Seizing the moment of opportunity

Supercharging the new energy era of renewables, efficiency, and electrification

United Nations

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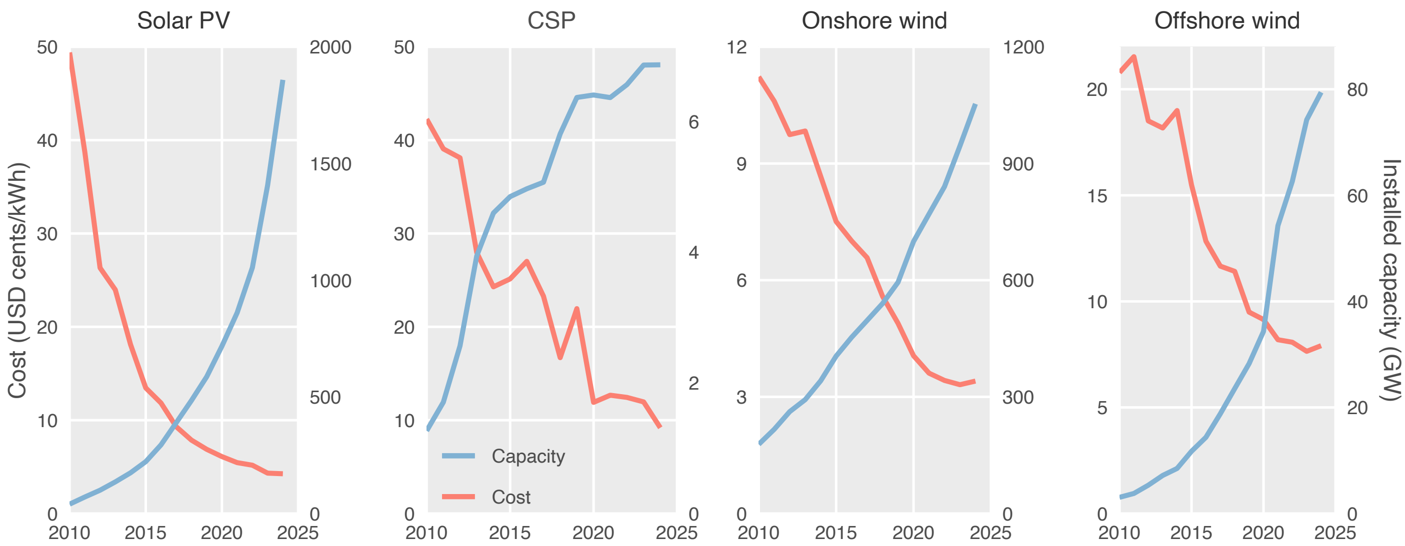
Executive summary

We stand at a unique and defining moment in history. In the ten years since the Paris Agreement was adopted, renewable energy technologies have undergone a remarkable transformation. With spectacular cost declines and manufacturing capacity growth, the global deployment of solar, wind, and electric vehicles (EVs) has exceeded even the most optimistic projections and continues to advance exponentially (Figure ES1). **The world is poised for a breakthrough in the rapid and widespread transition from energy systems dominated by fossil fuels to those dominated by homegrown, low-cost renewables. However, seizing this moment of opportunity is not a given as significant political and economic barriers and obstacles remain.**

This special report provides a high-level synthesis of the state of play of — and the economic imperative and opportunity for — accelerating the transition away from fossil fuels to clean energy, with a particular focus on the roles of renewables, electrification, and energy efficiency.[i]

Solar and wind are now almost always the least expensive — and the fastest — option for new electricity generation. Between 2010 and 2022, solar and wind power became cost-competitive with fossil fuels without financial support in many countries. **By 2023, an estimated 96% of newly installed, utility-scale solar photovoltaics (PV) and onshore wind capacity had lower power generation costs than new coal and gas plants, while around 75% of new wind and solar PV plants offered cheaper power than existing fossil fuel facilities globally.** In 2024, the global average electricity generation cost from solar PV was 41% cheaper, and onshore wind 53% cheaper, than the least-cost new fossil fuel-fired power plant, with solar PV reaching USD 4.3 cents per kilowatt-hour (kWh) and onshore wind USD 3.4 cents/kWh. On average, project lead times for solar PV and onshore wind are one to three years (less for small-scale solar), whereas coal- and gas-fired power plants can take up to five years or more and nuclear power plants 10–15 years.

Figure ES1. Rapid cost declines and growth in installed electricity capacity of solar and wind technologies globally, 2010–2024.



Data source: IRENA.[1] (The cost shown represents the levelized cost of electricity; CSP = concentrated solar power.)

i See Annex for the definitions of renewable energy and clean energy used in this report.

The plummeting costs mean that solar and wind have become the fastest growing sources of electricity in history, and growth in renewable energy is now outpacing that in fossil fuels in the power sector. In 2024, renewables made up 92.5% of all new electricity capacity additions and 74% of electricity generation growth. Between 2015 and 2024, global annual electricity capacity of renewables increased by around 2,600 gigawatts (GW) (140%), while that of fossil fuels increased by around 640 GW (16%). Consequently, the shares of fossil fuels and renewables in global installed electricity capacity now stand at almost 1:1. In terms of global annual electricity generation, renewables increased by 4,470 terawatt-hours (TWh) (81%), while fossil fuels increased by 2,150 TWh (13%). Meanwhile, the sales of EVs have increased by 3,300%, from 0.5 million (1% of all car sales) in 2015 to over 17 million (>20% of all car sales) in 2024. **Experts believe that solar, wind, and EVs have irreversibly crossed a positive tipping point and entered a virtuous cycle of cost decline and widespread adoption.**

As a result, a new clean energy economy is emerging, contributing to growth in gross domestic product (GDP) and creating jobs while helping to decouple growth from emissions. Global annual clean energy investments exceeded USD 2 trillion for the first time in 2024, having surpassed those for fossil fuels for the first time in 2016. Clean energy jobs reached a total of 34.8 million in 2023, of which 16.2 million are in renewables. In 2023, the sector added around USD 320 billion to the global economy, accounting for 10% of GDP growth globally and nearly one-third in the European Union (EU). In 2024, the clean energy sector accounted for 10% of the economy of the People's Republic of China (hereafter referred to as China) and drove a quarter of the country's GDP growth. Since 1990, economic growth has decoupled from greenhouse gas (GHG) emissions for more than five years at least in more than 40 countries.

Accelerating the transition away from fossil fuels to renewables brings with it myriad positive social and economic benefits. In particular, renewable energy can boost energy access, affordability, and security. Around 74% of the global population lives in countries that are net importers of fossil fuels. **Dependence on fossil fuel imports exposes countries to volatile prices, supply disruptions, and geopolitical turmoil.** Following the outbreak of war in Ukraine in early 2022, the price of natural gas — and consequently electricity prices in some markets — reached record highs, while oil prices hit their highest level since 2008. **This directly increased the costs of heating, cooling, lighting, and mobility, and indirectly pushed up the costs of other goods and services throughout global supply chains, exacerbating the cost-of-living crisis in 2022.** On average, consumers worldwide spent 20% more on energy bills than the previous five-year average; the increase was much greater for consumers living in countries with high gas import reliance.

Centralized and decentralized renewables-based systems also offer the most cost-effective and fastest solutions for delivering universal clean energy access by 2030. The combination of grid, mini-grid, and off-grid renewable solutions can be leveraged to deliver fast and lasting access, especially in difficult-to-reach rural locations where eight out of ten people without access to electricity live. Stand-alone, off-grid solar solutions served 490 million people in total by 2022. **Multiple studies show that the systematic adoption of renewables and improvements in energy efficiency, combined with progressive policies, can continue to lead to net gains in jobs, GDP, and other social welfare benefits as the transition progresses in the short, medium, and long term.** The implementation of small-scale renewable energy microgrids in developing countries has been shown to significantly contribute to sustainable development by improving livelihoods, reducing poverty and pollution exposure, and enhancing food security, health, and education.

Despite this, renewable energy is not replacing fossil fuels in energy systems at the pace and scale needed. To enable all countries to seize the benefits of the emerging clean energy economy, structural barriers and major challenges will need to be overcome. These include: developing enabling policy and regulatory frameworks that provide a level playing field for clean energy; prioritizing modernization and expansion of critical enabling energy infrastructure such as grids and storage; enhancing the resilience and diversity of clean energy supply chains; increasing the availability, accessibility, and affordability of energy-transition finance for developing economies; and addressing political resistance from vested fossil fuel interests.

The deployment of and investment in renewable energy technologies have so far been highly concentrated in advanced economies and China. Of the 4,448 GW of total renewable capacity installed globally by the end of 2024, 41% was in China, 39% in OECD countries, and almost half of the remaining 20% in Brazil and India. **Africa made up a mere 1.5%, despite accounting for 85% of the global**

population without electricity access, and despite possessing renewable resource potential ten times larger than the continent's projected electricity demand in 2040 under a 1.5°C-aligned scenario. Since the Paris Agreement came into force in 2016, less than one in every five dollars invested in clean energy has gone to emerging markets and developing economies (EMDEs) outside China. **The geographic concentration of raw materials processing and manufacturing capacity for clean energy technologies also creates risks for the security and resilience of supply chains.**

In addition to this geographic concentration, the deployment of renewables-based technologies has also thus far been mainly confined to the power generation and light-duty transport sectors. This, combined with limited progress on improving energy efficiency and on the electrification of all end-use sectors, as well as continued fossil fuel expansions, means that the share of fossil fuels in global total energy supply only decreased from 83% to 80% between 2015 and 2024.

On the domestic side, governments must also do more to create the enabling conditions to attract investments and drive implementation. Discordant policies can impede and undermine progress. Government subsidies for fossil fuels also remain high, while effective carbon pricing remains insufficient. Long-term, integrated national energy strategies are a vital planning tool for guiding the transition to a net-zero and increasingly renewables-dominant energy system, but few countries have developed such roadmaps. **Lagging investments in expanding and modernizing electricity grids also means that grids are becoming a bottleneck for the energy transition: at least 3,000 GW of renewable power projects are waiting in grid connection queues.**

Most crucially, the biggest challenge lies in scaling up clean energy-transition financing and investments for EMDEs beyond China. To keep the 1.5°C limit of the Paris Agreement within reach and deliver on the Sustainable Development Goals (SDGs), experts estimate that annual clean energy spending in these countries will have to increase by around five to seven times from 2022 levels to USD 1.4–1.9 trillion a year by 2030, and to over USD 2 trillion a year by 2035. **This hinges upon tackling persistent and systemic barriers in the international financial architecture, demystifying perceived risks, and addressing real risks to bring down the cost of capital — for both debt and equity financing.** For example, the cost of capital for utility-scale solar PV projects in EMDEs is well over twice as high as it is in advanced economies. **Trade policies and investment agreements must also be aligned with, and actively support, the transition to sustainable and inclusive development — rather than hinder progress.**

We have an unprecedented moment of opportunity to invest in the policies, frameworks, and infrastructure needed to capitalize on the falling costs, manufacturing capacity, and abundant resource endowment of renewable energy to unlock the transition globally — particularly in developing countries where renewable resources are vast and energy access needs are greatest. Governments, international institutions and partners, and development finance institutions (DFIs), as well as the private sector, all have vital roles to play. This report lays out six key areas of action for accelerating the transition:

1. **Provide policy coherence, clarity, and certainty — governments should align policies, incentives, and resources to accelerate the just energy transition.**
2. **Invest in enabling infrastructure for the 21st century energy system.**
3. **Meet new electricity demand with renewables, especially for rapidly growing sectors like Big Tech — in particular for Artificial Intelligence (AI) and data centres.**
4. **Place people and equity at the heart of the just energy transition to drive inclusive economic development.**
5. **Supercharge the transition by increasing cooperation on trade and investment.**
6. **Dismantle structural barriers to mobilize energy-transition finance for developing countries.**

The race to develop and deploy clean energy technologies to replace fossil fuels is the defining economic imperative and opportunity of this decade — one that will power the new, green industrial revolution of the 21st century. With smart and pragmatic policies — and greater international cooperation — a clean, secure, affordable, and equitable global energy system is within our reach. We should seize the solutions at hand to grasp it.

Section 1 — Introduction

The year 2015 marked a turning point in global climate governance, with the adoption of the landmark Paris Agreement at COP21.[2] It has an overarching goal of holding the increase in global average temperature relative to pre-industrial levels to well below 2°C and pursuing efforts towards 1.5°C. Subsequent COPs have resolved to limit the temperature increase to 1.5°C, recognizing that this would significantly reduce the risks and impacts of climate change compared to 2°C. **At COP28, Parties delivered a comprehensive vision for a 1.5°C-aligned energy system transformation, establishing global targets that include tripling renewable energy capacity by 2030, doubling the annual rate of energy efficiency improvements by 2030, and transitioning away from fossil fuels in line with global net-zero emissions by 2050, with accelerated near-term action.**[3]

The collective ratcheting up of global climate ambition and action over the last ten years means that projected global warming has been progressively declining.[ii] According to the UNEP Emissions Gap Report series, between the 2015 and 2024 assessments, the maximum level of global warming within this century under a current-policies scenario fell from just below 4°C to 3.1°C. Meanwhile, under a scenario in which Parties' conditional nationally determined contributions (NDCs) are fully implemented, projected global warming fell from 3–3.5°C to 2.6°C, and lower still to 1.9°C if net-zero pledges are also fully achieved.[4,5]

The strengthening of international and national climate policies has created positive multiplier and spillover effects, catalyzing commitments and action by sub-national and non-state actors, driving low-carbon technological innovation and adoption, and stimulating economies to decarbonize.[6,7] Bhutan was the first country to set a net-zero target in 2015. As of June 2025, 141 countries, 284 cities, and 1,191 companies had set net-zero targets, covering at least 76% of global GHG emissions and 78% of global GDP.[8,iii] Between 2015 and 2023, the coverage of global GHG emissions with carbon pricing approximately doubled from 12% to 25%.[9] Major global milestones such as the issuance of the first Intergovernmental Panel on Climate Change (IPCC) report in 1990 and the adoption of the Paris Agreement in 2015 have boosted the impact of domestic policies on green patent filings.[10]

Over the past few decades, the climate imperative has been instrumental in helping to drive innovation and investments in renewable energy technologies, spurring them to reach economies of scale.[iv] **Experts believe that solar, wind, and EVs have irreversibly crossed a positive tipping point and entered a virtuous cycle of cost decline and widespread adoption.**[11,12] The cost of utility-scale solar PV has fallen by 80–90% each decade since 1960, whereas the costs of fossil fuels are highly volatile and show no long-term decrease. New solar PV has been undercutting new coal- and gas-fired power plants in most of the world for six years, and the gap in their average lifetime electricity generation costs continues to widen in favour of solar. **Meanwhile, global manufacturing capacity of renewable energy technologies is outstripping demand: announced solar PV and battery projects can already cover the global deployment needs of the tripling renewable capacity by 2030 goal.**[13]

The IEA projects several significant renewable energy milestones to be reached in the power sector in the next five years. In 2025, renewables-based electricity generation is set to overtake coal-fired generation for the first time. Non-fossil fuel sources are expected to meet all global demand growth out to 2027, with renewables set to meet

ii The term global warming represents global mean surface temperature, averaged over decades, relative to pre-industrial levels. All global warming projections quoted are for at least a 66% likelihood and come with large uncertainty ranges. For example, for conditional NDCs submitted as of September 2024, which are contingent upon climate finance support, the central estimate and uncertainty range are 2.6°C (1.9–3.6°C). See full details in the 2015 and 2024 UNEP Emissions Gap Reports.

iii This estimate only considers country-level targets — including states in the United States of America, for example, would raise GDP coverage to at least 84% and increase the emissions coverage.

iv The term economies of scale refers to the phenomenon where the average cost per unit of output decreases with an increase in the scale or magnitude of production.

around 95%. Solar and wind power generation are both set to surpass nuclear in 2026. In 2029, solar PV electricity generation is expected to surpass hydropower to become the largest single renewable power source, and wind will surpass hydropower in 2030.[14,15]

While economic pragmatism and energy security concerns will now drive the transition away from fossil fuels to renewables, progressive policies — as well as greater international cooperation — will be vital to dismantle barriers and accelerate progress, and to ensure a just, orderly, and equitable transition in line with delivering on the Paris Agreement and SDGs.

At the same time, the economic case for accelerating climate action to minimize damages has never been clearer. Extreme weather events are intensifying in frequency and ferocity, devastating lives, livelihoods, and economies, disrupting supply chains, increasing the debt burden of developing countries, and driving up the cost of living across the world.[16–18] In 2024, economic losses due to weather-related extreme events were estimated to be USD 320 billion, of which 56% were uninsured.[19] **Study after study has shown that the cost of inaction is far greater than the cost of action.**[20–22] For example, recent analyses by the Network for Greening the Financial System estimate that climate damages could result in regional economic losses amounting to 6% of GDP in Asia and up to 12.5% in Africa over the next five years; by 2050, losses could reach 15% of GDP globally.[23]

Without further action, climate impacts will intensify and continue to reshape economic and financial systems, jeopardizing long-term development and security, especially in vulnerable countries. The latest assessments from the World Meteorological Organization (WMO) found that 2024 was the warmest year in the 175-year observation record, and likely the first in which the 12-month average exceeded 1.5°C above pre-industrial levels. Between 2025 and 2029, there is now an 86% chance that at least one year will be warmer than 1.5°C, and a 70% chance that the five-year average will also exceed 1.5°C.[24,25] Despite these long-standing and increasingly stark warnings, global carbon dioxide (CO_2) emissions from fossil fuels continue to hit record high levels.[26]

Ten years on from the Paris Agreement, 2025 must mark another pivotal turning point: the year in which we seize the opportunities and solutions at hand to kickstart a decade of accelerated clean energy implementation and finally peak and reduce global emissions — especially from the energy sector.

This special report aims to synthesize the latest evidence for the economic imperative and benefits of accelerating the transition away from fossil fuels to clean energy with a particular focus on renewables, electrification, and energy efficiency. While these three solutions will play central roles in the clean energy system of the 21st century, they do not represent the full picture, and this report does not aim to comprehensively capture all dimensions of the energy system transformation needed to deliver on the Paris Agreement's goals.[v] Section 2 provides an assessment of the current state of play of the transition. Section 3 summarizes the socioeconomic benefits of accelerating the transition, while Section 4 highlights the key barriers and challenges of the current transition. Section 5 highlights priority action areas for accelerating a fast, fair, and funded transition to deliver a safe, resilient, and prosperous future for all.

v For a comprehensive overview of such discussions, see, for example, the IEA's Net Zero by 2050 Roadmap (2023) and IRENA's World Energy Transitions Outlook: 1.5°C Pathway (2024).[27,28]

Section 2 — The energy transition today: Progress since Paris

The year 2024 saw multiple records broken for the clean energy transition and for renewable energy in particular. Global installed capacity of renewable power increased by 585 GW, marking a record annual growth rate of 15.1% and accounting for 92.5% of power capacity additions from all sources.[29] The share of clean energy sources in global electricity generation surpassed 40% for the first time, with renewables accounting for 32%.[30] Meanwhile, global investments in the clean energy transition exceeded USD 2 trillion for the first time.[31] (See Annex for the definitions of clean energy and renewable energy used throughout this report, and for definitions of electricity capacity and generation.)

This section explores six indicators that illustrate how the clean energy transition is well underway and accelerating. Table 1 summarizes how some of

Table 1. Summary of progress in the global clean energy transition between 2015 and 2024.
(References for data sources are denoted in the first column. All data shown represent annual values.)

		2015	2024 (*2023 latest year available)	Percent change in the absolute value since 2015
Total energy supply, EJ (and % share of total from all sources)[32,33]	Fossil fuels	465 EJ (83%)	519 EJ (80%)	+12%
	Renewables	70 EJ (12%)	97 EJ (15%)	+39%
Electricity generation, TWh (and % share of total from all sources)[32,33]	Fossil fuels	16,122 TWh (66%)	18,267 TWh (59%)	+13%
	Renewables	5,519 TWh (23%)	9,992 TWh (32%)	+81%
Installed electricity capacity, GW (and % share of total from all sources)[29,33]	Fossil fuels	3,908 GW (62%)	4,548 GW (47%)	+16%
	Renewables	1,849 GW (29%)	4,448 GW (46%)	+141%
	Battery storage	2 GW (0.03%)	*89 GW (1%)	+4,350%
Electricity capacity additions, GW (and % share of total from all sources)[29]	Fossil fuels	100 GW (38%)	43 GW (7%)	-57%
	Renewables	153 GW (59%)	585 GW (93%)	+282%
Sales of electric vehicles (and % of all car sales)[34]		0.5 million (1%)	>17 million (over 20%)	+3,300%

Global average cost of electricity generation (LCOE), USD cents/kWh[1,35]	Coal	9.5	*7.2	-24%
	Gas	5.3	*8.3	+57%
	Utility-scale solar PV	13.5	4.3	-68%
	Concentrated solar power (CSP)	25.1	9.2	-63%
	Onshore wind	7.5	3.4	-55%
	Offshore wind	15.5	7.9	-49%
Investments, USD[31]	Fossil fuels	1,493 billion	1,198 billion	-20%
	Clean energy:			
	Total	1,209 billion	2,033 billion	+68%
	Renewable power	374 billion	760 billion	+103%
	Grids and storage	332 billion	445 billion	+34%
	Energy efficiency and end-use	450 billion	729 billion	+62%
Jobs[36,37]	Fossil fuels	No data	*32.6 million	
	Clean energy		*34.8 million	
	Renewable energy	9.4 million	*16.2 million	+72%
GDP growth from clean energy sector, USD (and % of total GDP growth)[38]		No data	*320 billion (10%)	

the key underlying metrics have evolved since 2015, the year the Paris Agreement was adopted.

i) Cost declines of renewable power

Due to steadily improving technologies, competitive supply chains, and economies of scale, renewable energy technologies have seen spectacular cost declines since 2010, as shown in Figure ES1. As detailed in *IRENA's Renewable Power Generation Costs in 2024* report, the global weighted average levelized cost of electricity (LCOE) generated from new utility-scale solar PV was 414% higher than that from the least-cost new fossil fuel-fired option in 2010.[1,vi] By 2024, solar PV was 41% cheaper, averaging USD 4.3 cents/kWh. In 2010, the cost of onshore wind was 23% higher than fossil fuels; by 2024, it was 53% lower, averaging USD 3.4 cents/kWh. **Globally in 2024, 91% of new renewable projects offered cheaper electricity than the lowest-cost, new-build fossil fuel alternative.** The significant cost reduction also extends to enabling technologies such as battery storage. Between 2010 and 2024, the costs of utility-scale battery energy storage systems for grid applications fell by 93%, from USD 2,571/kWh in 2010 to USD 192/kWh in 2024. The abundance of renewable energy technology manufacturing capacity in China was a key driver behind their cost declines in recent years.[39]

For comparison, the 2023 global average costs of electricity generation from new coal- and gas-fired

vi See Annex for definition of LCOE.

power plants were around USD 7.2 and 8.3 cents/kWh respectively, and around USD 12 cents/kWh when coupled with carbon capture and storage (CCS), while that from new nuclear power plants was USD 23.1 cents/kWh.[35] **In 2023, an estimated 96% of newly installed, utility-scale solar PV and onshore wind capacity had lower power generation costs than new coal and gas plants, while around 75% of new wind and solar PV plants offered cheaper power than existing fossil fuel facilities globally.**[40]

At the national level, solar and wind power became cost-competitive with fossil fuels without financial support in many countries between 2010 and 2022.[41] **By 2022, most major markets had achieved cost parity, with most of the newly commissioned projects delivering electricity at lower costs than fossil fuel-based alternatives** — this trend is shown in Figure 1 for 20 countries. Although comprehensive LCOE estimates for renewables coupled to battery energy storage systems remain limited, available data indicate that such systems are becoming increasingly cost-competitive with coal- and gas-fired power plants in key markets including Australia, China, the EU, India, and the United States of America (USA), and their costs are projected to continue to fall rapidly in the coming years.[1,42] For example, IRENA found that in 2024, 17 operational hybrid solar-battery projects in the USA achieved average LCOE of USD 7.9 cents/kWh, which is comparable to the midpoint of the LCOE range for combined-cycle gas turbine (CCGT) power plants (USD 7.6 cents/kWh) and below that for coal-fired power plants (USD 11.8 cents/kWh).[1,43] In Australia, eight hybrid projects combining solar, wind, and battery storage reported average LCOE of USD 5.1 cents/kWh, outperforming new-build coal (USD 8.4 cents/kWh) and CCGT (USD 10.3 cents/kWh) power plants.[44]

ii) Pace and scale of renewable energy technologies deployment

When new power capacity is under consideration today, solar PV and onshore wind not only offer the cheapest option, but also the fastest. On average, project lead times (planning, development, and construction) for utility-scale solar PV and onshore wind take one to three years, whereas coal- and gas-fired power plants can take up to five years or more, and 10–15 years for nuclear power plants.[45,46] For other renewables, small-scale solar PV systems take less than a year, while concentrated solar power (CSP), hydropower, and offshore wind projects can take up to five years or more on average.

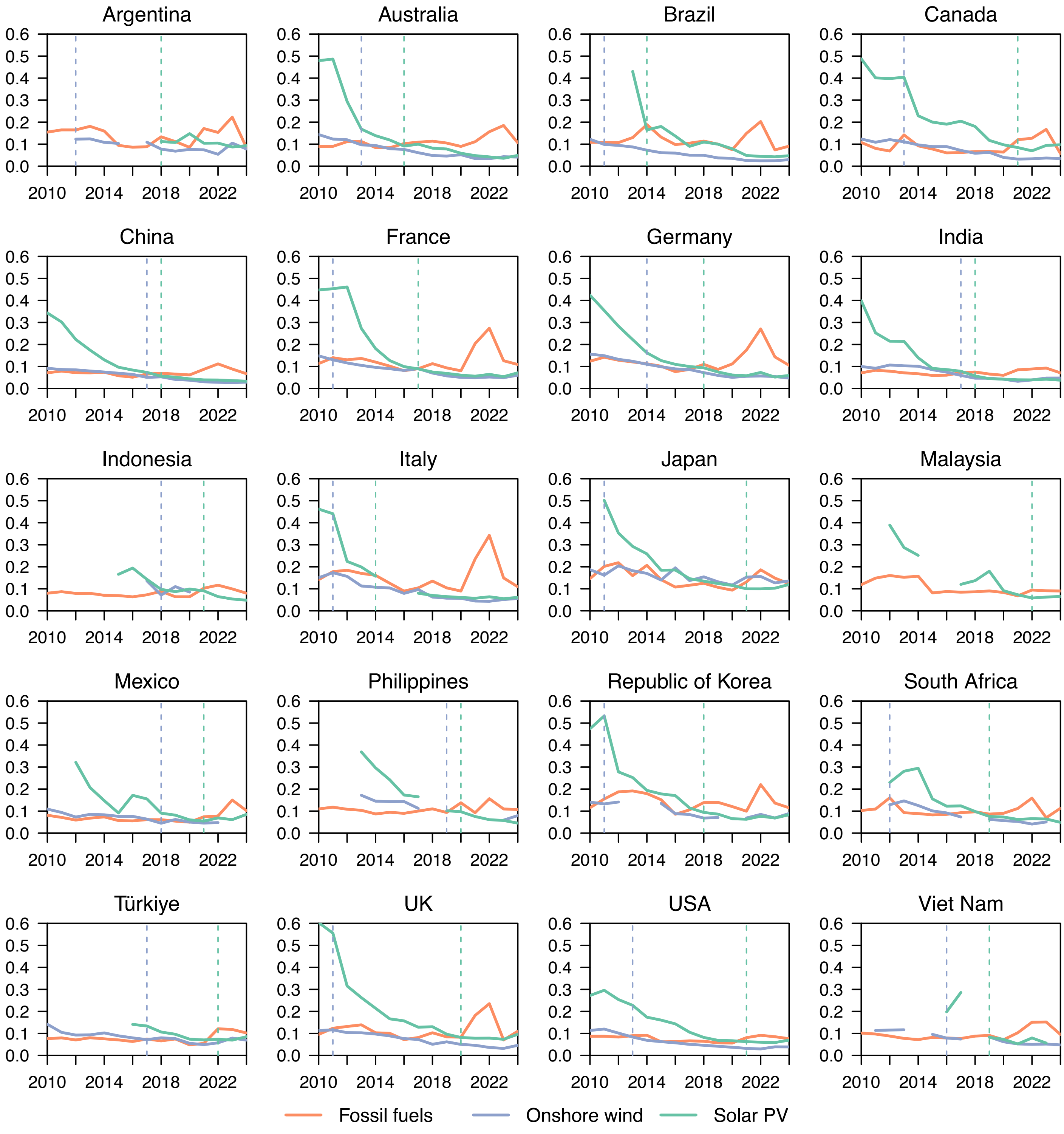
With their cost competitiveness and relatively short project lead times, solar PV and onshore wind are experiencing dramatic growth that is continuously exceeding even the most optimistic forecasts.[47] In 2024, global installed capacity of renewable power saw a record annual growth rate of 15.1% (585 GW), with solar making up over three-quarters of this expansion (452 GW), followed by wind (113 GW).[29] This is the 23rd year in a row that renewable capacity additions set a new record. Moreover, renewables also accounted for the largest share of the growths in global power generation (74%) and total energy supply (38%).[32]

As the middle panel of Figure 2 shows, **each year since 2015, over 50% of global power capacity additions have come from renewables, and over 75% since 2020. In particular, solar and wind have become the fastest sources of electricity to scale up in history, with rapid growth in installed capacity on all continents**.[48] In 2024, absolute capacity additions from renewables exceeded those from fossil fuels in all regions shown in Figure 3 except for the Middle East. Nevertheless, as further discussed in Section 4, the deployment of solar and wind capacity remains highly concentrated in developed countries and in China, India, and Brazil. In 2024, the top 10 countries with the largest absolute solar capacity additions were China (278 GW), the USA (38.3 GW), India (24.5 GW), Brazil (15.2 GW), Germany (15.1 GW), Türkiye (8.6 GW), Spain (6.7 GW), Italy (6.7 GW), Australia (5.2 GW), and France (4.1 GW).[29]

Still, new solar markets are emerging rapidly in other EMDEs. For example, in the first seven months of 2024, Pakistan imported 12.5 GW of solar panels, while Saudi Arabia imported 9.7 GW. Oman, the Philippines, Thailand, and the United Arab Emirates (UAE) have also increased imports recently.[49] Meanwhile, although Africa remains the continent with the lowest share of solar and wind in the electricity mix globally, new solar installations are projected to increase by more than 40% in 2025 from 2024, when around 2 GW were added.[50] Between 2011–2013 and 2021–2023, the annual average number of internationally-financed renewable projects increased from 42 to 127 in Africa, and from 89 to 248 in Latin America and the Caribbean.[51]

Figure 1. Levelized cost of electricity (LCOE) from weighted-average fossil fuels versus onshore wind and utility-scale solar PV (USD/kWh) in 20 countries, 2010–2024.

The dashed vertical lines mark the year in which the LCOE of onshore wind (blue line) or solar PV (green line) first became lower than the weighted-average LCOE from fossil fuels.



Data source: IRENA.[1]

As a result, the share of renewables in global electricity generation has increased from around 23% in 2015 to 32% in 2024 (Figure 2). For non-biomass variable renewables, the share increased from 21% to 30%. By 2022, 61 countries generated more than 50% of electricity from non-biomass renewable sources, 31 countries more than 75%, and 15 countries more than 90% (Figure 4). **In particular, solar power is surging worldwide, with 99 countries doubling the amount of electricity generation from solar energy between 2020 and 2024.[30]**

For variable renewable sources like solar and wind, energy storage and smart grid technologies will be essential for integrating large quantities of renewable power securely and reliably. The use of digital technologies can also help to improve energy and material efficiency in end-use sectors.[52] Grid-related investment in digital technologies grew by over 50% between 2015 and 2022 to USD 63 billion.[53] The global battery market is also advancing rapidly as demand rises sharply and prices continue to decline. Strong growth occurred in both the power sector — for utility-scale battery projects as well as mini-grids and solar home systems — and in the transport sector as an essential component of EVs. **In 2023, 42 GW of battery storage capacity was added to electricity systems worldwide.[42]**

Meanwhile, sales of EVs have been rapidly growing globally, increasing by over 33 times, from 0.5 million (1% of all car sales) in 2015 to over 17 million (>20% of all car sales) in 2024.[34] EVs now account for almost half of all car sales in China, 20% in Europe, and over 10% in the USA. Emerging markets in Asia and Latin America are becoming new centres of growth, with EV sales jumping by over 60% in 2024 to almost 600,000 — about the size of the European market in 2019. Electric car sales in 2025 are expected to exceed 20 million worldwide to represent over 25% of all cars sold.

On the other hand, global progress on energy efficiency has been limited to date. In 2022, the global economy produced 2% more GDP for every unit of energy consumed compared with 2021. This formed the baseline for the goal of doubling energy efficiency agreed at COP28.[vii] However, the annual average rate of improvement between 2022 and 2024 fell to 1% a year.[55] **Meanwhile, the share of electricity in total final energy consumption only increased from 18% in 2015 to 20% in 2023.[56] Much greater effort is needed to speed up the electrification of and energy efficiency improvements in the transport, industry, and building end-use sectors.**

In terms of total energy supply, fossil fuels continue to dominate the share, decreasing from 83% in 2015 to 80% in 2024 globally — with renewables accounting for 15% in 2024.[32,viii] In 2022, in around half of all countries fossil fuels exceeded 75% of the total energy mix (Figure 4). This is primarily for six reasons. First, given the scale and complexities of the energy system, its transformation will inevitably take time due to the slow capital-stock turnover of energy infrastructure. Second, actual progress in terms of adding or replacing energy equipment with new renewables-based technologies has thus far been confined to a few sectors (i.e. power generation and light-duty transport) and regions (i.e. the advanced economies and China). Third, as discussed above, there has been far too little progress on energy efficiency and electrification. Fourth, global energy demand has been growing, especially in EMDEs, and renewables have thus far largely added to expanding overall energy production rather than replacing fossil fuels.[58,59] Fifth, new fossil fuel production and consumption projects continue to be developed and added to the global energy mix. Between 2015 and 2024, total energy supply from fossil fuels grew by 12%, and a cumulative total of 736 GW of fossil fuel-based electricity capacity was added.[33,54] Finally, certain methodological accounting conventions make the share of renewables in total primary energy supply a poor indicator of their role in providing useful energy services. Section 4 further explores some of the major barriers to accelerating the transition away from fossil fuels.

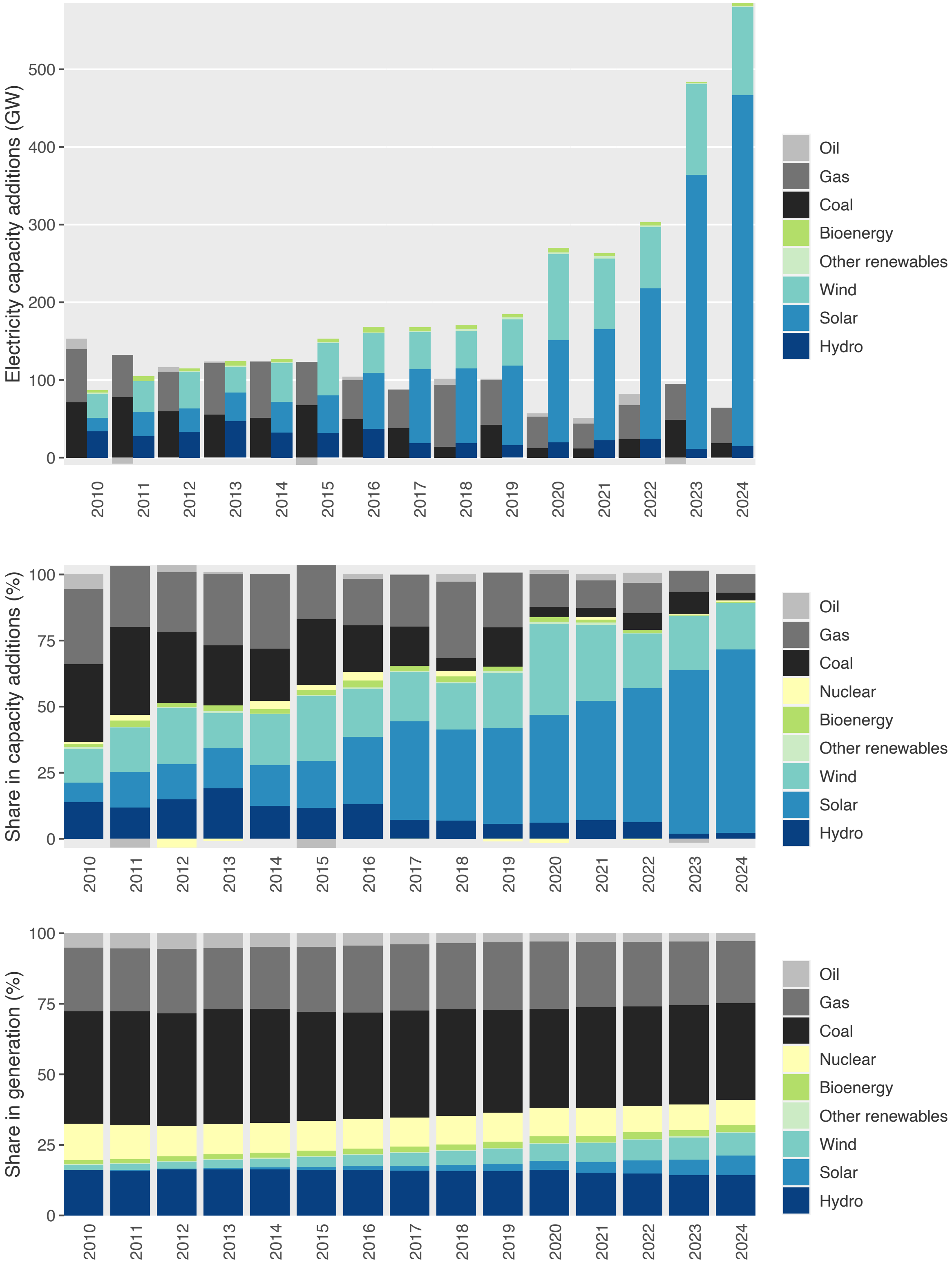
iii) Investments in the clean energy transition

In 2016, global clean energy investments surpassed those for fossil fuels for the first time by a narrow margin of USD 34 billion; by 2024, that difference stood at USD 835 billion.[31] **Total clean energy**

vii The doubling energy efficiency goal means increasing the rate of improvement to around 4% on average every year between now and 2030.

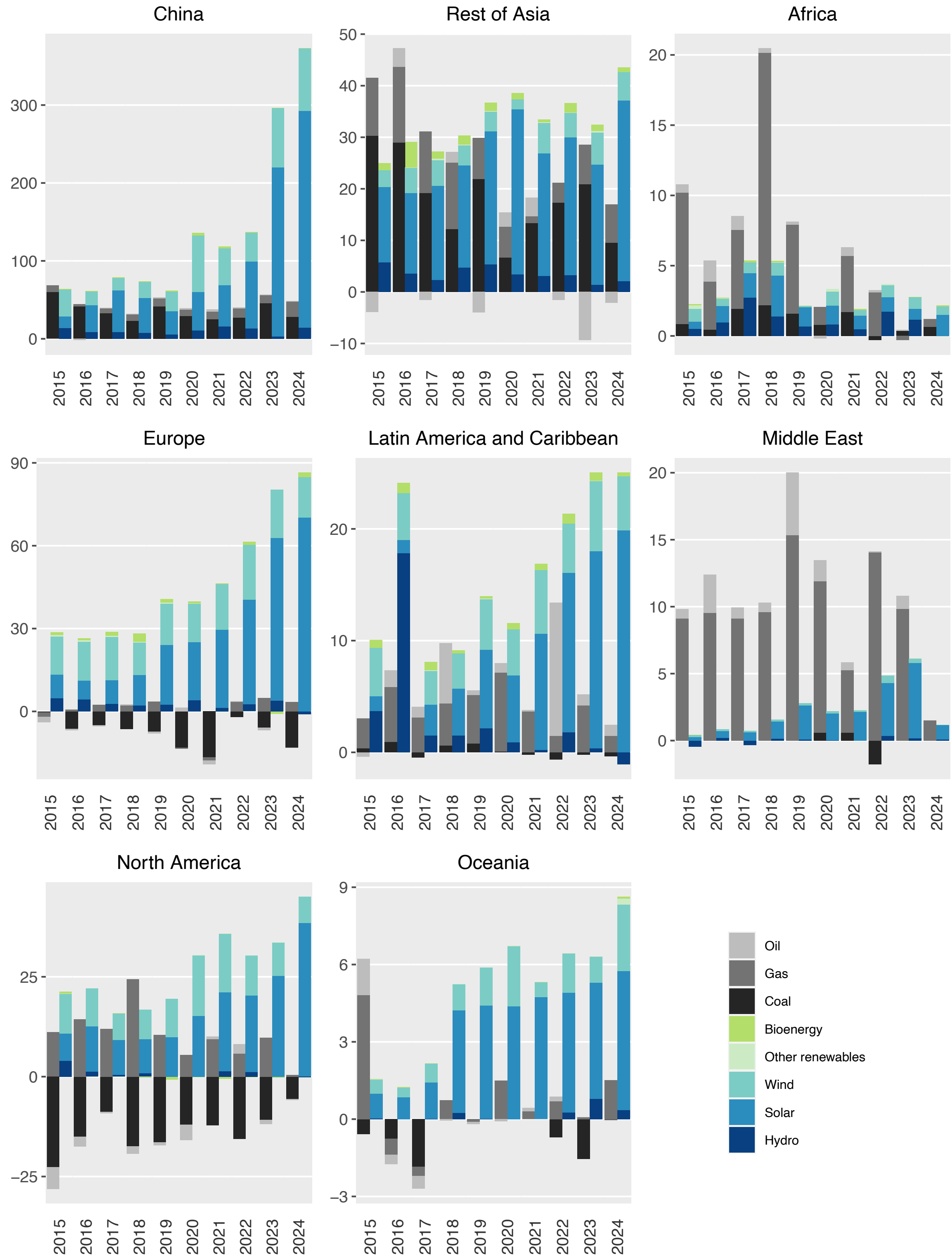
viii In the IEA's world energy balances and statistics datasets, total energy supply (TES) for a given primary fuel (e.g. fossil fuels or renewables) represents the sum of electricity generation and heat, other transformation activities, and total final consumption (TFC).[57] In 2022, global TFC was distributed as follows: industry (30%), transport (28%), residential and commercial buildings (28%), non-energy uses of fuels (10%), agriculture and forestry (2%), and others (2%).[56]

Figure 2. Global annual electricity capacity additions (top), share of different sources in installed capacity additions (middle), and share of different sources in electricity generation (bottom), 2010–2024.



Data source: Ember.[54]

Figure 3. Annual electricity capacity additions of renewables versus fossil fuels by region and in China (GW), 2015–2024.



Data source: Ember.[54]

investments exceeded USD 2 trillion for the first time in 2024, with USD 760 billion going towards renewable power, USD 729 billion for energy efficiency and end-use, and USD 445 billion for grids and storage — albeit at high concentration in the advanced economies and China, as discussed further in Section 4. The IEA projects that clean energy investments will reach around USD 2.2 trillion in 2025, while fossil fuel investments will total USD 1.1 trillion. **This means that today, for every dollar going to fossil fuels, two dollars are invested in the clean energy transition**.[ix]

Moreover, the diffusion of clean energy technologies through trade and foreign direct investment (FDI) has surged since the adoption of the Paris Agreement. Between 2014 and 2022, global clean energy FDI — primarily in renewable energy, EVs, and green hydrogen — tripled as a share of global GDP, accounting for 40% of all new announced greenfield FDI in 2022.[10,60] Since 2015, the total number of international investment projects in SDG-related sectors has grown by 25%, primarily driven by renewable energy projects, underscoring their critical importance in the broader push for sustainable development.[51] Nevertheless, the momentum is facing strong headwinds. Between 2023 and 2024, greenfield FDI in renewable energy declined by 24% to a total of around USD 267 billion.[61] (See Annex for definitions of FDI and greenfield FDI.)

iv) Contributions of the clean energy sector to jobs and economic growth

The dramatic rise in clean energy deployment means that a new clean energy economy is emerging. The sector is now powering economic development and jobs in many countries around the world.[62] In 2024, the clean energy sector is estimated to have accounted for more than 10% of China's economy for the first time, driving 26% of the country's GDP growth.[63] The year before, the sector added around USD 320 billion to the global economy, accounting for 10% of GDP growth globally; almost 5% in India, 6% in the USA, 20% in China, and nearly one-third in the EU.[38] **Clean energy jobs (direct and indirect) surpassed those from fossil fuels for the first time in 2021. In 2023, clean energy jobs grew by 1.5 million, bringing the total to 34.8 million**, while jobs in the fossil fuel sector grew by 940,000 to a total of 32.6 million.[36] **Within the clean energy sector, renewable energy jobs were estimated at 16.2 million — with 7.4 million in China, 1.8 million in the EU, 1.6 million in Brazil, just over 1 million each in India and the USA, 324,000 in Africa, and 91,000 in Oceania.**[37] Both centralized and decentralized renewable energy systems are spurring job creation. For example, in 2021 the number of people directly employed in decentralized renewable energy — used by households and commercial and industrial enterprises for both electricity and clean cooking applications — reached more than 80,000 in India (mostly in solar PV), 50,000 each in Kenya and Nigeria, almost 30,000 in Uganda, and almost 14,000 in Ethiopia.[64]

v) Decoupling economic growth from emissions

There are signs of a weakening link between CO_2 emissions and GDP growth on a global scale.[65,66] Between 2023 and 2024, the growth in energy-related CO_2 emissions slowed to 0.8% while the global economy expanded by more than 3%. Clean energy technologies deployed since 2019 are helping to avoid around 2.6 billion tonnes of CO_2 emissions annually (of which 87% are due to solar PV and wind power), which are roughly equivalent to annual fossil-CO_2 emissions in the EU.[32,67]

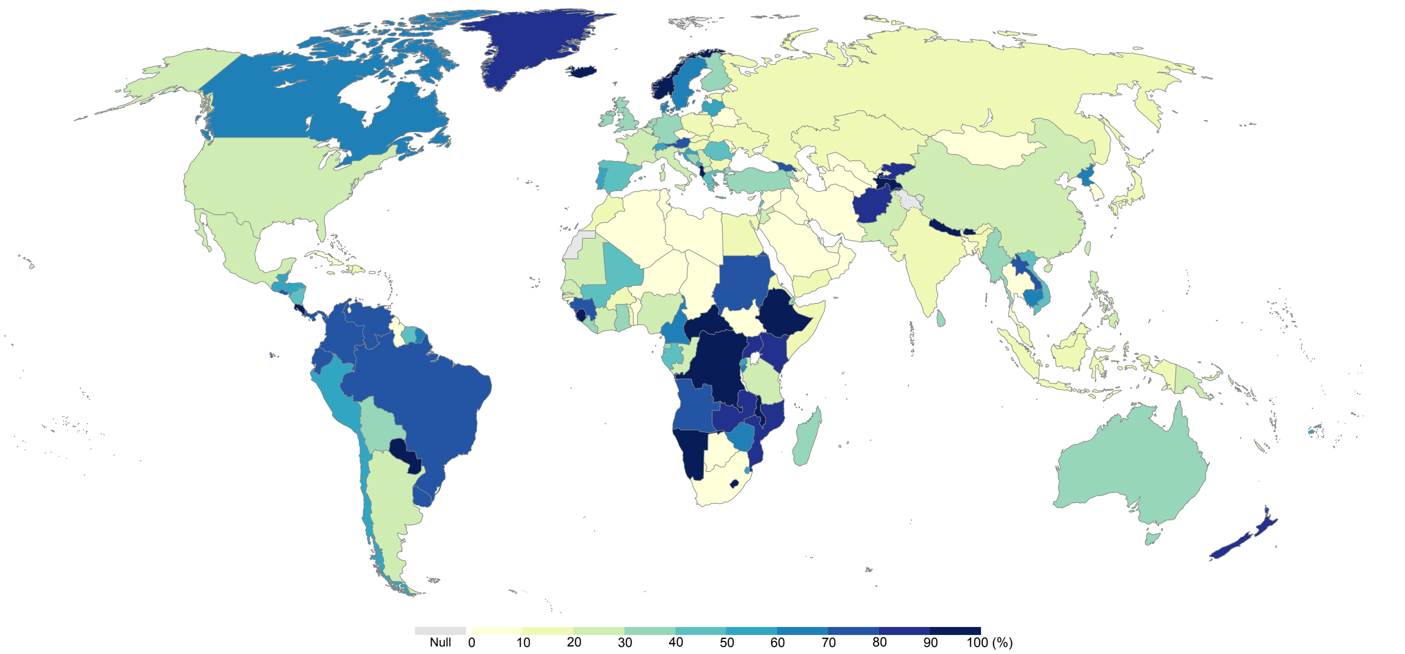
Since the 1990s, more than 40 countries, including 15 non-OECD countries, have decoupled economic growth from GHG emissions for more than five years at least.[68] In aggregate, advanced economies have seen CO_2 emissions peaking and declining from 2007 onwards, while GDP growth has continued, even when consumption of goods manufactured overseas is accounted for.[69] Such diverging trends of economic activity and emissions are also starting to become apparent in the African, Eurasian, and Latin American regions, as well as in China and India.[66]

vi) Innovative mechanisms to support just energy transitions in developing countries

Recent years have seen a proliferation of international alliances focused on various aspects of advancing a global just energy transition, as well as the emergence of innovative support mechanisms for developing countries. In particular, so-called "country platforms" — voluntary, government-led, and multi-stakeholder partnerships used to attract and coordinate international public finance in support of common goals — have the

ix These values are expressed in terms of real 2024 USD.

Figure 4. Percent share of electricity generation from non-biomass renewable sources (top) and percent share of fossil fuels in total energy supply (bottom), 2022 (the latest year with complete country-level data).



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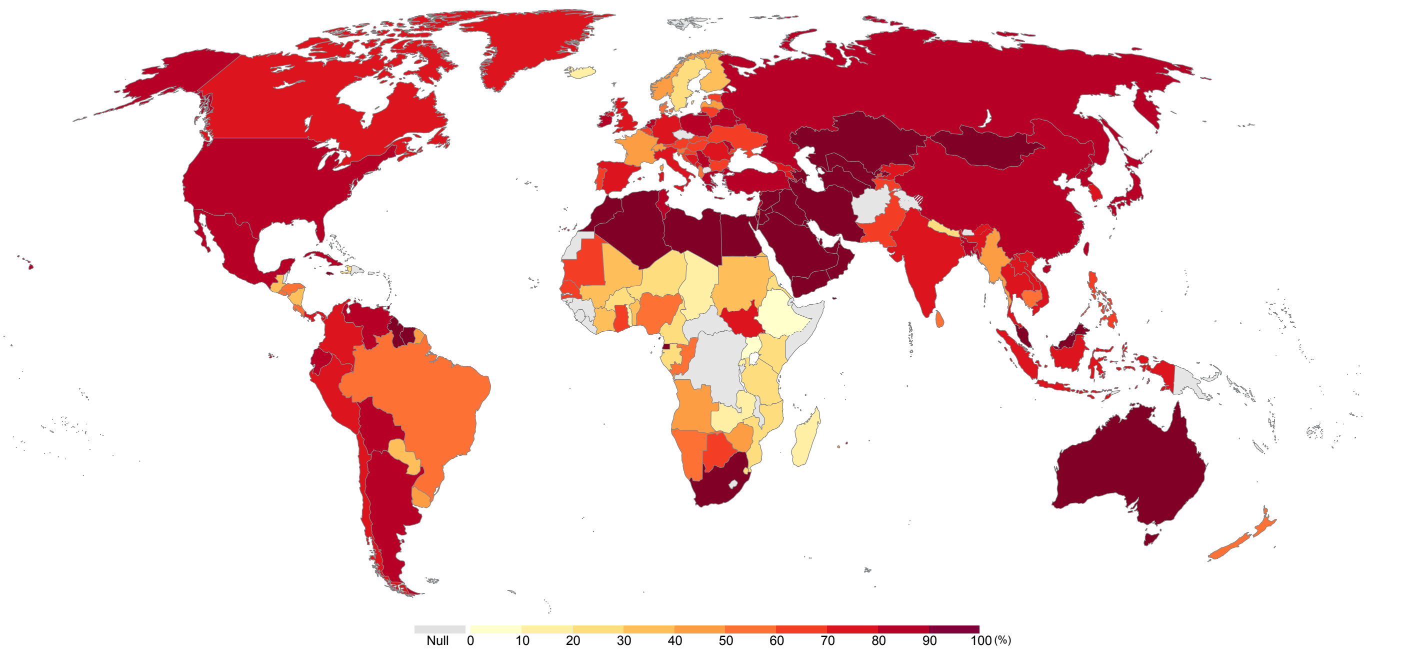
Map No. 4700
June 2025



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Map No. 4701
June 2025

Sources of statistical data: Ember;[54] IEA.[56]

These maps are intended only to show statistical data where available and do not imply official endorsement or acceptance by the data providers.

potential to serve as a powerful mechanism to accelerate country-driven, context-specific action on climate and the energy transition that aligns with national priorities.[70–72]

The Just Energy Transition Partnerships (JETPs) that were launched for South Africa, Indonesia, Viet Nam, and Senegal between 2021 and 2023 are one example of these country platforms — with the specific goal of accelerating the energy transition in partnership with a selected number of developing countries. As of June 2025, the International Partners Group (IPG) of donors included Canada, Denmark, France, Germany, Italy, Japan, Norway, the EU, and the United Kingdom of Great Britain and Northern Ireland (UK), with additional private sector and public finance institution commitments coordinated through the Glasgow Financial Alliance for Net Zero (GFANZ). While the scope of the JETPs varies between countries, most have focused on reducing emissions from the power sector by accelerating the retirement of coal power, ramping up renewable energy deployment, and upgrading grid infrastructure to enable high renewables penetration. **Notwithstanding ongoing challenges and complexities given the scale of transformation required, JETPs have been instrumental in driving country-level just energy transitions and investment planning, the setting of ambitious fossil fuel phase-down and renewable phase-in targets, and bringing together relevant stakeholders across governments and society.**[73,74]

South-South cooperation on the clean energy transition has also been scaling up in recent years, particularly by China through its Belt and Road Initiative (BRI), which accounted for 10–15% of international project finance deals in Sub-Saharan Africa in recent years.[75] Furthermore, intra-regional support mechanisms also exist, such as the EU's Just Transition Fund to support member states in their economic diversification and workforce reskilling towards net zero.

Section 3 — Opportunities and benefits of accelerating the energy transition

As the previous section showed, the clean energy transition has made significant strides in multiple areas over the past decade. **In this section, we explore six key dimensions of the socioeconomic benefits that can be gained by accelerating this transition beyond its essential role in driving rapid, deep, and sustained GHG emissions cuts to minimize climate damages and keep 1.5°C within reach.**

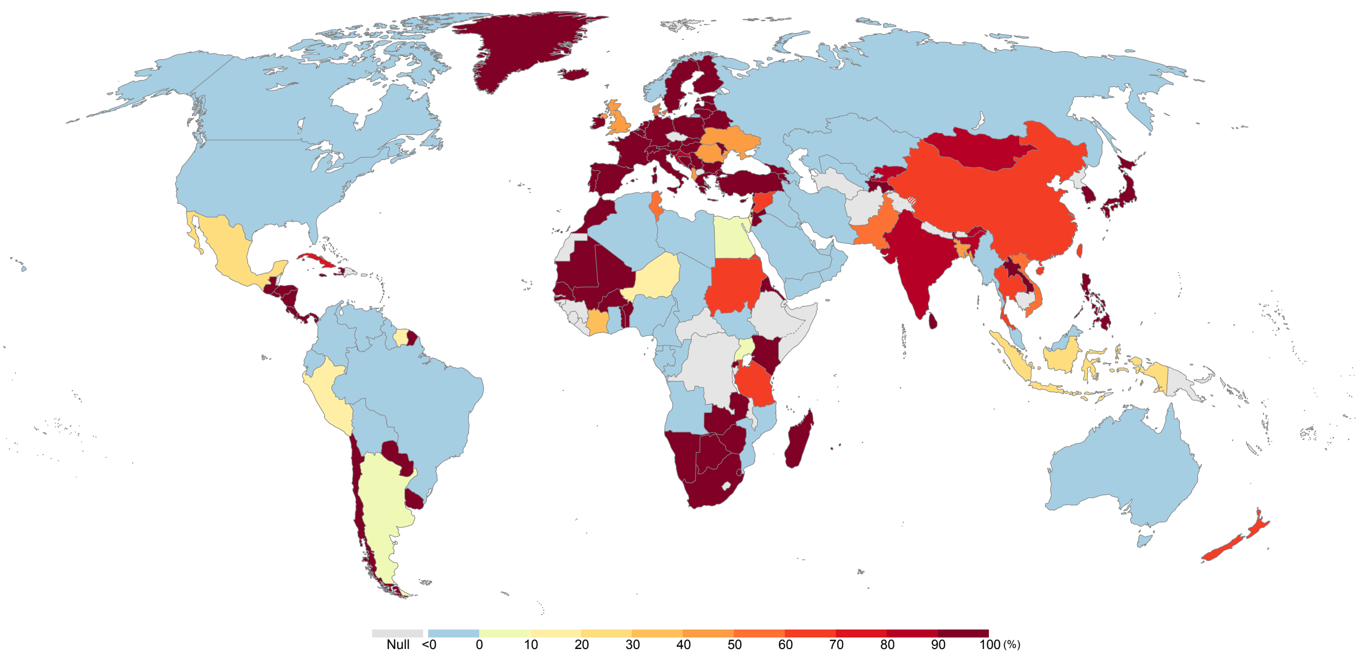
i) Energy security and sovereignty

Around 74% of the global population currently lives in countries that are net importers of coal, oil, and gas, and one in four people live in countries that spend at least 5% of their annual GDP on fossil fuel imports.[76,77] For oil and gas, as of 2022, 93 countries (out of 147 countries with reported data) are net importers, with 69 countries being fully reliant on imports to meet their domestic consumption (Figure 5).

Dependence on fossil fuel imports creates vulnerability to volatile prices, supply disruptions, and geopolitical turmoil. According to the IEA's assessment, energy markets began to tighten in 2021 primarily due to the rapid economic rebound following the COVID-19 pandemic, but the situation escalated dramatically into "a full-blown global energy crisis" following the Russian Federation's invasion of Ukraine.[78] **The price of natural gas — and**

Figure 5. Oil and gas net import dependence (total imports minus exports as percent of total energy supply), 2022.

Countries with values less than 0% are net exporters and shaded in blue. Grey denotes no data.



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Map No. 4702
June 2025

Statistical data source: IEA.[56]

This map is intended only to show statistical data where available and does not imply official endorsement or acceptance by the data provider.

consequently electricity prices in some markets — reached record highs, while oil prices hit their highest level since 2008. This directly increased the costs of heating, cooling, lighting, and mobility, and indirectly pushed up the costs of other goods and services throughout global supply chains, exacerbating the cost-of-living crisis in 2022.

The IEA estimates that in 2022, consumers worldwide spent on average USD 1,200 per person on energy bills, even after considering the subsidies and emergency support mobilized by governments. This is 20% more than the average over the previous five years.[80] Countries relying on high gas imports were hit particularly hard. For example, another study found that in the Republic of Korea, which has 100% reliance on gas imports, the cost of liquefied natural gas (LNG) for power generation was USD 17 billion higher in 2022 than 2021, translating to an average increase of USD 326 per person.[81]

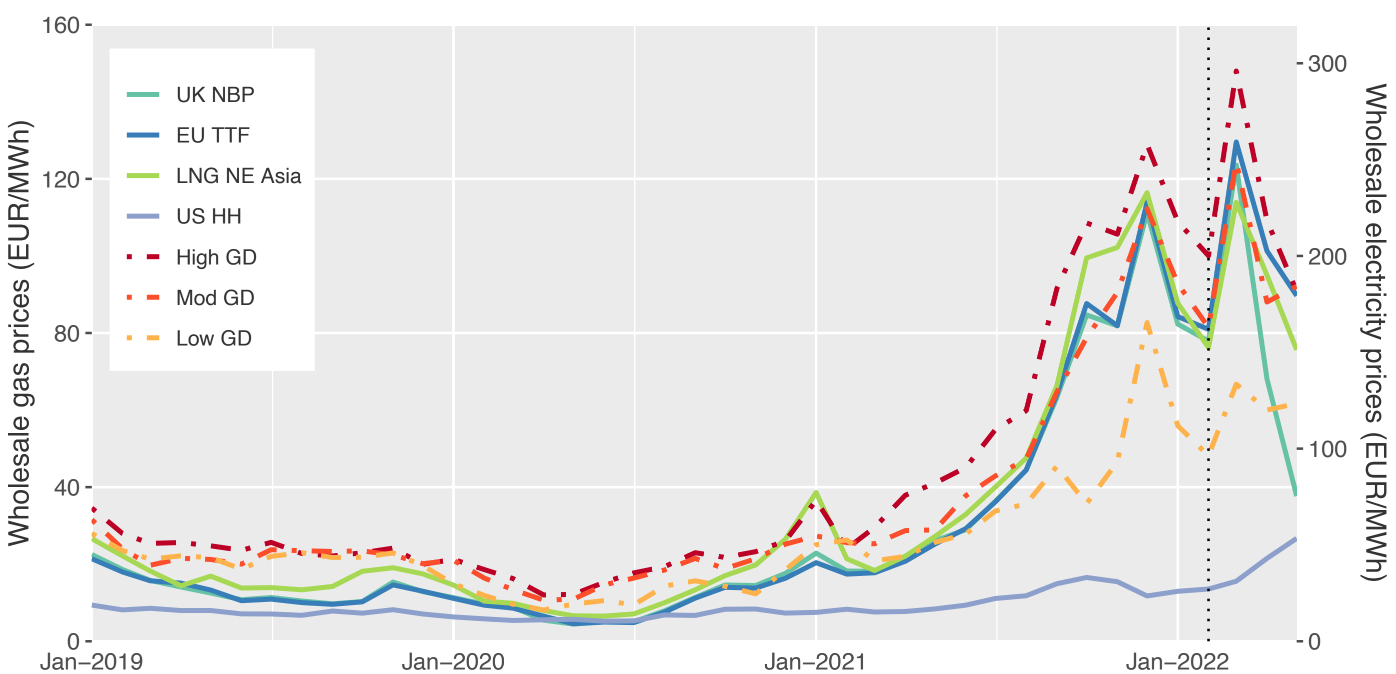
In the UK, wholesale gas prices increased more than fivefold in 2022 compared to the 2016–2019 average, resulting in the average household spending GBP 800 (USD 990) more on energy bills, and the government GBP 50–60 (USD 62–74) billion more on gas imports.[82] Were it not for renewables providing around 40% of the UK's electricity, gas power generation could have been twice its actual level, dramatically increasing prices and household bills even further. **Wholesale spot prices for natural gas also increased to record highs across European continental markets, leading to significant increases in wholesale electricity prices** (Figure 6). According to one study, in 2021–2022 the rise in natural gas prices accounted for around 90% of the increase in wholesale electricity prices, while higher carbon prices in the EU Emissions Trading System accounted for the remaining 10%.[79]

ii) Energy affordability

There are pervasive misconceptions that clean energy technologies are always more expensive than fossil fuel technologies, and that the energy transition and net-zero policies are driving up the cost of living.[83] Yet, as the previous section demonstrates, **renewables are now almost always**

Figure 6. Wholesale natural gas prices (solid lines) and wholesale European electricity prices (dashed lines) from January 2019 to May 2022 (EUR/MWh).

Gas prices shown: UK National Balancing Point (NBP); European Benchmark TTF; LNG Northeast Asia JKM; and US Henry Hub. Electricity prices across Europe were aggregated by gas dependency (GD) of electricity generation (high, moderate, or limited) and grid interconnectedness (limited for high GD; well-connected for moderate GD). See details in Ari et al. (2022), Figure 3.[79]

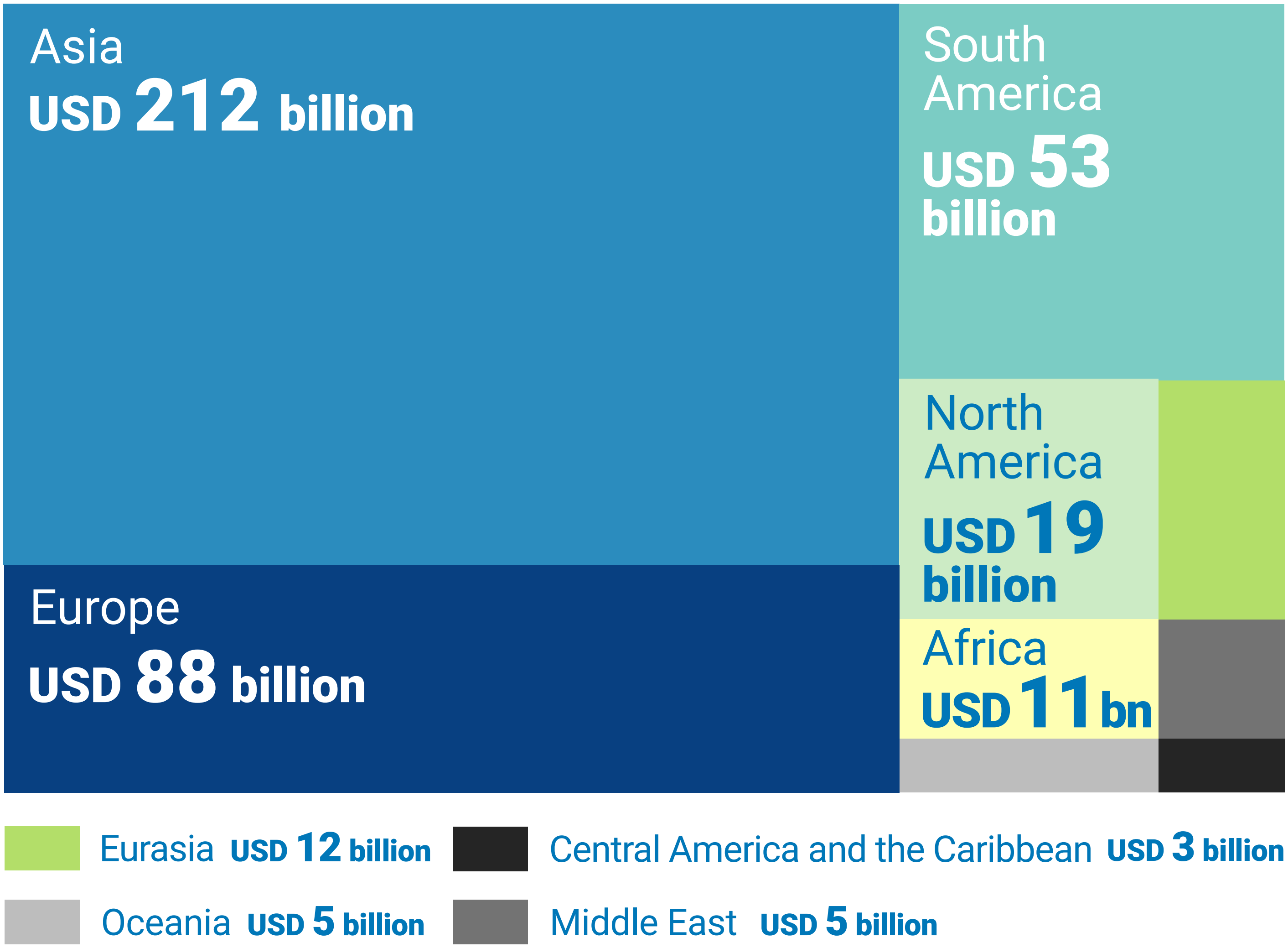


the least expensive option for new and existing electricity generation. Other technologies such as EVs and energy-efficient appliances also typically result in cost savings over their lifetimes, even if they sometimes incur higher upfront costs.[80] **In fact, growing pressures on today's cost of living stem in part from our continued fossil fuel dependency — directly through their volatile prices and impact on commodity prices as well as the high cost of maintaining fossil fuel subsidies, and indirectly through the mounting toll of fossil-fuelled climate disasters and disruptions.**

Even discounting abnormally high oil and gas prices, the cost competitiveness of renewables means they will yield energy cost savings in the near and long term — for both governments and consumers alike. According to IRENA, the deployment of renewable power since 2000 had cumulatively saved around USD 409 billion in fossil fuel costs for the electricity sector alone by 2023, with the highest savings occurring in Asia, followed by Europe and South America (Figure 7).[45] **Whereas importing fossil fuels entails a recurring expense, importing renewable technologies is a one-off investment.** At 2024 prices, importing 1 GW of solar panels could lead to savings equivalent to 30 years of gas import costs over the average 30-year lifespan of solar panels.[76]

Heavy reliance on importing fossil fuels with high and volatile prices places a particularly heavy strain on government budgets and constraint on economic development in developing countries

Figure 7. Cumulative fossil fuel cost savings in the electricity sector from renewable power additions between 2000 and 2023 in different regions.



Data source: IRENA.[45]

saddled with growing debt servicing costs. For example, around 60% of Small Island Developing States (SIDS), who are among the most indebted countries in the world, currently import over 90% of their fossil fuel supply for electricity generation, which on average costs around 10% of their GDP. The Seychelles' fossil fuel imports cost almost 18% of the country's GDP, while its debt amounts to almost 85% of GDP.[84,85]

The IEA's *Strategies for Affordable and Fair Clean Energy Transitions* report details how, with targeted additional policies and investments, **following a 1.5°C-aligned pathway towards global net-zero emissions by 2050 can reduce the operating costs of the global energy system by more than half over the next decade compared with a trajectory based on current policies.** The net result is a more affordable energy system for consumers, businesses, and governments worldwide.[80]

iii) Energy access

By the end of 2023, almost 92% of the world's population had access to electricity. Yet more than 666 million still lacked access, while some 2.1 billion people (26%) lacked access to clean cooking technologies, leading to significant negative environmental, public health, and human livelihood impacts.[86] For example, the World Health Organization (WHO) estimates that around 3.2 million people die prematurely from illnesses attributable to household air pollution caused by the incomplete combustion of solid fuels and kerosene used for cooking.[87] **Energy access gaps are largest in Sub-Saharan Africa, where some 565 million people still had no access to electricity in 2023, accounting for 85% of the global population without electricity access.**[86]

As a joint 2024 report by the IEA, IRENA, UN, World Bank, and WHO highlighted, **achieving universal electricity access by 2030 will only be possible by deploying a combination of grid, mini-grid, and stand-alone off-grid solutions that leverage the faster deployment of distributed renewables to meet demand quickly, especially in difficult-to-reach rural locations where eight out of 10 people without electricity access live.**[88] In 2022, 2.5 million households gained electricity access via solar home systems and smaller solar lighting systems. Stand-alone off-grid solar solutions were estimated to serve 490 million people in total. **Access to energy brings with it many other benefits, and the implementation of small-scale renewable energy microgrids has been shown to significantly contribute to sustainable development by improving livelihoods, reducing poverty, and enhancing food security, health, and education.**[89,90]

The World Bank has further highlighted how solar mini-grids could provide the least-cost solution to bring high-quality, uninterrupted electricity to 380 million people across Sub-Saharan Africa by 2030 — a region with the largest access gap and where development gains are most urgently needed.[91]

ILO, IRENA, and UNEP have also highlighted the importance of focusing more on renewables-based rather than fossil fuel-based clean cooking solutions.[64,92] Over the last decade, more policy and financing attention has been given to liquefied petroleum gas (LPG)-based solutions, through the support of large governmental contributions and programmes. As a result, LPG has accounted for over 70% of the progress made towards providing clean cooking access.[88] **However, guidelines for "clean cooking" fuels and technologies (unlike for "clean energy") generally pertain only to fine particulate matter ($PM_{2.5}$) and carbon monoxide emissions standards.**[93] **LPG still emits GHG emissions and other harmful air pollutants such as nitrogen oxides** (see Annex for further details). For example, the multi-stakeholder Solar-Electric Cooking Partnership, supported by UNEP, aims to provide affordable clean cooking solutions across the African continent through solar e-cooking. This not only reduces household air pollution and GHG emissions but also addresses gender-based violence and deforestation while fostering economic development.[94]

Both IEA and IRENA have developed global energy-transition pathways that are consistent with limiting long-term warming to 1.5°C and that also deliver universal clean energy for all by 2030 (SDG 7).[27,28] **At the country level, the World Bank has developed "Country Climate and Development Reports (CCDRs)" that explore how development goals can be aligned with climate mitigation and adaptation efforts for 72 countries and economies.**[x] Power-sector modelling in these

x The World Bank Group's individual CCDRs and synthesis reports are accessible at https://www.worldbank.org/en/publication/country-climate-development-reports.

CCDRs shows that solar and wind energy play a significant role in meeting the growing demand for electricity at the lowest cost to consumers, even without considering climate objectives and driven by economic considerations alone under current-policies scenarios.[95] **When climate objectives are considered in low-emissions development pathways, renewable energy plays an even larger role and represents almost all new capacity additions.** For example, in Moldova, investing in renewables and energy efficiency is estimated to reduce energy import dependence from 78% to 40% by 2050. In fragile or conflict countries, such as the Republic of Yemen or Lebanon, distributed solar power can build community resilience by providing power for critical facilities, such as schools and hospitals. **In most CCDRs, this transition towards renewable energy takes place with total electricity costs declining over time, providing a gain for households and businesses.**

iv) Power system resilience

Power systems are increasingly under strain from extreme weather events, aging grid infrastructure, and growing electricity demand, which threaten the efficiency and reliability of power generation, as well as the physical resilience of energy infrastructure.[15,96] While some have mistakenly blamed the increasing integration of variable renewables like wind and solar, the primary causes are aging grid infrastructure and growing weather extremes, as further discussed in the next section. Renewables-dominant power systems can come with high reliability with proper governance, while fossil fuels-dominant systems do not necessarily guarantee reliability. **For example, in 2023, the shares of variable renewables in the electricity mix of Denmark, Germany, and the USA were 68%, 44%, and 22% respectively, and their average power outage rates were around 30, 13, and 366 minutes per consumer respectively.**[97–99]

Decentralized and diversified renewables-based power systems also have an inherent potential to provide more resilience in the face of growing extreme weather events.[15,100] Many solar-and-storage microgrid initiatives are being developed throughout the Caribbean, a region highly susceptible to hurricanes.[101,102] Decentralized renewable energy can provide both immediate disaster response and long-term climate resilience, especially in island contexts where traditional fossil fuel-dependent grid infrastructure remains vulnerable.

Beyond extreme climate conditions, renewables also contribute to insulating power generation from external shocks, such as fossil fuel price fluctuations and international trade and supply chain disruptions. For example, a recent study found that if EU member states achieved their 2030 solar and wind capacity targets, the sensitivity of annual electricity prices to the cost of natural gas would be reduced by 29% on average. If solar and wind capacity installations were 30% higher than the 2030 targets, the sensitivity would be reduced by 65%.[103] **Furthermore, once installed, wind and solar power plants are shielded from supply chain disruption risks for the rest of their operating lifetime, unlike fossil fuel-fired power plants that usually have fuel reserves of a few months.**[104]

v) Job creation, economic growth, and industrial competitiveness

The implementation of climate policies to date has substantially boosted the amount of green FDI countries are able to attract. Policies to support green products also have a more prominent impact on competitiveness and innovation in these products than policies targeting non-green products.[10,60,105] As previously discussed, green industries and green investments are already helping to boost economic development and jobs worldwide. **The systematic adoption of renewables and improvements in energy efficiency, combined with progressive policies, can continue to lead to net gains in jobs and GDP as the transition progresses in the short, medium, and long term.**

Under IRENA's 1.5°C Scenario for the global energy transition, the world could see an average annual increase in GDP of 1.5% between 2023 and 2050, compared to a current-policies ("Planned Energy") scenario, due to macroeconomic effects such as greater levels of public and private investment.[106] The annual average GDP increase for the Group of Twenty (G20) is estimated to be 1.3% — with individual increases of 1.3% for Brazil, 2.8% for India, 6.0% for China, and 8.3% for South Africa. Meanwhile, increases of 5.4–15.3% are estimated for different regions in Africa and 2.6% for Southeast Asia. (These estimates do not factor in avoided climate damages.) **The renewable energy sector is predicted to grow significantly by 2050 under the 1.5°C Scenario, creating about 40 million direct jobs worldwide.** Solar would make up nearly 66% of renewable energy jobs in the Middle East and North

Africa (MENA), 52% in Asia, 38% in Europe, 32% in North and South America, and 28% in Sub-Saharan Africa.

Furthermore, ILO has assessed the employment potential of the wider green transition for select countries, and explored the social, economic, and employment impacts of green industrial growth opportunities for the MENA region.[xi] **The assessment found that MENA countries may face welfare losses if they remain passive by-standers in the global energy transition. Conversely, active engagement could lead to 3.5% higher employment (with a net total of 6.6 million jobs created) and 4.8% higher GDP.**[107] This scenario implies strong industrial and just transition policies — including social protection and relocation programmes for fossil fuel workers — alongside enhanced climate policies, especially in solar power, electric mobility, and renewables-based hydrogen production.

The World Bank's CCDRs also explored opportunities for countries to increase their participation in key green technology value chains, creating new jobs while boosting incomes and exports. They found that short-term economic growth could be similar or even faster in low-emissions development scenarios than in current-policies scenarios in most countries, assuming well-designed policies and synergies between structural reforms and a supportive environment.[95]

The energy transition also offers opportunities to improve the gender balance of the energy workforce. Despite accounting for 39% of the global labour force, women made up less than 20% of the energy industry workforce in 2023.[36] **Globally, women form a greater share of the renewable energy workforce (32%) than that of the oil and gas industry (22%).**[108] For example, decentralized solar PV employs 41% women in Kenya, 37% in Ethiopia, 35% in Nigeria, and 28% in Uganda.[37] Nevertheless, their roles and participation across the renewable industry are not balanced. For example, the representation of women in senior management positions is very low in both the wind and solar PV sectors.[36] **A robust supply of science, technology, engineering, and mathematics (STEM)-educated workers and a more equal treatment of women can also amplify the effectiveness of climate policies by preventing bottlenecks in the expansion of the workforce and boosting green innovation.**[109]

vi) Additional socioeconomic and environmental benefits

As the above assessments alluded to, **the transition away from fossil fuels can help to deliver myriad other social, economic, and environmental objectives, including but not limited to poverty reduction, improved air quality and health, and enhanced economic development and resilience.**[95,110] For example, IRENA has found that, compared to a current-policies scenario, a systematic shift away from fossil fuels towards a renewables-based energy system could lead to 6.4% higher GDP, 3.5% more economy-wide jobs, and 25.4% higher social welfare across Africa between now and 2050.[111] Similarly, Southeast Asia could see 3.4% higher GDP, 1.0% more economy-wide jobs, and 10.9% higher social welfare.[112]

One of the social welfare metrics assessed by IRENA in the above studies is improved air quality and public health.[xii] **Air pollutants are released at every stage of the fossil fuel lifecycle, from exploration and extraction to end-use combustion.** Decades of epidemiological research has established that air pollution can cause, complicate, or exacerbate many adverse health conditions, leading to respiratory, heart, and neurological diseases and increasing the risks of cancer and pregnancy complications.[113] **Globally, outdoor $PM_{2.5}$ pollution from fossil fuel combustion is estimated to cause over five million premature deaths each year — accounting for 82% of all premature deaths from outdoor $PM_{2.5}$ pollution from human activities.**[114] Traffic-related air pollution from fossil fuel combustion is estimated to cause two to four million new cases of asthma in children each year.[115,116] **One study estimated the economic cost of air pollution from fossil fuels in 2018 to be USD 2.9 trillion, or 3.3% of global GDP.**[117] Moreover, oil and gas production activities release a

xi ILO's reports for Bangladesh, Brazil, China, India, Jordan, Lebanon, Malaysia, Mauritius, Mexico, Nigeria, the Philippines, Tunisia, Türkiye, Uruguay, and Zimbabwe are accessible at https://www.ilo.org/topics/just-transition-towards-environmentally-sustainable-economies-and-societies/green-jobs-assessment-reports.

xii The IRENA "Energy Transition Welfare Index" considers five dimensions — economic, social, environmental, distributional, and access — of the energy transition. IRENA's *Socio-economic footprint of the energy transition* reports are available for Africa, Egypt, Indonesia, Japan, Southeast Asia, and South Africa.

wide variety of harmful, toxic, and even radioactive air, water, and waste pollutants that are known to be carcinogenic or have adverse reproductive and developmental effects.[118–120]

As a recent OECD-UNDP report explores in detail, more ambitious climate policies can simultaneously accelerate inclusive economic growth and significantly reduce emissions through increased investment in clean technologies, improved energy efficiency, and the strategic reinvestment of revenues from carbon pricing or removal of fossil fuel subsidies.[68] Compared to a current-policies scenario, enhancing climate action would boost global GDP by 0.1% in 2030 and by 0.23% in 2040 due to macroeconomic effects alone.[xiii] When some of the avoided climate damages are also accounted for in the longer term, such as physical impacts related to sea-level rise or on agricultural crop yields, the benefits are estimated to be 0.2–3% by 2050.

Beyond GDP impacts, the OECD-UNDP report also shows that more integrated climate and development policies could help to advance climate action while also driving progress on other SDGs. **The enhanced-action scenario envisions a new paradigm of energy security, with fossil fuel import volumes decreasing by 30% in high-income countries and by 17% in low-income countries in 2040 compared to current levels.** As previously discussed, this would reduce exposure to volatile fossil fuel markets, lower import bills, stabilize energy prices, and enhance self-sufficiency. If investments in the energy transition are complemented by specific measures that deliver on food security, basic services access, and governance reforms, **nine out of ten low-human-development countries could significantly improve development by 2050, lifting 175 million additional people out of extreme poverty while strengthening resilience and energy equity.**

Nevertheless, the clean energy transition will also entail adverse impacts that must be addressed, such as loss of jobs and revenues for fossil fuel-dependent workers and communities, and the social and environmental harms that can come from mining the critical minerals that are essential for renewable energy technologies. The next section explores some of these challenges in more detail, as well as the major barriers impeding a rapid and equitable transition.

xiii This scenario is associated with end-of-century warming of 1.7°C, compared to a current-policies scenario associated with 2.45°C.

Section 4 — Barriers and challenges of the current transition

As Section 2 showed, while the world has seen remarkable progress in renewable energy deployment in certain sectors and regions over the past decade, far less progress has been made in other aspects of the just energy transition. Consequently, we remain far off track from meeting the overall global 1.5°C-aligned energy-transition goals agreed to at COP28 (Table 2).[xiv] **This section explores some of the key challenges, risks, and barriers that must be addressed to accelerate the just energy transition globally.**

CHALLENGES AND RISKS

i) Mobilizing adequate, accessible, and affordable finance for developing countries to accelerate their energy transitions:

Most of the additional energy demand over the next few years and decades is poised to come from EMDEs, driven by rapid economic development, urbanization, and population growth. **However, progress on the clean energy transition has thus far largely been concentrated in advanced economies and China. Of the 4,448 GW of global total renewable capacity installed by the end of 2024, 41% was in China and 39% in OECD countries. The remaining 20% was concentrated within a handful of countries, with Brazil and India accounting for almost half.[29] In 2023, China, the EU, and the USA accounted for 95% of global EV sales.[122]**

Since the Paris Agreement entered into force in 2016, less than one out of every five dollars invested in clean energy has gone to EMDEs outside China.[55] In 2024, they received around USD 300 billion, or 15% of global clean energy spending (Figure 8). Africa, home to 20% of the world's population and 85% of the global population without electricity access, received a mere 2%

Table 2. Select global energy-transition goals in the first Global Stocktake and projections for 2030 under current-policies and 1.5°C-aligned scenarios modelled by the IEA and IRENA.

The annual values for 2022 are shown as the reference benchmarks, and those for 2024 demonstrate progress, or lack thereof, since then.

	2022	2024	2030 projections	
			Current plans and policies	1.5°C-aligned
Renewables electricity capacity (GW)[a]	3,380	4,450	6,770	11,200
Annual rate of energy efficiency gain[b]	2%	1%	2%	4%
Total energy supply/demand from fossil fuels (EJ)[b]	505	519	505	375

Sources: (a) Based on IRENA, with numbers shown here rounded to three significant figures;[29,121] (b) IEA.[55]

xiv See also the UNEP Emissions Gap Report 2024, Table 6.1, for sub-sectoral 2030 energy-transition targets under 1.5°C-aligned scenarios assessed in the IPCC Sixth Assessment Report (AR6).[4]

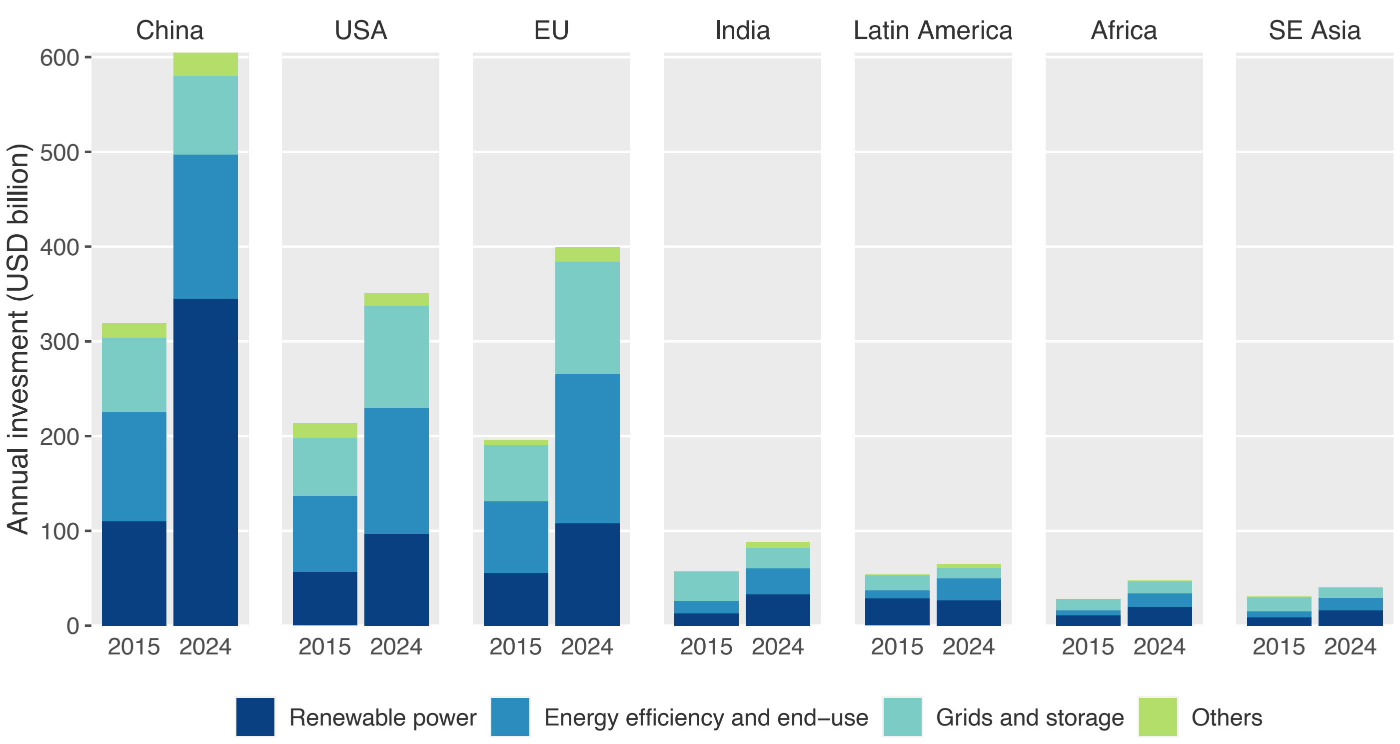
of the global total.[31,86] Yet, according to IRENA's new analysis for this report, Africa's renewable resource potential is ten times larger than the continent's projected demand for electricity in 2040 under a 1.5°C-aligned scenario.[xv] On a per capita basis, the disparity in financial flow has been increasing over time: in 2016–2019, advanced economies attracted 14 times more clean energy investment than the 154 EMDEs excluding China; in 2020–2023, this had increased to 18 times.[123] As of 2023, more than 30 developing countries have yet to register a single utility-sized international investment project in renewables.[75]

The IEA and the Independent High-Level Expert Group (IHLEG) on Climate Finance both estimate that clean energy-transition investments in EMDEs outside China would have to scale up to around USD 1.4–1.9 trillion a year by 2030, and to over USD 2 trillion a year by 2035, to keep 1.5°C in reach and deliver on the SDGs.[124,125] Getting on track for net-zero emissions by 2050 will therefore require clean energy spending in EMDEs outside China to increase by around five to seven times by 2030 from the USD 260 billion invested in 2022 — far beyond the capacity of public financing alone and thereby demanding an unprecedented mobilization of private capital. This represents a formidable investment imperative — and opportunity.

Since the Addis Ababa Action Agenda in 2015, policymakers have been advocating for the use of public resources to leverage private investment through mechanisms like risk mitigation. However, these expectations have not been met — in quantity or quality. **Because the private sector seeks risk-adjusted financial returns, it needs a clear financial case for investing in clean energy technologies. However, as discussed below, the cost of capital for clean energy projects remains disproportionately high in EMDEs outside China due to real and perceived market risks.[75,123,126]**

Furthermore, it is critical that public resources do not undermine energy-transition and climate

Figure 8. Annual clean energy investment in selected countries and regions in 2015 and 2024, USD billion.



Data source: IEA.[31]

xv Analysis based on IRENA's Global Atlas for Renewable Energy, https://globalatlas.irena.org.

policy goals: countries should redirect the lending policies of national, regional, and multilateral development banks and DFIs, as well as investments by state-owned enterprises, accordingly. In particular, DFIs should lead the financing of energy-transition projects where upfront costs are high and returns may be slow to materialize, such as grid infrastructure expansion and modernization projects.[127,128]

Currency risks and debt vulnerabilities have also been identified as key barriers to sustainable infrastructure investments in developing countries, which are facing the worst debt crisis since records began, with debt service absorbing an average of 38% of budget revenue, rising to 54% in Africa.[129] At the same time, investments in developing local clean energy supply chains, which are crucial for increasing supply chain diversification and resilience, minimizing reliance on imports, and maximizing socio-economic benefits, are increasingly concentrated in a small number of countries. For instance, China accounted for 88% of global investments in the solar PV supply chain between 2018 and 2023. The USA and Europe accounted for 2% each, while the remainder was shared between Southeast Asian economies (4%), India (1%), and the rest of the world (3%).[121]

As further detailed below, such barriers would need to be addressed to scale up clean energy finance and investments for developing countries: on the demand side, the lack of policy and regulatory frameworks and project pipeline readiness to attract clean energy investments; on the intermediation side, insufficient and inefficient use of blended finance and other risk mitigation instruments to lower clean energy financing costs; and on the supply side, the lack of domestic financial markets for clean energy.

ii) Structural increases in electricity demand:

- **In recent years, advanced economies have seen a surge in electricity demand from bitcoin mining, which has intensified with the rapid development of AI and the proliferation of energy-intensive data centres.** A typical AI-focused data centre today consumes as much electricity as 100,000 households, but the largest currently under construction will consume 20 times as much. **Data centres accounted for around 1.5% of the world's electricity consumption in 2024, or 415 TWh. This figure is set to more than double by 2030 to around 945 TWh, which is roughly equivalent to Japan's total annual electricity consumption today. So far, both natural gas and renewables have been the main sources of electricity supply for data centres.**[130] IMF simulations show that renewable energy expansion has the potential to mitigate the impact of increased energy demand on energy prices while reducing AI-related GHG emissions.[131] At the same time, digital technologies including AI have the potential to help speed up the energy transition as electricity networks become more decentralized and digitalized. For example, AI can help improve the forecasting and integration of variable renewable energy generation and electricity-access mapping.[130,132]
- **Extreme heat in urban centres drove up demand for cooling in 2024, accounting for almost all of the 1.4% increase in fossil fuel-based electricity generation from the previous year.**[30] **Cooling is a double burden on the climate:** air conditioners and refrigerators create indirect emissions from electricity consumption and direct emissions from the release of refrigerant gases, the majority of which are much more potent global warming pollutants than CO_2. **Cooling currently accounts for almost 20% of global electricity use in buildings.** Based on current policies, the global installed capacity of cooling equipment is set to almost triple between 2022 and 2050, reaching 58,000 GW in 2050. This would require an estimated 2,000–2,800 GW of additional electricity capacity under business-as-usual energy efficiency assumptions.[133]

iii) Vulnerabilities and risks in clean energy technology supply chains:

- **The geographic concentration of raw materials processing and manufacturing capacity for clean energy technology creates risks for the security and resilience of supply chains.** Almost all of today's global manufacturing capacity for solar PV is in the Indo-Pacific region, most notably in China. China currently holds at least 60% of the world's manufacturing capacity for solar PV, wind systems, and batteries. Meanwhile, **the production and processing of critical minerals is also highly concentrated geographically.** Currently, the Democratic Republic of Congo supplies 70% of cobalt, China 60% of rare earth elements (REEs), and Indonesia 40% of nickel. Australia and Chile account for 55% and 25% of lithium mining respectively. China is responsible for the refining of 90% of REEs and 60–70% of lithium and cobalt.[134]

- **Furthermore, without proper governance, increasing demand for critical minerals risks perpetuating commodity dependence and exacerbating both geopolitical tensions and environmental and social challenges, including impacts on livelihoods, the environment, health, human security, and human rights — all of which can undermine the just energy transition.** Demand for critical minerals is set to almost triple by 2030 as the world transitions from fossil fuels to renewable energy. A transition of this magnitude brings with it tremendous opportunities but also substantial challenges. At all scales, mining has too often been linked with human rights abuses, environmental degradation, and conflict. **Resourcing the clean energy transition requires a new paradigm rooted in equity and justice.**[135,136]

iv) Weather and climate volatility:

Centralized and decentralized renewable energy systems are increasingly exposed to climate risks: droughts reducing hydropower, shifting wind patterns, extreme heat impeding solar efficiency, and rising sea levels and coastal floods threatening energy infrastructure. As a result, these forms of power generation will require robust infrastructure frameworks to ensure these assets are able to withstand extreme weather conditions. This means designing technical specifications and construction practices that account for increasingly severe climate conditions and allowing project operators to monitor systems in real-time and respond pre-emptively.[137] Integrating seasonal climate forecasts into energy planning will also be increasingly important to navigate the challenges of climate variability to secure a stable and resilient clean energy future.[138]

v) Ensuring a just, orderly, and equitable global transition away from fossil fuels:

The production and consumption of coal, oil, and gas need to decline rapidly and substantially to limit long-term warming to 1.5°C.[139,140] The transition risk associated with stranded fossil fuel assets has been estimated in the billions to trillions of dollars, with different geographic distributions for coal versus oil and gas.[141,142] However, the associated development ramifications for fossil fuel-producing low- and lower-middle income countries, as well as adequate international responses, remain underexplored.[143] **A growing body of research, rooted in the equity and climate justice movement, argues that a global equitable transition should recognize that countries' circumstances differ widely depending on their financial and institutional capacity to transition, as well as their level of socioeconomic dependence on fossil fuels.**[144,145] Based on these principles, one might expect higher-income countries and those less dependent on the fossil fuel economy for social welfare and jobs to lead the transition, while lower-capacity countries will require finance and support to pursue alternative low-carbon and climate-resilient economic development and just transitions. **However, left to existing policies and market forces alone — without further international cooperation and without coordination of demand- and supply-side policies — the transition risks being highly inequitable and disorderly.**[115,144,145]

INSTITUTIONAL, MACROECONOMIC, AND LEGAL BARRIERS

i) A lack of enabling energy infrastructure:

- **Parallel developments, investments, and governance in enabling infrastructure — especially in storage capacity; grid modernization, flexibility, and digitalization; and electrification of end-use sectors — will be vital for allowing renewable capacity installations to be integrated securely to displace fossil fuel-based power generation.** While investment in renewable power has been increasing rapidly, global investment in grids has barely changed, remaining static at around USD 300 billion/year. **Today, for every dollar spent on renewable power, only 60 cents are spent on grids and storage; this investment ratio needs to rebalance to 1:1.**[55] **There are already signs of grids becoming a bottleneck for the energy transition.** At least 3,000 GW of renewable power projects, of which 1,500 GW are in advanced stages, are waiting in grid connection queues.[146] **Greater attention must also be paid to addressing the flaws and limitations of existing governance systems for how grids are planned, built, and operated.**[147]

ii) Policy incoherence exists across multiple levels and dimensions:

- **Discordant policies and silos between ministries can impede and undermine progress.** Across NDCs submitted as of August 2024, 149 Parties have included quantifiable renewable energy targets, primarily for the power sector. **These commitments combined are set to deliver less than half the required 1.5°C-aligned growth in renewable power by 2030.**[121] Many commitments remain conditional on international financial assistance, particularly among Least Developed Countries and SIDS. At the same time, among the top 20 largest fossil fuel-producing countries, nearly half of the NDCs and around one-third of long-term low-emissions development strategies (LT-LEDS) submitted as of March 2024 include plans to continue or increase fossil fuel production.[148] **As the UNEP Production Gap Report series has shown, government plans for coal, oil, and gas production under national energy strategies and outlooks assessed as of 2023 would lead to global levels of fossil fuel production in 2030 that are more than double those aligned with 1.5°C, with the production gap widening over time to 2050.**[140]

- **Global decarbonization incentives remain insufficient and skewed.** Carbon pricing continues to be adopted by countries, having doubled in global GHG emissions coverage from 12% in 2015 to 25% in 2023, but the global average carbon price stands at only USD 5 per tonne of CO_2e (USD/tCO_2e), compared to the minimum of 85 USD/tCO_2e needed to achieve 2°C, and even higher for 1.5°C.[9] **A mix of context-specific policies, including carbon pricing, is needed to incentivize decarbonization.**[149]

- **Government subsidies for fossil fuels remain high.** While various estimates differ in terms of the underlying scope and methodologies, subsidies typically reflect policies that reduce the cost of production or the price for consumers. For example, **the IEA estimates that in 2023, governments spent USD 620 billion subsidizing fossil fuel consumption. This amount is significantly above the USD 70 billion that was spent on support for consumer-facing clean energy investments,** including grants or rebates for EVs, efficiency improvements, or heat pumps.[80] The IISD-OECD tracker estimates that subsidies for fossil fuel production and consumption amounted to USD 1.1 trillion in 2023.[150] In an analysis by Black et al. (2023) that considers both the undercharging of energy supply costs (explicit subsidies) and the environmental costs and forgone consumption taxes (implicit subsidies), total fossil fuel subsidies are estimated at USD 7 trillion in 2022 (7.1% of global GDP), with implicit subsidies making up 82% of the total.[151]

- **At COP26 in 2021, 34 countries and five public finance institutions signed the Clean Energy Transition Partnership (CETP) Statement to end international public finance for unabated fossil fuel projects by the end of 2022 and instead prioritize the clean energy transition.**[152] Collectively, signatories still sent USD 5.2 billion to the fossil fuel sector in 2023, but this was nonetheless a reduction of up to two-thirds from the 2019–2021 average. Meanwhile, support for clean energy has not scaled up significantly, with an increase of only 16% in this timeframe.[153]

iii) A lack of or insufficient long-term strategies for net-zero energy systems:

- **Long-term, integrated national energy strategies are a vital planning tool for guiding the transition to a net-zero and increasingly renewables-based energy system, but few countries have developed them.**[154] More policy attention needs to be paid, for example, to designing what has been termed the "mid-transition", during which new, zero-carbon energy systems are developed under existing fossil fuel-based system constraints.[155]

iv) A lack of focus on social justice and just energy-transition policies:

- At the same time, **a lack of policy attention to ensure a truly just energy transition — especially for affected fossil fuel workers and communities and the wider local economy — can cause political backlash and opposition to climate action.**[68] The IPCC AR6 underscored that "adaptation and mitigation actions that prioritize equity, social justice, climate justice, rights-based approaches, and inclusivity, lead to more sustainable outcomes, reduce trade-offs, support transformative change, and advance climate resilient development".[156] It will be vital to integrate just transition measures within energy-transition planning, such as promoting decent work and equitable access to reskilling/upskilling opportunities for workers in the fossil fuel industry, financing the energy transition using progressive measures, and building social and political acceptance of new policies.[157,158] Inclusive planning processes, including through social dialogue and meaningful public engagement, will be key to ensure public trust and support.

- In some countries, other sectors will also be impacted. For example, in Nigeria the firewood and charcoal industry is completely informal but involves some 41 million workers and provides an estimated 530,000 full-time equivalent direct jobs, compared to 70,000 direct jobs in the oil and gas sector. A just energy transition in Nigeria thus requires a focus on charcoal- and wood-producing workers and households in addition to fossil fuel-based energy sector workers.[159]

v) A lack of enabling conditions to scale up clean energy financing for developing countries:

- **Improving domestic enabling conditions will be key for building investor confidence** — by developing clear and stable policy and regulatory frameworks, creating robust net-zero roadmaps and investment strategies aligned with broader economic development goals, and improving project pipeline preparation and visibility. For example, national policies — including incentives for EV adoption to create domestic markets, tax breaks for charging stations, and production subsidies to incentivize investors — have been instrumental in mobilizing FDI for EVs in countries like Hungary, Indonesia, Mexico, and Thailand.[60]
- **Designing and implementing innovative financing, de-risking, and economic instruments will be crucial for lowering the cost of capital.** The public sector can, for example, strategically provide concessional capital to mobilize private capital and mitigate certain risks that private sector capital cannot yet absorb. It can also improve debt structuring and management, and reform credit rating methodologies.[124,126,160,161] **Although the LCOEs for solar PV and onshore wind are now almost always cheaper than those for fossil fuels, high upfront cost of capital due to real and perceived risks — combined with limited fiscal space and lack of affordable finance — remain a major barrier for EMDEs outside China.** For example, a 2023 survey by the IEA found that the cost of capital for utility-scale solar PV projects in EMDEs is well over twice as high as it is in advanced economies.[162] A survey by IRENA found that in 2019–2021, average regional cost of capital for onshore wind was 3% in China, 3.3% in Western Europe, 5.1% in North America, 6.4% in Latin America, and 7.2% in other Asia-Pacific countries and Africa. For utility-scale solar PV, average regional cost of capital was 3.9% in China, 4% in Western Europe, 5.4% in North America, 6.1% in other Asia-Pacific countries, 6.6% in Latin America, 7.7% in Eastern Europe, and 8.7% in the Middle East and Africa.[163]

vi) Trade policies and investment agreements can serve as barriers or enablers:

- **As noted by the IPCC AR6, many international investment agreements (IIAs) include Investor-State Dispute Settlement (ISDS) provisions that could be used by fossil fuel interests to challenge national legislation aimed at transitioning away from fossil fuels.**[164] Governments worldwide could face up to USD 340 billion in legal and financial risks for cancelling fossil fuel projects that are subject to treaties with ISDS clauses, with more than two-thirds of the estimated risk borne by developing countries.[165,166] Fossil fuel-related disputes account for nearly 20% of all known ISDS cases, making the sector the most litigious within the ISDS system.[167] This underscores the urgent need to reform the IIA regime to align with global climate and energy-transition goals.[168,169]
- **Trade costs along solar and wind energy technology value chains remain high.** Currently, developing countries' average tariffs on such goods range from 2.5% in Asia and Oceania to 7.1% in Africa. Non-tariff border measures add additional costs of 0.4–0.7%.[170] **The rise in trade restrictions poses significant risks to renewable energy technologies and critical mineral markets.**[171] Under an illustrative model scenario, IMF simulations suggest that a disruption in the trade of critical minerals could lower investment in renewable energy and EVs by as much as 30% by 2030.[172]
- **Lowering tariffs on goods across renewable energy value chains and other supportive**

provisions in trade agreements can help to increase imports and green FDI into EMDEs. For example, Hasna et al. (2023) found that a one standard deviation reduction in tariffs on low-carbon technologies (LCT) is associated with a 4% increase in the LCT-trade-to-GDP ratio and a 6% increase in LCT imports.[10] An analysis of renewable energy policies worldwide by UNCTAD found that the use of auctions and tenders is gaining momentum across all countries.[75]

- **South-South trade and regional integration can also help to strengthen developing countries' participation in renewable energy value chains.**[170]

vii) Continued fossil fuel expansions and lock-in:

The committed CO_2 emissions from existing fossil fuel production and consumption infrastructure each exceed the remaining carbon budget for limiting warming to 1.5°C with a 50% likelihood, rendering any new fossil fuel projects incompatible with the 1.5°C goal and creating asset-stranding risks.[156,173] **Yet, on the consumption side, as of January 2025, the world has around 611 GW of coal-fired power capacity under development, and 800 GW of gas- and oil-fired power capacity under development.**[174,175] In 2024, global coal power additions dropped to their lowest level in 20 years, but the world's coal fleet still increased by 0.9%. Just ten countries now account for 96% of global coal power development, led by far by China, followed by India and Indonesia. **On the production side, in 2024, a total of 895 licences were awarded for, and USD 22.9 billion of capital invested in, oil and gas exploration. The licences could lead to emissions of around 1.7 billion tonnes of CO_2 if the reserves are burnt.**[176]

viii) Lobbying, disinformation, greenwashing, and delaying tactics by fossil fuel interests and enablers:

- Political action to mitigate climate change has been impeded at the national, regional, and international levels through direct lobbying by fossil fuel companies and through the funding of political actors that remains largely undisclosed. A growing body of academic research and investigative journalism has also documented how, for decades, vested interests have developed strategies to both directly discredit climate science and spread disinformation and misinformation that delay the need to reduce fossil fuel reliance, including false claims about renewable energy technologies to undermine support for them.[177–180]
- To date, the oil and gas industry has done little to diversify their activities into clean energy.[181] In 2022, the industry invested USD 20 billion — 2.5% of its total capital spending — on clean energy projects, compared to the USD 800 billion annual investments in oil and gas supply.[182]

Section 5 — Seizing the moment of opportunity

As the previous sections demonstrated, the world stands on the cusp of a new energy era that can deliver immense economic, climate, and sustainable development benefits. We are presented with an unprecedented moment of opportunity to deliver the policies, frameworks, and infrastructure needed to capitalize on the falling costs and abundant potential of renewable energy to unlock the transition globally — particularly in developing countries where renewable resources are vast and access needs are greatest. But this window of opportunity will be missed if we fail to act with urgency or to work together. The barriers and challenges outlined in Section 4 must be addressed to accelerate a fast, fair, and funded transition.

This section identifies six priority areas for the international community to accelerate the new era of energy powered by renewables, efficiency, and electrification.

#1 PROVIDE POLICY COHERENCE, CLARITY, AND CERTAINTY

Governments should align policies, incentives, and resources to seize the benefits of the emerging renewable energy economy:

i) Develop just energy-transition roadmaps as part of national strategies for strengthening green industrialization and economic competitiveness, and to help coordinate the rapid rollout of renewable energy technologies and transition away from fossil fuels towards net-zero energy systems by 2050 at the latest, with developed countries taking the lead.

ii) Seize the opportunity presented by the next generation of NDCs by COP30 to lay out concrete and quantifiable energy-transition priorities and targets out to 2035 and provide the policy clarity necessary to attract investments. New NDCs should follow the first Global Stocktake guidance in terms of aligning with 1.5°C and covering all sectors and all GHGs. They should also demonstrate how countries will contribute to global 1.5°C-aligned energy-transition goals and align with long-term net-zero strategies.

iii) Strengthen domestic enabling environments to attract renewable energy investments and develop domestic markets — including embedding climate and energy-transition goals into national legislation, clear and stable regulatory and legal frameworks for investment and offtake pricing commitments, governance reforms, improved project pipeline readiness and visibility, and, where relevant, regional energy integration.

iv) Leverage public-private partnerships to drive the transition and green industrial development.

v) Reform or end domestic fossil fuel subsidies and implement effective domestic carbon pricing mechanisms while protecting low-income and vulnerable communities through progressive policy design.

vi) End public finance for international fossil fuel projects to redirect resources towards the just energy transition.

#2 INVEST IN ENABLING INFRASTRUCTURE FOR THE 21st CENTURY ENERGY SYSTEM

The surge in renewable capacity must be supported by parallel developments in modern and flexible grid and storage infrastructure to rapidly scale up the share of renewables in total power generation. Meeting the global goals of tripling renewable capacity and doubling energy efficiency should lead to the share of renewables in global power generation reaching around 60–70% by 2030 and 80% by 2035.[xvi]

xvi Based on 1.5°C-aligned global energy-transition scenarios modelled by the IEA and IRENA.[27,28]

i) Prioritize investments in energy storage, EV charging stations, and grid expansion, modernization, and flexibility — including through leveraging digital technologies:

- Achieve a global energy storage capacity of 1,500 GW by 2030, including 1,200 GW in battery storage.
- Double investments in electricity transmission and distribution grids from current levels, reaching USD 680 billion/year by 2030.
- Invest in regional grid interconnections that can help drive faster renewable energy integration and improve the security of supply.
- Reforms in grid governance will also be crucial, especially in countries with full or majority state-owned utilities.

ii) Accelerate energy efficiency improvements and electrification of all end-use sectors: buildings, transport, and industry. In particular:

- Achieve a share of electricity in global final energy consumption of at least 30% by 2030.
- Near-zero emissions and climate-resilient buildings should be the new normal by 2030.
- Improve energy efficiency of cooling and heating technologies by 50% by 2030.

#3 MEET NEW ELECTRICITY DEMAND WITH RENEWABLES, ESPECIALLY FOR RAPIDLY GROWING SECTORS LIKE BIG TECH — IN PARTICULAR FOR AI AND DATA CENTRES

Growing energy demand can and should be met by renewables and other clean energy sources. Renewables are now the cheapest and quickest option for new power generation, making up 92.5% of global power capacity additions and 74% of global power generation growth in 2024.

i) Governments should strive to meet all new electricity demand with renewables, leveraging the lower average lifetime costs of renewables compared to fossil fuels for new power generation and avoiding future stranded assets.

ii) Major tech firms should commit to powering their operations with 100% renewables by 2030.

#4 PLACE PEOPLE AND EQUITY AT THE HEART OF THE JUST ENERGY TRANSITION TO DRIVE INCLUSIVE ECONOMIC DEVELOPMENT

i) Deliver universal clean electricity and clean cooking access for all by 2030 by leveraging the combination of grid, mini-grid, and off-grid renewables-based solutions.

ii) Ensure energy affordability in the transition. As discussed in Section 3, transitioning to primarily renewables-based energy systems will deliver cost savings for consumers, businesses, and governments. Nevertheless, governments should include progressive policies to ensure they are not exacerbating economic hardship for lower-income and vulnerable communities.

iii) Ensure a just transition for workers and communities affected by the transition through strengthening social protection measures, providing training and reskilling opportunities, and engaging all relevant stakeholders through inclusive dialogues and consultations.

iv) Expand opportunities for technical and vocational education and training in the clean energy sector for women, youth, minorities, and other marginalized and vulnerable groups.

v) Recognize that countries' existing dependence on, and capacity to transition away from, the fossil fuel economy vary widely, and countries will therefore have different transition pathways. Encourage those with higher capacity to transition faster, while supporting low-capacity and high-dependence developing countries. Country platforms offer a promising mechanism for support, but key challenges need to be overcome for effective implementation, including: aligning political commitments with national strategies and regulatory frameworks; increasing concessional finance targeted at mobilizing greater private capital; developing in-country technical, planning, and modelling capacity; and addressing vested interests and the political economy of transitioning away from fossil fuels.

vi) Apply the seven Guiding Principles and implement the five Actionable Recommendations from the UN High-Level Panel on Critical Energy Transition Minerals throughout the critical minerals value chain.[135]

#5 SUPERCHARGE THE TRANSITION BY INCREASING COOPERATION ON TRADE AND INVESTMENT

Trade policies and investment agreements should be designed to boost the energy transition. Governments should pursue robust cooperation to:

i) Increase the diversification, resilience, and security of global clean energy supply chains, including broadening opportunities for developing countries to participate by supporting them to design and implement integrated green energy-industry strategies to enter the renewable energy value chain and attract investment.

ii) Strengthen trade and investment in clean energy technologies by lowering tariffs and other barriers on clean energy goods, and through new models of bilateral and plurilateral clean energy cooperation — including through South-South cooperation and collaboration.

iii) Fast-track the replacement and modernization of investment treaties. IIAs should be reformed and redesigned to align with climate and sustainable development imperatives, mitigate risks and liabilities of ISDS provisions, reduce policy constraints to pursue clean energy-based industrialization, and foster cooperation for the promotion and facilitation of sustainable investment.

#6 DISMANTLE STRUCTURAL BARRIERS TO MOBILIZE ENERGY-TRANSITION FINANCE FOR DEVELOPING COUNTRIES

Mobilizing funds for the clean energy transition in developing countries hinges upon tackling persistent and systemic barriers in the international financial architecture, demystifying perceived risks, and addressing real risks to bring down the cost of capital — for both debt and equity financing.

In addition to the calls outlined in the UN Pact for the Future to reform the international financial and debt architecture so that developing countries can achieve their climate and sustainable development goals, solutions targeted at mobilizing energy-transition finance and investments include, but are not limited to:[183]

- **Expand the capacities of multilateral, regional, and national development banks to support just energy transitions** — including through increasing concessional financing, strengthening credit enhancement tools, increasing local currency lending and risk hedging, and expanding capacity building and technical assistance.
- **Leverage innovative de-risking and risk-sharing mechanisms to mobilize private finance at scale, especially for renewable energy and grid infrastructure projects where upfront costs are high and returns may be slow to materialize.** DFIs should expand their support for such projects, take on more risk, and avoid crowding out private investments.
- **Work with credit rating agencies to update their methodologies** to reduce the gap between real and perceived risks stemming from subjective biases and to account for the economic growth prospects in developing countries through accelerating the clean energy transition.
- **Work with capital providers (domestic and international) to better distinguish between real and perceived risk** when investing in developing countries with high renewable resource potential including through increasing understanding of clean energy technologies so that risk is adequately priced.
- **Create long-term currency financing mechanisms through domestic financial market development.** Leverage models that have scaled in EMDEs (such as mobile banking) by working with domestic financial institutions to develop green lending capabilities.
- **Build robust project preparation and pipeline development facilities.** Work with technical assistance providers to establish dedicated facilities that bring clean energy projects to bankable standards before presenting them to investors.

Annex: Data and terminology

Throughout the report, unless otherwise specified, "renewable energy" refers to both "infinite" renewable sources such as solar, wind, hydropower, and geothermal as well as "cyclical" sources such as modern biofuels — consistent with the UN International Recommendations for Energy Statistics. The definition of "clean energy" can vary among the cited data and references but generally refers to sources that produce little to no GHG emissions during energy generation. For example, the IEA's definition of clean energy technologies includes renewable power, EVs, heat pumps, energy efficiency measures, and nuclear. Please refer to the citations for details.

Given the variety of data sources analyzed and cited throughout the report, some minor discrepancies can exist between datasets from different institutions. This report reflects data finalized as of 24 June 2025.

The term "clean cooking" defines cooking solutions that achieve ISO Tier 4 and 5 of the multi-tier frameworks for clean cooking or technologies that attain the fine particulate matter and carbon monoxide levels recommended in the WHO's global air quality guidelines.[93] Clean cooking fuels and technologies include stoves powered by electricity, LPG, natural gas, biogas, solar, and alcohol. Renewables-based clean cooking solutions narrow down the specificity of the clean cooking definition to encompass only technologies that utilize renewable fuel sources. These include biogas, bioethanol, solid biomass, and renewables-based electricity.

Electricity capacity refers to the maximum amount of output that an electricity generator can physically produce (or accept in the case of an electricity storage device), and is typically measured in watts (W). Electricity generation refers to the amount of output that is actually generated over a given period of time and is typically measured in kilowatt-hours (kWh). (1 kW = 1,000 W, and 1 kWh is one hour of using electricity at a rate of 1,000 W.)

LCOE represents the average cost of electricity generation from a technology considering all costs incurred over its lifetime, including upfront investment, financing costs, operation and maintenance, fuel costs, and carbon pricing where relevant. It is often used as a metric for power plants and can also be used for the average cost of battery storage, if the charging costs are considered as fuel costs. It can be applied to battery storage in stand-alone applications or when paired with other technologies, such as solar PV. For technologies that operate in similar ways, the LCOE provides a common and suitable metric for comparison.

FDI is defined as an investment involving a long-term relationship and reflecting a lasting interest and control by a resident entity (the foreign direct investor or parent enterprise) of one country in an enterprise (foreign affiliate) resident in a different country. FDI can take the form of either greenfield investment or a merger or acquisition. Greenfield FDI is new investment made by setting up a new foreign affiliate.

On fossil fuel and clean energy employment statistics, the IEA's estimates include the direct employment effects of investment and activity in the energy supply sectors (e.g. oil, gas, power) and energy-using technologies (e.g. heat pumps, vehicles). They also include indirect jobs generated through the manufacture, construction, and installation of core energy-supplying and energy-using facilities and devices. For the renewable sector specifically, the estimates by IRENA and ILO include direct jobs generated by renewable energy deployment (e.g., rooftop solar installations) and indirect jobs from activities in the upstream and midstream industries that supply and support the core activities of renewable energy deployment (e.g., manufacturing, construction, and operation of facilities).

References

1. IRENA. *Renewable Power Generation Costs in 2024.* (2025)
2. UNFCCC. Paris Agreement. (2015).
3. UNFCCC. Decision 1/CMA.5: Outcome of the first Global Stocktake. Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement. (2023).
4. UNEP. *Emissions Gap Report 2024: No More Hot Air … Please! With a Massive Gap between Rhetoric and Reality, Countries Draft New Climate Commitments*. (2024). doi:10.59117/20.500.11822/46404.
5. UNEP. *Emissions Gap Report 2015*. (2015).
6. IPCC. *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge University Press, Cambridge, UK, and New York, USA, 2022).
7. Sovacool, B. K. et al. The acceleration of low-carbon transitions: Insights, concepts, challenges, and new directions for research. *Energy Res. Soc. Sci.* 121, 103948 (2025).
8. Net Zero Tracker. (Accessed 18 June 2025).
9. Black, S., Parry, I. & Zhunussova, K. *Is the Paris Agreement Working? A Stocktake of Global Climate Mitigation*. IMF Staff Climate Note. (International Monetary Fund, Washington, D.C., 2023). doi:10.5089/9798400257889.066.
10. Hasna, Z., Jaumotte, F., Kim, J., Pienknagura, S. & Schwerhoff, G. *Green Innovation and Diffusion: Policies to Accelerate Them and Expected Impact on Macroeconomic and Firm-Level Performance*. IMF Staff Discussion Note. (International Monetary Fund, Washington, D.C., 2023). doi:10.5089/9798400256950.006.
11. Nijsse, F. J. M. M. et al. The momentum of the solar energy transition. *Nat. Commun.* 14, 6542 (2023).
12. Way, R., Ives, M. C., Mealy, P. & Farmer, J. D. Empirically grounded technology forecasts and the energy transition. *Joule* 6, 2057–2082 (2022).
13. IEA. *The State of Clean Technology Manufacturing.* (2023).
14. IEA. *Renewables 2024*. (2024).
15. IEA. *Electricity 2025*. (2025).
16. Romanello, M. et al. The 2024 report of the Lancet Countdown on health and climate change: facing record-breaking threats from delayed action. *The Lancet* 404, 1847–1896 (2024).
17. Kotz, M., Kuik, F., Lis, E. & Nickel, C. Global warming and heat extremes to enhance inflationary pressures. *Commun. Earth Environ.* 5, 116 (2024).
18. WMO. *Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019).* (2021).
19. Munich Re. Climate change is showing its claws: The world is getting hotter, resulting in severe hurricanes, thunderstorms and floods. (2025).
20. Kotz, M., Levermann, A. & Wenz, L. The economic commitment of climate change. *Nature* 628, 551–557 (2024).

21. Wingenroth, J., Prest, B. C. & Rennert, K. The economic benefits of achieving the Paris Agreement goals. (2023).

22. Alberti, C. The cost of inaction. Climate Policy Initiative. (2024).

23. Thomasson, E. NGFS scenarios foresee climate hit to global growth before 2030. (2025).

24. WMO. *State of the Global Climate 2024.* (2025).

25. WMO. *WMO Global Annual to Decadal Climate Update (2025-2029).* (2025).

26. Friedlingstein, P. et al. Global carbon budget 2024. *Earth Syst. Sci.* Data 17, 965–1039 (2025).

27. IEA. *Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach*. (2023).

28. IRENA. *World Energy Transitions Outlook 2024: 1.5°C Pathway*. (2024).

29. IRENA. *Renewable Capacity Statistics 2025 (March edition)*. (2025).

30. Graham, E., Fulghum, N. & Altieri, K. *Global Electricity Review 2025*. (2025).

31. IEA. *World Energy Investment 2025*. (2025).

32. IEA. *Global Energy Review 2025*. (2025).

33. IEA. *World Energy Outlook 2024*. (2024).

34. IEA. *Global EV Outlook 2025*. (2025).

35. BNEF. *Energy Transition Factbook 2024 — Prepared for the 15th Clean Energy Ministerial Meeting*. (2024).

36. IEA. *World Energy Employment 2024*. (2024).

37. IRENA & ILO. *Renewable Energy and Jobs: Annual Review 2024*. (2024).

38. Cozzi, L., Gül, T., Spencer, T. & Levi, P. Clean energy is boosting economic growth. International Energy Agency. (2024).

39. BNEF. *Energy Transition Investment Trends 2025*. (2025).

40. IEA. *Renewables 2023*. (2024).

41. IRENA. *Renewable Power Generation Costs in 2022*. (2023).

42. IEA. *Batteries and Secure Energy Transitions*. (2024).

43. Lazard. *Levelized Cost of Energy+*. (2024).

44. Graham, P., Hayward, J. & Foster, J. *GenCost 2024-25: Consultation Draft*. (2024).

45. IRENA. *Renewable Power Generation Costs in 2023*. (2024).

46. IAEA. *Milestones in the Development of a National Infrastructure for Nuclear Power*. (2024). doi:10.61092/iaea.zjau-e8cs.

47. The Economist. Sun machines. *The Economist.* (2024).

48. Wiatros-Motyka, E., Jones, D. & Fulghum, N. *Global Electricity Review 2024*. (2024).

49. Graham, E. & Fulghum, N. Solar power continues to surge in 2024. Ember. (2024).

50. Global Solar Council. *Africa Market Outlook for Solar PV 2025–2028*. (2025).

51. UNCTAD. *International Investment in SDG-Relevant Sectors, Excluding Renewable Energy, Has Stalled since 2015*. (2024).

52. Koperniech, J. & Otsuka, R. Four ways digital can power a just energy transition. United Nations Development Programme. (2023).

53. IEA. Digital-related investment in grid technologies, 2015–2022. (2023).

54. Ember. Yearly electricity data. (2025).

55. IEA. *From Taking Stock to Taking Action: How to Implement the COP28 Energy Goals*. (2024).

56. IEA. World energy statistics and balances (2024 edition). (2024).

57. IEA. World energy balances database documentation (2024 edition). (2024).

58. York, R. & Bell, S. E. Energy transitions or additions? *Energy Res. Soc. Sci*. 51, 40–43 (2019).

59. Murphy, R. What is undermining climate change mitigation? How fossil-fuelled practices challenge low-carbon transitions. *Energy Res. Soc. Sci.* 108, 103390 (2024).

60. Jaumotte, F., Kim, J., Pienknagura, S. & Schwerhoff, G. *Policies to foster green FDI: Best practices for Emerging Market and Developing Economies.* IMF Staff Climate Note (International Monetary Fund, Washington, D.C., 2024).

61. UNCTAD. Global FDI Estimated 8% down in 2024. *Global Investment Trends Monitor*. (2025).

62. OECD. *Green Industrial Policies for the Net-Zero Transition*. (2024). doi:10.1787/ccc326d3-en.

63. Myllyvirta, L., Qi, Q. & Chengcheng, Q. Analysis: Clean energy contributed a record 10% of China's GDP in 2024. Carbon Brief. (2025).

64. IRENA & ILO. *Renewable Energy and Jobs: Annual Review 2022*. (2022).

65. Freire-González, J., Padilla Rosa, E. & Raymond, J. Ll. World economies' progress in decoupling from CO2 emissions. *Sci. Rep.* 14, 20480 (2024).

66. Singh, S. The relationship between growth in GDP and CO2 has loosened; it needs to be cut completely. International Energy Agency. (2024).

67. European Commission Joint Research Centre & IEA. *GHG Emissions of All World Countries*. (Publications Office, LU, 2024).

68. OECD & UNDP. *Investing in Climate for Growth and Development: The Case for Enhanced NDCs.* (OECD Publishing, 2025). doi:10.1787/16b7cbc7-en.

69. Ritchie, H. Many countries have decoupled economic growth from CO2 emissions, even if we take offshored production into account. Our World in Data. (2021).

70. G20 Saudi Arabia. G20 reference framework for effective country platforms. (2020).

71. G20 Brazil. The G20 taskforce on a global mobilization against climate change (TF-CLIMA) outcome document. (2024).

72. Hadley, S., Mustapha, S., Colenbrander, S., Miller, M. & Quevedo, A. *Country Platforms for Climate Action*. (2022).

73. Rockefeller Foundation & Environmental Defense Fund. *Scaling the JETP Model: Prospects and Pathways for Action*. (2024).

74. Jain, G. & Bustami, G. Realizing the potential of just energy transition partnerships in the current geopolitical environment. Columbia University Center on Global Energy Policy. (2025).

75. UNCTAD. Chapter IV: Investing in sustainable energy for all. *World Investment Report 2023.* (United Nations Trade and Development, New York, 2023).

76. Jones, D. Three facts that show how solar and wind strengthen energy security. Ember. (2025).

77. Bond, K., Walter, D. & Butler-Sloss, S. Energy security in an insecure world. Ember. (2025).

78. IEA. Global energy crisis. (2025).

79. Ari, A. *et al. Surging Energy Prices in Europe in the Aftermath of the War: How to Support the Vulnerable and Speed up the Transition Away from Fossil Fuels.* IMF Working Paper. (International Monetary Fund, Washington, D.C, 2022). doi:10.5089/9798400214592.001.

80. IEA. *Strategies for Affordable and Fair Clean Energy Transitions*. (2024).

81. Kim, M. C. South Korea's Power Trilemma. Institute for Energy Economics and Financial Analysis. (2024).

82. Energy & Climate Intelligence Unit. *The Cost of Gas since the Russian Invasion of Ukraine*. (2023).

83. Evans, S. & Lempriere, M. Factcheck: Why expensive gas — not net-zero — is keeping UK electricity prices so high. Carbon Brief. (2025).

84. IRENA. *Small Island Developing States at a Crossroads: The Socio-Economics of Transitioning to Renewables*. (2024).

85. UNDP. *Advancing a Just Energy Transition in SIDS*. (2024).

86. IEA, IRENA, UN, World Bank, & WHO. *Tracking SDG7: The Energy Progress Report 2025*. (2025).

87. WHO. Household air pollution. (2024).

88. IEA, IRENA, UN, World Bank, & WHO. Tracking SDG7: *The Energy Progress Report 2024*. (2024).

89. Prasad, R. D., Chand, D. A., Lata, S. S. S. L. & Kumar, R. S. Beyond energy access: How renewable energy fosters resilience in island communities. *Resources* 14, 20 (2025).

90. Tamasiga, P., Onyeaka, H., Altaghlibi, M., Bakwena, M. & Ouassou, E. H. Empowering communities beyond wires: Renewable energy microgrids and the impacts on energy poverty and socio-economic outcomes. *Energy Rep*. 12, 4475–4488 (2024).

91. ESMAP. *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision-Makers*. (2022).

92. IRENA. *Advancing Renewables-Based Clean Cooking Solutions: Key Messages and Outcomes*. (2024).

93. WHO. Defining clean fuels and technologies. (2025).

94. UNEP. How Uganda's push for "clean cooking" could save lives and counter climate change. (2025).

95. World Bank Group. *People in a Changing Climate: From Vulnerability to Action — Insights from World Bank Group Country Climate and Development Reports Covering 72 Economies*. (2024).

96. Lovins, A. B. & Ramana, M. V. Three myths about renewable energy and the grid, debunked. Yale Environment360. (2021).

97. Larson, A. U.S. power distribution system reliability has declined over the past decade: How to make it better. *POWER Magazine* (2024).

98. McGovan, J. German electricity supply continued to be highly reliable during energy crisis, nuclear phase-out. *Clean Energy Wire.* (2024).

99. Danish Ministry of Climate, Energy, and Utilities. Denmark will continue to have a high level of security of electricity supply. KEFM. (2025).

100. Xu, L. et al. Resilience of renewable power systems under climate risks. *Nat. Rev. Electr. Eng*. 1, 53–66 (2024).

101. Misbrener, K. First three solar + storage microgrids in the works for Puerto Rico resilience initiative. *Solar Power World.* (2022).

102. Stone, L. Keeping the lights on during hurricanes. Rocky Mountain Institute. (2021).

103. Navia Simon, D. & Diaz Anadon, L. Faster deployment of renewables stabilizes electricity prices in Europe. *Nat. Energy* 10, 291–292 (2025).

104. Denis, B. & Roche, J. Why clean energy is key to building a more resilient future in uncertain times. World Economic Forum. (2025).

105. Baquie, S. *et al. Industrial Policies: Handle with Care*. IMF Staff Discussion Note. (International Monetary Fund, Washington, D.C, 2025). doi:10.5089/9798229000642.006.

106. IRENA. *World Energy Transitions Outlook 2023: 1.5°C Pathway*. (2023).

107. ILO & IsDB. *The Social, Economic and Employment Impacts of Decarbonization and Green Industrial Growth Scenarios for the Middle East and North Africa Region*. (2023).

108. IRENA. Gender. (2025).

109. Alexander, N.-R. *et al. Green Jobs and the Future of Work for Women and Men*. (International Monetary Fund, Washington, D.C, 2024). doi:10.5089/9798400286049.006.

110. World Bank Group. *The Development, Climate, and Nature Crisis: Solutions to End Poverty on a Livable Planet — Insights from World Bank Country Climate and Development Reports Covering 42 Economies*. (2023).

111. IRENA & AfDB. *Renewable Energy Market Analysis: Africa and Its Regions*. (2022).

112. IRENA. *Socio-Economic Footprint of the Energy Transition: Southeast Asia*. (2023).

113. Schraufnagel, D. E. *et al.* Air Pollution and Noncommunicable Diseases. *Chest* 155, 409–416 (2019).

114. Lelieveld, J. *et al.* Air pollution deaths attributable to fossil fuels: observational and modelling study. *BMJ* e077784 (2023). doi:10.1136/bmj-2023-077784.

115. Achakulwisut, P. & Erickson, P. Trends in Fossil Fuel Extraction: Implications for a Shared Effort to Align Fossil Fuel Production with Climate Limits. Stockholm Environment Institute. (2021).

116. Anenberg, S. C. *et al.* Long-term trends in urban NO2 concentrations and associated paediatric asthma incidence: estimates from global datasets. *Lancet Planet. Health* 6, e49–e58 (2022).

117. Myllyvirta, L. *Quantifying the Economic Costs of Air Pollution from Fossil Fuels*. (2020).

118. Achakulwisut, P., Calles Almeida, P. & Arond, E. It's time to move beyond "carbon tunnel vision". Stockholm Environment Institute. (2022).

119. Garcia-Gonzales, D. A., Shonkoff, S. B. C., Hays, J. & Jerrett, M. Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature. *Annu. Rev. Public Health* 40, 283–304 (2019).

120. PSR. Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking. Physicians for Social Responsibility. (2023).

121. IRENA, COP28 Presidency, Global Renewables Alliance, Ministry of Energy of the Republic of Azerbaijan, & Government of Brazil. *Delivering on the UAE Consensus: Tracking Progress toward Tripling Renewable Energy Capacity and Doubling Energy Efficiency by 2030*. (2024).

122. IEA. *Global EV Outlook 2024*. (2024).

123. IRENA. *A Just and Inclusive Energy Transition in Emerging Markets and Developing Economies: Energy Planning, Financing, Sustainable Fuels and Social Dimensions*. (2024).

124. IEA. *Scaling up Private Finance for Clean Energy in Emerging and Developing Economies*. (2023).

125. Bhattacharya, A., Songwe, V., Soubeyran, E. & Stern, N. *Raising Ambition and Accelerating Delivery of Climate Finance: Third Report of the Independent High-Level Expert Group on Climate Finance*. (2024).

126. Sachs, J. D., Sachs, L. E., Camelo Vega, A. M. & Willis, B. M. *The Cost of Capital: Lowering the Cost of Capital for Climate and SDG Finance in Emerging Markets and Developing Economies (EMDEs)*. (2025).

127. Sachs, J. D. *et al.* *Roadmap to Zero-Carbon Electrification of Africa by 2050: The Green Energy Transition and the Role of the Natural Resources Sector (Minerals, Fossil Fuels, and Land)*. (2022).

128. Manley, D., Furnaro, A. & Heller, P. *Riskier Bets, Smaller Pockets: How National Oil Companies Are Spending Public Money amid the Energy Transition*. (2023).

129. Walker, I. Dollar-denominated debt: the hidden threat to global climate ambitions. Green Central Banking. (2024).

130. IEA. *Energy and AI*. (2025).

131. IMF. *World Economic Outlook: A Critical Juncture amid Policy Shifts.* (International Monetary Fund, Washington, D.C., 2025).

132. UNDP. Digital, data, and AI for the future of sustainable energy. (2024).

133. UNEP. *Global Cooling Watch 2023*. (2023).

134. IEA. *Energy Technology Perspectives 2023*. (2023).

135. United Nations. *Resourcing the Energy Transition: Principles to Guide Critical Energy Transition Minerals towards Equity and Justice*. (2024).

136. OECD. *Mainstreaming Biodiversity into Renewable Power Infrastructure* (2024). doi:10.1787/357ac474-en.

137. IRENA. *Quality Infrastructure for Renewables Facing Extreme Weather*. (2025).

138. WMO, IRENA, & ECMWF. *2023 Year in Review: Climate-Driven Global Renewable Energy Potential Resources and Energy Demand*. (2025).

139. Achakulwisut, P. *et al.* Global fossil fuel reduction pathways under different climate mitigation strategies and ambitions. *Nat. Commun.* 14, 5425 (2023).

140. SEI, Climate Analytics, E3G, IISD, & UNEP. *The Production Gap: Phasing down or Phasing up? Top Fossil Fuel Producers Plan Even More Extraction despite Climate Promises*. (2023). doi:10.51414/sei2023.050.

141. Edwards, M. R. *et al.* Quantifying the regional stranded asset risks from new coal plants under 1.5 °C. *Environ. Res. Lett*. 17, 024029 (2022).

142. Semieniuk, G. et al. Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nat. Clim. Change* 12, 532–538 (2022).

143. Foster, V. et al. Development transitions for fossil fuel-producing low and lower–middle income countries in a carbon-constrained world. *Nat. Energy* 9, 242–250 (2024).

144. SEI, IISD, ODI, E3G, & UNEP. *The Production Gap: Special Report 2020*. (2020).

145. Civil Society Equity Review. *An Equitable Phase out of Fossil Fuel Extraction: Towards a Reference Framework for a Fast and Fair Rapid Global Phase out of Coal, Oil, and Gas*. (2023).

146. IEA. *Electricity Grids and Secure Energy Transitions*. (2023).

147. Klass, A., Macey, J., Welton, S. & Wiseman, H. *The Key to Electric Grid Reliability: Modernizing Governance*. (2024).

148. Jones, N. & Yanguas Parra, P. A. *How the Transition Away from Fossil Fuel Production Can Be Included in New Climate Commitments and Plans*. (2024).

149. IMF, OECD, UN, World Bank, & WTO. *Working Together for Better Climate Action: Carbon Pricing, Policy Spillovers, and Global Climate Goals*. (2024).

150. IISD & OECD. Fossil fuel subsidy tracker. (2025).

151. Black, S., Liu, A., Parry, I. & Vernon, N. *IMF Fossil Fuel Subsidies Data: 2023 Update*. IMF Working Paper. (International Monetary Fund, Washington, D.C, 2023). doi:10.5089/9798400249006.001.

152. Clean Energy Transition Partnership. Statement on international public support for the clean energy transition. (2025).

153. Jones, N., O'Manique, C., McGibbon, A. & DeAngelis, K. *Out with the Old, Slow with the New: Countries Are Underdelivering on Fossil-to-Clean Energy Finance Pledge*. (2024).

154. IRENA. *Long-Term Energy Scenarios and Low-Emission Development Strategies: Stocktaking and Alignment*. (2023).

155. Grubert, E. & Hastings-Simon, S. Designing the mid-transition: A review of medium-term challenges for coordinated decarbonization in the United States. *WIREs Clim. Change* 13, e768 (2022).

156. IPCC. *IPCC AR6 Synthesis Report: Summary for Policymakers*. (2023).

157. ILO. *The Future of Work in the Oil and Gas Industry: Opportunities and Challenges for a Just Transition to a Future of Work That Contributes to Sustainable Development*. (2022).

158. UNDP. *Issue Brief: Just Transition*. (2022).

159. ILO. *Nigeria Green Jobs Assessment Report*. (2021).

160. IRENA. Closing the financing gap in the Global South requires a multi-pronged approach. (2025).

161. World Bank. *Scaling up to Phase down: Financing Energy Transitions in the Power Sector*. (2023).

162. IEA. *Reducing the Cost of Capital: Strategies to Unlock Clean Energy Investment in Emerging and Developing Economies*. (2024).

163. IRENA. *The Cost of Financing for Renewable Power*. (2023).

164. Patt, A. *et al.* International cooperation. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the IPCC Sixth Assessment Report.* (2022).

165. Tienhaara, K., Thrasher, R., Simmons, B. A. & Gallagher, K. P. Investor-state disputes threaten the global green energy transition. *Science* 376, 701–703 (2022).

166. UN Special Rapporteur on human rights and the environment. *A/78/168: Paying Polluters: The Catastrophic Consequences of Investor-State Dispute Settlement for Climate and Environment Action and Human Rights*. (2023).

167. UNCTAD. *Facts and Figures on Investor–State Dispute Settlement Cases*. (2024).

168. UNCTAD. *Trends in the Investment Treaty Regime and a Reform Toolbox for the Energy Transition*. (2023).

169. Mehranvar, L. *et al.* *Breaking Free: Strategies for Governments on Terminating Investment Treaties and Removing ISDS Provisions*. (2024).

170. UNCTAD. *Powering Trade: Fine-Tuning Trade Policy for Solar and Wind Energy Value Chains*. (2024).

171. Miller, H. & Martinez, J.-P. *The Changing Dynamics in Global Metal Markets: How the Energy Transition and Geo-Fragmentation May Disrupt Commodity Prices*. (2025). doi:10.1787/b0182773-en.

172. IMF. *World Economic Outlook: Navigating Global Divergences.* (International Monetary Fund, Washington, D.C., 2023).

173. UNEP. *Emissions Gap Report 2023: Broken Record — Temperatures Hit New Highs, yet World Fails to Cut Emissions (Again)*. (2023). doi:10.59117/20.500.11822/46404.

174. Global Energy Monitor. Global oil and gas plant tracker. (2025).

175. Global Energy Monitor. Global coal plant tracker. (2025).

176. Bois von Kursk, O. & Posada, E. *January 2025: Carbon Minefields Oil and Gas Exploration Monitor*. (2025).

177. Stoddard, I. *et al.* Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve? *Annu. Rev. Environ. Resour.* 46, 653–689 (2021).

178. Eisenson, M. *et al.* *Rebutting 33 False Claims about Solar, Wind, and Electric Vehicles*. (2024).

179. Noor, D. Big oil privately acknowledged efforts to downplay climate crisis, joint committee investigation finds. *The Guardian* (2024).

180. Westervelt, A. The drilled guide to global climate disinformation: The terms and narratives the fossil fuel industry is using to obstruct climate action. (2025).

181. Rekker, S. *et al.* Evaluating fossil fuel companies' alignment with 1.5 °C climate pathways. *Nat. Clim. Change* 13, 927–934 (2023).

182. IEA. *The Oil and Gas Industry in Net Zero Transitions*. (2023).

183. United Nations. Pact for the Future (Resolution A/RES/79/1). (2024).