interconnected markets working together, each with a specific purpose and each with a different level of volatility (Table 4.1). The wholesale cost of electricity in the spot market is determined by the merit order of generation. This means that the cost of electricity is determined by the most expensive power plant that is required to generate sufficient electricity to meet demand. In many electricity markets, this is natural gas, resulting in a high degree of correlation between the wholesale prices of gas and electricity.

The contract, or hedging, market provides a way to manage price risks, and its long-term nature makes it less volatile than the spot market. The retail market, being the closest to end consumers, typically has the least price volatility. It tends to be carefully regulated and to work on the basis of long-term contracts, and it includes additional costs such as generator profit margins and network costs that may include balancing and congestion charges. Volatility in the wholesale markets is thus rarely fully passed on to the end user. In addition, there are often separate markets for power and ancillary services such as frequency response and reserves.

Table 4.1 ⊳ Price formation and volatility in liberalised electricity markets

Market segment	Market participants	Description	Relative price volatility
Wholesale spot market	Generators, retailers, traders	Market participants buy and sell electricity at prices that reflect supply-demand dynamics at a specific point in time.	High: Prices reflect near real-time supply and demand.
Contract/forward market	Generators, retailers, traders	Market participants contract future volumes, often at predetermined prices, to reduce financial exposure to price volatility.	Medium: Prices reflect expectations about future supply-demand dynamics.
Retail market	Retailers, consumers	Retail companies sell electricity to end consumers such as households and businesses.	Low: long-term contracts are usually in place between end users and retailers, often at fixed prices.

With these variations in market structure, pressures on electricity systems and on consumers manifest themselves in different ways and over different time horizons in different markets. Strains can be reflected in prices and bills, or in the financial performance of utilities, or in some cases in load-shedding, rationing and blackouts. Given the rising importance of electricity to all aspects of modern life, managing these stresses while moving to a low-emissions power system is a central preoccupation of policy makers. Market designs and regulations need to be adapted to make the best use of existing assets, incentivise the introduction of a mix of low-emissions technologies at scale, and encourage investments in resilience and flexibility.

Case study: Electricity shortages in Texas in 2021

In mid-February 2021, a series of winter storms caused record low temperature in Texas, resulting in a spike in electricity demand. Since most of Texas's electricity demand is met by gas, this in turn pushed up gas demand. However, the extreme cold hampered gas production and disrupted the functioning of unwinterised power equipment at various power plants. As a result, around 45% of the system's gas-fired generators (31 gigawatts) were unavailable during this time; wind, coal and nuclear generation were also constrained. This led to more than 4 million customers (10 million people) being left without electricity during the freeze.

The cost of gas rose to unprecedented levels. Intraday prices at the Oneok Gas Transmission (OGT) hub in Oklahoma reached a historic high of USD 999/MBtu on 16 February 2021, and Henry Hub prices climbed to USD 16.95/MBtu, the highest level since February 2003. The constraints in the gas system also led to electricity prices hitting the market cap of USD 9 000 per megawatt-hour. These spikes were not necessarily felt by consumers – most were insulated to some degree by their contractual arrangements with suppliers – but all felt the impact of curtailments in supply.

4.3 How might the risk of abrupt price shocks evolve in energy transitions?

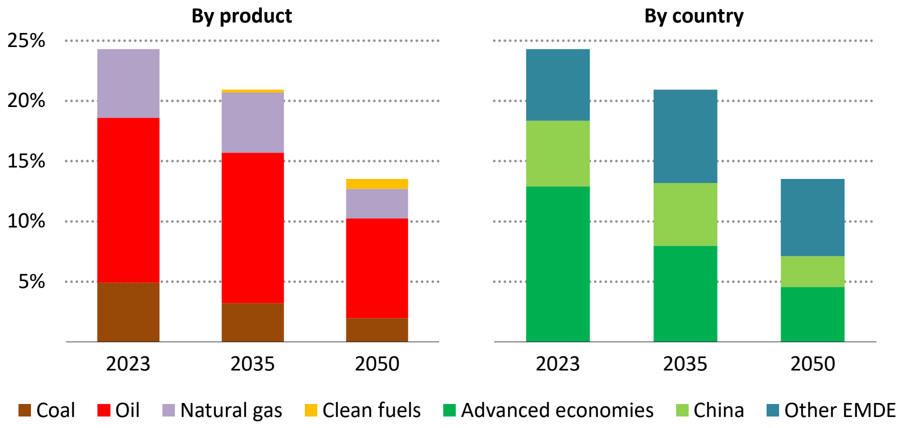
Price trajectories are smooth in IEA scenarios but – as we have seen in the previous section – that is not the way the energy world operates in reality. The scenarios reflect prices that are necessary to bring energy supply and demand into balance under different sets of assumptions about government policies and technology costs. They assume timely investment across different elements of the energy system, alongside well-sequenced actions by policy makers. Normative scenarios that reach climate and other Sustainable Development Goals assume a broadly co-operative framework among countries that are united in their commitment to pursue these goals. None of these assumptions can be taken for granted; the risk of imbalances in investment is particularly high during a period of rapid change, and new potential hazards may emerge. Moreover, while energy transitions can change and diminish some of the price risks discussed in the previous section, these traditional risks do not disappear. The discussion below considers some of the main factors in play.

4.3.1 The geography and composition of energy demand

Rapid energy transitions have huge implications for the way that demand for energy services is met, and all of the IEA scenarios also feature major changes in the geography of energy demand, reflecting the growing influence of emerging market and developing economies. These factors affect the distribution and nature of risks to affordability. The transition to a more electrified, efficient, renewables-rich energy system reduces exposure to volatility in fossil fuel markets, but the speed at which this takes place varies widely by country and region, and meanwhile some new risks come into view.

One important broad trend is that as the move away from fossil fuels gathers pace, more energy tends to be produced or generated closer to the final consumer, and this reduces the share of energy traded internationally (Figure 4.5). At present, 25% of primary energy consumed worldwide is traded across international borders, mainly in the form of oil and gas. In the Announced Pledges Scenario (APS), this falls to 14% by 2050, and in the Net Zero Emissions by 2050 (NZE) Scenario it falls to 12%.

Figure 4.5 ▷ Share of primary energy supply traded between regions in the Announced Pledges Scenario



IEA. CC BY 4.0.

The energy system becomes less reliant on interregional energy trade in rapid transitions, but a rising share of this trade goes to emerging and developing economies outside China

Note: Clean fuels trade covers hydrogen, ammonia, synthetic oil products and methanol.

However, there are significant regional variations. In advanced economies, aggregate fossil fuel use peaked in 2007, and in the APS it declines by around 45% from today's levels by the mid-2030s. In China, fossil fuel demand plateaus in the 2020s in all our scenarios, and in the

APS it falls back by 40% by the mid-2030s. However, the pattern in other emerging market and developing economies is different. In the APS, a scenario that features a rapid worldwide scale-up in clean energy deployment, demand for oil and gas in these economies rises moderately this decade. This is led by relatively robust demand in developing economies in Asia outside China, most of which do not have large domestic hydrocarbon resources of their own and accordingly rely to a large extent on imports.

Among oil and gas exporters, our scenarios project an increased market share over time for low-cost producers in the Middle East, and the Middle East-Asia route remains an essential artery for seaborne trade in oil and gas for the duration of energy transitions. As a result, consumers in Asia remain heavily exposed to price risks and physical disruptions to supply arising from geopolitical events in the Middle East or accidents near trade chokepoints such as the Straits of Hormuz or Malacca.

The new clean energy economy involves some continuing trade over long distances, notably for clean fuels and critical minerals (the latter are not reflected in the figures above as they are not consumed as energy but are inputs to the manufacturing process). The combined market share of hydrogen and critical minerals in the global energy-related commodities market increases twelve-fold from 1.5% today to 18% by 2050 in the APS. In the NZE Scenario, the share rises further to 55% by 2050 as the value of fossil fuels trade declines significantly, reshaping the present dynamics of international energy-related trade.

4.3.2 The transformation of the power sector

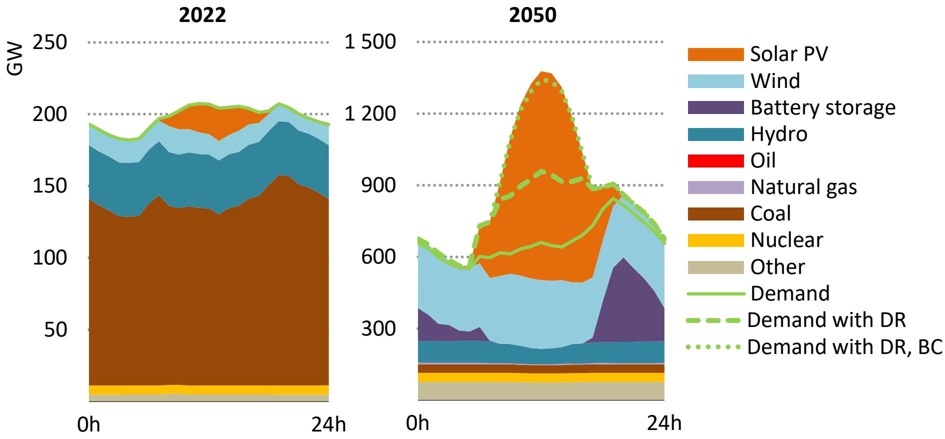
Our scenarios show diverging trends on many issues, but one issue on which they agree is that electricity demand is set to rise strongly in the years to come. More widespread use of ever-cleaner electricity supply is a central feature of energy transitions. Existing electricity systems need to be not just expanded but also transformed in fundamental ways.

- Renewable sources of electricity are increasing their share of supply, led by solar PV and wind. These new variable sources require rapid grid connections, flexibility in the system to cover their variability, and more fine-grained forecasting of their output compared with dispatchable thermal and hydropower plants.
- Variable renewables are more distributed in nature than conventional sources of generation. Systems with distributed resources have the potential to be more resilient to disruption than centralised systems, but operators and networks need to adapt in order to make the most of them.
- As peak electricity demand rises and consumers use electricity for an increasing range of end uses, notably for heat and for transportation, network operators need to rely more on demand-side response as a key source of flexibility, and to find ways of increasing its scale.

- Digital technologies play increasingly vital roles in managing such complex systems, bringing significant benefits but also exposing the systems to new cybersecurity risks. Regulators and network operators need to ensure that effective action is taken to tackle these risks.

The prospects for India's power system as it transitions to clean energy highlight many aspects of this transformation (Figure 4.6). They include the rapid growth of overall demand in India, the huge excess of solar generation during the daytime, how curtailment is brought down by expanded deployment of batteries and demand response, and a reduced role for thermal generation.

Figure 4.6 ▷ Hourly electricity generation by source for a sample day in India in August in the Announced Pledges Scenario, 2022 and 2050



IEA. CC BY 4.0.

The operation of power systems changes fundamentally as the world moves through transitions; there are risks to affordability if these changes are not well managed

Notes: DR = demand response; BC = battery charging. Demand response includes the flexible operation of electrolysers.

The analysis in Chapter 1 highlights that the overall costs of a decarbonising system are no higher than a traditional one, but that there are nonetheless significant risks to affordability if the process of change is poorly sequenced or poorly managed. Many of these relate to the adequacy and timeliness of investment, and whether policy and regulatory measures are incentivising the right mix of capital spending across different generation technologies, storage and robust grids while also incentivising demand-side response. The risk of underinvestment is compounded by the uncertainty created for investors by the increased complexity of electricity systems, the challenges of cost recovery and indebtedness, and the high cost of capital for clean energy projects.

The implications of the transformation of the power sector are wide-ranging. Intraday electricity price spreads are expected to widen, and this trend is likely to accelerate as electricity markets and contracts become more financialised. Simultaneously, advances in forecasting techniques are leading to more granular and accurate predictions of supply and demand in renewable energy systems. These improved forecasts will also be helpful in managing other components of the electricity system, including storage.

As a result of these trends, electricity contract markets are set to change in fundamental ways. While power purchase agreements (PPAs) are expected to remain a key instrument for procuring renewable electricity, their structure is likely to evolve. Instead of being solely based on the physical delivery of electricity units, as is currently the case, PPAs are likely to offer a wider range of hedging and investment options to market participants. Financial contracts such as virtual and indexed PPAs would allow system operators to address intermittency challenges more effectively, while also ensuring that the share of low-emissions generation continues to increase.

At the retail level, time-of-use or dynamic pricing is likely to become more widespread, encouraging more consumers to shift demand more often to maximise the utility of variable sources of generation during the day. Dynamic pricing depends on smart meters, and advanced technologies such as smart meters that can manage multiple tariffs across different appliances and devices will help to facilitate demand-side flexibility. They could be used to ensure that consumers can benefit from the increased affordability of electricity during the day without exposing them to full spot market volatility (Box 4.1).

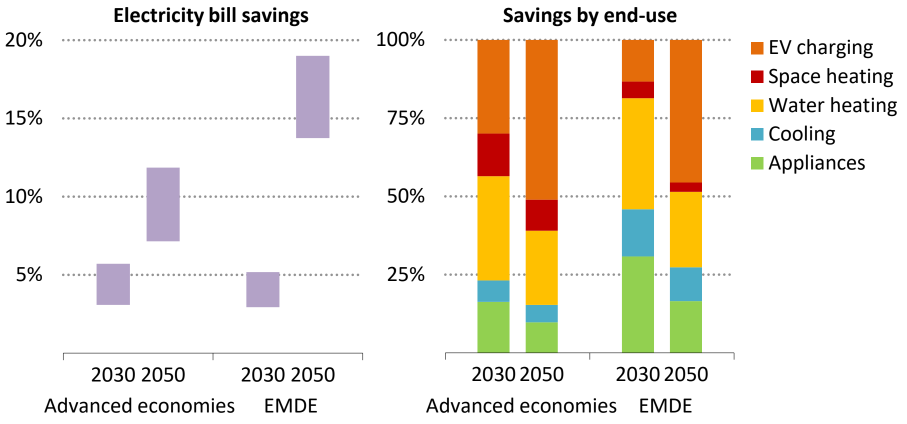
These technologies mean that average consumers may be exposed to more electricity price volatility than under traditional long-term contracts, but they also mean that average costs are likely to be lower, thanks to greater exposure to low-marginal-cost renewable generation and the ability to engage in demand-side reduction.

As discussed in Chapter 3, these technological changes have some regressive aspects as households with larger, more flexible loads are likely to be best positioned to take advantage of these market changes. Lower-income households with inflexible, need-based energy demand profiles centred around basic services such as cooking and lighting are not going to be able to leverage the potential cost benefits to the same extent. Furthermore, the increasing penetration of variable renewable generation is likely to increase the value of ancillary services. These costs have traditionally been rolled into fixed system costs rather than being included in usage-based tariffs. Assessing higher fixed costs on a per-connection level may result in a regressive cost profile that disproportionately impacts low-income households. This all underlines the need for regulations to be carefully designed to ensure that the most economically vulnerable households are not disadvantaged by the structural transition under way in the electricity market.

Box 4.1 ▷ Demand response and affordability

Demand response measures can lower consumer bills by allowing consumers to schedule their use of electricity so as to reduce usage during peak hours. In a system with high shares of solar PV and wind, this responsiveness on the demand side can also help limit curtailment and therefore make the best use of technologies with very low marginal costs. Consumers do not need to make all the choices themselves; increasingly, providers are offering to optimise on their behalf. A household with an electric vehicle (EV), for example, can simply specify how much charge they need for their battery, and this will automatically be scheduled for when electricity is cheapest.

Figure 4.7 ▷ Electricity bill savings from demand response for households and by end use in the Net Zero by 2050 Scenario, 2030 and 2050



IEA. CC BY 4.0.

Consumers have important levers to save on electricity bills if they can shift the timing of EV charging, space and water heating, cooling, and appliance use to lower-cost hours

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 for demand response measures account for limitations on technology and acceptability.

4.3.3 Effects of the new wave of LNG supply

Another important element in the context of affordability and price volatility is the wave of new LNG projects that have taken final investment decisions and that are due to start operation in the second half of the 2020s. More than 250 bcm/year of annualised export capacity is at various stages of development, almost 70% of which is in the United States and Qatar. From today's starting point of scarcity and concerns about high prices in the wake of Russia's cuts to pipeline deliveries to Europe, these new LNG supplies could exert significant downward pressure on natural gas prices in the second half of this decade and, potentially, into the 2030s.

This ample availability of LNG also provides something of a buffer against the risk of sharp price shocks, although the effects in practice depend on the ability of alternative sources of supply to reach a country or region affected by the shortfall within a fairly short time frame. Local or regional disruptions remain a distinct possibility if a key supplier or piece of infrastructure is unavailable.

Whether cheaper natural gas is a help or a hindrance for the pace and affordability of energy transitions is a matter of vigorous debate. The debate hinges on three points.

- Is there confidence in the environmental credentials of natural gas?
- Is the gas cheap enough to displace more polluting fuels, notably coal in Asia?
- Does the availability of cheaper gas facilitate or slow the adoption of clean technologies that can make the journey to net zero emissions?

On the first question, confidence in the environmental credentials of gas depends on demonstrable progress in reducing methane emissions. Methane leaks from the energy sector go well beyond the gas value chain, which accounts for less than 30 million tonnes (Mt) of the estimated 120 Mt of methane released to the atmosphere from energy operations in 2023; emissions from the oil sector (an estimated 49 Mt) and coal (40 Mt) are both higher (IEA, 2024). However, the stakes are particularly high for natural gas precisely because the gas industry is claiming a supporting role in energy transitions. Proving that these emissions have been minimised via credible monitoring, measurement, reporting and verification programmes is the entry ticket for natural gas to the energy transition debate. Action on methane leaks and flaring reduction also makes significant additional volumes available to the market.

On the second question, the potential for competitively priced natural gas to displace coal and bring down carbon dioxide emissions is well-established, notably in the United States, where the share of coal in the power generation mix fell from 46% in 2010 to 17% in 2023 with the rise of renewables and the advent of shale gas. However, displacing coal via LNG in distant export power markets is a taller order. In India, for example, gas needs to be available at less than USD 4/MBtu to undercut coal use in the power sector (and natural gas infrastructure is in any case poorly developed in parts of India where it would be needed to displace coal), but most US LNG export projects need a realised price of between USD 7/MBtu to USD 9/MBtu to recover their capital costs, and would need something like USD 4/MBtu to USD 6/MBtu just to cover their short-run marginal costs. There are, however, other significant opportunities for LNG to displace coal in Asia, notably for industrial uses, flexibility and system balancing and residential heat. It could also replace the oil used in transport in some countries.

The last question, on the interactions between cheaper gas and clean energy deployment, requires nuanced treatment as the linkages differ between sectors and over time.

In some circumstances, gas-fired power can facilitate the deployment of larger shares of variable renewable technologies in the power sector and can have a durable role in meeting seasonal variations in electricity demand. Gas can also provide a degree of insurance for energy systems during clean energy transitions against the risk that the deployment of cleaner technologies will turn out to be slower than expected (for example because of problems with permitting, social acceptance or financing).

However, there is direct competition between gas-fired and clean technologies in some end-use sectors, and notably for home heating; as noted in Chapter 1, the cost-competitiveness of a heat pump versus a gas-fired boiler is very sensitive to the price of natural gas, and this is exemplified by the 5% year-on-year decline in heat pump sales seen in Europe in 2023 as gas prices came down from the sky-high levels seen during the crisis. Moreover, low natural gas prices could also slow the scaling up of some new and emerging technologies, including low-emissions gases and long-duration energy storage technologies.

Additional investments in natural gas infrastructure clearly present a long-term risk of locking in emissions and thereby slowing progress towards net zero goals. Some of this infrastructure could ultimately be used to transport biogases, or repurposed for low-emissions hydrogen, but our projections suggest that the extent of infrastructure required for gases in a net zero emissions system is less than exists in most markets today.

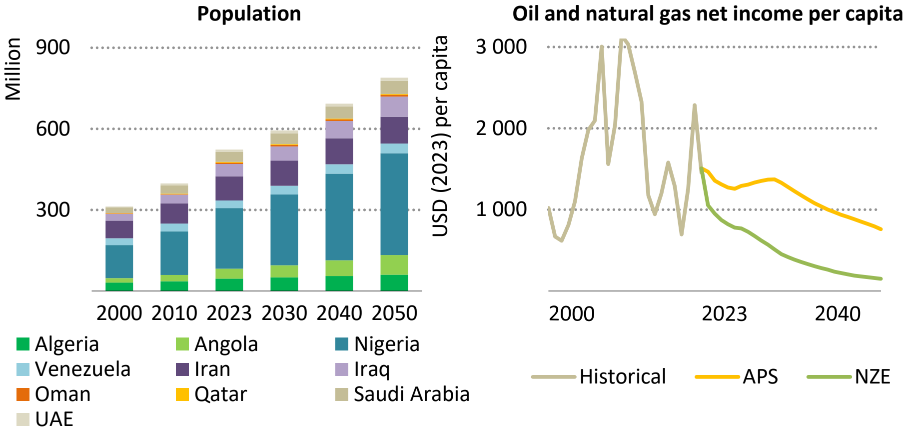
4.3.4 Geopolitical risks

Energy and geopolitics have always been closely linked, and geopolitical events have been one of the primary causes of sudden energy market disruption and price shocks in the past. Might such geopolitical risks increase as the world moves through energy transitions? The range of risks has the potential to increase in the years ahead; the world will face a combination of traditional concerns related to oil and gas and some new ones related to clean energy supply and manufacturing. Moreover, both traditional and new risks are heightened in today's more fragmented international system, which is increasingly characterised by rivalries and low levels of co-operation.

The outlook for major oil and gas producers is central to this discussion. Circumstances vary widely from country to country, and depend in particular on the cost-competitiveness of each, but the overall position of today's large producers as mainstays of the global energy economy does not look likely to disappear quickly. As competitive providers of traditional fuels, they are well placed to retain or indeed increase market share, even as demand for these fuels comes down; many also have high potential to produce low-emissions fuels and power, and to create new industries and employment opportunities on that basis.

However, calibrating and financing movement in that direction is far from simple, and there could well be bumps along the way that increase the chances of sharp market imbalances. Transitions create strong incentives to diversify economic activities and energy systems, but they simultaneously reduce a source of revenue that could support the diversification process. The analysis in Chapter 1 highlights the dramatic revenue effects: compared with the annual average between 2010 and 2022, per capita net income from oil and natural gas among producer economies is 28% lower by 2030 in the APS and 60% lower in 2030 in the NZE Scenario (Figure 4.8). Transitions of this kind could well be destabilising for fragile producing states, especially those that face demographic pressures from large youthful populations. This underscores the need for continued dialogue between countries with different interests and positions in oil and gas supply chains in order to help mitigate the risk of turbulent and volatile markets.

Figure 4.8 ▹ Population and per capita net income in selected producer economies in the APS and NZE Scenario



IEA. CC BY 4.0.

Clean energy transitions and rising populations increase the pressure for economic diversification in producer economies while reducing the means to support it

Note: UAE = United Arab Emirates.

Renewable energy potential is much more widely distributed than fossil fuel resources, and therefore represents a stabilising factor in international energy affairs. But while renewable resources are widely distributed, the same is not true for clean energy manufacturing and supply chains, which are heavily concentrated (see also section 4.3.7). 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 tracking of project announcements for these technologies indicates that current plans for rapid growth in overall manufacturing capacity (notably in the case of solar panels and batteries) will only help to improve diversity at the margins. The same countries and regions as now are set to retain a predominant position in manufacturing through to 2030 and beyond.

A similar picture emerges for critical minerals: resources are spread quite widely, but today's production is heavily dependent on a handful of producers – much more so than is the case for fossil fuel supply. Midstream refining and processing are extremely concentrated as a result of extensive Chinese investment in recent years and, more recently, a wave of new Indonesian projects in nickel smelting. A high degree of concentration in any value chain brings some risks to affordability, as companies or countries with significant market share exercise a lot of pricing leverage (making life difficult for new market entrants). Moreover, supply can more easily be disrupted by natural disasters, geopolitical events and trade disputes than would be the case with a lower level of market concentration.

4.3.5 Climate risks

Climate-driven disruptions are already a major risk factor for the security and affordability of energy, and these risks are set to grow in the coming decades. The severity of longer-term impacts depends on the world's success in bringing down annual greenhouse gas emissions, but all parts of the energy system are already becoming increasingly vulnerable to extreme weather events, whether related to storms, cold snaps or heatwaves.

LNG plants and refineries are typically located in coastal areas, exposed to risks from storm surges and damaging cyclones – 25% of today's refineries are at risk of destructive cyclones, and around one-third of refineries are threatened by rises in sea level and storm surges. The operation of thermal power plants could be interrupted by a shortage of water for cooling, and the availability of hydropower could be reduced by variability in patterns of precipitation.

Grid infrastructure also faces higher risks. More intense tropical cyclones and storms could damage transmission and distribution lines, poles, and transformers, while more frequent extreme heat events and wildfires could disrupt electricity networks and reduce the efficiency of transmission and distribution. Around half of today's global electricity networks are exposed to weather conditions conducive to triggering and sustaining wildfires for more than 50 days each year, and 18% to more than 200 days of such weather conditions.

Clean technologies face challenges from a changing climate as well. The performance of renewable power technologies such as wind and solar is naturally dependent on weather conditions and, as with many other sources of power, tends to degrade when conditions become extreme. The efficiency of a solar panel generally degrades by 0.3-0.5% per degree above a temperature of 25° C. Standard wind power installations are usually designed for a 25° C environment and may be shut down above 45° C to protect critical components from damage caused by high temperatures.

Stable supplies of many critical minerals are also dependent on water availability. In 2019, severe drought affected mining operations in Chile, the world's largest copper-producing region. Droughts have also had similar effects in Australia, Zambia and elsewhere. Around half of today's global copper and lithium production is concentrated in areas of high water stress.

On the demand side, rising global temperatures are set to lead to greater use of electricity for cooling, although this is partially offset by lower demand for heat as a result of milder temperatures in winter. Increasing aridity and prolonged droughts would require more energy for water pumping and desalination, particularly in the Middle East and Africa. Global energy demand for desalination – an energy-intensive process – has already almost doubled since 2010; there are currently some 21 000 desalination plants operating worldwide. Current trends point to another doubling by 2030.

Affordability can be affected in multiple ways by climate-related weather events. The various risks cannot be treated in isolation since they can accumulate and reinforce one another. A strong heatwave, for example, pushes up demand for electricity for cooling, while simultaneously degrading the performance of supply infrastructure.

For the moment, investment in climate resilience in the energy sector remains far below what is required. This is mainly due to investment decisions having a relatively short time horizon, limited consideration of indirect impacts and limited information on climate risks. A greater focus on the long term and on the indirect social and economic risks of inaction in the light of the best available information on climate risks would be likely to raise the current level of investment.

4.3.6 Effectiveness of some existing safety nets

Today's energy system incorporates some buffers and safety valves that help accommodate unexpected shifts in supply-demand balances or relative prices, at least up to a point. Well-functioning markets have proven their worth, as have safety nets such as the spare capacity held by key producers and the IEA co-ordinated system of oil stocks. Stored energy and the ability to switch between fuels also provide valuable sources of flexibility. As the energy system changes, however, new sources of flexibility will need to be developed. As discussed above, this will be particularly important in the power sector. But policy makers will also need to be mindful of the potential for some existing safety valves to become less effective over time, since this could make the system more vulnerable to price spikes and shocks.

One example is the reduced potential to adjust between coal and natural gas for power generation. The ability to switch demand between these fuels has been a way to absorb price shocks on both sides when relative prices change. This buffer will become considerably smaller and less effective as and when coal plants are removed from the system. In parallel, as discussed in the opening section of this chapter, gas demand in an increasingly renewables-rich power sector is set to be determined more by weather (and the way that it affects wind and solar output) than by price. This increases the potential for sharp, short-term price volatility.

Another example is emergency oil stocks, which can be released in response to global or regional supply disruptions caused by geopolitical events or extreme weather. They are typically designed and used to manage physical interruptions to supply rather than price swings resulting from other causes, and their efficacy and role is set to change as countries move through energy transitions (Box 4.2).

Box 4.2 ▻ Emergency stocks

Emergency stocks represent an insurance policy against the significant economic and social harm that supply disruptions – and the resulting price shocks – can bring. Their use, for the moment, is most common for oil. The costs of building up and maintaining these stocks is ultimately borne by consumers, although some countries finance stocks directly from the public purse and others do so indirectly via an obligation on suppliers.

The IEA co-ordinates emergency releases of oil stocks across its member countries; each IEA country has an obligation to hold oil stocks equivalent to at least 90 days of net oil imports and to be ready to contribute to a collective response to severe supply disruptions. Since the creation of the IEA, there have been five such collective actions: in the build-up to the Gulf War in 1991; after Hurricanes Katrina and Rita damaged offshore oil rigs, pipelines and oil refineries in the Gulf of Mexico in 2005; in response to the prolonged disruption of oil supply caused by the Libyan Civil War in 2011; and twice in quick succession following Russia’s invasion of Ukraine, first in March 2022 and then again in the following month.

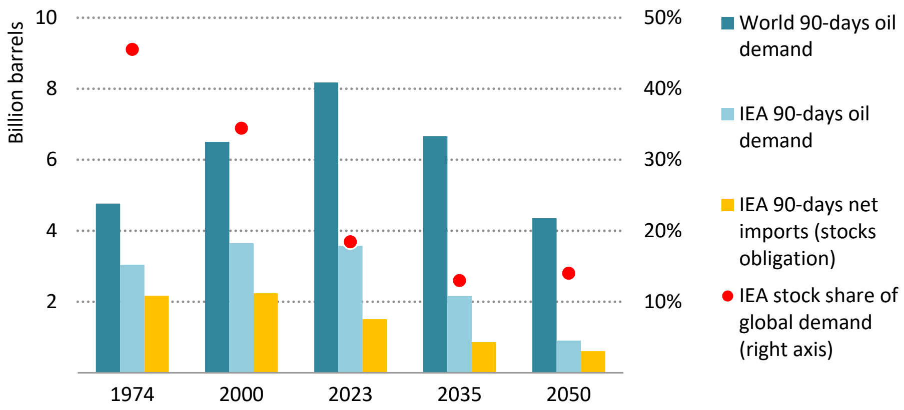
Quantifying the precise impact of emergency stock releases on prices is challenging because of the difficulty in isolating the influence of stock releases from the multitude of factors that contribute to price formation. Nonetheless, the United States Department of the Treasury estimated that the release of stocks from the Strategic Petroleum Reserve (SPR) in 2022 could have lowered US gasoline prices by as much as USD 0.40 per gallon (USD 0.11 per litre) (US Department of the Treasury, 2022), providing considerable relief to consumers.

The implications of holding emergency oil stocks extend beyond the (relatively rare) occasions when stocks are released. Their existence provides reassurance to market participants that additional supplies can be made available, should they be required. This can dampen market reactions in the early stages of a disruption and prevent damaging price spikes from occurring when they otherwise might.

Energy transitions have a variety of potential implications for oil emergency stockholding systems. The share of oil in the global energy mix falls back, but – as discussed in the previous sections – the risks of disruption may increase. The balance of global demand also moves away from advanced economies (and current IEA members). When founded in 1974, the stockholding obligation of IEA member countries represented over 40 days of global oil demand. In the APS, the amount of oil represented by the stockholding obligation of IEA countries falls to 13 days of global consumption in 2050 (Figure 4.9).

In addition, shifts in refining capacity may lead advanced economies to consider holding a larger share of their emergency stocks in the form of oil products, even though this might be more expensive than holding crude oil stocks. The beneficiaries of stockholding regimes likewise shift as countries, and segments of populations within them, decrease their reliance on oil for transportation at different speeds.

Figure 4.9 ▹ **90 days' oil demand and stockholding coverage of IEA member countries in the Announced Pledges Scenario**



IEA. CC BY 4.0.

In the APS, the stockholding obligation of IEA member countries would cover only 13 days of global oil demand in 2050

Note: The figures consider only obligated volumes that can cover 90 days of net imports. In practice, most IEA member countries currently have stockholding that can cover more than 90 days of net imports.

All governments will need to make considered decisions about emergency oil stockholding in the coming years, weighing up the costs of stockholding to citizens against the benefits for energy security even as they reduce reliance on oil. Some emerging market and developing economies are already building up their stockholding systems: India, where the security of oil supply has become an increasingly pressing concern, is currently engaged in expanding its own SPR. A planned second phase involving the construction of new storage terminals is estimated to require over USD 1.4 billion from the state budget, a figure that does not include the purchase of oil to fill the tanks.

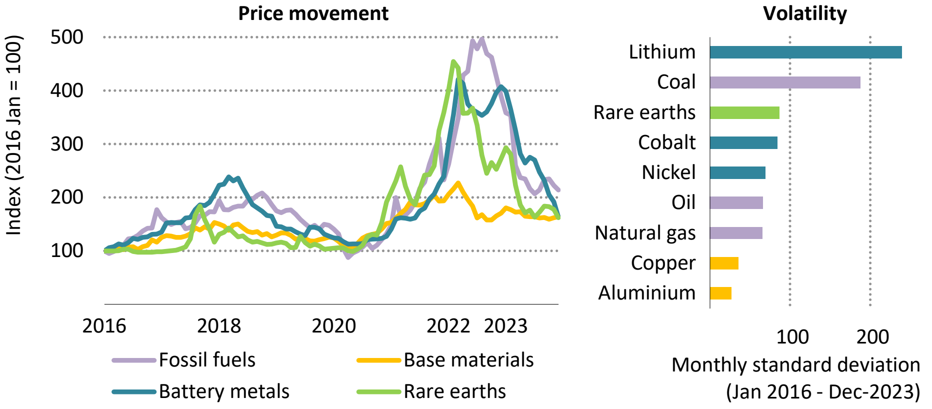
As countries move through energy transitions, discussions about emergency buffers in the system inevitably move beyond oil. However, the cost-benefit calculations for stockholding vary considerably for different parts of the energy system. For example, although gas is stored underground or in LNG facilities in many countries to manage seasonal or other fluctuations in demand, the cost of building and maintaining strategic stocks in sufficient quantities to make a meaningful impact during emergencies might well be prohibitive. A more fragmented international market for gas also makes co-ordinated action in this area more difficult.

There is a case for some form of stockholding for some of the critical minerals that are vital inputs to the manufacture of many clean energy technologies, especially where markets are relatively small and open to manipulation. This is an issue that is being considered under the IEA's new Voluntary Critical Minerals Security Programme. But stockholding is not a panacea. It is most effective as part of a broad portfolio of measures which address both supply and demand to bolster security and affordability during energy transitions.

4.3.7 Clean energy supply chains and critical minerals

Even though critical mineral supply chains do not typically have a direct impact on affordability at the consumer level in the way that oil and gas do, disruptions and price risks nonetheless pose risks for the pace of energy transitions. Volatility in critical minerals markets is often related to their relatively small size (and poor transparency), which means that even minor shifts in demand or supply can exert significant influence on global prices (Figure 4.10). The supply chains of many critical minerals are also highly concentrated in a few countries, especially in the refining and processing segments, where China has a dominant position. This means that physical disruptions, regulatory changes or technical failures in major producing countries can have large impacts on global prices. In 2023, geopolitical risks were highlighted by a series of trade restriction measures which affected a range of critical minerals from gallium and germanium to graphite together with rare earth elements-related technologies.

Figure 4.10 ▻ Price movement and volatility of selected commodities

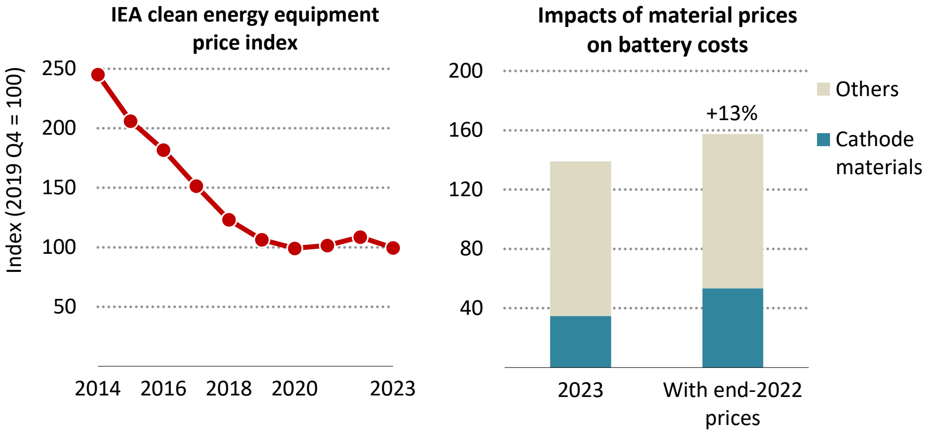


Price volatility is also an important feature of critical mineral markets, although this does not have the same direct impact on energy consumers as volatility in fuel or electricity markets

Notes: Base metals include aluminium and copper. Battery metals include lithium, nickel, cobalt and graphite. Prices for rare earths are based on neodymium prices.

Over the past decade, technology learning and economies of scale have pushed down the costs of key energy technologies significantly. However, this trend also means that raw material costs now loom larger as an element in the total cost of clean energy technologies. Higher or more volatile mineral prices could therefore have a significant effect on the costs of transforming our energy systems. According to the IEA's clean energy equipment price index, clean energy technology costs continued to decline until the end of 2020, but high material prices, along with supply chain bottlenecks and high energy prices, then reversed this decade-long trend in 2021 and 2022 (IEA, 2023b). In 2023, costs began to trend downwards again due in part to falling material prices, but the increase in clean energy costs in 2021 and 2022 illustrates how critical minerals may affect the affordability and speed of energy transitions (Figure 4.11).

Figure 4.11 ▻ Clean energy equipment price index and impacts of recent material price increases on battery costs



IEA. CC BY 4.0.

Recent price spikes for critical minerals fed through directly to the cost of battery packs, the critical cost component in electric vehicles

Note: Cathode materials for EV batteries include lithium, nickel, cobalt and manganese.

These risks apply to clean energy technologies across the board. If cathode material prices had remained at the levels seen at the end of 2022, for example, electric vehicle battery pack costs in 2023 would have been 13% higher than they actually were. While prices for base metals such as steel, aluminium and copper have been less volatile, certain segments of high-grade products may face sharp price movements, and these could also affect clean energy deployment. For example, the price of grain-oriented electrical steel, a specialised steel used in the cores of electrical transformers, has doubled since January 2020 as a result of supply chain inflexibilities, pushing up transformer prices by 60-80% (Wood Mackenzie, 2023). These risks could delay the pace of clean energy deployment, with disproportionate impacts on consumers in emerging market and developing economies, who tend to be more price-sensitive. Minimising these impacts requires a comprehensive set of policies and actions that encompasses supply investment, innovation, recycling and sustainability standards.

4.4 Lessons from the global energy crisis

Consumers were hit hard by the extreme price shocks seen during the recent global energy crisis. Governments were forced to take measures as the crisis unfolded, with varying degrees of success and often at high cost. This concluding section reflects on what happened during the crisis, and then considers what governments might do to be better prepared to cope with price shocks in the future.

4.4.1 Consumers and the global energy crisis

The price impacts arising from the turmoil in energy markets that followed cuts in Russian gas supply to Europe came in waves. The first market to be affected was the European wholesale gas market, which is where European gas supply and demand are balanced. The search for new sources of supply drove up prices, attracting any LNG cargoes that could be rerouted to Europe, tightening supply in other gas-importing markets and causing energy shortages and power outages in some south Asian markets. Higher gas prices also pushed up coal and carbon prices since, as discussed above, gas-fired power generation in many European markets provides the marginal unit of generation that determines the price.

These wholesale price rises fed through into higher retail prices, although the speed with which this happened depended on the contractual conditions in place in different countries. In some markets, wholesale prices fed directly into retail prices, while in others most retail contracts had a fixed price for at least a short period of time, providing some temporary protection. Markets were severely strained by the sudden deficit of gas but continued to function: the price shocks provided a very strong signal both to bring additional supply to Europe and to reduce demand.

We estimate that over 40% of the overall deficit of gas in the European Union in 2022[3] was filled by additional supply from producers around the world, with LNG from the United States playing the largest role, while almost 60% was due to lower demand. Gas use in industry fell by around 20% year-on-year, more than half of which was the result of curtailment in energy-intensive industries. A relatively mild winter helped to reduce heating demand, and this took care of around 10% of the overall deficit; the combined contribution from new renewable capacity and efficiency improvements accounted for a further 10%.[4] In the face of large increases in domestic energy bills, many residential consumers limited consumption, which

---

[3] The overall deficit of gas was caused mainly by cuts in Russian supply, but other contributory factors were the relatively low EU storage levels going into the crisis (linked also to Russian strategic behaviour) and a poor year for hydropower and nuclear output.

[4] Contrary to the perception that coal played a significant role, additional coal consumption filled less than 4% of the gap left by shortfalls of gas in the European Union in 2022.

in some cases meant falling into energy poverty (IEA, 2023a). Eurostat found that the number of people in the European Union unable to keep their homes adequately warm spiked to more than 40 million – almost one in ten of the EU population (European Commission, 2023).

The energy shock also contributed to sharp rises in the cost of food in many parts of the world. Although these rises largely reflected the damaging effect of the invasion on Ukraine's agricultural sector and exports, it was also driven in part by rising energy costs for food production that affected farming, fertilisers, food processing and transportation.

Government responses to these escalating price developments included collective actions, notably at EU level. EU initiatives included a toolbox in October 2021 outlining measures that member states could introduce within the EU framework to protect consumers, and the RePowerEU plan published in May 2022. In October 2022, the EU Council published a Regulation on Emergency Intervention to address high energy prices. In addition, the European Union agreed some specific measures, including a 15% targeted reduction in gas consumption (compared with the five-year average); efforts to cut peak electricity demand; a temporary revenue cap on so-called "inframarginal" power producers, which aimed to reduce the impact of high gas-driven wholesale prices on the revenues of low-marginal cost generators such as renewables and nuclear; and a market correction mechanism designed to limit sharp upward price movements for gas. Actions at national levels, in the EU and elsewhere, were mostly aimed at protecting consumers from the impact of the price shocks, and many of them were costly (Box 4.3). While most governments were relatively quick to put energy price support measures in place, withdrawing them took more time, even when market prices came down.

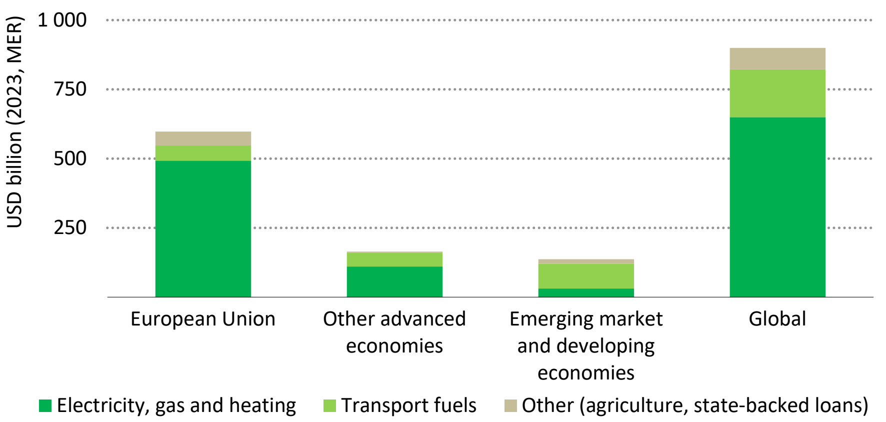
Box 4.3 ▷ Affordability in the global energy crisis

The global energy crisis led governments around the world to enact short-term energy affordability support policies to help households and corporate consumers manage higher energy prices. By the end of April 2023, IEA tracking put these expenditures at some USD 900 billion in direct grants, vouchers, tax reductions and price regulations, the latter often triggering compensation to energy companies for operating losses (Figure 4.12).

EU member states accounted for two-thirds of the global total, although the approaches adopted across Europe were far from uniform. The amount of money spent on the energy crisis varied from 7% of gross domestic product (GDP) for both the Czech Republic and Croatia to less than 1% of GDP for Denmark, Ireland and the Slovak Republic. All countries allocated support predominantly to households. Most, including Germany, France and Spain, relied heavily on retail price interventions such as subsidies, discounts, price caps, reduction of taxes and levies, and reduction of network tariffs. Others, including Austria, Denmark, Bulgaria and Finland, provided vouchers or one-off subsidies to energy-intensive corporate consumers.

The surge in European gas prices created strong incentives for suppliers and traders to divert available supply from other markets. Although some importing countries outside the European Union were somewhat shielded from volatility by long-term supply contracts with fixed volume commitments and oil-linked prices, natural gas prices for end users in emerging markets in Asia rose by about 70% in 2022 compared with the five-year average. There were also shortfalls in the power and industry sectors in countries such as Pakistan and Bangladesh. The effects of these price rises and shortfalls were borne directly by consumers in the countries concerned.

Figure 4.12 ▷ Energy affordability measures enacted in response to the global energy crisis by fuel, Q4 2021-Q2 2023



IEA. CC BY 4.0.

Most government measures adopted to keep retail energy prices affordable during the global energy crisis supported all consumers through tax reductions and price caps

Overall, the amount earmarked by policy makers for affordability measures during the crisis was around 70% of the amount that countries had allocated to clean energy investment support since 2020. In emerging market and developing economies, allocations for affordability measures (USD 140 billion) were considerably higher than those made to support clean energy investment (USD 90 billion).

Two-thirds of the affordability measures put in place were not targeted. Untargeted support has the advantage that it is easy to administer and can be implemented quickly, and this was probably one of the main reasons why most governments chose such measures. There was also a case for some support for all consumers on a time-limited basis, given the scale and speed of the shock. However, such blanket measures are ultimately an expensive and inefficient way to protect those most in need.

One of the innovative approaches developed during the crisis came from the Austrian government, which decided to provide partial compensation to electricity consumers for the rise in their energy bills. This compensation took the form of an automatic subsidy up to an annual limit of 2 900 kilowatt-hours (kWh) per household, which represented 80% of an average household's annual electricity consumption. Germany developed a similar scheme, under which households and small businesses were charged a fixed price of EUR 0.12/kWh for 80% of their gas and heat consumption of the previous year, with any additional consumption over and above this charged for at market prices. The aim of these schemes was to strike a balance between safeguarding basic energy consumption on the one hand and maintaining incentives to save energy and invest in greater efficiency on the other.

In the difficult circumstances of the crisis, consumers needed timely and reliable information about what was happening, what their government was doing about it and what they themselves could do. Governments, energy companies and consumer associations all provided such information through various campaigns, which played a positive role in informing consumers about the need to reduce energy consumption and gave practical advice on how to do so.

4.4.2 Strategies to reduce the risk of future price shocks

Based on the analysis earlier in this chapter, we propose in this section a set of preventative approaches that can help to promote orderly transitions and reduce the risk of price shocks. We then consider some approaches that can help prepare for the eventuality of such shocks, although the precise responses in specific cases will depend on a range of factors, including the nature and extent of the shock, the funding available and the consumers most at risk.

Promoting orderly energy transitions

The acceleration in clean energy deployment in recent years has shown how 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 and risks provoking a social and political backlash. Successful transitions ultimately require a process that is orderly and inclusive, and the approaches below provide some high-level guidance for policy makers on how to make this possible.

- **Be alert and adaptable**: transitions rely on a myriad of supply-side and demand-side interventions which may not all have the effects in the real world that were expected or intended. This uncertainty puts a premium on vigilance and rigorous market monitoring to provide early indications to policy makers of elements that are misaligned or that could affect energy security or affordability. Policy-making in energy transitions requires a willingness to adjust approaches quickly in response to new developments and risks as they arise.

- **Pay particular attention to demand-side measures and infrastructure**: many of the areas of risk ultimately hinge on the adequacy and timeliness of investment, which in turn depends on well-functioning markets and clear policy frameworks. Scaling up clean energy investment rapidly is essential to mitigate future price risks while reducing emissions. However, the sequencing of change matters. Cutting investment in fossil fuels ahead of actual declines in their consumption pushes up prices but does not necessarily advance secure transitions. Moreover, to be effective, investment in renewable technologies needs to be accompanied by spending on essential infrastructure, notably electricity grids and storage, and by demand-side measures. These have been lagging behind in many countries. A key risk is that neither investment in supporting infrastructure nor demand-side measures that accelerate clean electrification and efficiency improvements get the attention that they need.
- **Give poorer countries and communities access to the clean energy economy:** a central message of this report is that, in the absence of targeted policy support to manage the upfront costs, disadvantaged communities and countries may struggle to access affordable, secure and sustainable modern energy. This risks leaving a large part of the global population reliant on polluting fuels and inefficient equipment to meet their energy needs. An energy transition of this kind would not be just or inclusive, and nor would it be at all likely to reduce emissions at the speed required to avoid severe impacts from climate change.
- **Manage the retirement and reuse of existing infrastructure:** even in very rapid energy transitions, some parts of the fossil fuel infrastructure will remain critical to the reliable and affordable operation of the energy system during the transition. For example, in some countries peak requirements for gas-fired power may increase in transitions even as overall demand goes down, particularly where gas-fired plants play important roles in meeting seasonal fluctuations in demand. One of the tasks for policy makers is to identify which parts of the system need to be maintained and managed carefully during the transition, and which are more amenable to rapid transformation. Unplanned, chaotic or premature retirement of some existing assets could increase vulnerability to price shocks.
- **Tackle the specific risks facing producer economies**: fuel price stability during energy transitions will depend in large part on major oil and gas exporting countries grappling successfully with the task of economic diversification during a period in which their revenue from oil and gas markets is under pressure. This in turn requires bilateral and multilateral dialogue among countries along oil and gas value chains to align views on the pace and direction of change, bring down the emissions intensities of traditional fuels, unlock investment and trade in low-emissions fuels and other clean energy technologies, and work together on technology development.
- **Put a premium on flexibility as a key to electricity security**: electricity accounts for a rising share of final consumption in all our transition scenarios, but power systems are becoming more complex, with higher variability on both the supply side and the demand side. Avoiding damaging shortfalls and strains on the system will require power

generators to be more responsive and agile, consumers to be more adaptable, and grid infrastructure to be strengthened and digitalised to support more dynamic flows of electricity and information.

- **Promote diverse energy supply chains:** there are important distinctions to be made between critical mineral security and oil or gas security: a price spike for oil affects all consumers driving oil-fuelled cars; a shortage or price spike in critical minerals affects only the production of new EVs or solar panels for the market. Nonetheless, high and volatile critical material prices and highly concentrated clean energy supply chains could delay energy transitions and make them more costly. A comprehensive and co-ordinated approach is required to develop and expand global clean energy technology supply chains that are secure, resilient and sustainable.
- **Integrate climate resilience and digital security into strategies for emergency preparedness**: future price shocks in a more electrified and renewables-rich energy system are increasingly likely to be linked to extreme weather events or to intentional or accidental disruptions to power supply. Climate and cyber resilience need to be fully integrated into government approaches to energy security and affordability. Preparatory actions include risk assessments, systems monitoring and the creation of frameworks that incentivise investments in resilience.

Readiness for price shocks when they do occur

Despite the best efforts of governments to promote orderly energy transitions, price shocks have been a regular feature of energy history and will no doubt be part of its future as well. Governments and other stakeholders need to take measures to ensure that energy systems and infrastructure are as resilient as possible and that they are ready to mitigate the worst impacts of emergency situations when they arise.

One of the lessons from the global energy crisis is that short-term interventions can involve trade-offs between affordability and other policy objectives. Blanket measures such as price caps, circuit breakers and energy tax reductions are relatively easy to administer but distort market and investment signals. They should be used sparingly because of their high costs and their potential to delay the point at which markets rebalance. By contrast, investments in emergency preparedness and measures to promote energy efficiency and demand restraint are less likely to have unintended consequences. Readiness to cope with price shocks should involve:

- **Prior design of emergency support programmes**: much of the necessary preparatory work relates to clarifying objectives and finding or developing information systems that allow policy makers to identify and target the most vulnerable energy consumers, within the limits of concerns about data privacy. As in the Austrian and German examples discussed above, one approach worth considering is to design policies to safeguard a certain level of essential consumption at an affordable price (also known as minimum vital supply), while exposing consumers to market prices above that level. An alternative approach could be to provide direct assistance to certain households, including those with low incomes, in the form of a rebate. Plans could be built up from and integrated with existing policies to help poorer households with their energy bills.

- **Provision for time-limited interventions**: the experience of recent years highlights that withdrawing emergency support, once granted, is difficult. The political challenges can be lessened if there are clear conditions stipulated in advance. This could mean a sunset or review clause with a clear end date, or a link to a decrease in the wholesale energy price, or some built-in transition mechanism that phases out the exceptional support.
- **Possibilities for emergency demand restraint**: there are many ways in which governments and consumers can limit demand for energy in times of crisis. These include adjusting heating and cooling controls while maintaining essential thermal comfort; working from home or reducing speed limits to curb transport fuel demand; and incentivising the use of public transport use. It will be essential in all cases to make plans in advance for effective and well-targeted communications, and to ensure that consumers have the technical means and incentives, including smart metering, to adjust their consumption.
- **Emergency mechanisms on the supply side**: this includes ensuring that energy storage facilities and stockholding mechanisms are adequately regulated and fit for purpose, and that viable possibilities for short-term switching are explored and prepared for in advance. In some countries there may also be short-term ways to increase domestic production in case of a shortfall in supply.
- **Co-ordination and emergency preparedness**: the capability to react to price shocks requires regular training and careful testing of emergency preparedness. It also requires the establishment and testing of co-ordination mechanisms both within individual governments and between countries. The IEA, for example, conducts regular emergency response exercises with member and partner countries to ensure the operational readiness of the oil stockholding mechanism and to test the effectiveness of crisis decision-making processes within national administrations.

ANNEXES

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

Distance	km	kilometre
	pkm	passenger kilometre demand
Emissions	t CO_2	tonnes of carbon dioxide
Energy	EJ	exajoule (1 joule x 10^{18})
	GJ	gigajoule (1 joule x 10^9)
	Boe	barrel 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
	Gcal	gigacalorie
Gas	bcm	billion cubic metres
Mass	kg	kilogramme
	t	tonne (1 tonne = 1 000 kg)
	Mt	million tonnes (1 tonne x 10^6)
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}
Oil	barrel	one barrel of crude oil
	kb/d	thousand barrels 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)
	Wp	watt-peak
Efficiency	W/W	the ratio of the cooling capacity (W) versus power consumption (W)
Other	bps	basis points

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	0.80
Chinese Yuan Renminbi	7.08
Euro	0.92
Indian Rupee	82.60
Japanese Yen	140.49

Source: IMF International Financial Statistics (database): Exchange rates (indicator), https://data.imf.org/?sk=cb5462fc-9197-43d1-af26-18d6e8e4e784&hide_uv=1, accessed May 2024.

Definitions

Agriculture: Includes all energy used on farms, in forestry and for fishing.

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.

Battery storage: Energy storage technology that uses reversible chemical reactions to absorb and release electricity on demand.

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.

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.

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.

Clean cooking systems: Cooking solutions that release less harmful pollutants and 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 cookstoves, 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, 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.

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.

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.

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.

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 vehicles (EV)**:** Electric vehicles comprise 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 services: See useful energy.

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 subsurface 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 pump: A heat pump extracts heat from a source, such as the surrounding air, geothermal energy stored in the ground, or nearby sources of water or waste heat from a factory. It then amplifies and transfers the heat to where it is needed.

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 cookstoves: Intermediate and advanced improved biomass cookstoves (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.

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-2023 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.

Low-emissions fuels: Include modern bioenergy, low-emissions hydrogen and low-emissions hydrogen-based fuels.

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 on-site 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.

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 bioenergy: Includes all modern solid, liquid and gaseous bioenergy products. Solid bioenergy products excludes the traditional use of biomass and includes the use of solid bioenergy in intermediate and advanced improved biomass cookstoves (ISO tier > 1), requiring fuel to be cut in small pieces or often using processed biomass such as pellets. Modern liquid bioenergy products include biogasoline, biodiesel, biojet kerosene and other liquid biofuels. Modern gaseous bioenergy products include both biogas and biomethane.

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).

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.

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.

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.

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.

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.

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 17 chemical elements in the periodic table, specifically the 15 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).

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.

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.

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 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 (SDGs). 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 cookstoves (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.

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 a 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 (ZCRB): 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.

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.

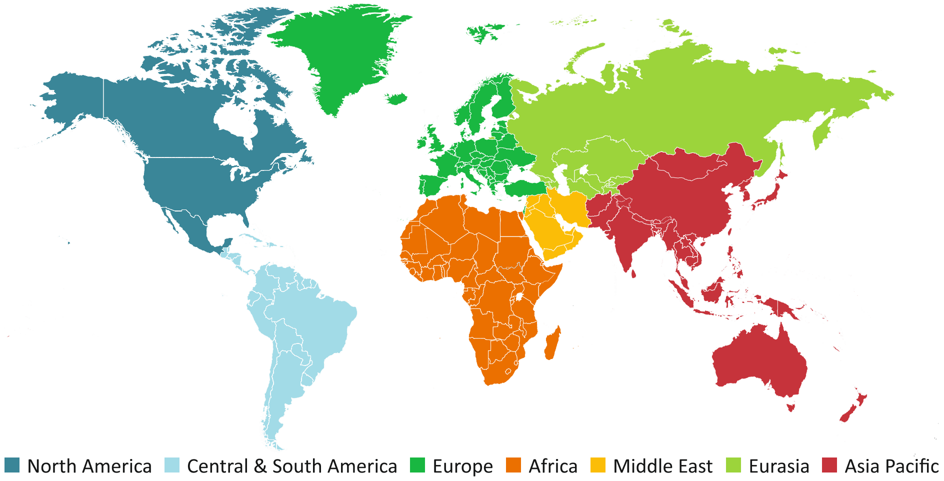
Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, 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

APS	Announced Pledges Scenario
BCR	benefit to cost ratio
BEV	battery electric vehicles
BNDES	National Bank for Economic and Social Development (Brazil)
CCGT	combined-cycle gas turbine
CCUS	carbon capture, utilisation and storage
CEEW	Council on Energy, Environment and Water
CEEPI	IEA's clean energy equipment price index
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-eq	carbon-dioxide equivalent
COP	Conference of Parties (UNFCCC)
DFI	development finance institutions
EEO	energy efficiency obligation
EMDE	emerging market and developing economies
EPA	Environmental Protection Agency (United States)
ESCO	energy service company
ETS	emissions trading system
EU	European Union
EU ETS	European Union Emissions Trading System
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of Electric Vehicles (India)
FID	Final investment decision
G7	Group of Seven
G20	Group of 20
GDP	gross domestic product
GHG	greenhouse gases
HHCRO	Home Heating Cost Reduction Obligation (United Kingdom)
ICE	Internal Combustion Engine
IDCOL	Infrastructure Development Company Limited (Bangladesh)
IEA	International Energy Agency
ISDE	Sustainable Energy Investment Subsidy (Netherlands)
IMF	International Monetary Fund
INSEE	The National Institute of Statistics and Economic Studies (France)

IRA	Inflation Reduction Act (United States)
LCOE	levelised cost of electricity
LED	light-emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MEPS	minimum energy performance standards
MER	market exchange rate
NDC	Nationally Determined Contribution
NEA	National Energy Administration (China)
NEP	Nigeria Electrification Project
NGFS	Network for Greening the Financial System
NOC	national oil company
NZE	Net Zero Emissions by 2050 Scenario
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PayGo	Pay-as-you-go
PHEV	plug-in hybrid electric vehicles
PLDV	passenger light-duty vehicle
PPA	power purchase agreement
PPP	purchasing power parity
PV	photovoltaics
ROC	return on capital
R&D	research and development
REA	Rural Electrification Agency
SAVE	Sustainability Achieved Via Energy Efficiency (Malaysia)
SCC	social cost of carbon
SDG	Sustainable Development Goals (United Nations)
SEAI	Sustainable Energy Authority of Ireland
SEER	seasonal energy efficiency ratio
SEPAP	Solar Energy Poverty Alleviation Programme (China)
SHS	solar home systems
SMEs	small and medium enterprises
SOE	state-owned enterprise
SPR	Strategic Petroleum Reserve (United States)
STEPS	Stated Policies Scenario
TCO	total cost of ownership

UAE	United Arab Emirates
UN	United Nations
UNEP	United Nations Environment Programme
US	United States
VALCOE	value-adjusted levelized cost of electricity
WACC	weighted average cost of capital
WEO	World Energy Outlook
WTO	World Trade Organisation

References

Chapter 1: Exploring affordable energy transitions

BNEF (Bloomberg New Energy Finance). (2023). Electric Vehicle Outlook 2023. https://about.bnef.com/electric-vehicle-outlook/

ECB (European Central Bank). (2023). The road to Paris: stress testing the transition towards a net-zero economy. https://doi.org/10.2866/49649

EPA (United States Environmental Protection Agency). (2023). Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. https://www.epa.gov/environmental-economics/scghg

Eurostat. (2024). Harmonised indices of consumer prices (HICP) Database. https://ec.europa.eu/eurostat/web/hicp/database

FRED. (2024). Consumer price Indexes (CPI and PCE). https://fred.stlouisfed.org/categories/9

IEA (International Energy Agency). (2020). Projected Costs of Generating Electricity. https://www.iea.org/reports/projected-costs-of-generating-electricity-2020

IEA. (2022). The Future of Heat Pumps. https://www.iea.org/reports/the-future-of-heat-pumps

IEA. (2023a). Emissions from Oil and Gas Operations in Net Zero Transitions. https://www.iea.org/reports/emissions-from-oil-and-gas-operations-in-net-zero-transitions

IEA. (2023b). Energy Technology Perspectives 2023. https://www.iea.org/reports/energy-technology-perspectives-2023

IEA. (2023c). Global Energy and Climate Model. https://www.iea.org/reports/global-energy-and-climate-model

IEA. (2023d). The Oil and Gas Industry in Net Zero Transitions. https://www.iea.org/reports/the-oil-and-gas-industry-in-net-zero-transitions

IEA. (2024a). Global Critical Minerals Outlook. https://www.iea.org/reports/global-critical-minerals-outlook-2024

IEA. (2024b). Advancing Clean Technology Manufacturing. https://www.iea.org/reports/advancing-clean-technology-manufacturing

IEA. (2024c). Global EV Outlook 2024. https://www.iea.org/reports/global-ev-outlook-2024

IEA. (2024d). Reducing the Cost of Capital. https://www.iea.org/reports/reducing-the-cost-of-capital

IEA. (2024e). Batteries and Secure Energy Transitions. https://www.iea.org/reports/batteries-and-secure-energy-transitions

IMF (International Monetary Fund). (2023). Climate Change Dashboard. https://climatedata.imf.org/pages/ngfs/#ngfs7

JATO Dynamics. (2023). EV price gap: a divide in the global automotive industry. https://info.jato.com/ev-price-gap-report

Kotz, M., F. Kuik, E. Lis et al. (2024). Global warming and heat extremes to enhance inflationary pressures. Communications Earth & Environment. https://doi.org/10.1038/s43247-023-01173-x

MotorCycles Data. (2024). (database). https://www.motorcyclesdata.com/

Rentschler, J., M. Salhab and B.A. Jafino. (2022). Flood exposure and poverty in 188 countries. Nature Communications. https://doi.org/10.1038/s41467-022-30727-4

Stern, N., J. Stiglitz, K. Karlsson and C. Taylor. (2022). A Social Cost of Carbon Consistent with a Net-Zero Climate Goal. https://rooseveltinstitute.org/publications/a-social-cost-of-carbon-consistent-with-a-net-zero-climate-goal/

Ueckerdt, F., L. Hirth, G. Luderer and O. Edenhofer. (2013). System LCOE: What are the costs of variable renewables? Energy. https://doi.org/10.1016/j.energy.2013.10.072

UNECE (United Nations Economic and Social Council). (2017). Consolidated Resolution on the Construction of Vehicles. https://unece.org/fileadmin/DAM/trans/main/wp29/wp29resolutions/ECE-TRANS-WP.29-78r5e.pdf

US EIA (United States Energy Information Administration). (2022). Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

Chapter 2: Investment and energy bills

Bloomberg Terminal. (2024). https://www.bloomberg.com/professional/products/bloomberg-terminal/

Department for Environment Food & Rural Affairs. (2024). Statistical Digest of Rural England: communities and households. https://www.gov.uk/government/collections/statistical-digest-of-rural-england

Department for Transport. (2022). National Travel Survey 2021: Travel by region and rural and urban classification of residence. https://www.gov.uk/government/statistics/national-travel-survey-2021/national-travel-survey-2021-travel-by-region-and-rural-and-urban-classification-of-residence

European Commission. (2023). Annual Report on European SMEs 2022/2023. https://op.europa.eu/en/publication-detail/-/publication/12f499c0-461d-11ee-92e3-01aa75ed71a1/language-en

I4CE (Institute for Climate Economics). (2023). Global Carbon Accounts in 2023. Institute for Climate Economics. https://www.i4ce.org/en/publication/global-carbon-accounts-2023-climate/

Iberdrola. (2024). Results presentation 2023. https://www.iberdrola.com/documents/20125/3894078/results-23FY.pdf

IEA (International Energy Agency). (2022). Africa Energy Outlook. https://www.iea.org/reports/africa-energy-outlook-2022

IEA. (2023a). A Vision for Clean Cooking Access for All. https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all

IEA. (2023b). Financing Clean Energy in Africa. https://www.iea.org/reports/financing-clean-energy-in-africa

IEA. (2024). Energy Prices (database). https://www.iea.org/data-and-statistics/data-product/energy-prices

IMF (International Monetary Fund). (2023). Annual Report. https://www.imf.org/external/pubs/ft/ar/2023/english/

IMF. (2024a). (database). https://www.imf.org/en/home

IMF. (2024b). Key Challenges Faced by Fossil Fuel Exporters during the Energy Transition. https://www.elibrary.imf.org/view/journals/066/2024/001/article-A001-en.xml

Kompil, M., C. Jacobs-Crisioni, L. Dijkstra and C. Lavalle. (2019). Mapping accessibility to generic services in Europe: A market-potential based approach. Sustainable Cities and Society. https://doi.org/10.1016/j.scs.2018.11.047

Miotti, M., Z. Needell and R. Jain. (2023). The impact of urban form on daily mobility demand and energy use: Evidence from the United States. Applied Energy. https://doi.org/10.1016/j.apenergy.2023.120883

OECD (Organisation for Economic Co-operation and Development). (2022). Financing SMEs and Entrepreneurs 2022. https://www.oecd-ilibrary.org/industry-and-services/financing-smes-and-entrepreneurs-2022_e9073a0f-en

OECD. (2023). Structural and Demographic Business Statistics. https://www.oecd.org/sdd/business-stats/structuralanddemographicbusinessstatisticssdbsoecd.htm

OECD. (2024). Latest Developments in Steelmaking Capacity. https://www.oecd.org/industry/ind/latest-developments-in-steelmaking-capacity-2024.pdf

S&P Global. (2024). Capital IQ. https://www.capitaliq.spglobal.com/

Transport and Environment. (2023). Leasing sector could flood second hand market with electric cars. https://www.transportenvironment.org/articles/leasing-sector-could-flood-second-hand-market-with-electric-cars

US Department of Transportation. (2022). Household Spending on Transportation: average household spending. https://data.bts.gov/stories/s/ida7-k95k#household-expenditures-in-urban-and-rural-areas

World Bank. (2022). Indonesia Economic Prospects, June 2022: Financial Deepening for Stronger Growth and Sustainable Recovery. https://www.worldbank.org/en/country/indonesia/publication/indonesia-economic-prospects-iep-june-2022-financial-deepening-for-stronger-growth-and-sustainable-recovery

World Bank. (2023). Poverty and Inequality Platform. Poverty and Inequality Platform: https://pip.worldbank.org/home

World Bank. (2024a). State and Trends of Carbon Pricing Dashboard. https://carbonpricingdashboard.worldbank.org/

World Bank. (2024b). World Development Indicators. https://datacatalog.worldbank.org/search/dataset/0037712

World Bank. (2024c). World Bank Open Data. https://data.worldbank.org/

Chapter 3: Policies promoting affordability

AFDB (African Development Bank Group). (2024). Nigeria - Nigeria Electrification Project. https://projectsportal.afdb.org/dataportal/VProject/show/P-NG-F00-020

Anderson, W., V. White and A. Finney. (2010). Coping with low incomes and cold homes. Energy Policy. https://doi.org/10.1016/j.enpol.2012.01.002

BASE (Basel Agency for Sustainable Energy). (2023). Supporting the transition to sustainable domestic cooling in Ghana and Senegal. https://energy-base.org/projects/ecofridges-initiative-in-west-africa/

Buettner, T. and B. Madzharova. (2021). Promoting Sales of Energy Efficient Household Appliances: Outcomes and Cost Effectiveness of Rebate Programs. Munich Society for the Promotion of Economic Research - CESifo GmbH. https://doi.org/10.1086/728610

CA-EED (Concerted Action – Energy Efficiency Directive). (2024). Energy poverty and health – infographic & report. https://www.ca-eed.eu/expert-study-group-report/

California Air Resources Board. (2023). Cap-and-Trade Program Summary of 2013-2021 Electrical Distribution Utility Use of Allocated Allowance Value. https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program

California Climate Investments. (2022). Investment Targets for Agencies Administering FY 2022-23 Funds. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cci_fy2022-23_ab1550_investmenttargets.pdf

CEEW (Council on Energy, Environment and Water). (2023). How decentralised renewable energy-powered technologies impact livelihoods. https://www.ceew.in/publications/how-decentralised-renewable-energy-powered-technologies-impact-sustainable-livelihoods

CSO (Central Statistics Office). (2016). Domestic Building Energy Ratings from a Social Perspective 2016. https://www.cso.ie/en/releasesandpublications/ep/p-dbersp/domesticbuildingenergyratingsfromasocialperspective2016/mainresultsatstatelevel

Department for Energy Security and Net Zero. (2024). Household Energy Efficiency Statistics. https://www.gov.uk/government/statistics/household-energy-efficiency-statistics-headline-release-january-2024

European Union. (2023). Regulation (EU) 2023/955 of the European Parliament and of the Council. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0955

Eurostat. (2024). Estimated average age of young people leaving the parental household by sex.
https://ec.europa.eu/eurostat/databrowser/view/yth_demo_030/default/table?lang=en

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). (2023). Assessing the Impact and Effectiveness of Mini-Grid Results-based Financing Programmes.
https://gruene-buergerenergie.org/wp-content/uploads/230616_GBE-EAD-Study_09-002.pdf

IDCOL (Infrastructure Development Company Limited). (2023).
https://www.idcol.org/an-reports.

IEA (International Energy Agency). (2016). World Energy Outlook 2016.
https://www.iea.org/reports/world-energy-outlook-2016

IEA. (2019). Renewables 2019. https://www.iea.org/reports/renewables-2019

IEA. (2022). Africa Energy Outlook 2022.
https://www.iea.org/reports/africa-energy-outlook-2022

IEA. (2023). Unlocking Smart Grid Opportunities in Emerging Markets and Developing Economies. https://www.iea.org/reports/unlocking-smart-grid-opportunities-in-emerging-markets-and-developing-economies

IEA. (2024a). Renewable Energy Progress Tracker.
https://www.iea.org/data-and-statistics/data-tools/renewable-energy-progress-tracker

IEA. (2024b). The oil and gas industry in net zero transitions.
https://www.iea.org/reports/the-oil-and-gas-industry-in-net-zero-transitions

LBNL (Lawrence Berkeley National Laboratory). (2023). Residential Solar-Adopter Income and Demographic Trends: 2023 Update. https://emp.lbl.gov/publications/residential-solar-adopter-income-2

Ministère de la Transition Écologique. (2020). Les voitures des ménages modestes : moins nombreuses mais plus anciennes. https://www.ecologie.gouv.fr/sites/default/files/Théma%20-%20Les%20voitures%20des%20ménages%20modeste%20-%20%20moins%20nombreuses%20mais%20plus%20anciennes_0.pdf

Ministère de la Transition Écologique et de la Cohésion des Territoires. (2023). LES RÉNOVATIONS ÉNERGÉTIQUES AIDÉES PAR MaPrimeRénov' ENTRE 2020 ET 2022. https://www.statistiques.developpement-durable.gouv.fr/media/6700/download?inline

Ministry of Heavy Industries. (2019). Scheme for Faster Adoption and Manufacturing of Electric Vehicles in India. https://fame2.heavyindustries.gov.in/content/english/11_1_PolicyDocument.aspx

Ministry of Heavy Industries. (2022). Models under FAME. https://fame2.heavyindustries.gov.in/ModelUnderFame.aspx

Motu Economic and Public Policy Research. (2022). Evaluation of the Warmer Kiwis Homes Programme. https://www.motu.nz/our-research/urban-and-regional/housing/warmer-kiwis-study/

National Bureau of Statistics of China. (2023). China Statistical Yearbook.

NEA (National Energy Administration). (2023). Press release. https://www.nea.gov.cn/2022-07/27/c_1310646889.htm

Nigeria SE4All. (2024). Mini-grids (database). https://nigeriase4all.gov.ng/mini-grids

Odyssee-Mure. (2021). Energy poverty in the EU. https://www.odyssee-mure.eu/publications/policy-brief/european-energy-poverty.pdf

OECD (Organisation for Economic Co-operation and Development). (2022). The distribution of housing assets. https://www.oecd-ilibrary.org/sites/63dec4c1-en/index.html?itemId=/content/component/63dec4c1-en

PwC (PricewaterhouseCoopers). (2023). Sustainable transport incentives for 2023. https://www.pwc.com/mt/en/publications/tax-legal/sustainable-transport-incentives-for-2023.html

REA (Rural Electrification Agency). (2024). NEP Achievement Data Board. https://nep.rea.gov.ng/neptool/

SEAI (Sustainable Energy Authority of Ireland). (2024). Statistics for National Home Retrofit Programmes. https://www.seai.ie/grants/home-energy-grants/home-upgrades/

Secretaría de Energía. (2018). Análisis del impacto de las Normas Ociales Mexicanas de E ciencia Energética en el ingreso-gasto del sector residencial de México a partir de datos de INEGI (1990-2016). https://www.conuee.gob.mx/transparencia/boletines/Cuadernos/cuadernoNo9.pdf

SMEV (Society of Manufacturers of Electric Vehicles). (2024). (database). https://www.smev.in/ev-industry

Statistics Norway. (2020). The wealthiest bought 4 out of 10 EVs. https://www.ssb.no/en/transport-og-reiseliv/artikler-og-publikasjoner/the-wealthiest-bought-4-out-of-10-evs

TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek). (2023). Effecten van fixers/energiecoaches, renovaties en witgoedregelingen. https://www.tno.nl/nl/newsroom/2023/07/steunmaatregelen-energiearmoede/

Ministry of Environment and Energy. (2024). Renovate my house and save energy - for young people. https://www.gov.gr/en/ipiresies/periousia-kai-phorologia/epidoteseis-politon/exoikonomo-anakainizo-to-spiti-mou-gia-neous

World Bank. (2021). Electrification of Public Transport : A Case Study of the Shenzhen Bus Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/708531625052490238/electrification-of-public-transport-a-case-study-of-the-shenzhen-bus-group

World Bank. (2022). India - Toolkit for Enabling Gender Responsive Urban Mobility and Public Spaces. https://openknowledge.worldbank.org/entities/publication/128bcb06-0fc4-5c1d-9a2b-fc6e9ce47b03

World Bank. (2023a). World Bank Open Data. https://data.worldbank.org/

World Bank. (2023b). World Development Indicators. https://datatopics.worldbank.org/world-development-indicators/

World Bank. (2024a). Disclosable Version of the ISR - Nigeria Electrification Project - P161885. http://documents.worldbank.org/curated/en/099031324181039832/P1618851b3f9ef0e41bf7b1bcafc815c295

World Bank. (2024b). Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India. https://doi.org/10.1596/978-1-4648-2055-7

Zhang, H., K. Wu, Y. Qiu et al. (2020). Solar photovoltaic interventions have reduced rural poverty in China. Nature Communications. https://doi.org/10.1038/s41467-020-15826-4

Chapter 4: Secure and people-centred energy transitions

Argus Media. (2024). Natural gas (price database). https://www.argusmedia.com/en/commodities/natural-gas

European Commission. (2023). EU guidance on energy poverty. https://energy.ec.europa.eu/system/files/2023-10/SWD_2023_647_F1_OTHER_STAFF_WORKING_PAPER_EN_V5_P1_3016190.PDF

Eurostat. (2024). Supply, transformation and consumption of gas (database). https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_gasm/default/table?lang=en

IEA (International Energy Agency). (2023a). Government Energy Spending Tracker. https://www.iea.org/reports/government-energy-spending-tracker-2

IEA. (2023b). A new tool to track transitions - the IEA clean energy equipment price index. https://www.iea.org/commentaries/a-new-tool-to-track-transitions-the-iea-clean-energy-equipment-price-index

IEA. (2024). Global Methane Tracker. https://www.iea.org/reports/global-methane-tracker-2024

US Department of the Treasury. (2022). The Price Impact of the Strategic Petroleum Reserve Release. https://home.treasury.gov/news/press-releases/jy0887

US EIA (United States Energy Information Administration). (2024a). Europe Brent Spot Price FOB (database). https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=m

US EIA. (2024b). Natural Gas Prices (database). https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm

Wood Mackenzie. (2023). Supply shortages and an inflexible market give rise to high power transformer lead times. https://www.woodmac.com/news/opinion/supply-shortages-and-an-inflexible-market-give-rise-to-high-power-transformer-lead-times/

Revised version, June 2024
Information notice found at:
www.iea.org/corrections

International Energy Agency (IEA)

Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

IEA Publications
International Energy Agency
Website: www.iea.org
Contact information: www.iea.org/contact

Typeset in France by IEA - May 2024
Cover design: IEA
Photo credits: © Shutterstock

Strategies for Affordable and Fair Clean Energy Transitions

World Energy Outlook Special Report

Issues of affordability and fairness have moved towards the centre of debates about clean energy transitions in many countries. The global energy crisis revealed the vulnerabilities and risks inherent to today's fossil fuel-based energy system, while bringing the benefits of transitions – such as greater energy security, improved air quality, reduced emissions and less exposure to volatile fuel prices – into sharper relief. But even as clean energy technologies become increasingly cost-competitive, they still require a step-change in investment to overcome the inertia that favours incumbent fuels and technologies.

As living costs have increased around the world, important questions have emerged about how to pay for clean energy transitions, as well as how the costs and benefits will be shared. Low-income households, in particular, risk being locked out of transitions if they cannot afford the upfront costs.

The IEA's new special report, *Strategies for Affordable and Fair Clean Energy Transitions*, explores these challenges and how they might be addressed. Its first-of-its-kind analysis provides a comprehensive evidence base for this discussion and a pragmatic look at policy approaches that can safeguard affordability and fairness as transitions advance.