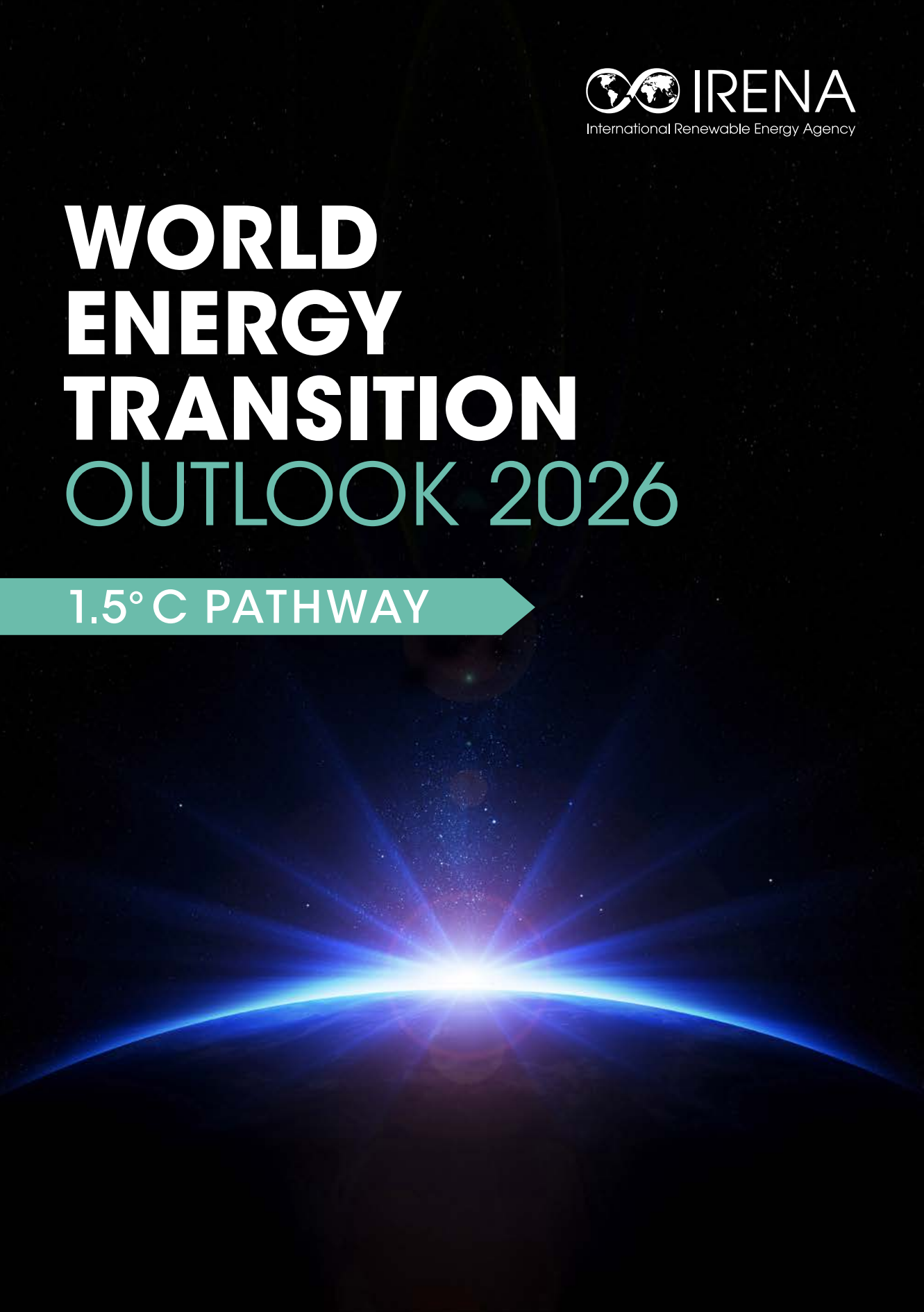
IRENA
International Renewable Energy Agency

WORLD ENERGY TRANSITION OUTLOOK 2026

1.5°C PATHWAY



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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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WORLD ENERGY TRANSITION OUTLOOK 2026

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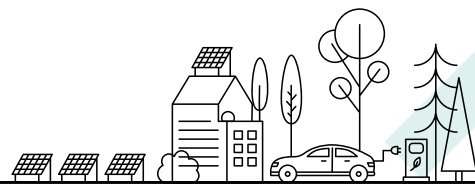
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FOREWORD

The global energy transition has entered a decisive new phase. Renewable energy costs have continued to fall, renewable capacity additions have set new records each year and electrification is advancing across transport, buildings and industry.

Yet, this 2026 edition of the *World Energy Transition Outlook* shows that progress remains far too slow and uneven, recognising an increasingly difficult climate reality – that the policy challenge has shifted from avoiding any overshoot of 1.5°C, to limiting its magnitude and duration to enable a return to a 1.5°C-aligned pathway.

This troubling conclusion is coupled with an equally concerning realisation that the transition now faces the prospect of slower growth. Whist renewable power capacity has expanded dramatically over the past decade, culminating in the exponential annual increases witnessed since 2021, the lack of infrastructure required to connect new renewable power to the grid is now beginning to hamper renewable capacity additions. This emphasises the urgent need for the transition to be holistic and system-wide; advancements in some areas can no longer compensate for delays in others.

The essential pillars of the transition, that IRENA has consistently emphasised across all aspects of its work, are becoming ever more important. The world urgently requires infrastructure that is fit for a new energy system founded on renewable power and end-use electrification, including expanded and modernised power grids, as well as storage and system flexibility. Progress in these areas requires robust enabling market design, legislation and regulation, complemented by accessible and affordable finance, as well as institutional and human resource capacities to support the transition – the training, skilling and re-skilling that will enable the wholescale shift to the new energy system. Without progress on these essential foundations, the transition remains in danger of losing momentum.

Governments, industry, financial institutions and international organisations all have a role to play in turning the tide. Stronger international co-operation will be indispensable to mobilise affordable finance, strengthen and diversify supply chains, accelerate technology transfer, build skills and ensure that developing economies can capture greater value from the transition.

Renewables-based electrification must also be placed at the centre of the implementation agenda for the decade to 2035. Economic development and expanding access to modern energy services are adding to growing global demand for electricity; while electric mobility, rising cooling needs, digitalisation and data centres are creating new and increasingly concentrated loads.

Electricity is becoming the principal link between renewables and the transformation of energy demand. Under IRENA's revised 1.5°C Scenario, electricity's share of global final energy consumption would rise from around 23% today to 35% by 2035 and to more than 50% by 2050, transforming transport, buildings and industry, and fundamentally reshaping the delivery of energy services.

The quality of the energy transition will matter just as much as its breadth and speed. Accelerated decarbonisation can strengthen investment, productivity, employment and welfare; but affordability, social protection and equitable access to new economic opportunities must be addressed from the outset. A transition that is perceived as fair and beneficial will help build the public acceptance required for implementation at the scale and pace required.

This also requires that energy transition pathways reflect the unique energy systems, resource endowments, levels of development, infrastructure conditions and institutional capacities of countries. The common direction is clear, but implementation must be tailored to national and regional circumstances. Integrated national energy planning must become a central pillar of implementation – energy supply, demand, infrastructure and investment can no longer be planned for separately – and regional planning can help countries make better use of complementary resources, strengthen cross-border interconnections, improve energy security, and align infrastructure and investment across markets. In this regard, the regional analysis in this report reinforces the value of integrated planning for capturing comparative advantages and strengthening co-operation and resilience.

Renewable energy remains the foundation of the transition. Electrification provides the backbone connecting renewable power to end-use sectors. Energy efficiency allows us to deliver more with less. Grids, storage and flexibility make the system work. Sustainable fuels complement the transition where direct electrification is more difficult. Hence, integrated planning must bring these elements together and turn ambition into implementation, rapidly and at scale.



Francesco La Camera
Director-General, IRENA

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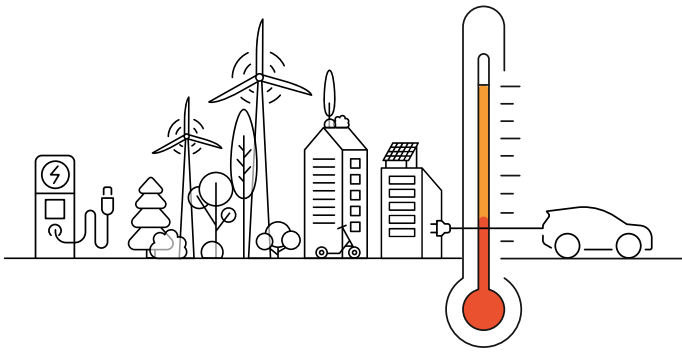
ABBREVIATIONS

AI	artificial intelligence
ASEAN	Association of Southeast Asian Nations
BECCS	bioenergy, carbon capture, utilisation and storage
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CDD	cooling degree day(s)
CO_2	carbon dioxide
CSC	China Scholarship Council
CSP	concentrated solar power
DC	direct current
DES	Decarbonising Energy Scenario
DES-IC	Decarbonising Energy Scenario – International Collaboration
DH	district heating
DRC	Democratic Republic of the Congo
DRE	decentralised renewable energy
EC	European Commission
EJ	Exajoule
ETAF	Energy Transition Accelerator Financing platform
ETWI	Energy Transition Welfare Index
EU	European Union
EUR	euro
EV	electric vehicle
GDP	gross domestic product
GEEA	Global Energy Efficiency Alliance
GHG	greenhouse gas
$GtCO_2$	gigatonnes of CO_2
$GtCO_2eq$	gigatonnes of CO_2 equivalent
GVA	gross value added
GW	gigawatt
GX	green transformation (Japan, policy)
HDD	heating degree day(s)
HH	household
IEA	International Energy Agency
ILO	International Labour Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITP	Independent Transmission Projects programme (South Africa)
KPI	key performance indicator
MENA	Middle East and North Africa
METI	Ministry of Economy, Trade and Industry (Japan)
MW	megawatt
PES	Planned Energy Scenario
PPP	purchasing power parity
PV	photovoltaic
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme (South Africa)
RETO	Regional energy transition outlook
SAF	sustainable aviation fuel
SDG	(UN) Sustainable Development Goal
TAFF	Transitioning Away from Fossil Fuels (initiative)
TFEC	total final energy consumption
TPES	total primary energy supply
TW	terawatt
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	United States dollars
VRE	variable renewable energy
WHO	World Health Organization

WORLD ENERGY
TRANSITION OUTLOOK 2026

EXECUTIVE SUMMARY





From climate imperative to energy security, competitiveness and socio-economic development

The global energy transition has entered a new phase. Renewable energy deployment continues to break records, technology costs have fallen significantly and electrification is advancing across transport, buildings and industry. Compared with previous editions of the *World Energy Transition Outlook*, current government plans target higher renewable energy deployment, greater electrification of end-use sectors and a growing focus on clean hydrogen and enabling technologies.

Yet geopolitical tension, conflict, trade fragmentation, supply-chain disruption and resource competition have propelled energy security, competitiveness and economic resilience to the top of political agendas worldwide. Recent crises have again exposed the economic vulnerability of fossil-fuel dependence, while the expansion of renewable energy systems is creating new dependencies linked to manufacturing capacity, critical materials, infrastructure and technology supply chains. The energy transition does not eliminate geopolitical and economic risks; rather, it changes their nature. Yet – unlike fossil fuel reserves – manufacturing capacity, processing facilities and clean energy industrial ecosystems can be expanded, diversified and replicated through investment, innovation and international co-operation.

This changing context reinforces one of the central messages of this report: beyond the climate imperative, the energy transition increasingly represents an essential means to achieve energy security, industrial competitiveness, economic resilience and socio-economic development.

Progress, however, remains insufficient. Renewable deployment is accelerating, but electricity demand is growing rapidly as economies develop, access to modern energy services expands and new sources of demand emerge – including electric mobility, cooling during more frequent heat waves, digitalisation, artificial intelligence (AI) and data centres. The rapid expansion of AI and data centres observed in recent years is particularly significant as their loads can be large, geographically concentrated and grow faster than power-system infrastructure, creating new challenges for generation adequacy, grid planning and system flexibility. Energy efficiency improvements, electricity networks and enabling infrastructure are simply not keeping pace.

The challenge is therefore increasingly one of accelerating implementation. The technologies required for the energy transition are widely available and many are becoming increasingly competitive. The central question is how rapidly they can be deployed together at the scale required, while maintaining energy security, affordability and public acceptance.

Modelling for 1.5°C

WETO 2026 assesses three global energy transition pathways that provide a framework for understanding the implications of different levels of ambition and implementation.

The **Planned Energy Scenario (PES)** reflects existing government energy plans, targets and policies in place through end-2025. It shows that policy ambition has strengthened evaluations, particularly in renewable energy deployment and electrification. Nevertheless, the PES remains consistent with a temperature outcome above 2°C (degrees centigrade) and with the Intergovernmental Panel on Climate Change (IPCC)'s AR6[1] C5/C6 pathways (Riahi *et al.*, 2022). It serves as a benchmark that enables assessment of what current commitments mean for future energy systems, which in turn carry implications for emissions, energy security, investment and socio-economic outcomes.

The **Decarbonising Energy Scenario (DES)** describes a more ambitious pathway. It assumes accelerated renewable energy deployment, stronger energy efficiency improvements and faster electrification across end-use sectors to move the global energy system onto a pathway consistent with limiting global temperature rise to below 2°C of pre-industrial levels in the range of the IPCC AR6 C4 pathway. The differences between the DES and the PES serve to illustrate regional transition efforts but also reflect insufficient and uneven progress by highlighting implementation gaps to announced targets.

IRENA's revised **1.5°C Scenario** illustrates the additional transformation required to return the energy system to a 1.5°C-compatible pathway, following a limited and temporary overshoot owing to delayed action. It is equivalent to an IPCC AR6 C2 pathway and requires deeper and faster renewable deployment, greater efficiency gains, widespread electrification and additional carbon removals. Exceeding 1.5°C should not be interpreted as safe or acceptable; the United Nations Environment Programme (UNEP) recently stressed that the global objective remains limiting long-term warming to 1.5°C, but that this goal must now be approached retroactively. In this context, existing commitments need to be met and strengthened, while mitigation and adaptation advance in parallel. Limiting the magnitude and duration of the overshoot therefore requires faster near-term emissions reductions, with any subsequent return towards 1.5°C dependent on sustained decarbonisation and carbon removals (UNEP, 2026a). Cumulative energy related carbon dioxide (CO_2) emissions over 2026–2050 would be around 840 gigatonnes ($GtCO_2$) under the PES and around 480 $GtCO_2$ under the DES, compared with approximately 400 $GtCO_2$ under the 1.5°C Scenario.

These scenarios are not competing visions of the future; rather, they intend to provide a framework for understanding the implementation gaps, *i.e.* what current plans could deliver, what stronger decarbonisation policies could achieve, and what further transformation is required to remain aligned with 1.5°C pathway.

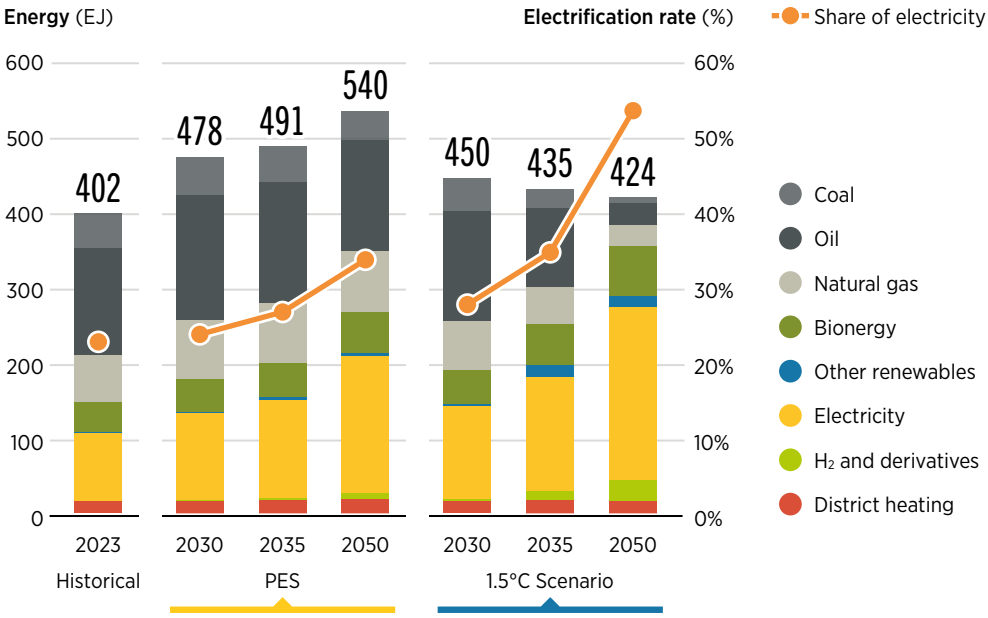
The analysis shows that no single technology can deliver this transformation. Renewable power, electrification, direct uses of renewables including sustainable fuels, energy efficiency measures, clean hydrogen, grids, storage, system flexibility and carbon management all have complementary roles. The transition depends on simultaneous progress across these dimensions and on integrated planning that connects them across sectors and regions.

[1] *The Sixth Assessment Report produced by the Intergovernmental Panel on Climate Change*

Renewable-based electrification as the backbone of the energy system

Under the 1.5°C Scenario, the share of electricity in global total final energy consumption (TFEC) would rise from around 23% today to approximately 35% by 2035 and over 50% by 2050 (Figure S1). Electrification would expand across all major end-use sectors (*i.e.* buildings, transport and industry), replacing fossil fuel combustion with electric technologies that are more efficient and can be powered by renewable energy.

FIGURE S1 Global total final energy consumption (EJ) and global electrification (%) by scenario, 2023-2050



Source: Historical values (IEA, 2025b).

Notes: "Other renewables" include solar thermal and geothermal uses; "Bioenergy" includes sustainable and traditional bioenergy; non-energy is excluded from TFEC.

EJ = exajoule; H_2 = hydrogen; PES = planned energy scenario; TFEC = total final energy consumption.

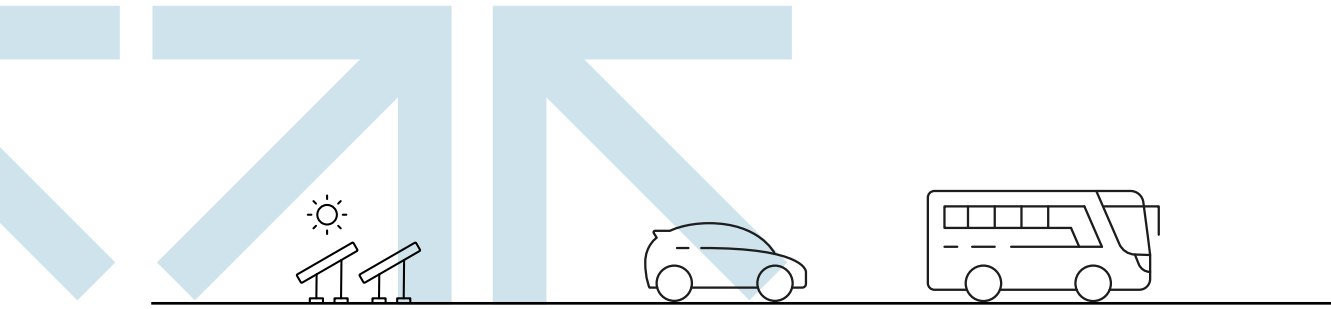
Transport would experience particularly rapid change as electric mobility expands. Buildings would increasingly rely on heat pumps, electric cooking, water heating and efficient appliances. Industry would combine electric motors, heat pumps, heat storage, electric furnaces and electrochemical processes with renewable hydrogen and renewable-based fuels for those applications where direct electrification remains technically or economically difficult. The rapid expansion of digitalisation and AI-enabled data centres adds another dimension. These new loads are emerging alongside electric mobility, heating, cooling and industrial electrification. They can create additional pressure on grids and system planning but can also reinforce the business case for renewable energy and electricity infrastructure when anticipated through integrated planning.

Electrification should therefore be understood as the backbone of the transition. Sustainable bioenergy, renewable hydrogen and its derivatives and other sustainable fuels remain essential complements, particularly for aviation, shipping and hard-to-abate industrial processes.

The significance of electrification goes well beyond decarbonisation, however. Electric technologies can provide the same energy services with considerably lower final energy requirements than combustion-based alternatives. Renewable-based electrification therefore links two fundamental transformations: decarbonising energy supply and improving the efficiency with which energy services are delivered.

IRENA's analysis finds that renewable-based electrification together with energy efficiency could account for around one-third of cumulative CO_2 emission reductions between 2026 and 2050. At the same time, electrification can reduce exposure to imported fossil fuels, improve local air quality, strengthen industrial competitiveness and create new value chains around batteries, power, renewable hydrogen and digital energy systems.

In the past few decades, rising energy demand has often resulted in "energy addition", with new energy sources expanding alongside existing ones, rather than replacing them at scale (Yergin *et al.*, 2025). The transformation required today is fundamentally different. A genuine energy transition requires renewable energy and more efficient technologies to displace fossil fuel-based systems progressively, rather than simply adding new capacity to an otherwise unchanged energy mix. Renewable-based electrification is central to this shift because it enables renewable electricity to replace fossil fuel combustion across end-use sectors while simultaneously reducing the amount of energy required to deliver the same or higher levels of energy services.



Energy efficiency: A critical dividend of electrification

Energy efficiency deserves particular attention because its progress remains well below what is needed. The average annual improvement in global energy intensity over the past three years has remained just below 2%, compared with the approximately 4% annual improvement required to meet the global objective, outlined in the Outcome of the First Global Stocktake, of doubling energy efficiency improvement by 2030 (IRENA *et al.*, 2026). Under the PES, improvement would reach only around 3% annually over 2026–2030. IRENA's 1.5°C Scenario requires more than 4% per year over the remaining years to 2030 to compensate for the shortfall of recent years.

Electrification itself provides an important source of these efficiency gains. Electric vehicles, heat pumps and electric industrial technologies can replace combustion processes that shed large quantities of energy as heat. Consequently, an increasingly electrified renewable-based system can deliver greater mobility, comfort and productive output while requiring less primary and final energy.

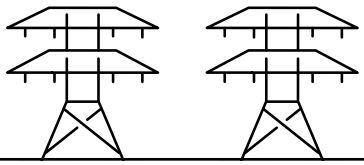
This point is important in assessing the economic implications of the transition. Falling primary energy consumption under a 1.5°C-aligned pathway does not imply declining economic activity or lower energy services. It largely reflects a more efficient energy system.

But electrification alone will not deliver the required efficiency improvements. Building performance, appliance standards, efficient industrial processes, transport systems, demand management and behavioural change remain critical. The implication is important: if efficiency improvements fail to accelerate while electricity demand continues to grow, significantly more renewable generation, infrastructure and investment will be needed to deliver the same energy services.

Energy efficiency, grids and flexibility therefore represent potential binding constraints on the pace of the transition. They should no longer be treated as secondary components behind renewable deployment. They are among the fundamental conditions determining whether the transition can be implemented rapidly, reliably and affordably.

Renewable power must expand together with grids, storage and flexibility

Achieving the 1.5°C goal would require expansion of renewable power generation technologies across all regions based on their respective technical potential, resource availability and the pace of end-use sector electrification, and supported by substantial cumulative investment needs (Figure S2).



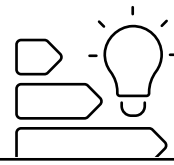
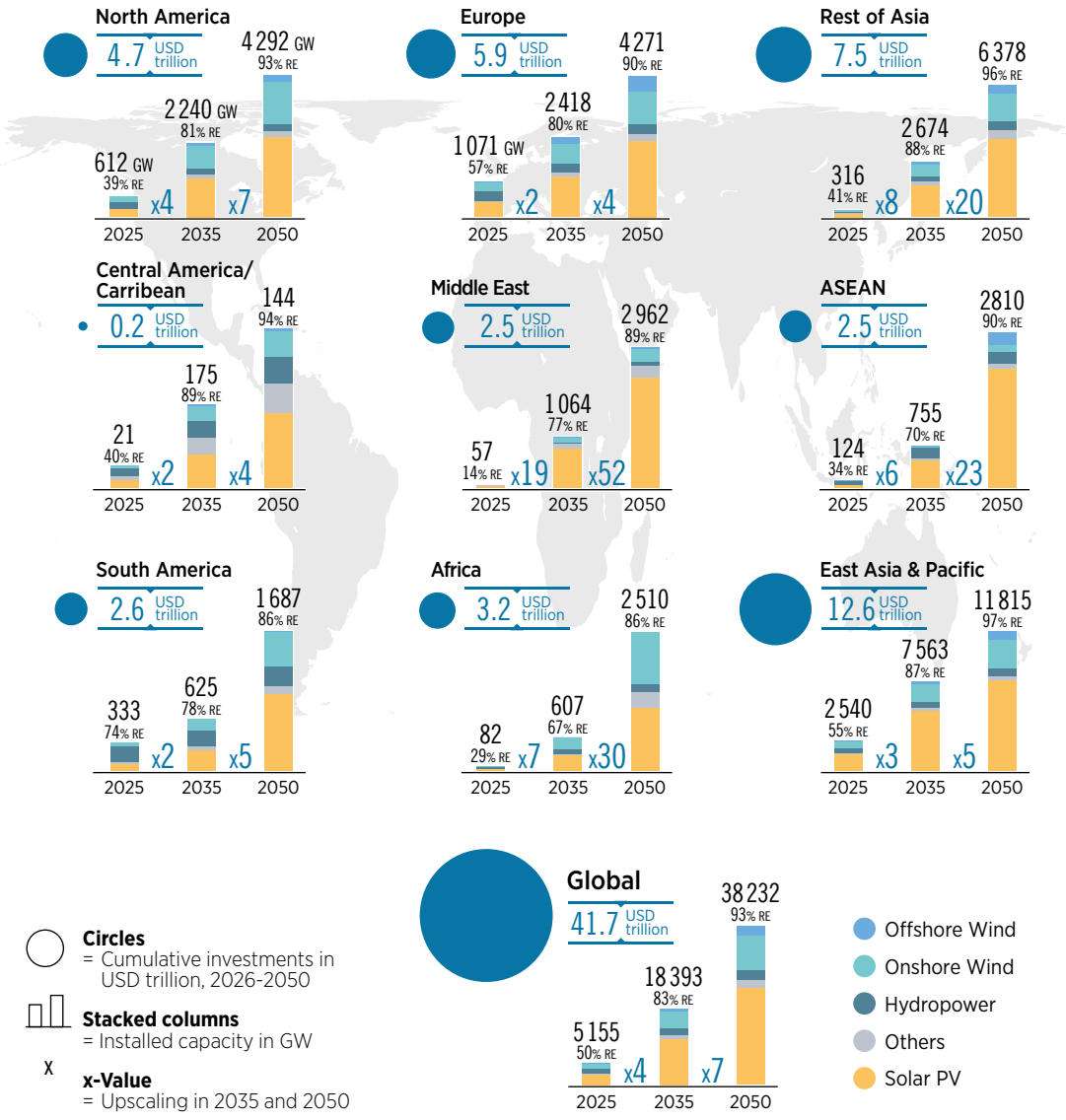


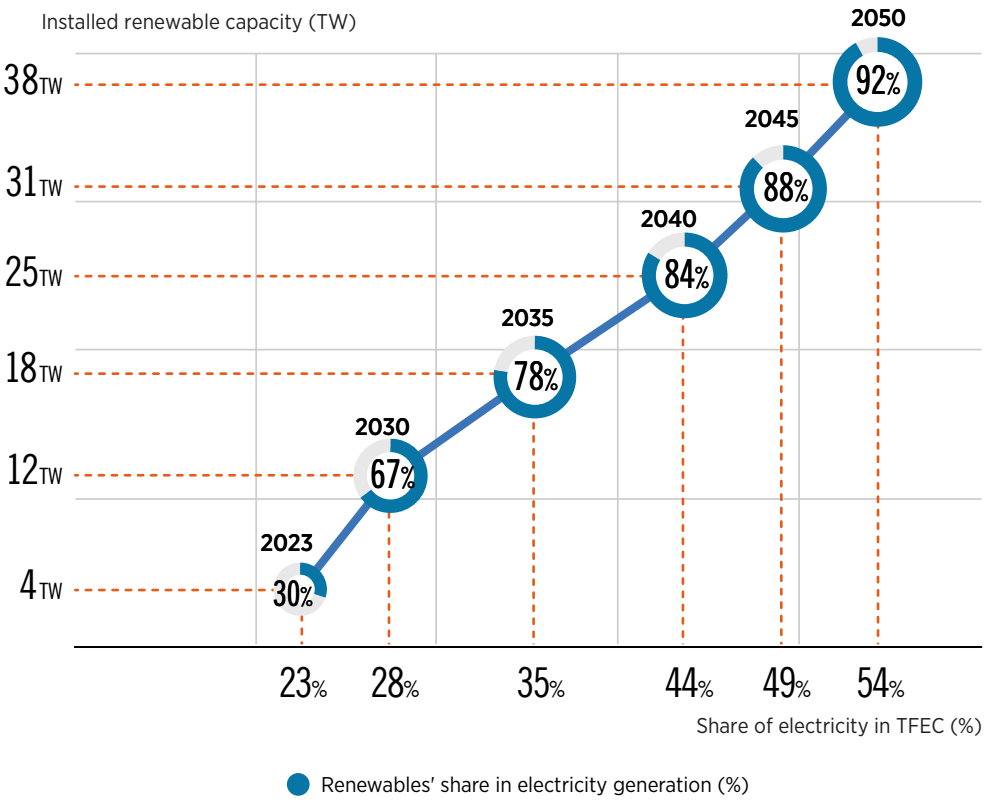
FIGURE S2 Regional distribution of renewable capacity and cumulative investments in renewable power for selected regions under the 1.5°C Scenario



Notes: GW = gigawatt; PV = photovoltaic; RE = renewable energy; Maritime and aviation bunkers are excluded. Regional values may not sum exactly to the global total owing to differences in aggregation in the underlying analysis. Europe includes the United Kingdom, the Western Balkans, Ukraine, Moldova, the Russian Federation and Türkiye. ASEAN-10 comprises the ten member states of ASEAN prior to October 2025; Timor-Leste acceded in that month and is analysed here within East Asia and the Pacific, consistent with the country coverage of the underlying modelling. Africa and South America each cover the full continent, with the Middle East reported separately. Components may not sum to totals owing to rounding.

The electrification of end-use sectors requires an unprecedented expansion of renewable electricity. Global installed renewable power capacity reached around 5.2 terawatts (TW) in 2025 following another record year of deployment. Under the 1.5°C Scenario, capacity would need to reach approximately 18.4 TW by 2035 and 38.2 TW by 2050. Average annual net additions would therefore have to exceed 1.3 TW during 2026–2035 and remain at similar levels thereafter. Solar photovoltaic (PV) and wind would provide the largest share of this expansion. Yet generation capacity alone is not sufficient. Electricity systems must simultaneously become larger, more interconnected, more digitalised and substantially more flexible. The trajectory in Figure S3 illustrates the complementary growth in the electrification rate, renewable share in electricity generation and renewable power capacity expansion under IRENA's 1.5°C Scenario. These dimensions must evolve together – alongside grids, storage and flexibility measures, and planning for the strategic phase-out of fossil fuel infrastructure – to enable a reliable and large-scale transition away from fossil fuels.

FIGURE S3 The energy transition under the 1.5°C Scenario, 2023–2050



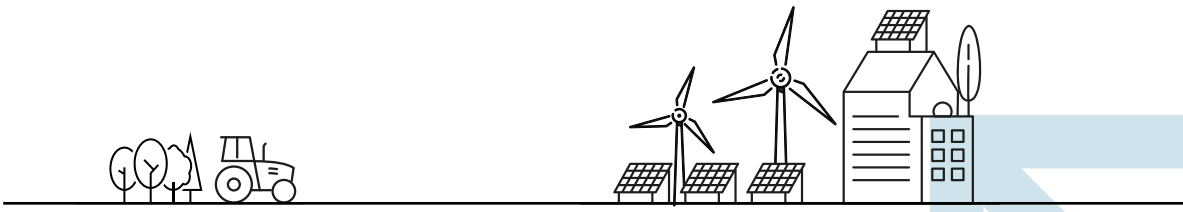
Source: (IRENA, 2026d).

Average annual grid investment would need to rise from around USD 0.5 trillion today to approximately USD 1 trillion annually between 2026 and 2035, followed by around USD 1.2 trillion annually over 2036–2050. Global installed storage capacity would increase from around 416 gigawatts (GW) in 2025 to approximately 2 530 GW by 2035 and almost 6 860 GW by 2050. At the same time, system flexibility requirements would also increase substantially across different timescales, from short-term and daily balancing to weekly and seasonal needs, depending on the generation mix and characteristics of each power system.

Future flexibility will increasingly come from a portfolio of technologies and system resources, including batteries, pumped storage, interconnections, demand-response, sector coupling, dispatchable renewable generation, sustainable fuels and digital system management. No single technology will be capable of providing all the flexibility required across seconds, hours, days and seasons.

Grids, storage, flexibility and energy efficiency are therefore not supporting elements at the margins of the transition; they are the core infrastructure of the emerging energy system. If their deployment falls behind, they risk becoming the bottlenecks that prevent otherwise competitive renewable and electrification technologies from scaling rapidly enough.

Grids, storage, flexibility and energy efficiency are not supporting elements at the margins of the transition; they are the core infrastructure of the emerging energy system.



A common direction, but different regional electrification pathways

The global direction of the energy transition is becoming clearer, but there is no single pathway for all countries. Economic structures, resource endowments, levels of industrialisation, infrastructure readiness, demographic trends, access to finance and development priorities differ significantly. This report therefore places greater emphasis on the regionalisation of transition pathways and, in particular, on how electrification evolves across different parts of the world.

Under the 1.5°C Scenario, electricity would account for around 64% of final energy consumption in the European Union by 2050, reflecting widespread electrification across transport, buildings and industry. Africa would approach 50%, but through a fundamentally different pathway in which electrification also expands energy access, replaces traditional biomass, supports urbanisation and enables industrial development. Latin America and the Caribbean would also approach 50%, building on already high shares of renewable electricity, while ASEAN would reach around 53%, reflecting rapid economic growth, industrialisation and urbanisation combined with renewable deployment.

Regional renewable deployment requirements are equally differentiated. Africa, for example, experienced record renewable additions in 2025, but the scale remains far below that required. Under the 1.5°C, the region's renewable power capacity would need to grow by around seven times by 2035 and by around thirty times by 2050 from its 2025 level. Europe, North America, South America, Asia and the Middle East are proceeding from various starting points and have different requirements, but all require substantial increases in renewable power and enabling infrastructure.

Priorities differ across sectors. Transport electrification advances rapidly in many advanced and emerging economies. Buildings represent particularly important opportunities in developing and emerging regions where modern electricity access can simultaneously raise living standards and reduce dependence on traditional biomass. Industrial electrification varies according to the structure of national economies and the prevalence of energy-intensive processes.

Decentralised renewable energy also has a critical role. In Sub-Saharan Africa, more than 565 million people still lack electricity access. IRENA's regional analysis indicates that around 60% of the additional electricity connections needed by 2030 – corresponding to approximately 401 million people – could most economically be provided through mini-grids and standalone solar PV. Such solutions are not substitutes for national electricity grids, but complementary elements of integrated electrification strategies.

The global destination may therefore be increasingly common, but countries are starting from different staging points and will prioritise different sectors and technologies. Regional and national energy planning must translate global objectives into pathways adapted to development needs, resource endowments and institutional circumstances.

Investment must scale up and become much more geographically balanced

The transition is already attracting record investment, but the scale and distribution remain far from what is required. Under the 1.5°C Scenario, cumulative investment and expenditure[2] needs are estimated at over USD[3] 256 trillion over the 2026–2050 period, equivalent to around USD 10.3 trillion annually. This is around USD 78 trillion more than under the PES over the same period (Figure S4). Compared with the 2023 edition of this report, the annual requirement for a 1.5°C-aligned pathway has increased by around USD 3.8 trillion. This increase reflects the consequences of delayed progress, alongside greater granularity in regional coverage, updated technology costs and technological developments, as well as the additional measures captured under the more ambitious, revised 1.5°C Scenario introduced in this edition.

The geographical distribution of investment remains particularly uneven. China and advanced economies currently account for the overwhelming majority of energy transition investment, while Africa and least developed countries receive only a small fraction despite substantial renewable resources, rapidly growing energy demand and major development needs.

High financing costs, limited fiscal space, currency risks, weak domestic financial markets and perceived project risks continue to constrain investment in many emerging and developing economies. The challenge is therefore not only to mobilise more global capital, but to direct it towards the countries, infrastructure and technologies where additional investment can have the greatest impact.

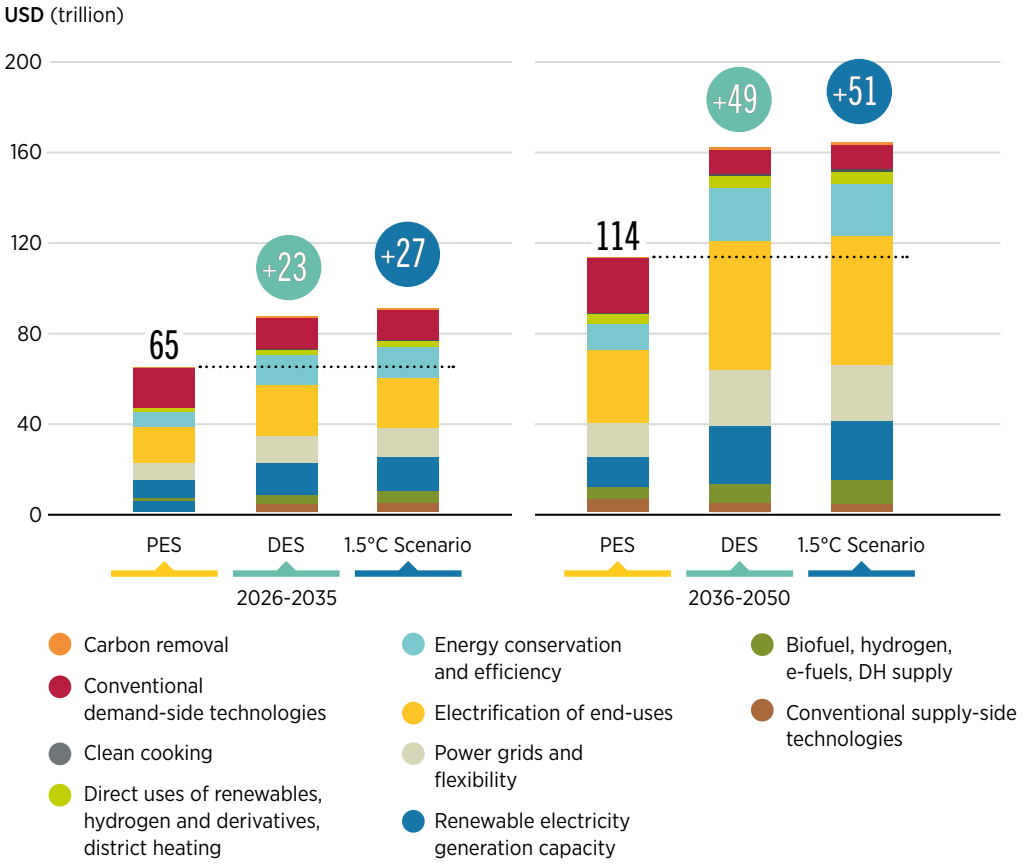
Stable policy frameworks, stronger domestic capital markets, concessional finance, guarantees and other risk-mitigation instruments will remain essential. Public financial institutions should use scarce resources strategically to mobilise larger volumes of private investment, particularly in markets where commercial financing alone will not deliver the required scale.

International collaboration is equally important. WETO's socio-economic analysis indicates that international financing can produce particularly significant welfare gains in regions where fiscal space, productive capabilities and social expenditure are constrained. Financing the energy transition should therefore not focus only on physical assets. Supporting skills, social protection and productive capacity can strengthen both implementation and the domestic economic benefits generated by investment.

[2] *The Outlook includes investment and expenditure components: investment refers to the capital costs of infrastructure, e.g. industrial production plants, power plants and grids, fuelling and/or charging stations for transport sector; expenditure refers to the acquisition of technologies/devices for end-use sectors, e.g. vehicles in transport, boilers or cookstoves in buildings.*

[3] *In 2025 prices.*

FIGURE S4 Global cumulative investment and expenditure, 2026-2050.



Notes: DES = Decarbonising Energy Scenario; DH = district heating; PES = Planned Energy Scenario. Investment refers to capital costs in infrastructure (*e.g.* power plants and grids, manufacturing plants, charging stations), expenditure considers acquisition costs of technologies in end-use sectors. All costs are in 2025 USD.



The transition strengthens economic performance; industrial policies are key

WETO 2026 finds a strong economic case for accelerating the energy transition. Under the DES, global gross domestic product (GDP) would be around 0.7% higher on average than under the PES through 2050, producing a cumulative economic gain of approximately USD 32 trillion.[4] Under the 1.5°C Scenario, average annual global GDP would be around 1.1% above the PES, generating cumulative gains of around USD 47 trillion by 2050.

Investment is the main driver of these gains. Renewable energy, electrification, grids and energy efficiency stimulate activity across construction, manufacturing, engineering, electricity supply and business services. The transition also changes the productive structure of economies. Activity progressively shifts away from fossil fuel extraction and refining and towards higher-value manufacturing, electricity infrastructure and transition-related services.

Electricity competitiveness contributes to this transformation. By 2035, the DES would lead to average end-user electricity prices approximately 9% lower than under the PES, falling to 15% lower by 2050. This is due to the growing role of renewable electricity and the reduced exposure to fossil fuel costs.

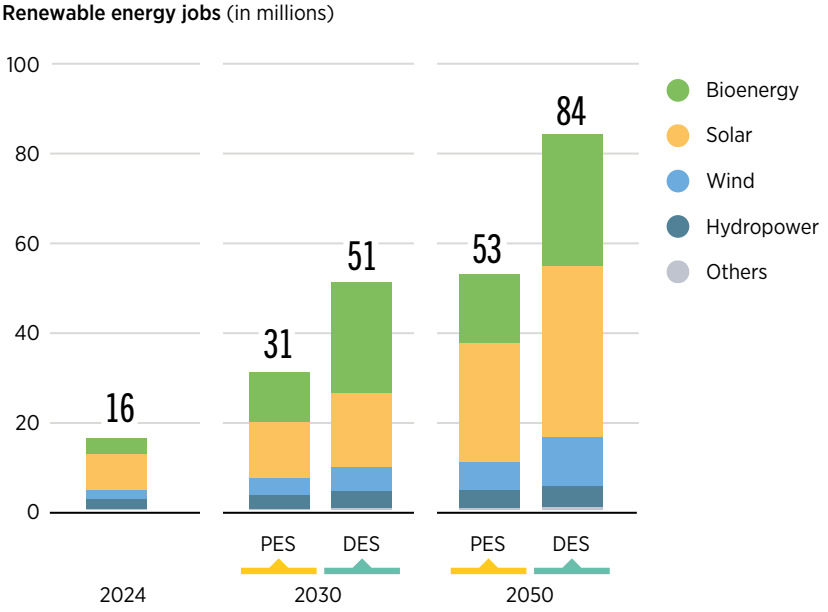
Renewable energy employment would reach around 84.2 million jobs in 2050 under the DES, around 60% higher than under the PES, with solar remaining the largest renewable employer at around 38.3 million jobs (Figure S5). Wider energy-sector employment also expands substantially as investment shifts towards electricity systems, energy efficiency, infrastructure and emerging technologies.

These benefits will not, however, be distributed uniformly. Economies with strong existing industrial capabilities can capture significant value from clean energy manufacturing and services. Fossil fuel-dependent economies face greater structural adjustment as fossil fuel revenues, production and employment decline. Developing economies can realise substantial investment-led growth, but only if they develop domestic capabilities that allow them to participate in the emerging value chains rather than relying predominantly on imported technologies.

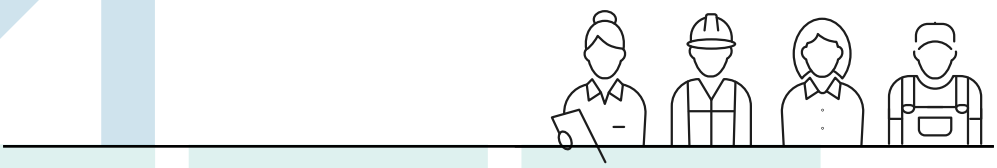
Industrial policy therefore becomes an increasingly important component of the energy transition. The objective should not be for every country to reproduce every segment of global supply chains, but to build on national and regional comparative advantages while investing in skills, productive capacity, innovation and competitive industries.

[4] *In 2025 USD.*

FIGURE S5 Global renewable energy jobs under the PES and DES, by technology, 2024–2050



Notes: Others include geothermal and tidal/wave. DES = Decarbonising Energy Scenario; PES=Planned Energy Scenario.



Long-term gains do not remove short-term household pressures

The positive aggregate economic outlook does not mean that the transition is costless at every stage or that all households benefit immediately. This is one of the most important socio-economic conclusions of this edition of the *World Energy Transition Outlook*. Greater climate ambition can reinforce investment and productivity, but it can also increase household pressures if social protection and transition management do not keep pace.

Under the DES, global real household income remains below the PES during the early years of the transition period before improving strongly after 2030–2035 and reaching approximately 1.6% above the PES by 2050. The initial pressure reflects, among other factors, front-loaded investment, changes in energy prices and policy measures including carbon pricing and fossil fuel subsidy reform. Over time, these effects are outweighed by technological learning, higher energy efficiency, lower electricity prices, new employment opportunities and productivity gains.

The welfare analysis reinforces this finding. In the early transition period, energy contributes a larger share of modelled inflation under accelerated decarbonisation. In the medium-term, the pattern reverses as households benefit both from lower exposure to fossil fuel prices, and the greater efficiency of renewable-based electrification. Household energy affordability consequently improves over time.

The policy implications are significant. Much of the public debate surrounding the transition focuses on whether it will increase household costs or weaken national economies. The modelling shows that such a binary framing is misleading – the transition produces positive long-term economic, employment and welfare outcomes; but it can create real short-term pressures that should neither be ignored nor underestimated.

Households in many countries are already experiencing broader cost-of-living pressures. Poorly designed or poorly sequenced policies can compound these pressures, weaken public acceptance and ultimately slow implementation. The issue is therefore not simply the total cost or benefit of the transition, but when costs occur, who bears them, how benefits are distributed and whether households have the means to leverage the opportunities it creates.

Targeted affordability measures, progressive fiscal policies, carefully sequenced pricing reforms, social protection, workforce support and investment in affected communities will therefore be essential. Maintaining public acceptance is not peripheral to the energy transition, it is essential for sustaining the required pace of the transition over several decades.



The quality of the transition matters as much as its pace

IRENA's Energy Transition Welfare Index (ETWI) examines the transition beyond GDP through four dimensions: economic, social, environmental and distributional. The analysis shows that accelerated decarbonisation improves global welfare, with the largest improvement occurring between the PES and DES. Economic welfare benefits mainly from stronger energy-adjusted productivity, while environmental welfare rises substantially as cumulative emissions decline. International collaboration could improve outcomes further, particularly by strengthening social expenditure, affordability and productive capacity in countries with limited fiscal space.

The comparison between the DES and the 1.5˚C Scenario introduces an important qualification. Moving towards a more ambitious 1.5°C-aligned pathway reinforces investment, productivity and environmental outcomes, but can also increase household affordability and inflation pressures when stronger social policies are not introduced simultaneously.

Regional results show that the policy priorities required to maximise welfare vary considerably. Africa can derive significant additional benefits from international collaboration that simultaneously supports social expenditure and productive capacity. The Middle East benefits strongly from diversification and productivity improvements but continues to face distributional challenges. Southeast Asia experiences gains across several welfare dimensions, while more mature economies increasingly depend on improvements in productivity, affordability, inequality and material efficiency.

The analysis therefore identifies five welfare priorities. Accelerated decarbonisation remains the foundation for higher welfare. Early affordability and inflation pressures must be anticipated and managed. International collaboration should support both social expenditure and productive capacity, particularly where domestic fiscal space is constrained. Distributional policies should broaden participation in ownership, investment and high-productivity employment. Circular-economy and material-efficiency measures should be incorporated into transition planning from the outset.

The distributional dimension is especially important. Investment opportunities, productive assets and high-skilled employment do not automatically accrue evenly across households, countries or regions. Without deliberate policies, the transition can reproduce existing inequalities even while raising overall economic welfare.

Environmental impacts also need to be carefully managed. While replacing fossil fuels with renewables cuts emissions, pollution and some environmental pressures, the rapid expansion of renewables, grids, batteries and electric technologies increases demand for minerals and construction materials and adds pressure to already-threatened natural areas and biodiversity.

Responsible siting, recycling, circular design, material substitution and longer product lifetimes will become increasingly important. Well-planned renewable projects can also generate local environmental co-benefits, including degraded-land restoration, improved land-use efficiency and synergies with agriculture.

The strongest transition is therefore not simply the fastest pathway to lower emissions. It is one that combines decarbonisation with affordability, productive development, social protection, equitable participation and responsible use of natural resources.

The transition away from fossil fuels must be a system-wide transformation

The implications for the transition away from fossil fuels follow directly from this analysis. Reducing fossil fuel dependence must proceed in parallel with the expansion of renewable energy, electrification, energy efficiency, grids, flexibility and sustainable fuels. The sequencing and pace of this transformation will differ across countries and sectors, but clean energy supply and enabling infrastructure need to expand sufficiently to maintain reliable and affordable energy services throughout the transition. The transition is inherently gradual and structural, occurring over several decades and via very different national pathways.

For energy-importing countries, renewables can reduce exposure to volatile international fossil fuel prices and geopolitical disruptions. For fossil fuel-producing economies, the transition creates both challenges and opportunities. Domestic renewable energy deployment can diversify energy systems, support broader economic diversification and enable the development of new industries while fossil fuel-dependent workers, regions and public finances adjust progressively.

The central task for governments is therefore to manage this transformation in an orderly way that safeguards reliability, affordability and energy security while accelerating the deployment of clean alternatives. If well managed, the transition away from fossil fuels will not constrain economic development; rather, it can strengthen competitiveness, resilience, public health and long-term prosperity.

The transition must therefore increasingly be managed as a single system-wide transformation rather than a collection of separate policy agendas.

Seven implementation priorities for the decisive decade to 2035

Seven concrete priorities emerge for action over the coming period to 2035. These priorities do not imply a centrally planned transition. Governments have an important role in setting clear long-term direction, providing enabling infrastructure and correcting market and institutional barriers, while competitive markets, effective price signals and private-sector investment should be harnessed wherever they can accelerate efficient deployment and innovation.

1. **Develop integrated planning and market frameworks** that align the deployment of renewable energy, electrification pathways, infrastructure development and investment, while delivering clear long-term signals and facilitating efficient responses by competitive markets and private investment. Such frameworks should identify and reduce bottlenecks to implementation, without constraining solutions that are market driven.

2. **Develop and implement country-tailored transition roadmaps** that combine renewable energy deployment, electrification, energy efficiency, sustainable fuels and just energy transition policies to accelerate the transition away from fossil fuels while strengthening energy security, household affordability and economic resilience.

3 **Accelerate investment in the expansion and modernisation of energy infrastructure,** particularly transmission and distribution networks, storage, system flexibility and digital infrastructure, accompanied by market reforms that provide effective price signals, reward flexibility and system services, and enable efficient investment and operation as electricity systems accommodate higher shares of renewable and growing electrification.

4 **Design integrated industrial strategies** that support internationally competitive clean energy industries, strengthen domestic and regional value chains, expand workforce capabilities and maximise local value creation while remaining connected to international markets and technology partnerships.

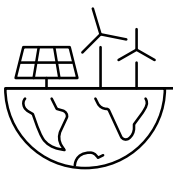
5 **Build stable policy and investment frameworks** that reduce the cost of capital, provide predictable investment signals, deepen domestic financial markets and strategically deploy public finance to support renewable energy, infrastructure, inclusive workforce development and industrial transformation, while mobilising additional private capital, particularly in emerging and developing economies.

6 **Maximise the social, economic and environmental benefits of the transition** through policies in order to protect household affordability, strengthen social and environmental protection and community benefits, expand equitable economic opportunities and support inclusive decision making. Public acceptance and social legitimacy will be essential for sustaining implementation at the necessary pace.

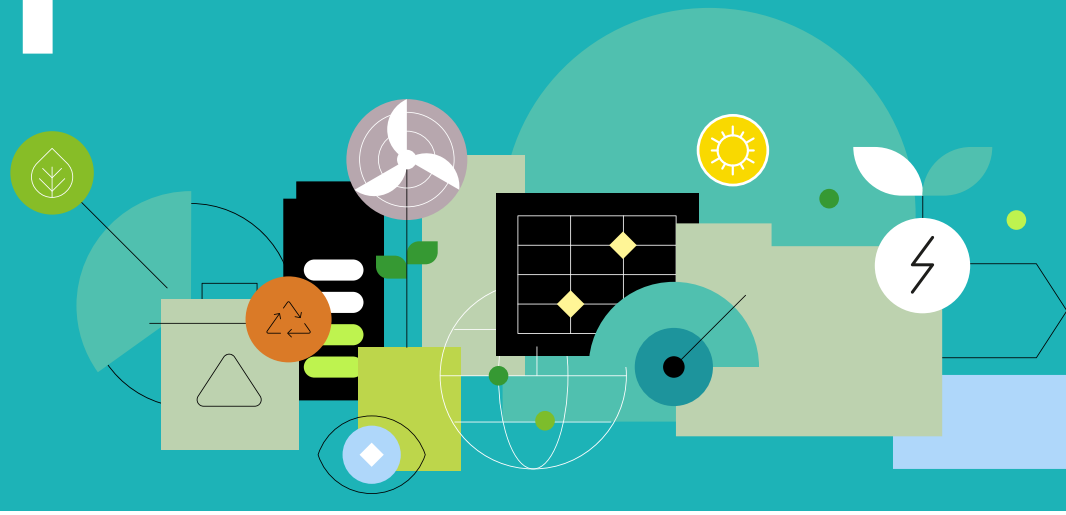
7 **Strengthen international co-operation** through technology transfer, diversified supply chains, regional industrial partnerships, South–South co-operation, knowledge exchange and greater access to affordable finance, enabling a more resilient, inclusive and secure global energy transition.

Together, these priorities demonstrate that the coming decade will be defined less by the announcement of new long-term ambitions than by the capacity to deliver those already established.

The defining challenge of the global energy transition is therefore accelerating implementation. While international momentum has grown around accelerating renewable energy deployment and doubling the rate of energy efficiency improvement (COP28), strengthening grids and flexibility (COP29), scaling up sustainable fuels (COP30), and advancing the transition away from fossil fuels, comparatively less attention has been given to the transformation of the demand-side of the energy system. This edition of the *World Energy Transition Outlook* identifies end-use electrification as a critical implementation pillar and the key link between the expansion of clean electricity supply and the transformation of transport, buildings and industry. Elevating electrification as a priority for the decade to 2035 would help complete this implementation agenda, translating existing global ambitions into structural change across the energy system and accelerating the transformation needed to keep a 1.5°C pathway within reach, while ensuring that its economic and social benefits are broad enough to sustain the transition itself.



INTRODUCTION



The world in 2026: The energy transition under stress

Since the publication of IRENA's first *World Energy Transition Outlook* and its 1.5°C Scenario in 2021, the global energy landscape has evolved significantly. While limiting the risks associated with climate change is as important as ever, energy security, competitiveness and economic resilience have moved to the centre of political agendas. Recent geopolitical shocks have reinforced that the global fossil fuel-based energy system can no longer be viewed as if it were based on a stable, predictable and co-operative international order. Ongoing conflicts, trade tensions, supply chain disruptions and strategic competition for resources have exposed vulnerabilities across energy systems and highlighted the risks associated with dependence on volatile global fossil fuel markets and concentrated supply chains.

At the same time, progress on the energy transition is evident. Renewable energy deployment continues to break records, technology costs have declined significantly and electrification is advancing across sectors. Governments have strengthened their ambitions through higher renewable energy targets, greater electrification of end-use sectors and growing support for clean hydrogen and related technologies. Countries that have already invested substantially in renewables, electrification and system flexibility have shown greater resilience to recent shocks (IRENA, 2026a), highlighting the strategic value of the energy transition. These developments increasingly demonstrate that the energy transition is not only a climate imperative, but also a strategic pathway to strengthen energy security, support industrial development, improve competitiveness and enhance economic resilience.

Yet important challenges remain. While international momentum has grown in accelerating the deployment of renewable energy, increasing the rate of energy efficiency improvement, strengthening grids and flexibility, scaling up sustainable fuels, and transitioning away from fossil fuels, the electrification of end uses has emerged as a critical factor requiring much greater attention.[5] Electricity demand is growing rapidly but energy efficiency improvements are not keeping pace, and the deployment of enabling energy infrastructure continues to lag. As a result, the central question is no longer whether the transition *should* occur, but how it can be accelerated in a world characterised by growing uncertainty, fragmentation and competing priorities. The world in 2026 therefore faces a defining challenge: It must speed up the deployment of renewable energy and electrification technologies in order to pursue climate goals, strengthen energy security, enhance competitiveness and build more resilient energy systems.

This chapter sets the context for the 2026 report by examining the changing risk landscape, the growing strategic role of electrification using renewables and the policy implications of navigating the energy transition in an increasingly uncertain and fragmented world.

Progress is evident, and acceleration is an effective defence strategy

In recent years, significant progress has been made in the energy transition. The deployment of renewables has been accelerating owing to falling technology costs, enabling policies and rising investment (IRENA, 2026b). Solar PV, onshore wind, offshore wind and battery storage are becoming more cost competitive, with costs declining by 88%, 59%, 48% and 95% respectively between 2010 and 2025 (IRENA, 2026c). These reductions have translated into highly competitive generation costs in many regions, reinforcing the economic case for renewable energy deployment.

Compared with previous editions (IRENA, 2021, 2022a, 2023a, 2024a), current government plans point to higher renewable energy deployment, greater electrification of end-use sectors and a modest increase in the deployment of clean hydrogen and related technologies. These changes should lead to lower projected fossil fuel use and emissions than previously expected. The evolution of government plans reflects not only changing policy ambitions, but also the impact of recent developments, including the recovery from COVID-19, energy market volatility, supply chain disruptions, geopolitical tensions and rapid technological advancement. Such developments have reinforced the strategic importance of the deployment of renewable energy, stronger and resilient electricity systems and reduced exposure to the volatility of fossil fuel markets.

Yet the current trajectories remain insufficient relative to the scale and pace of transformation required under IRENA's revised 1.5°C Scenario, not just from a climate-change-mitigation perspective but also in terms of enhancing energy security and competitiveness. While renewable energy deployment continues to set records, electricity demand is also growing faster owing to increasing electrification, expanding access to modern energy services, fast economic development and emerging applications such as artificial intelligence (AI), digitalisation and data centres. At the same time, progress in energy efficiency has been too slow to offset this growing demand (IRENA, 2026d). The latest synthesis of Biennial Transparency Reports by the UN Framework Convention on Climate Change reinforces the need to accelerate renewable energy deployment, electrification and energy efficiency if the 1.5°C goal is to remain within reach (UNFCCC, 2025). Achieving this acceleration requires a greater focus on key aspects of the energy transition such as grids, storage, flexibility, institutions, financing and supply chains.

[5] *The targets mentioned here were among the major themes of the last three conferences of the parties (COP28, COP29, and COP30) to the UN Framework Convention on Climate Change.*

Risk mitigation to reinforce the energy transition

As noted, recent geopolitical developments and conflicts have caused trade disruptions and exposed structural weaknesses across energy systems, particularly in countries dependent on energy imports. Also growing competition for strategic resources such as critical minerals, are currently revealing the vulnerabilities within the global energy systems and supply chains.

Fossil fuels systems are exposed to risks related to fuel availability, transport routes and international commodity markets. Energy exports are also heavily concentrated in key shipping lanes and pipeline networks such as the Strait of Hormuz, the Strait of Malacca and the Strait of Bab El Mandeb, implying economic and geopolitical vulnerabilities. Disruption to fossil fuel supply chains can translate rapidly into energy price volatility, inflation and more widespread economic consequences, as recent crises have demonstrated.

Renewable energy systems have a different risk profile. Their vulnerabilities are related to manufacturing capacity, critical materials, technology supply chains and infrastructure deployment rather than recurring fuel availability. Strategic dependencies are thus shifting from fuel resources and transport routes towards the minerals and capabilities – for both processing and manufacturing – capabilities that are essential for clean energy technologies (Hache, 2024; Yergin *et al.*, 2025).

China today produces around 80% of the world's PV modules and 45% of its batteries; the country refines some 90% of the rare earth elements used in energy transition technologies (Dave, 2025; IEA, 2025a). This manufacturing scale reflects decades of industrial policy, investment and economies of scale. At the same time, global clean energy value chains are increasingly interconnected through trade, cross-border investment and industrial partnerships, while localisation of manufacturing, South-South co-operation and international partnerships are supporting technology diffusion and industrial development in many regions (Geng, 2021; Liu *et al.*, 2020).

The supply chain and industrial risks of renewable energy systems are much easier to address through industrial policy and international co-operation than the existing risks of fossil fuel systems (Liubachivska, 2025). This distinction is increasingly shaping how governments view the energy transition, not only as a climate strategy, but also as a pathway to strengthen energy security, economic resilience and long-term competitiveness.

Global trade and open flows of international finance have been key enablers of recent accelerations in renewable energy deployment. Robust supply chains facilitate cost-effective and timely access to key technologies and components, while international trade allows developers to benefit from manufacturing centres of expertise and economies of scale. At the same time, governments are increasingly looking at domestic industrial policy to reduce strategic dependencies. Although such efforts can indeed strengthen resilience and industrial development, they may also create tensions between resilience, competitiveness, affordability and sustainability. Balancing these objectives will become an increasingly important challenge for policy makers over the coming decade.

Critical materials have become another key dimension of supply chain resilience. Supply constraints may lead to bottlenecks in manufacturing value chains if demand outpaces the development of mining, processing and refining capacity. Several international and regional organisations and initiatives are tracking supply developments and exploring strategies to mitigate potential constraints (African Union, 2009, 2024; IEA, 2026a; IEF, 2025; IRENA and NUPI, 2024a, 2024b; MSP Forum, 2024). Expanded processing capacities, innovation in material circularity, recycling and substitution can all provide opportunities to reduce supply risks and improve resilience.

Ultimately, the energy transition lessens but does not eliminate geopolitical and economic risks. Rather, it changes their nature. Renewable energy systems lessen exposure to volatility and supply disruptions in fuel markets, though they are far more dependent on resilient infrastructure, diversified supply chains and secure access to technologies and critical materials. The challenge for policy makers is therefore not only to accelerate the deployment of renewable energy technologies, but also to ensure that the industrial, infrastructure and institutional foundations needed to support this transition evolve at the pace required.

These evolving risk dynamics are also reshaping the structure of energy systems themselves. As countries seek to strengthen resilience while advancing climate goals, energy security and competitiveness, electricity is becoming the central vector through which renewable energy is deployed and integrated across end-use sectors. The increasing importance of electricity marks the beginning of a new phase of the energy transition.

The decade of electricity: Rising electrification and emerging electricity markets

Previous editions of WETO have rightly highlighted the central role of electrification in achieving a 1.5˚C-compatible pathway (IRENA, 2021, 2022a, 2023a, 2024a). Electrification is advancing across buildings, industry and transport, while simultaneously supporting expanded access to modern energy services, sustainable industrialisation, and economic development in emerging and developing economies.

At the same time, new sources of electricity demand are fast emerging. Beyond end-use electrification, the growing power demand from data centres supporting AI and digital services (IRENA, 2025a, 2026e) – in addition to the continued expansion of electric mobility, heating and cooling demand and modern industrial processes – are adding pressure on generation capacity, grids and system planning. While AI-enabled data centres and digital services now represent a relatively small share of total electricity consumption, they are becoming increasingly important drivers of incremental demand growth due to their high load factors and continuous operation. This trend is highly concentrated geographically, with the United States, China, Europe and India dominating demand and growth, alongside emerging hubs in regions such as Southeast Asia and the Middle East.

These developments underscore the central role of electricity systems in the energy transition. Electricity systems need to decarbonise and grow simultaneously – and to become more flexible, resilient and digitalised. This requires significant investment in renewable generation, grids, storage, demand-side flexibility and digital infrastructure.

All of these factors reinforce the need for integrated energy system planning, operation and regulatory frameworks. Conventional approaches were largely based on predictable demand patterns and centralised generation. Future systems will have to be able to integrate higher penetration of variable renewable energy, increased numbers of distributed energy resources, greater needs for flexibility and changing patterns of demand. Digital technologies, AI and sophisticated system management tools can facilitate the transition through better forecasting, optimisation, and system operation (He *et al.*, 2023; Rajaperumal and Columbus, 2025; Singh *et al.*, 2025).



As highlighted in IRENA's *Transition Away from Fossil Fuels* (TAFF) (IRENA, 2026c), electrification powered by renewable energy is becoming one of the most viable and scalable pathways to simultaneously achieve climate goals, energy security and competitiveness (Box I.1). When supported by renewable energy deployment, energy efficiency improvements, grids, storage and sustainable fuels, electrification provides a critical pathway for reducing fossil fuel dependence while supporting economic development and resilience.

BOX I.1 Electrification with renewables: From climate ambition to national opportunity

The first Global Stocktake and the UAE Consensus reached at COP30 in Abu Dhabi set a global path towards tripling renewable power capacity and doubling the rate of energy efficiency improvements by 2030. Building on these commitments, the COP30 Presidency asked IRENA to prepare *Transitioning Away from Fossil Fuels: A Roadmap Powered by Renewables, Electrification and Grid Enhancement* to support international discussions in advance of COP31 (IRENA, 2026d).

The report demonstrates that electrification powered by renewable energy is the most effective path for transitioning away from fossil fuels while delivering multiple national benefits. Depending on national circumstances, these benefits may include strengthening energy security, improving industrial competitiveness, enhancing affordability, reducing air pollution and improving public health, expanding energy access and accelerating progress towards climate goals.



Rather than representing competing priorities, these objectives increasingly reinforce one another. The pace and sequencing of electrification will differ across countries, but electrification powered by renewable energy provides a common implementation pathway capable of responding to diverse national priorities while supporting the global objective of keeping the 1.5°C goal within reach.

Building on the TAFF report, this edition of WETO further explores how electrification pathways evolve across regions, the infrastructure and investment they require, and the broader socio-economic benefits they can deliver.

The coming decade is likely to be defined by the ability of countries to accelerate electrification while ensuring that grids, flexibility resources, sustainable fuels and supporting infrastructure evolve at the pace required. Increasingly, the challenge is not whether electricity will play a larger role in the global energy system, but how rapidly countries can build the systems needed to support its expansion.

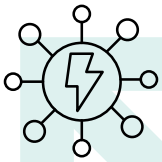
Strategic priorities for navigating the energy transition

The previous sections have shown that the energy transition is unfolding in a rapidly evolving geopolitical, economic and technological environment. The overall direction of the transition is becoming increasingly clear, although countries continue to move at different speeds and follow different pathways reflecting their development priorities, energy security considerations and resource endowments. Renewable energy deployment continues to accelerate, technologies are becoming more cost-competitive and electrification is emerging as a central pathway for transitioning away from fossil fuels. Countries will naturally follow different pathways according to their resource endowments, development priorities and national circumstances. Nevertheless, four strategic priorities consistently emerge for navigating the transition in an increasingly uncertain and fragmented world.

Energy security requires resilient energy systems. With the increasing electrification of energy systems, governments around the world will need to build energy systems that are resilient to geopolitical disruptions, market volatility and emerging technological risks. Renewable energy offers an opportunity to strengthen energy security in various ways. For fuel-importing countries, it can reduce exposure to imported fossil fuels and price volatility. For fossil-fuel-producing countries, it can diversify domestic energy systems, support economic diversification and free hydrocarbons for higher-value domestic uses or exports. Across all countries, it can strengthen domestic energy production, improve long-term affordability and enhance the resilience of energy systems.

At the same time, the transition brings new challenges associated with manufacturing capacity, critical materials, electricity infrastructure and digital systems. The priority is therefore not to eliminate risk, but to strengthen the resilience of future energy systems through co-ordinated industrial policies, modern infrastructure and international co-operation.

Competitiveness is increasingly shaped by the energy transition. The energy transition is also reshaping the foundations of economic competitiveness. Access to affordable renewable electricity, modern infrastructure, technological innovation and a skilled workforce is becoming an increasingly important determinant of investment decisions, industrial development and long-term productivity. Consequently, industrial policy is thus re-emerging as an important way to support domestic manufacturing, secure supply chains, create jobs and capture greater value from clean energy industries (Jomaa, 2026; IRENA, 2023a; IRENA and ILO, 2026). This has set off a new wave of industrial policy initiatives. Prominent examples are the Green Deal Industrial Plan in the European Union (European Commission, 2023a; IRENA, 2025b), the GX (Green Transformation) policy in Japan (GR Japan, 2023; METI, 2025), the manufacturing initiatives in India (PMINDIA, n.d.), and emerging industrial policies across the Global South (IRENA, 2024a).



Countries adopting ambitious energy transition policies in combination with forward-looking industrial strategies will be better positioned to attract investment, develop competitive industries and maximise the economic opportunities offered by clean energy supply chains. International co-operation will also be critical to facilitate technology transfer, strengthen industrial partnerships and ensure that the benefits of the transition are broadly shared.

Keeping the 1.5°C goal within reach requires faster implementation. The gap between current progress and the pace required to achieve the Paris Agreement objectives remains substantial. The policy challenge has shifted from avoiding overshoot to mitigating its magnitude and duration and enabling a return to 1.5°C (UNEP, 2026a). The United Nations Environment Programme (UNEP) stresses that the global objective remains limiting long-term warming to 1.5°C, but that this goal must now be approached from above. This does not weaken the case for climate action; rather, every fraction of a degree avoided, and every year in which the overshoot is reduced, reduces risks and damages. Mitigation and adaptation therefore need to advance together, while existing commitments are met and strengthened.

Although renewable energy deployment has accelerated significantly in recent years, much faster implementation is needed across renewable energy, electrification, energy efficiency, grids, flexibility, storage and sustainable fuels. Accelerating investment, strengthening institutions, mobilising finance and expanding international co-operation will all be essential to translate long-term ambitions into tangible progress.

Shared prosperity depends on an inclusive transition. The energy transition is taking place in an energy system characterised by structural inequalities, unequal starting positions and different level of capacities and access to resources, both within and between countries (IRENA, 2026g). Simultaneously, it also offers an unprecedented opportunity to eliminate current inequalities while creating new pathways for social and economic development through job creation, improved energy access, enhanced livelihoods and better environmental outcomes. In order to realise this potential, the transition must ensure that cost and benefits are shared fairly, especially for communities experiencing hardship because of energy affordability, cost-of-living pressures or economic uncertainty. A transition that is perceived as fair and beneficial will help build the public acceptance required for implementation at the scale and pace required (Bal *et al.*, 2023; IRENA, 2026g).



Organisation of this report

Across this introduction we have set out the strategic context and policy imperatives that drive the WETO 2026. The following chapters translate this vision into practice through an in-depth exploration of six key dimensions of energy system transformation.

CHAPTER 1: Integrated energy planning for accelerating the energy transition. The chapter suggests how to translate the scenarios analysed in this edition into actionable insights. The analysis presented in the chapter is framed within a system-transformation perspective built on a framework of key performance indicators (KPIs). These KPIs offer a structure for evaluating how the energy transition plays out across sectors and regions and over time.

CHAPTER 2: Advancing electrification as a key element of the energy transition. Chapter 2 addresses the practical reality that energy transition is not simply about replacing fossil fuel electricity with renewable electricity. It requires rapidly scaling clean electricity while simultaneously retiring fossil fuel capacity, electrifying transport and heating, and meeting the surging energy demands of AI while digitalising the power system to manage the change.

CHAPTER 3: Socio-economic and environmental impacts of transition pathways. The chapter models how different energy transition scenarios grounded in different co-operation assumptions and policy choices generate different distributional outcomes in gross domestic product (GDP), employment, energy access, and environmental stewardship. It makes explicit that the energy transition offers the possibility of multiple futures, with policy choices shaping which futures materialise.

CHAPTER 4: A way forward with 10-year actionable priorities. The last chapter distils recommendations from earlier chapters into specific proposed actions, forming the basis for a tangible and actionable agenda between 2026 and 2035.

The world in 2026 offers no credible alternatives to accelerating the energy transition. Renewable energy remains the foundation of this transition. Supported by electrification, energy efficiency and enabling infrastructure, it offers a pathway to advance climate goals, strengthen energy security, enhance competitiveness and improve long-term resilience. The question facing policy makers, therefore, is not whether the transition should occur, but how it can be implemented rapidly, equitably and at the scale required across different national contexts.

CHAPTER 01

INTEGRATED PLANNING TO ACCELERATE THE ENERGY TRANSITION



KEY INSIGHTS

- **Achieving IRENA's revised 1.5°C Scenario requires simultaneous progress across all energy transition avenues.** Direct electrification, direct uses of renewables, renewable power generation, energy efficiency, clean hydrogen and its derivatives, and carbon capture and removal must advance together, supported by enabling infrastructure and system flexibility. Integrated energy planning is essential to identify cost-effective pathways and ensure coherent implementation across technologies and sectors.
- **Electrification and renewable fuels are gaining momentum as key paths to decarbonisation across end-use sectors.** Under the revised 1.5°C Scenario, electricity would provide more than half of global final energy consumption by 2050, while the direct and indirect use of renewable energy would account for nearly 80%. Clean hydrogen and its derivatives remain important for hard-to-abate applications, complementing direct electrification and renewable fuels where these are technically or economically constrained.
- **The years to 2030 must become a decisive period of implementation.** Recent geopolitical developments have reinforced the importance of renewable energy for energy security and resilient supply chains. Accelerated deployment now depends increasingly on enabling conditions – including faster permitting and project development, grid connections and infrastructure, appropriate market design, flexible systems and the mobilisation of investment.
- **Renewable power deployment must accelerate substantially, but the required scale is achievable.** Under the revised 1.5°C Scenario, renewable power capacity would increase around sevenfold from 2025 levels by 2050, requiring average annual net additions of more than 1300 GW during 2026-2035 and sustained deployment thereafter. Variable renewables would become the dominant source of electricity, supported by an eight times expansion of battery storage by 2035 and a 22 times expansion by 2050, alongside a quadrupling in pumped storage hydropower.
- **Regional energy transition pathways are critical for translating global ambition into implementation.** Integrated regional planning can enable countries to capitalise on comparative advantages, strengthen cross-border co-operation and interconnections, improve energy security and supply-chain resilience, and maximise socio-economic benefits through pathways tailored to regional circumstances.
- **Delivering the transition requires an unprecedented mobilisation of investment.** Under the revised 1.5°C Scenario, cumulative investment needs are estimated at over USD 91 trillion during 2026-2035 and over USD 165 trillion during 2036-2050. Coherent policy frameworks, integrated energy planning and stronger public-private collaboration will be essential to mobilise capital at the required scale and deliver long-term economic, social and environmental benefits.

Three pathways for navigating the energy transition

Building on previous editions, this report continues the tradition of offering a forward-looking view of global and regional energy transition pathways grounded in robust scenario analysis. Previous editions have set a clear benchmark by laying out potential pathways consistent with reaching net-zero emissions by 2050 and limiting the rise in global temperature to 1.5°C, emphasising the key role of renewables, electrification and energy efficiency.

The 2026 edition retains this analytical foundation while updating it to a rapidly evolving global context characterised by heightened geopolitical uncertainty, significant shifts in investment dynamics and rising pressures on energy security and affordability. In this more fragmented world, the emphasis is not just on where the transition must go but also on how it can be delivered in the face of real-world constraints. With this in mind, the scenarios set out in this report offer a framework to help evaluate progress, ambitions and implementation gaps at the national and regional levels (Table 1.1).

The **Planned Energy Scenario (PES)** reflects a perspective based on existing government energy plans, targets and policies in place through the end of 2025. It falls above the 2˚C pathway and is more consistent with the Intergovernmental Panel on Climate Change (IPCC)'s AR6 C5/C6 pathways (Riahi *et al.*, 2022).[6] It serves as a benchmark and makes it possible to frame what current commitments mean for future energy systems, which in turn carry implications for emissions, energy security, investment needs and socio-economic outcomes.

TABLE 1.1 Alignment between IRENA scenarios and IPCC AR6 pathways

	PES	DES	1.5°C
Scenario	**Planned Energy Scenario (PES)**	**Decarbonising Energy Scenario (DES)**	**1.5°C Scenario**
Scenario objective	Current policy trajectory	Accelerated decarbonisation pathway	Return to a 1.5°C pathway after a limited and temporary overshoot
Temperature outcome	Above 2°C	Below 2°C	1.5°C (limited overshoot)
Comparable IPCC pathway	AR6 C5/C6	AR6 C4	AR6 C2

[6] *The Sixth Assessment Report produced by the Intergovernmental Panel on Climate Change.*

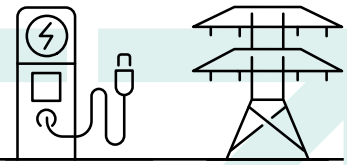
The **Decarbonising Energy Scenario (DES)** describes a more ambitious pathway. It assumes accelerated renewable deployment, greater gains in energy efficiency, and a more rapid ramp-up of electrification across end-use sectors. Although it does not align fully with the goal of global net-zero emissions by 2050 that underpins IRENA's previous WETO editions, it remains consistent with the ambition of limiting temperature rise below 2°C by end of the century. The DES lies in the range of the IPCC's AR6 C4 pathway (Riahi *et al.*, 2022). The differences between the DES and the PES illustrate the regional transition efforts but also reflect an imperfectly paced and uneven progress driven by the dynamics of competitiveness and energy and resource security.

As mentioned, the 2026 edition introduces a third scenario to reinforce the analytical framework. IRENA's revised **1.5°C Scenario** sets out a pathway consistent with achieving net-zero emissions by mid-century and keeping the global temperature increase to 1.5°C, while accounting for a limited and temporary overshoot caused by delayed action. It is equivalent to an IPCC AR6 C2 pathway, with cumulative emissions of 400 gigatonnes of carbon dioxide ($GtCO_2$) between 2026 and 2050 – in other words, a temporary overshooting of the 1.5°C carbon budget before returning to the 1.5°C pathway (Riahi *et al.*, 2022). Exceedance of 1.5°C should not be interpreted as safe or acceptable. The United Nations Environment Programme (UNEP) stresses that the global objective remains limiting long-term warming to 1.5°C, but that this goal must now be approached from above. In this context, existing commitments need to be met and strengthened, while mitigation and adaptation advance in parallel. Limiting the magnitude and duration of the overshoot therefore requires faster near-term emissions reductions, with any subsequent return towards 1.5°C dependent on sustained decarbonisation and carbon removals (UNEP, 2026a). This third IRENA scenario is characterised by an increase in ambition compared to the DES, with a deeper and faster deployment of renewables, greater efficiency gains, widespread electrification, and deployment of carbon removal solutions where appropriate. This scenario shows what further transformations are necessary beyond the DES to put the energy system back on track to a 1.5˚C-aligned trajectory.

The three scenarios are designed to serve complementary analytical purposes. Instead of standing as competing visions of the future, they constitute a coherent framework for assessing the implications of progressively higher levels of policy ambitious and implementation. Collectively, they show the implementation gap relative to current policies, the additional action needed to speed up the transition, and the additional transformations needed to align the energy system with a 1.5°C-compatible pathway. Where possible, scenarios are presented together throughout the report to make it possible to compare transition pathways at different ambition levels.

To translate these scenario narratives into actionable insights, the analysis presented in subsequent sections is framed within a system-transformation perspective built on a framework of key performance indicators (KPIs). These KPIs offer a consistent structure for evaluating how the energy transition plays out across sectors, regions and times. There are eight key dimensions:

- Electrification in end-use sectors (direct)
- Renewables (direct uses)
- Renewables (power generation)
- Energy intensity
- Clean hydrogen and its derivatives
- Carbon capture and removal measures
- Emissions
- Investment needs



For each KPI, the report assesses the current global trajectory and tracks progress across the scenarios to 2030, 2035 and 2050. This may mean identifying regional divergences, quantifying transition gaps and identifying the most severe bottlenecks and greatest interdependencies in the system. This approach identifies where acceleration most needed and how the various components of the transition must move in concert.

Building on this KPI-based assessment, the chapter also discusses cross-cutting enablers and constraints that shape the pace and feasibility of the transition. These include, but are not limited to, grid infrastructure and system flexibility, as well as broader system integration.

The Planned Energy Scenario (PES) presented in this edition reflects updated government plans, policies and targets and therefore provides an opportunity to assess how energy transition pathways have evolved since the publication of WETO 2023. The comparison between the current PES and that presented in WETO 2023 should be interpreted both as a reflection of evolving government ambitions, and as a response to significant changes in global economic, technological and geopolitical conditions over the past years. The economic recovery following the COVID-19 pandemic, energy market volatility, supply chain disruptions, rising geopolitical tensions and evolving technology trends have all reshaped the context in which the energy transition is unfolding. Appendix 1 summarises the evolution of selected key performance indicators from WETO 2023.

Energy transition ambitions have strengthened in several areas. Global targets for renewable energy deployment have been raised, reflecting growing recognition that the clean energy deployment needs to accelerate. Similar trends are seen in the electrification of end-use sectors, where electricity will play a larger role in final energy consumption than previously envisaged. Current plans also indicate greater uptake of clean hydrogen and related technologies, reflecting rising interest in decarbonisation options in hard-to-abate sectors. These changes are reflected in more marked transition away from fossil fuel (and lower net fossil CO_2 emissions) relative to the 2023 PES. This improvement is driven by higher targets for renewable energy deployment and increased expected uptake of efficient technologies, such as electric vehicles, heat pumps and other electrified end-use applications. More broadly, it also reflects how governments, industries and energy markets have responded to changing economic conditions, technology developments and energy security concerns over recent years.

The evolution of government plans in the last few years shows that energy transition ambitions continue to move in the right direction. Yet the pace of change remains insufficient to reach the scale of emission reductions needed under IRENA's 1.5°C pathway. While the gap between current plans and climate-aligned pathways has narrowed in several areas, substantial additional efforts will be required to accelerate implementation, mobilise investment and expand enabling infrastructure. Comparing WETO 2023 and 2026 thus highlights both encouraging progress and the persistent challenge of translating evolving ambitions, changing market conditions and shifting geopolitical realities into a transition pathway consistent with the objectives of the Paris Agreement.

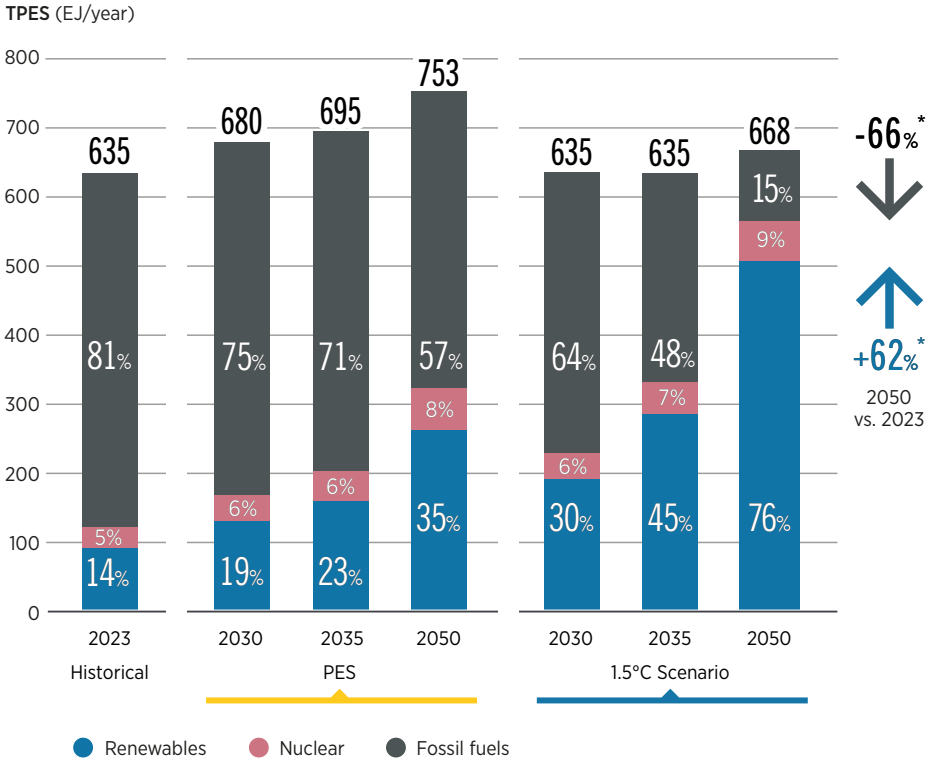


Delivering more energy services with less energy

The objective of the energy transition is not simply to add renewable energy capacity to existing fossil fuel systems, but to progressively replace fossil-fuel-based technologies with more-efficient electrified and renewables-based alternatives capable of delivering the same or higher levels of energy services. As a result, the transition is characterised by structural improvements in energy efficiency and a gradual decline in fossil fuel use, rather than by a simple addition of new energy sources to the existing system (Yergin *et al.*, 2025).

Currently, global total primary energy supply (TPES) is dominated by fossil fuels, which made up more than 80% of TPES in 2023. TPES has been growing approximately by 1.3% annually over the decade (IEA, 2025b). Under the PES, TPES would continue to grow by 0.7% per year from 2023 to 2035 and by 0.5% per year thereafter, with fossil fuels remaining dominant in the energy mix. By contrast, annual TPES growth over the same periods would remain below 0.1% under both the DES and the 1.5°C Scenario, alongside a declining share of fossil fuels. The slower growth in TPES and reduced reliance on fossil fuels under these scenarios reflect higher levels of renewables-based electrification across end-use sectors (Figure 1.1).

FIGURE 1.1 Evolution of global total primary energy supply (TPES) in exajoules (EJ) under the PES and 1.5°C Scenario, by source, 2023-2050



Source: Historical values (IEA, 2025b).

Note: Renewables include bioenergy, variable renewables (solar, wind) and others (hydropower, geothermal, solar thermal); fossil fuels include oil derivatives, coal and natural gas; maritime and aviation bunkers are included at the global level. *expressed in percentage points. EJ = exajoule; PES = Planned Energy Scenario.

At first glance, the declining primary energy demand observed in the 1.5°C Scenario may appear counterintuitive, particularly in a world where population, economic activity and demand for energy services continue to grow. However, this outcome reflects the much higher efficiency of renewables-based electrified systems compared with fossil-fuel-based systems. As a result, primary energy demand becomes a less informative measure of transition progress. This issue, often referred to as the "primary energy fallacy", is increasingly recognised as an important consideration in energy transition analysis (Box 1.1).

BOX 1.1 Interpreting primary energy metrics in the energy transition.

Energy systems are often assessed through total primary energy supply (TPES). While primary energy accounting remains important for statistical purposes, relying on it alone to compare fossil fuel and renewables-based systems can lead to misleading conclusions regarding the scale and efficiency of the energy transition.

Fossil fuel systems involve many stages of conversion, each characterised by large energy losses. In thermal power generation, for example, only 35–40% of the fuel input is turned into electricity, with most of the rest lost as heat. Additional losses occur during energy conversion in end-use applications such as internal combustion engines. Renewable technologies – such as solar PV and wind – generate electricity *directly* without combustion-related losses. Similarly, electrified technologies powered by renewables-based electricity are significantly more efficient at the end-use stage than their fossil fuel equivalents (Aramendia *et al.*, 2024; ETC, 2025; Eyre, 2021; Murphy *et al.*, 2022).

From primary energy to useful energy service, energy-system-level loss is estimated to average 65% for fossil-based energy systems, and around 5-10% in the case of renewables-based systems such as PV or wind (Figure 1.2).

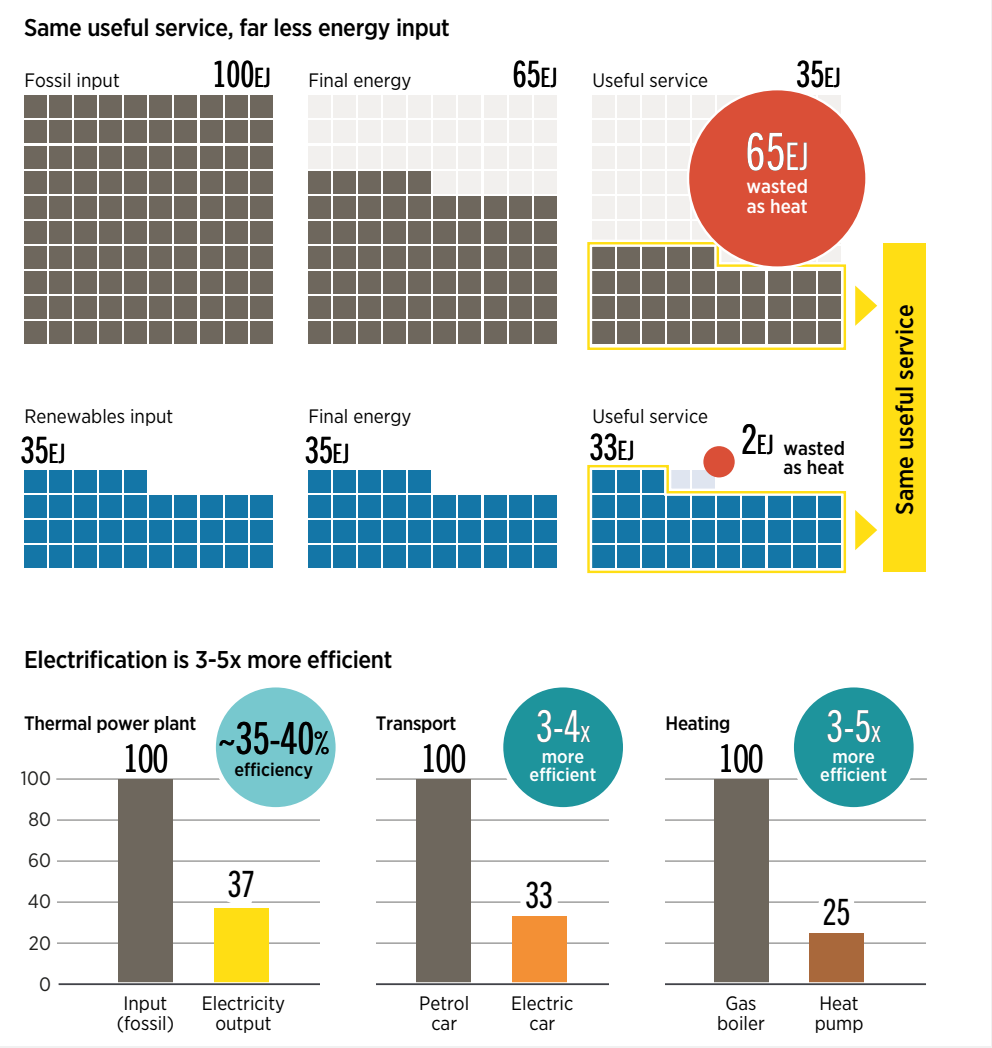
As a result, renewables-based electrified systems can provide the same or higher levels of energy services with substantially lower primary energy requirements. This explains why many 1.5°C Scenario exercises (in which renewables will make up 75% of the TPES by 2050) show declining primary energy demand (11% from the PES), even as economic activity and energy services continue to expand. The decrease is doubled (to 21%) when considering final energy consumption.

Recent literature has referred to this phenomenon as the "primary energy fallacy" (Martin, 2024; Rosenow, 2024), reflecting the misinterpretation that lower primary energy demand necessarily implies lower economic activity or reduced energy service. In reality, declining primary energy demand in renewables-based systems often reflects improved system efficiency and the avoidance of large combustion-related losses. The efficiencies have implications for policy. In the European Union's Renewable Energy Directive, for example, analysis has shown that reliance on primary energy accounting has at times distorted renewable energy metrics and created unintended disincentives for electrification in sectors such as heating and cooling (Gibb, Thomas and Rosenow, 2022).

Recognising these limitations, primary energy metrics should be complemented by indicators that better capture useful energy delivery, expanded electrification and emissions reductions, thereby providing a more accurate representation of progress towards efficient, resilient and low-carbon energy systems. While the most appropriate measure of progress in the energy transition should be based on useful

energy – because it directly reflects the energy services ultimately delivered to households, businesses and industries – consistent data are not yet available across most countries and sectors. As a result, electrification is conventionally measured as the share of electricity in total final energy consumption (TFEC). While this indicator does not fully reflect useful energy delivery, it provides a practical and internationally comparable proxy for structural efficiency improvements, given the generally higher end-use efficiency of electricity-based technologies. Considered together with renewable electricity deployment, it provides a more informative indicator of progress towards efficient and low-carbon energy systems.

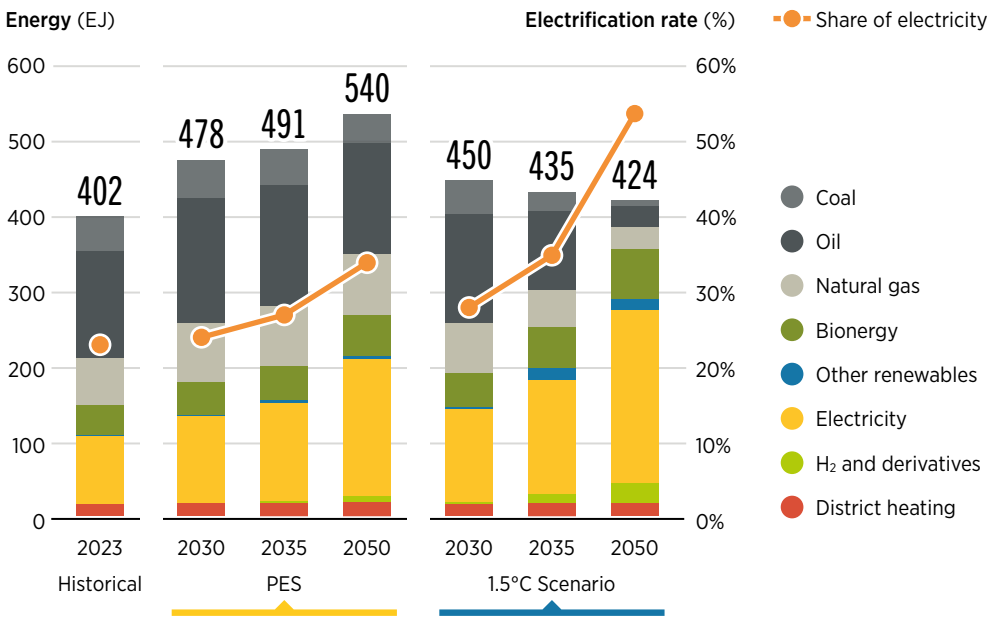
FIGURE 1.2 Understanding the structural efficiency gains of renewables-based electrification



Sources: (Aramendia *et al.*, 2024; ETC, 2025; Eyre, 2021; Murphy *et al.*, 2022).

Under the PES, total final energy consumption would grow annually on average by 1.7% from 2023 to 2035, and by approximately 0.6% thereafter through 2050. This slowdown in annual growth is driven by a gradual transition from end-use technologies using fossil fuels, which are inherently inefficient, towards significantly more efficient electric technologies, such as heat pumps and electric vehicles, among others. Electric end-use technologies are not only more energy efficient, but they are also clean technologies with zero direct CO_2 emissions. In addition to direct electrification, the use of modern bioenergy and clean hydrogen and its derivatives would also play an important role in decarbonising the energy sector, particularly industry and transport sectors, especially where electrification is hard to implement (Figure 1.3).

FIGURE 1.3 Evolution of global total final energy consumption (TFEC) in exajoules (EJ), by fuel (left axis) and global electrification rate (in %) (right axis) under the PES and 1.5°C Scenario, 2023-2050



Source: Historical values (IEA, 2025b).

Note: "Other renewables" include solar thermal and geothermal uses; "Bioenergy" includes sustainable and traditional bioenergy; non-energy is excluded from TFEC.

EJ =exajoule; H_2 = hydrogen; PES = Planned Energy Scenario; TFEC = total final energy consumption.

The PES indicates that the share of electricity in global final energy consumption would rise from 23% in 2023 to 27% in 2035, and then to approximately 35% in 2050 (Figure 1.3). Furthermore, the direct use of renewables in end-use sectors would increase, rising from 7% to 8% in 2035 and reaching 10% by 2050, while the share of clean hydrogen and its derivatives would grow from currently negligible levels to around 2% by 2050.

The DES and the revised 1.5°C Scenario require larger shares for these energy carriers across all end-use sectors compared to the PES, substituting them for fossil fuels, so as to reduce global CO_2 emissions and remain on track to meet the Paris Agreement goals. Under these scenarios, the share of electricity in TFEC that would have been achieved in 2050 under PES would be reached as early as 2035 (35%) before reaching over 50% in 2050. The direct use of renewables in end-use sectors would double by 2035 from 2023 levels and grow to nearly 20% by 2050. The share of hydrogen and its derivatives would increase from currently negligible levels to above around 3% by 2035 and above 5% by 2050 under the DES and the 1.5°C Scenario.

Electrification as the backbone of the energy system

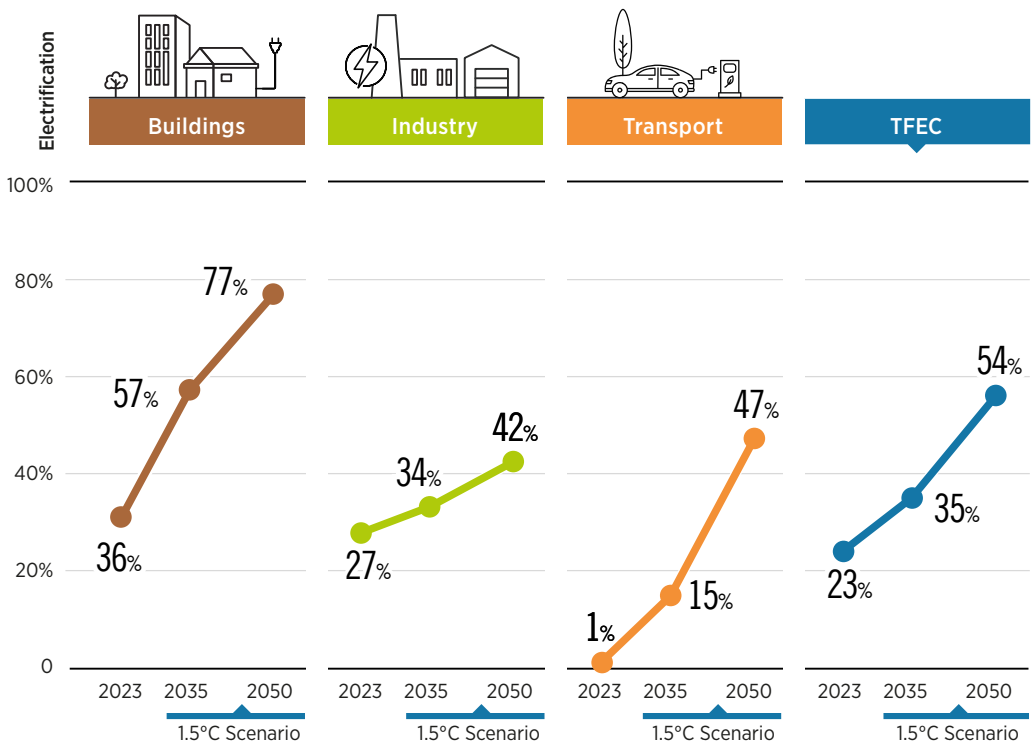
To recap, achieving climate targets consistent with the IRENA's 1.5°C-compatible pathway requires a systemic transformation of the global energy system, centred on the rapid electrification of end-use sectors. This decarbonisation pathway is based on a combination of end-use sector electrification, accelerated deployment of renewable power, improvements in energy efficiency, direct use of renewables (including bioenergy), the scale-up of clean hydrogen and the application of carbon capture and storage (CCS), including bioenergy with CCS (BECCS), alongside other carbon removal measures.

Electrification is set to accelerate significantly across all transition pathways, with the strongest growth under the DES and the 1.5°C Scenario. Globally, electricity's share in total final energy consumption (TFEC) rises from around one-quarter today to more than one-third by 2035, reflecting the growing electrification of transport, buildings and industry. The Group of Twenty (G20) nations follow an even faster trajectory, supported by greater deployment of electric vehicles, heat pumps and electrified industrial processes. By 2050, electricity supplies more than half of TFEC globally under the DES and the 1.5°C Scenario, highlighting direct electrification as a central pillar of the energy transition. Under the PES, progress is considerably slower, underscoring the need for stronger policies, infrastructure and investment to accelerate electrification.

Global electricity consumption is heavily dominated by the G20 countries, which accounted for approximately 85% of global consumption in 2023. Our analysis indicates that evolving macroeconomic and climate scenarios point to a shift in the relative distribution, moving from the G20's current high share towards an evolving balance between G20 and non-G20 economies. Under the PES, the G20/non-G20 ratio shifts to 80/20 by 2035 and down to 75/25 by 2050. In the DES and the 1.5°C Scenario, this ratio reaches 70/30 by 2050. For more details, see Appendix 2.



FIGURE 1.4 Global electrification in end-use sectors and TFEC under the 1.5°C Scenario, 2023, 2035 and 2050



Based on: (IEA, 2025b).
Notes: Data excludes non-energy use; TFEC = total final energy consumption.

The expansion of electrification across end-use sectors implies a substantial increase in electricity demand, requiring a rapid scale-up of renewable power generation. In both the DES and the 1.5°C Scenario, global renewable power capacity must increase significantly, reaching 3.3 to 3.6 times 2025 levels by 2035 and 7 to 7.5 times by 2050. This transformation is reflected in rising electrification rates across sectors (see Figure 1.4).

Meeting these targets requires widespread deployment of advanced technologies. The global stock of electric and plug-in hybrid light passenger vehicles at the end of 2025 was approximately 78 million (making up more than 4% of the global passenger vehicle fleet), with the EV share of new passenger vehicle sales reaching 26% (BNEF, 2025); that increases more than 12 times by 2035 under the revised 1.5°C Scenario, reaching nearly 1 billion vehicles. Residential heat pump capacity expands significantly under the 1.5°C scenario, growing from approximately 1500 GW in 2025 (IEA, 2026b) to around 8900 GW by 2030. In the same frame, indirect electrification using hydrogen requires a rapid scale-up of electrolysers. In 2025, global installed electrolyser capacity exceeded 4 GW, reflecting early commercial deployment of electrolysis-based hydrogen production (IEA, 2026c). Installed capacity increases to 320 GW by 2035 under the PES and to 1.24 TW (1241 GW) by 2050. Under the 1.5°C Scenario, the capacity increases to more than 1 TW (1084 GW) by 2035 and 4.5 TW (4524 GW) by 2050 (see Figure 1.9 below).[7]

This transformation requires parallel investments in enabling infrastructure, including grids, storage and digital technologies. Electrification, combined with energy efficiency improvements, supports system optimisation by reducing energy intensity and enhancing flexibility. Technologies such as smart grids and demand-side management further contribute to balancing supply and demand, particularly in systems with high shares of variable renewable energy (VRE).

Renewables expanding beyond the power sector

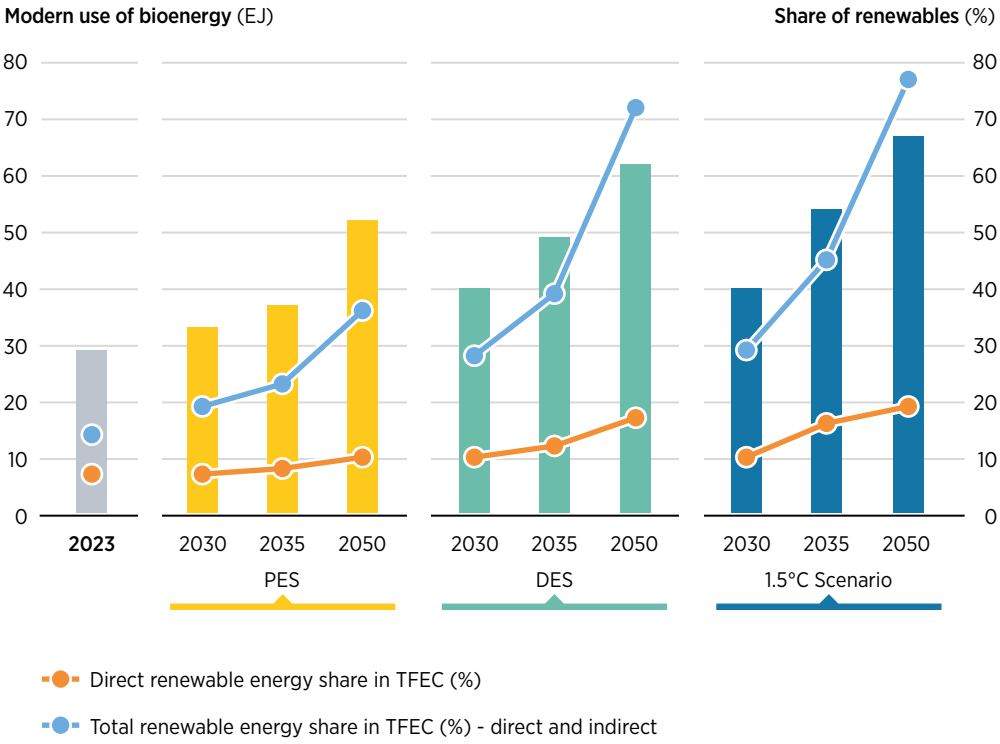
The use of renewables in end-use sectors is a key pillar of the energy transition, complementing electrification in sectors where direct electrification is less efficient or cost-effective. In both the DES and 1.5°C scenarios, decarbonisation is driven by energy efficiency, electrification, renewable power expansion, and the direct use of renewable energy sources such as modern bioenergy, solar thermal and geothermal. The share of direct renewables in TFEC increases from around 7% presently to 12–16% by 2035 and around 18% by 2050 in both scenarios (Figure 1.5). Modern bioenergy use would expand significantly, reaching 49–54 EJ by 2035 (of which around 36 EJ comes from G20 countries) from around 30 EJ in 2023. By 2050, modern use of bioenergy doubles from 2023 levels under both the DES and the 1.5°C Scenario (two-thirds from the G20). For more details, see Appendix 2.

The direct use of renewable heat and biomass (which includes solar thermal, biofuels and bio-based feedstocks), is critical in end-use sectors. In buildings, the energy transition depends on a combination of efficiency improvements, electrification through heat pumps and increased deployment of renewable heating solutions, all of which will depend on policy measures such as building codes and solar thermal mandates. The share of renewables in energy consumption in the buildings sector should be 13% by 2035 and 10% by 2050 In both the DES and the 1.5°C Scenario, due to the gradual decrease in bioenergy use after 2030.

In industry, the direct use of renewables plays a central role in decarbonising energy-intensive and hard-to-abate processes, especially those requiring high temperatures. Renewable heat and bio-based feedstocks can substitute for fossil fuels across sectors such as cement, chemicals and food processing. In applications constrained by energy density, infrastructure or operational requirements, bioenergy and renewables-derived fuels provide a key complement to hydrogen and electrification. As a result, the share of direct

[7] *Electrolyser capacity is expressed in electrical input terms. It is calculated using the final energy consumed by electrolysers over a year with a 50% capacity factor and 68% stack-level efficiency (based on the lower heating value of hydrogen).*

FIGURE 1.5 Share of renewable energy use in TFEC of end-use sectors under the PES, DES and 1.5°C Scenario, 2023-2050



Based on: recent year values are calculated from (IEA, 2025b).

Notes: DES = Decarbonising Energy Scenario; EJ = exajoule; G20 = Group of 20; PES = Planned Energy Scenario; TFEC = total final energy consumption; data excludes non-energy uses.

renewables use in industrial TFEC increases to 10% by 2030 in both the DES and the 1.5°C Scenario, by 2050, to 22% under the DES and 27% under the 1.5°C Scenario.

Sustainable aviation fuel (SAF) produced from biofuels such as waste oils and fats is rapidly boosting demand for biofuels in the transport sector. In the maritime and roads sectors, biofuels can use existing infrastructure to increase energy security and decarbonisation.

While electrification will account for a large share of emissions reductions, it is not sufficient on its own. The direct use of renewables in end uses provides a cost-effective and efficient complement, reducing conversion losses and infrastructure requirements. Accelerating deployment will be critical to reducing fossil fuel use in heating, cooling and industrial processes and to achieve climate targets, with international collaboration playing a key role in supporting implementation, especially in developing countries.

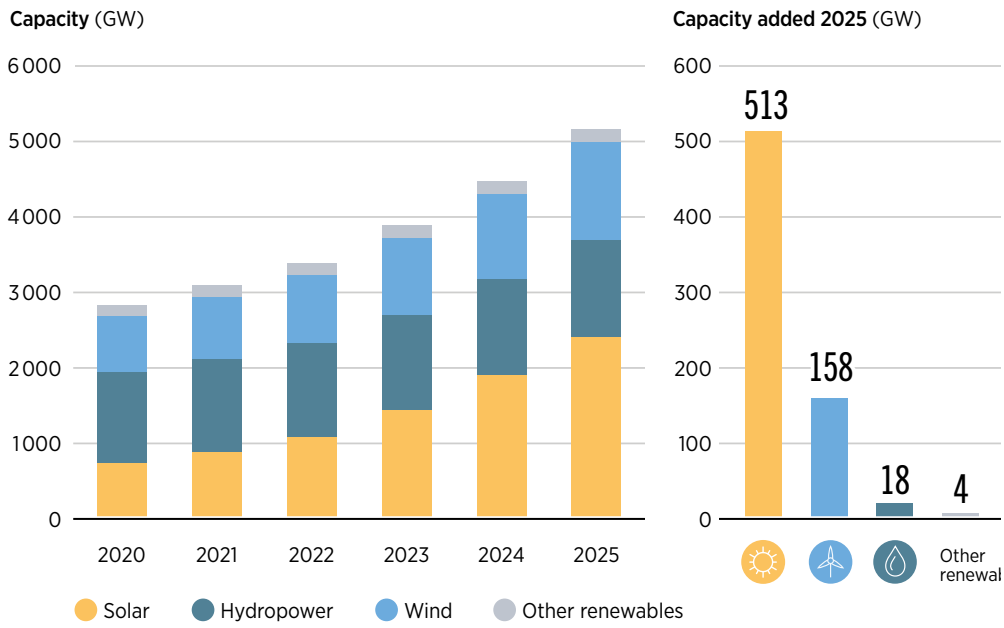
Renewable power: Underpinning the future energy system

The power sector is the globe's largest source of CO_2 emissions, accounting for approximately 37% in 2024 (IEA, 2025c, 2025d). Under all scenarios, the global power sector is set for substantial change, driven by electrification of end-use sectors and integration of renewables. Renewable power serves an essential role in decarbonising the global energy system by replacing fossil fuel-based electricity generation with better alternatives.

Renewable power at record levels, with uneven progress

The year 2025 marked the highest annual increase in renewable generation capacity to date (+693 GW) and the highest growth in percentage terms (+15.5%) (IRENA, 2026h). Global installed renewable capacity amounted to 5155 GW as of 2025 and accounted for 49.5% of the world's total power generation capacity (Figure 1.6). Solar PV, with a capacity of 2388 GW, accounted for the largest share of the total. Renewable hydropower and wind energy accounted for most of the remainder, with total capacities of 1296 GW and 1291 GW, respectively. Solar PV led capacity growth in 2025, contributing about three-quarters (+513 GW) of the overall renewable additions, and was followed by wind energy, with 158 GW. Renewable hydropower capacity increased by 18.3 GW, bioenergy by 2.9 GW and geothermal energy by 0.3 GW (IRENA, 2026h).

FIGURE 1.6 Evolution of the global installed renewable power capacity (in GW), 2020-2025



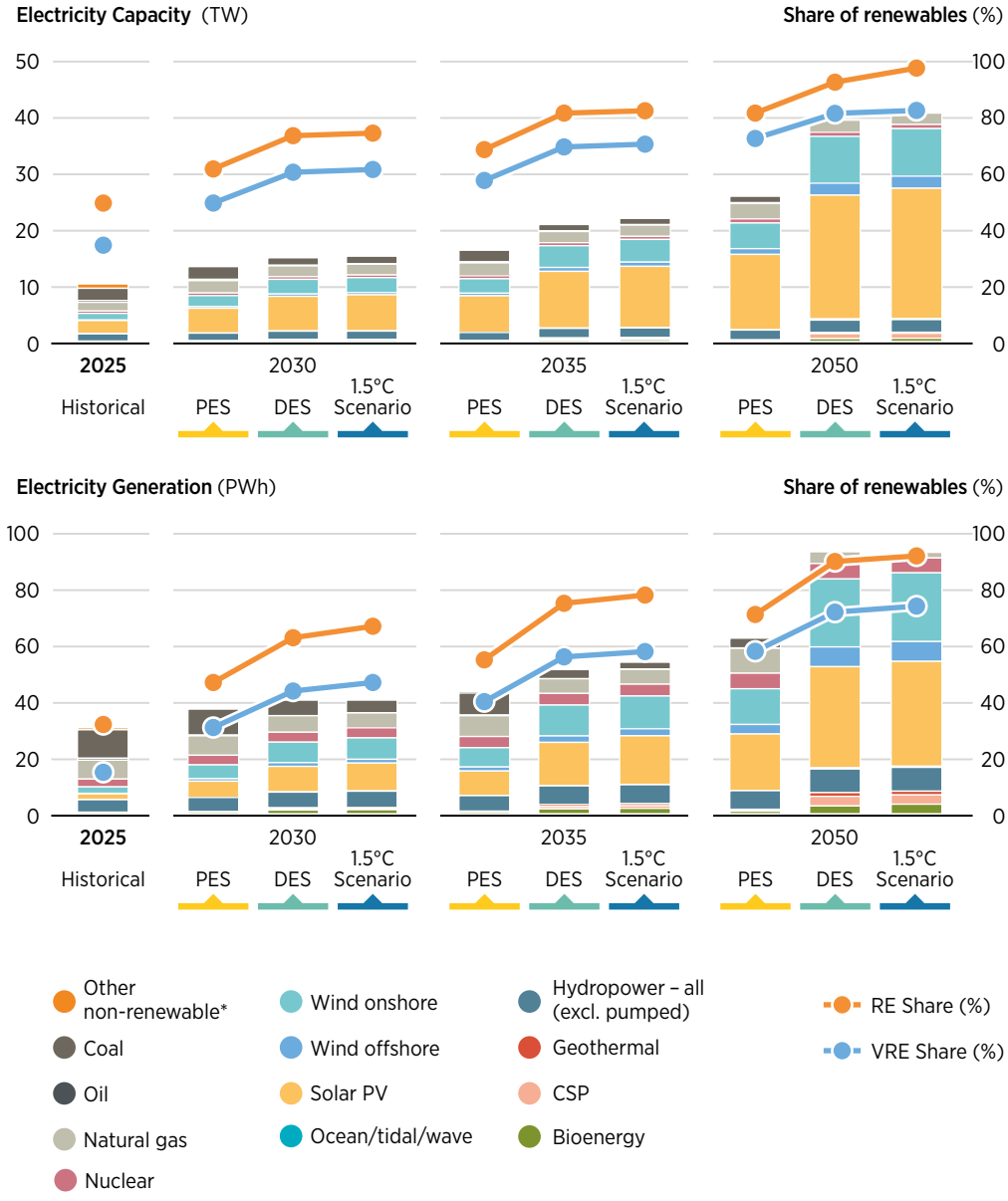
Source: (IRENA, 2026h).
Note: GW = gigawatt.

Building on these recent developments, this section explores the scaling required for renewable energy under IRENA's scenarios. The PES shows renewable capacity roughly quadrupling by mid-century and renewables rising from half to more than four-fifths of installed capacity, with VRE accounting for most of the increase (Figure 1.7). A crucial point is what this implies for deployment rates. Meeting these planned goals will require net capacity additions of 619 GW per year through 2035 and an average of 666 GW per year from 2036 to 2050. These requirements indicate a need to continue the pace of capacity additions of 693 GW achieved in 2025. These are net figures. Gross additions are higher, since a growing share of installed capacity reaches the end of its useful life and requires replacement, a divergence that is minor today but becomes material after 2035 as the solar and wind capacity built during the 2010s and 2020s begins to be retired. The manufacturing, supply chain and installation effort is therefore considerably greater than the net figures suggest, particularly in the second half of the period. Therefore, current plans indicate sustaining the recent pace of net capacity rollout rather than acceleration.

Two features of the capacity and generation mix of the PES trajectory stand out. First, the renewable share of the generation mix consistently lags the share of renewable capacity, a fact that reflects the lower capacity factors of solar and wind. This lag remains broadly consistent along the scenario, though it does shrink by 2050, as the system becomes more thoroughly renewable. It has direct implications for grid expansion, storage and flexible operation, since each increment of renewable capacity delivers proportionally less energy than the conventional capacity it displaces. Second, the PES does not represent a full decarbonisation pathway, falling well short of what is consistent with limiting the global temperature increase to 1.5°C. The PES reaches renewable shares of 82% and 71% in capacity and generation, respectively, by 2050.



FIGURE 1.7 Global installed power capacity (top) and electricity generation mix (bottom) under the PES, DES and 1.5°C Scenario, by technology, 2025-2050



Notes: CSP = concentrated solar power; DES = Decarbonising Energy Scenario; GW = gigawatt; RE = renewable energy; PES = Planned Energy Scenario; PV = photovoltaic; PWh = petawatt hour; TWh = terawatt hour; VRE = variable renewable energy.

The DES and 1.5°C Scenario close this decarbonisation gap. The distinction between them is primarily one of timing rather than direction, as shown in Figure 1.7. Under the DES, accelerated renewable deployment, improved gains in energy efficiency and rapid ramp-up of electrification across end-use sectors roughly double the renewable capacity by 2030, triple it by 2035 and raise it sevenfold by 2050. This translates to average annual net renewable capacity additions of approximately 1211 GW in the years to 2035. That gain is almost double that of 2025, and it rises to 1305 GW through 2050. As noted above, gross additions exceed these net rates – increasingly so towards mid-century. Sustaining additions at this level, rather than a single peak year, is the central challenge because it implies a stark change in everything needed to make it happen, including global manufacturing capacity, grid build-out, permitting and capital deployment.

The 1.5°C Scenario goes further and raises the rapidity and magnitude of the renewable capacity buildout. Annual net capacity additions would need to consistently exceed 1323 GW over the entire period from 2026 to mid-century. A defining aspect of this scenario is the emergence of solar PV as the central technology in the global mix, complemented by wind, while hydropower and other renewables – growing from a small base of 179 GW in 2025 – take on a supporting role that is disproportionate to their share, providing dispatchable and firm capacity as VRE approaches four-fifths of installed capacity. This would raise the renewable share in total installed capacity to 77% by 2030, 84% by 2035 and 94% by 2050, up from around 51% in 2025 (see Appendix 2).

From the demand perspective, widespread electrification across end-use sectors, economic growth and wider energy system decarbonisation raise the electricity generation needs (including consumption, transformation and losses) from 31 petawatt hours (PWh) in 2024 to approximately 41 PWh by 2030, 52–54 PWh by 2035 and 94 PWh by 2050 under both the DES and 1.5°C scenarios. Renewables meet the majority of this scale up in these scenarios, while the share of fossil fuels in the power generation mix drops rapidly.

The share of fossil fuels in power generation, under both the DES and 1.5°C scenarios, falls from 58% in 2024 to around half this level by the end of the decade in both scenarios, standing at around 5% and 2%, respectively, by 2050. Coal and oil generation are eliminated from the mix first, while natural gas retains a role for longer by shifting from providing bulk power generation to supporting system reliability at periods of low renewables-based generation. Fast-ramping gas-powered capacity thus persists well beyond the point at which wholesale gas generation has fallen away, an important distinction in terms of how remaining fossil assets are valued and remunerated.



Although nuclear capacity continues to expand over time, its share in the power generation mix would decline from 9% in 2024 to 6% of generation by 2050. In the near term, the most cost-effective contribution comes from long-term operation of the existing nuclear fleet,[8] which preserves low-carbon output at a fraction of new-build cost and is the only nuclear option able to contribute materially before 2035. Lifetime extensions nonetheless depend on management of aging, component replacement and regulatory approval. They also remain subject to national policy decisions that can change over the lifetime of a plant.

Realising this transition depends less on technology availability than it does on surmounting challenges such as integrating variable renewables at scale, modernising grid infrastructure and phasing out fossil-based generation without compromising energy security, adequacy or affordability.

Enabling high-renewable power systems: Flexibility, grids and infrastructure

System flexibility is critical to ensuring a reliable and cost-effective electricity supply and must expand at a pace that aligns with growth in renewables capacity during the energy transition. Power systems require flexibility across a wide range of time scales – from seconds and minutes to daily, weekly, seasonally and interannually – so as to continuously balance supply and demand in real time. This capability is fundamental to the secure and reliable operation of any power system.

Traditionally, flexibility has been predominantly provided by dispatchable generation assets capable of adjusting their output in response to demand variations. As power systems become increasingly electrified and renewables-based, flexibility will increasingly be delivered through a portfolio of complementary solutions rather than conventional thermal generation alone. These include storage (both short and long duration), active demand participation, sector coupling, interconnections, dispatchable renewable generation, thermal generation based on sustainable fuels, and nuclear generation (where available), noting that plants operated to serve as baseload provide limited flexibility unless designed or retrofitted for load following.

At the global level, under the PES, the power sector would require approximately six times more daily flexibility and four times more seasonal flexibility by 2050 than in the 2020s. Under the DES, flexibility needs increase to around eleven times more daily flexibility and seven times more seasonal flexibility by 2050, while the IRENA's revised 1.5°C Scenario requires even higher levels of system flexibility. Meeting these needs will require fast expansion of complementary flexibility solutions. Battery storage capacity would need to expand by four times in the PES, seven times in the DES, and by eight times in the 1.5°C Scenario by 2035, starting from around 257 GW in 2025 (see Appendix 2).

[8] *New buildings are considerably more capital-intensive than extending the operation of existing plants. Recent projects in Europe and North America have significantly exceeded initial cost and schedule estimates, with overnight construction costs of USD 7 600-15 000/kilowatt reported for the most recently completed Western projects (Böse et al., 2026; Rothwell, 2022), and average construction times in China have remained closer to six to seven years (Schneider et al., 2025). Small modular reactors (SMR) are widely proposed as a source of firm low-carbon capacity, but only a small number of SMR-class units operate commercially today, and the first units in North America and Europe are generally not expected before the early 2030s. They are therefore unlikely to contribute materially to 2030 or 2035 milestones, whatever their longer-term prospects.*

But power capacity alone understates the expansion needs, as average storage durations are becoming longer. New utility-scale projects commissioned in 2025 averaged around three hours, up from about two hours in 2023, and a growing share is now being built at four hours or more. Pumped hydro power would continue to provide flexibility. Under the PES it would increase 2.2 times by 2035 and 3.7 times by 2050 from a starting point of 160 GW of installed capacity in 2025. The corresponding figures would be even higher under the DES and the 1.5°C Scenario. Renewable hydrogen and hydrogen storage would further complement batteries by providing long-duration and seasonal balancing capabilities.

Countries increasingly recognise the importance of flexibility and have been making significant progress in the deployment of solutions. Energy storage has been fastest to be scaled up in the past few years. Globally, around 112 GW of battery storage was added in 2025, exceeding the 100 GW mark for the first time, a 48% increase from 2024 additions (BNEF, 2026a). Similarly, the deployment of pumped storage hydropower has also increased significantly, with the global installed capacity reaching 160 GW in 2025 (IRENA, 2026h). Numerous projects are currently under construction worldwide, including 218 GW in China (IHA, 2026), with approximately 136 GW expected to be completed by 2035 (IRENA, 2026c).

However, no single technology will be sufficient to cover all types of flexibility needs and services. The optimal portfolio of solutions will depend on national system characteristics and the time scales over which flexibility is required.

Flexibility and grid investments are best planned together rather than in isolation. While the recent expansion of battery storage has been successful, a systematic planning approach is needed to deliver an effective and efficient power system. Such an approach can reduce network congestion, support the optimisation of infrastructure investment and ensure the timely evolution of system infrastructure at the pace required for optimal renewable energy deployment and electrification.

The rapid rise of artificial intelligence and hyper-scale data centres is adding a significant new source of electricity demand, increasing pressure on grid infrastructure, storage and dispatchable low-carbon generation. Tightly coupled with rising temperatures, growth in cooling demand demonstrates the need for both climate adaptation and mitigation – adapting to a warmer world while limiting further warming. Box 1.2 looks at how electrification supports climate adaptation. While these developments strengthen the case for expanding electricity infrastructure, they also create opportunities to accelerate renewable energy deployment when supported by timely grid expansion, dedicated renewable capacity and appropriate connection policies.

The flexibility challenges faced by power systems vary across the world and depend on multiple factors. In the European Union, the transition challenge is primarily one of integrating renewables with the electrification of demand. Grid capacity has become the principal bottleneck, with renewable curtailment already affecting several member states. As shown in IRENA's *Regional Energy Transition Outlook: European Union*, accelerating the expansion of grids and strengthening domestic manufacturing of clean technology (such as electrolysers and heat pumps) have therefore become strategic priorities (IRENA, 2025b). In South America, as shown in IRENA's *Regional Energy Transition Outlook: South America*, climate-related droughts are accelerating wind and solar deployment while reinforcing the need for a more diversified and resilient power system (IRENA, 2025c). The region's exceptional renewable resources also position it as a potential global supplier of renewable hydrogen and its derivatives.

BOX 1.2 Electrification supports climate adaptation: Resilient grids in a warmer world

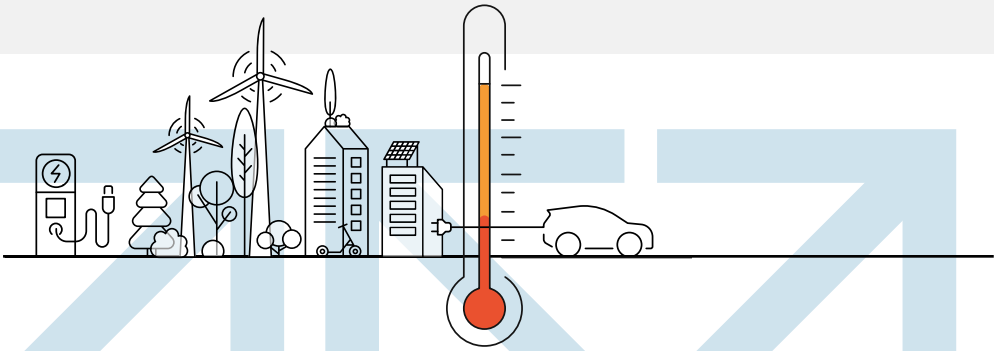
Climate adaptation and the energy transition are converging in the power sector. Electrification supports adaptation by improving resilience to rising temperatures and more frequent extreme weather events. Different regions of the world experience climate change differently. However, an important example is Europe, which has warmed at approximately twice the global rate since the 1980s. It is now the fastest-warming continent, where rising temperatures are already changing both the level and the shape of electricity demand (Copernicus Climate Change Service and World Meteorological Organization, 2025a). The core driver is the increase in the number of higher-temperature days combined with more frequent heatwaves and tropical nights.

In the EU, a near 300% increase in cooling degree days (CDD) and a 19% decline in heating degree days (HDD)[9] has occurred between 1979 and 2023 (Koukoufikis *et al.*, 2026). This asymmetry raises operational challenges given how concentrated cooling demand is during the hottest hours, whereas heating demand is more evenly spread across the season, with direct implications for electricity use. Warming nights further compound these challenges. The share of Europe recording at least one tropical night per year (when temperatures do not fall below 20°C) rose from 20% in the 1970s to 35% in the 2020s (Copernicus Climate Change Service and World Meteorological Organization, 2025b). When nights are not cool, the cooling load persists after sunset, which means that solar PV capacity (the dominant technology by capacity by 2050 in the PES, DES and IRENA's revised 1.5°C Scenario) cannot support the load alone, requiring other resources (notably storage and dispatchable capacity).

Heat also limits the operation of grids, which can limit their capability as demand peaks. Higher temperatures reduce the thermal ratings of transmission and distribution (T&D) equipment and increase losses. To adapt, countries around the world need efficient, electrified cooling technologies and a reliable electricity supply to meet the rise in peak demands. This reality highlights the need for grid modernisation and flexibility beyond renewable energy integration.

Future power systems should incorporate climate projections into demand forecasting and infrastructure planning while investing in T&D reinforcement, digitalisation, demand side flexibility, energy storage and climate-resilient assets.

[9] *HDD is an index that indicates the demand for heating when outdoor temperatures are below a base temperature. CDD is an index that indicates the demand for cooling when outdoor temperatures are above a base temperature.*



Delivering the DES and IRENA's revised 1.5°C Scenario will require overcoming persistent implementation bottlenecks, including lengthy permitting procedures, insufficient grid investment, high financing costs and supply chain constraints. Addressing these barriers through faster permitting, lower financing costs, resilient and circular supply chains and co-ordinated infrastructure planning will be essential for accelerating renewable energy deployment. In the end, enabling infrastructure has become one of the defining conditions for achieving a secure, competitive and sustainable development.

Energy efficiency: The first fuel of the transition

Doubling energy efficiency by 2030 from 2022 levels is a crucial complement to the tripling of renewable power capacity.

Over the past two years, annual primary energy demand has increased by 2% and 1.3%, respectively (IEA, 2026d), while global economic growth has been around 3.4%/year (IMF, 2026). Extrapolating, the improvement in energy intensity achieved in 2025 is slightly below 2%, and over the last three-year period, the average annual improvement in energy intensity has been just below 2% which is well below the energy efficiency target of 4% improvement every year between 2022 and 2030.[10] Under the PES, the annual improvement over the period 2026-2030 would be only about 3%.

But the 1.5°C Scenario requires an improvement of more than 4% per year over the next five years to make up for the shortfall accumulated in recent years and meet the 2030 energy efficiency target (Figure 1.8). Meeting that target will require greater ambitions in governments' plans and cross-sector policies, as well as co-ordination of a broad range of stakeholders to assemble the necessary policies, minimum standards, labelling and funding. The Global Energy Efficiency Alliance (GEEA), launched at COP29 in 2024, provides a platform to support progress towards the UAE Consensus goal to double global energy efficiency improvement by 2030 from 2022 levels, advancing international co-operation, finance mobilisation and technology deployment to this end.

Clean hydrogen and derivatives to address hard-to-electrify applications

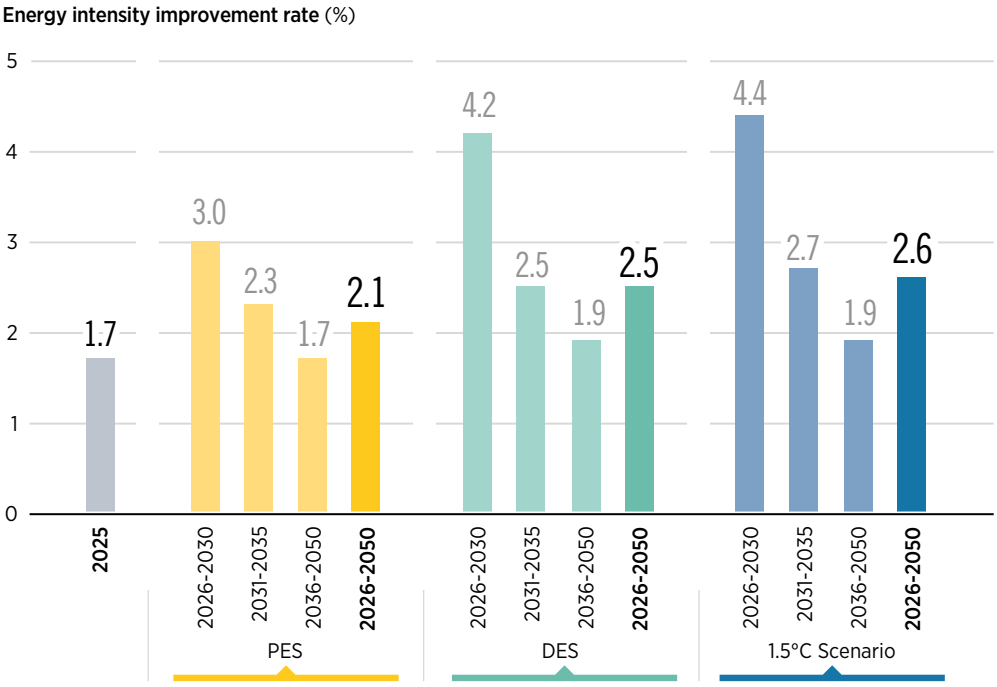
Alongside direct electrification, clean hydrogen and its derivatives would play an important role in decarbonisation of sectors that are particularly hard to electrify: industry, power and transport. In the industry sector, clean hydrogen can be a substitute for fossil-fuel-based feedstock in the production of iron, steel, and chemicals, while in transport, clean hydrogen and its derivatives can be used as fuel for long-haul aviation and shipping.

While so-called blue hydrogen[11] is essential for decarbonising hard-to-abate sectors, it should be viewed as a transitional solution. Green hydrogen, on the other hand, is not only cleaner but also contributes to energy security. It is therefore the preferable long-term solution.

[10] *Energy intensity improvement rates are a proxy for energy efficiency improvement rates. Energy intensity is calculated as the total primary energy supply divided by GDP. Its improvement is the compound rate at which energy intensity declines or increases over a given period.*

[11] *Clean hydrogen here refers to green hydrogen or blue hydrogen. Green hydrogen is produced by water electrolysis using renewable electricity while blue hydrogen is produced from natural gas using steam methane reforming where the CO_2 emissions produced are captured and stored or used in other processes.*

FIGURE 1.8 Average annual energy intensity improvement rate (in %) under the PES, DES and 1.5°C Scenario, by period, 2025-2050



Note: The energy intensity improvement achieved in 2025 is calculated as the rate of improvement of energy intensities in 2025 using the total energy supply and energy demand growth data from the International Energy Agency for total energy supply 2024 (IEA, 2026d) and the GDP and economic growth data from the International Monetary Fund (IMF, 2026). The GDP values used in calculations are based on 2025 purchasing power parity rates.

DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

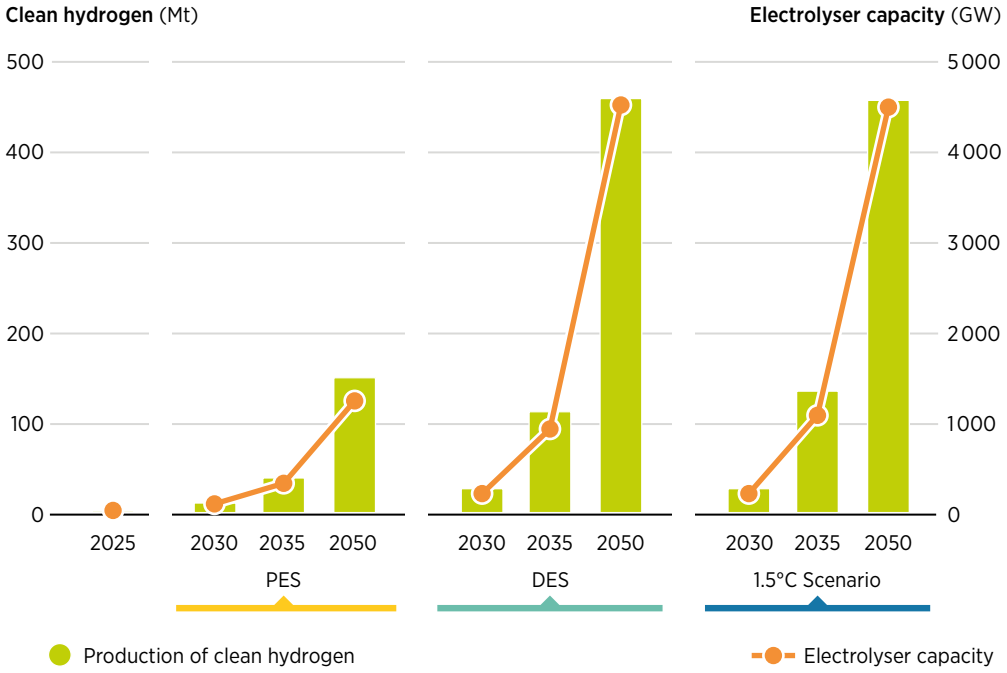
Green hydrogen contributes to energy security by 1) enabling a diversification of energy sources, thus avoiding dependence on a single fuel source and mitigating geopolitical risks; 2) facilitating long-term energy storage through its derivatives, such as ammonia and methanol, which allow for easy transport and storage; and 3) providing power grid flexibility and balancing, thereby facilitating the management of VRE.

Global annual production of clean hydrogen has seen notable growth since 2021, rising from 0.6 Mt to approximately 1 Mt in 2025, representing an average annual growth rate slightly above 10% (Hydrogen Council, 2025; IEA, 2026e). However, this still accounts for less than 1% of global hydrogen production, with green hydrogen being a third of the clean hydrogen produced in 2025 (Hydrogen Council, 2025; IEA, 2026e).

Under the PES, the use of clean hydrogen and its derivatives would increase from around 1 Mt in 2025 to slightly less than 40 Mt in 2035 with a sharp increase to 150 Mt by 2050 (Figure 1.9). Green hydrogen would dominate clean hydrogen deployment, climbing from 25% in 2025 to 83% in 2050. Despite the significant growth projected for global clean hydrogen use, keeping the global temperature rise below 1.5°C before the end of the century, the DES and the 1.5°C Scenario call for the acceleration of its use from current negligible levels to at least 110 Mt by 2035 and up to 460 Mt by 2050. Of these amounts, green hydrogen share would need to be at least 60% and 90% in 2035 and 2050, respectively. For more details, see Appendix 2.

To meet the required levels of use of clean hydrogen, policy frameworks must combine demand-side incentives, bankable tender mechanisms, and regulatory mandates (Hydrogen Business Alliance, 2025). These will bridge the cost gap between clean hydrogen and fossil-based hydrogen, raise market certainty and strengthen supply chains.

FIGURE 1.9 Evolution of clean hydrogen production (in Mt) under the PES, DES and 1.5°C Scenario, 2025-2050



Source: Data for hydrogen produced in 2025 is from IEA Hydrogen Projects Database (IEA, 2026a); 2025 electrolyser capacity value is from (IEA, 2026c)

Notes: DES = Decarbonising Energy Scenario; G20 = Group of 20; Mt = million tonnes; PES = Planned Energy Scenario.

Currently more than 90% of global clean hydrogen production and consumption is concentrated in the G20 nations (Hydrogen Council, 2025). The analysis under the DES and 1.5°C Scenario show that global clean hydrogen production and consumption would still be concentrated in the G20 in 2035 and afterwards (more than 80%). Therefore, leadership from these nations is key to putting in place policies that will create demand for clean hydrogen. For example, Europe leads the way on the adoption of sector-based quotas for hydrogen use in transport and industry under the EU Renewable Energy Directive and mandates for the aviation sector (IEA, 2025e). IRENA's Regional Energy Transition Outlook: European Union (IRENA, 2025b) also proposed that the deployment of hydrogen and its derivatives should be prioritised based on sector needs and cost-effectiveness (Box 1.3).

BOX 1.3 Energy security and the clean energy transition in the European Union

Energy security in the European Union (EU) is paramount for the well-being of its citizens and for industrial and economic development. Transitioning away from fossil fuels will help protect the environment and decrease the EU's dependence on other regions. In this regard, the EU has committed itself to be a climate-neutral region by 2050 through the adoption of the European Green Deal and the European Climate Law. Reducing emissions will require increasing renewables' share in the energy generation mix and energy efficiency across end-use sectors, while maintaining economic competitiveness. Innovative solutions – such as sector coupling, modern bioenergy, green hydrogen, energy storage, and smart grids that use digital technologies – can all play a key role in minimising and optimising costs across the energy sector.

The 2022 REPowerEU plan marked a milestone for diversifying and safeguarding the EU's energy supply while accelerating the transition to clean energy and stabilised prices. Green hydrogen has since gained relevance as an energy carrier for decarbonising the EU's economy. IRENA's *Regional Energy Transition Outlook: European Union* (IRENA, 2025b), prepared in collaboration with the EU Commission, proposed that the focus must be hard-to-abate sectors and engaging international co-ordination to ensure a cost-effective scale-up. IRENA's projections indicate that hydrogen and its derivative fuels will meet 2% and 5% of final energy consumption in the EU by 2030 and 2050, respectively. This would correspond to 37 Mt of hydrogen equivalent in 2050, including 9.2 Mt of hydrogen in the form of ammonia, 8.4 Mt in methanol and 8.5 Mt in e-fuels.

Investment in hydrogen production plants will need to exceed EUR 130 billion between 2025 and 2050, averaging EUR 5 billion/year and constituting a significant increase from recent levels. As hydrogen becomes more embedded in industrial decarbonisation and energy system flexibility, it must be properly integrated into broader energy and industrial strategies. Grid infrastructure will need upgrades to support large-scale electrolysis where this is deployed, ensuring that the system is able to handle larger shares of renewables.

The use of modern bioenergy will gain momentum in the EU to achieve its decarbonisation goals. In fact, after electrification, scaling up bioenergy production is the second most important measure to deliver decarbonisation across end uses. Modern use of bioenergy in the EU is expected to account for 15% and 12% of final energy consumption by 2030 and 2050, respectively, up from 9% in 2021. This means that total consumption of all forms of bioenergy would increase from 5.8 exajoules (EJ) in 2021 to 6.6 EJ in 2050. Modern bioenergy will be used to meet key energy demands in aviation, shipping, and heating, as well as supplying green gases to the power sector. Import-export dynamics will play a crucial role in balancing supply and demand, with imports being needed to supplement domestic production.

Closing the 1.5°C gap

Global greenhouse gas emissions have been increasing by nearly 1.5% annually since 1990 (Crippa *et al.*, 2025; UNEP, 2025a). After the COVID pandemic, emissions rose from 53.7 $GtCO_2eq$ in 2020 to 57.7 $GtCO_2eq$ in 2024 (Crippa *et al.*, 2025; UNEP, 2025a). In 2025 they reached a record high, with fossil CO_2 increasing by 1.1% to roughly 38.1 billion tonnes (Crippa *et al.*, 2025; IEA, 2026d). Fossil CO_2 makes up close to 70% of all GHG emissions.

Limiting human-caused global warming requires net-zero CO_2 emissions (IPCC, 2023; UNEP, 2025a). The level of emission reductions this decade will largely determine whether warming can be limited to 1.5°C (IPCC, 2023).

According to the IPCC, estimates of remaining carbon budgets depend on the level of reduction in non-CO_2 emissions. That is, the stronger the reductions in non-CO_2 emissions, the larger the remaining carbon budget for the same level of temperature change (IPCC, 2023). Therefore, CO_2 emissions should be considered with the reductions of other non-CO_2 emissions.

Among non-CO_2 emissions, methane is the most potent greenhouse gas. Due to its shorter atmospheric lifetime, reducing emissions of such a potent greenhouse gas can slow global warming within a decade. This makes methane mitigation one of the most effective complementary measures for reducing near-term warming alongside the rapid deployment of renewable energy and energy efficiency (UNEP, 2026b). The opportunities and tools available to reduce methane emissions vary across three relevant emitting sectors: fossil fuels, agriculture and waste. While technological hurdles remain in the agriculture and waste sectors, solutions, often highly cost-effective ones, are already available for the fossil fuel sector; the primary gaps lie instead in regulatory, financial, and policy measures (UN, 2026). Beyond their climate benefits, some methane mitigation measures can also contribute to energy and development benefits, reinforcing the case for accelerating implementation across sectors.



Rapid methane abatement also contributes to limiting the magnitude and duration of temperature overshoot.[12] Consistent with the IPCC's limited overshoot (C2) pathways (IPCC, 2023), early methane reductions can help preserve the remaining carbon budget by slowing near-term warming, thereby reducing the risk of exceeding 1.5°C by a larger margin or for a longer period. This complements long-term CO_2 emissions reductions and strengthens the likelihood of returning to 1.5°C following limited overshoot.

As set out by the United Nations Secretary-General's 2026 Call to Action on Methane, governments, industry, and investors have an opportunity for immediate action to slow warming during the current decade, help keep temperature overshoot as low as possible, preserve the upper end of the remaining carbon budget, and simultaneously accelerate the energy transition through nine priority actions across three sectors to be delivered by 2030 (UN, 2026).

Given cumulative CO_2 emissions from 2020 to the end of 2025, the remaining carbon budget at the beginning of 2026 was between 120 $GtCO_2$ and 420 $GtCO_2$ for a 50% probability of limiting global warming to 1.5°C.[13] Some reports suggest that the remaining budget is towards the lower end of the range, at less than 200 $GtCO_2$ (Friedlingstein *et al.*, 2025; UNEP, 2025a).

New analysis shows a more positive outlook within the PES than previously, thanks to the recent implementation of policies aimed at reducing CO_2 emissions reduction. Under the PES, global annual fossil CO_2 emissions would decrease by 26% from the current emissions levels by 2050, with an average annual reduction of 0.2% over the period 2025-2030 and 1.4% thereafter. It is expected that the cumulative emissions over the period 2026-2050 would be around 840 $GtCO_2$ (Figure 1.10). This level of emissions is still too high and would lead to a global temperature increase of likely at least 2°C above pre-industrial levels.

Under the DES, carbon neutrality would not be achieved until after 2050, with net fossil CO_2 emissions being around 4 $GtCO_2$ in 2050 – representing an average annual reduction rate of more than 8%. Under this scenario, the cumulative emissions until 2050 are around 480 $GtCO_2$, an increase of 160 $GtCO_2$ from IRENA's previous 1.5°C scenario. Under the DES Scenario, global temperatures would temporarily exceed 1.5°C before 2050.

Under the revised 1.5°C Scenario, cumulative emissions over the period 2026-2050 are slightly below 400 $GtCO_2$. This scenario limits the global warming to 1.5°C (>50%) with limited and temporary overshoot. This assumes greater energy efficiency and carbon capture than the DES, particularly through BECCS in power supply, industrial processes, and heating supply sectors. Under this scenario, net-zero fossil CO_2 emissions are achieved in 2050.

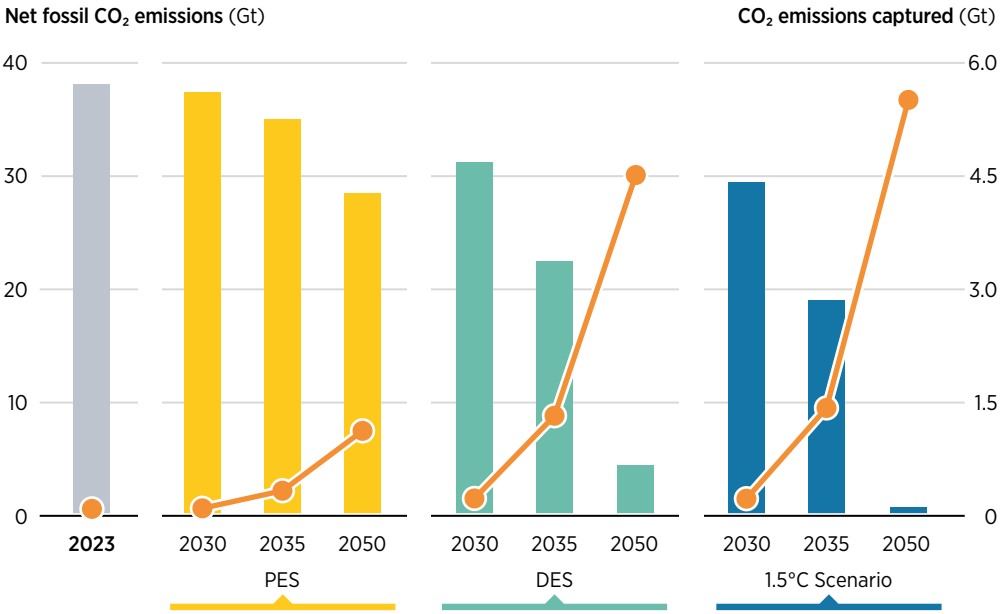


Delaying action narrows the remaining carbon budget and increases both the scale of emissions reductions required and the risk of a larger, longer overshoot.

[12] *Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C for several decades; high overshoot by up to 0.3°C.*

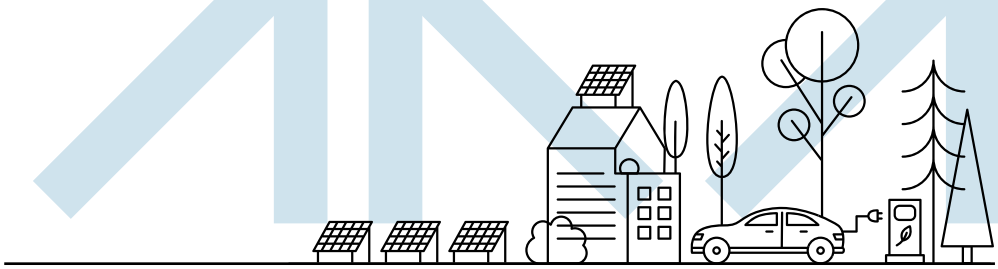
[13] *The range of the remaining carbon budgets is calculated based on the budget range at the beginning of 2020 (IPCC, 2023) and the cumulative CO_2 emissions from fossil fuels over the period 2020–2025 (Friedlingstein et al., 2025; IEA, 2021, 2026d).*

FIGURE 1.10 **Evolution of fossil CO_2 emissions ($GtCO_2$) and emissions captured ($GtCO_2$) under the PES, DES and 1.5°C Scenario, 2023-2050**



Source: CO_2 emissions captured data for 2025 are extracted from IEA CCUS Projects database 2026 (IEA, 2026b); Net fossil CO_2 emissions data for 2025 are from Global Energy Review 2026 (IEA, 2026a).

Notes: CCUS = carbon capture, utilisation and storage; CO_2 = carbon dioxide; DES = Decarbonising Energy Scenario; Gt = gigatonne; PES = Planned Energy Scenario.



Given the small size of the remaining carbon budget to limit global warming to 1.5°C, the deployment of CCS technologies will play a key role in complementing the use of renewables and other low-emissions technologies in energy sector.

Currently just over 62.5 Mt of CCS capacity is operational globally (IEA, 2026f). Under the PES, the CCS capacity would remain below 100 Mt by 2030. This scenario's results show that after 2030 the CCS capacity would sharply increase to reach 320 Mt in 2035 and to exceed 1000 Mt in 2050. However, the analysis shows that more CCS capacity would be required to meet the goals of the Paris Agreement.

Under the DES, CCS capacity would need to be at least 200 Mt by 2030, then to grow significantly to 1250 Mt in 2035 and 4500 Mt in 2050. This represents an additional capacity of at least 30 Mt/year until 2030, and 170 Mt thereafter. Under the IRENA's revised 1.5°C, the annual additions would exceed 200 Mt after 2030.

In all scenarios, the G20 countries play a key role in accelerating the deployment of CCS technologies. Under the PES, over 95% of the CCS capacity would be concentrated in these countries in 2050. The share is slightly less than the 80% of global capacity in the DES and the 1.5˚C Scenario. This highlights the need for global efforts to complement those of the G20 in achieving the goals of the Paris Agreement. For more details, see Appendix 2.

Substantial efforts beyond those already planned in key sectors such as power, heat and industry would be required, with negative emissions delivering the necessary additional carbon reductions required, particularly towards 2050 and beyond.

Nevertheless, fossil-based carbon capture should be considered as an intermediate solution enabling the continued, cleaner use of existing fossil fuel infrastructure while cleaner technology markets mature. On the other hand, BECCS should be considered as a long-term solution, as it is a negative emission technology essential for returning global temperatures to 1.5°C after a temporary overshoot.

Investment to set the pace of the transition

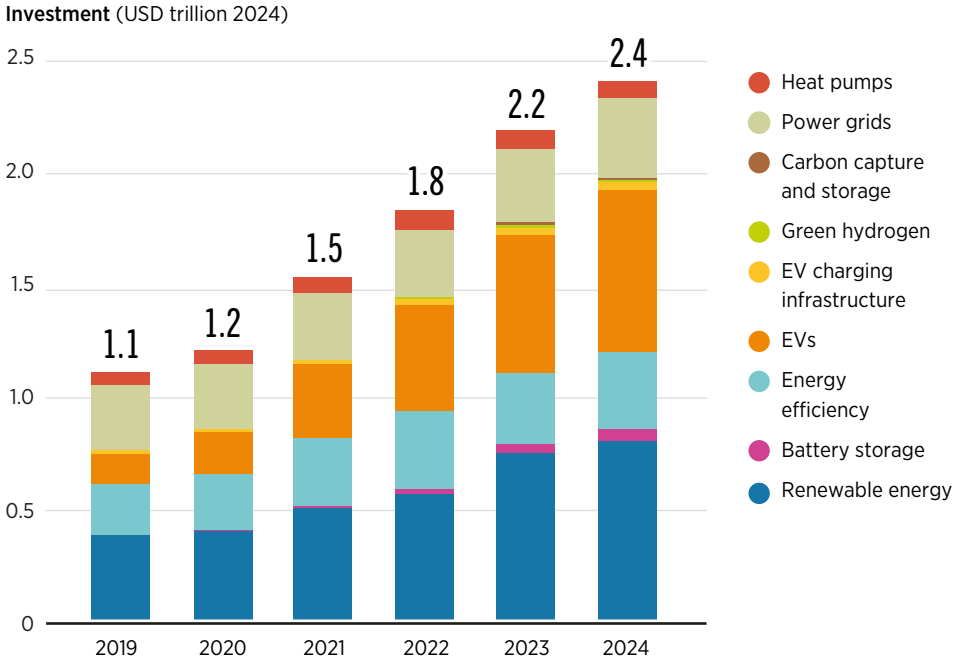
Current status

Global investments in energy transition technologies reached a record high of USD 2.4 trillion in 2024, a 9% increase from 2023 (IRENA and CPI, 2025) (Figure 1.11). Growth in relatively mature technologies – renewable energy, energy efficiency, grids, and electrified transport – continued in 2024, owing to strong policy support, market dynamics, and cost declines. Despite this progress, investments across key energy transition technologies still fall short of the level required to align with IRENA's 1.5°C pathway (see Chapter 2).

The recent growth in investments has been driven primarily by China and advanced economies. These are the primary hubs for innovation, deployment and value creation, accounting for more than 90% of investments in the deployment of energy transition technologies in 2024,[14] while many emerging markets and developing economies remain starkly underfunded. Africa has received less than 1% of investment in recent years, and least developed countries (LDCs) – 33 of which are located in Sub-Saharan Africa – received less than 0.5% (IRENA and CPI, 2025).

[14] This excludes energy efficiency investments as country-level data is limited.

FIGURE 1.11 Annual energy transition investments (USD_{2024} trillion) by technology, 2019-2024



Source: (IRENA and CPI, 2025).

However, large parts of the developing world continue to attract only a small fraction of global capital flows despite pressing needs for greater access to energy, abundant renewable resources and growing energy demand (IRENA and CPI, 2025). This imbalance not only slows progress towards climate and development goals but also limits opportunities to enhance energy security, create local value, and foster inclusive socio-economic development. Many developing countries remain constrained by high capital costs, limited fiscal space and insufficient access to affordable external finance. They are hobbled by their dependence on external funding, which remains either unaffordable or inaccessible. Moreover, private sector participation remains highly limited in such contexts.

Many developing countries struggle to attract funding to exploit their abundant renewable resources.

At the same time, investment in clean energy manufacturing and supply chains has become increasingly concentrated geographically, raising concerns about resilience, diversification and equitable participation in the emerging energy economy. While some major economies are increasingly able to finance their own transitions, many developing countries remain constrained by high capital costs, limited fiscal space and insufficient access to affordable external finance.

Continued fossil fuel investment highlights persistent misalignments between capital allocation and global climate objectives (IRENA and CPI, 2025). Addressing these misalignments is key to accelerating the transition. It will require carbon pricing that accurately reflects the true cost of emissions, the gradual phase-out and elimination of fossil fuel subsidies, and the redirection of freed-up public resources to underserved markets and safety nets.

In 2024, global investments (based on final investment decisions[15]) in renewable energy reached USD 807 billion, up 22% from the annual average of 2022/23. About 96% of final investment decisions (also referred to in this report as "investments") in 2024 were in the power sector (USD 773 billion), and only 1% (equivalent to USD 10 billion) went to projects for direct use of renewables in heating and transport.[16]

But year-on-year growth has slowed down. Annual investments grew just 7.3% in 2024 compared to 32% in 2023. Solar PV and wind technologies continue to dominate, making up a combined share of 93% in 2024, up from 89% in 2022/23. Investments in other renewable technologies – bioenergy, geothermal, hydropower and marine – made up the remaining 11% in 2022/23. Stronger public support for these technologies is still needed, especially to achieve more diversified portfolios of renewable energy sources and to drive renewable energy deployment for non-power uses such as heating/cooling and transport.

Closing the investment gap will require dedicated policy support and financing solutions tailored to a variety of energy transition technologies and contexts, particularly in developing markets, where the cost of capital is much higher. A substantial share of the risk premium investors apply in such markets reflects conditions in the energy sector: uncertainty over offtake and counterparty creditworthiness, grid access and curtailment, permitting and project development timelines, and regulatory uncertainty. Host governments, international development partners and the private sector can work together to introduce the necessary policy reforms and risk mitigation measures to improve these conditions. In addition, broader macroeconomic and financial sector changes may be needed. These may include expanding local capital markets to promote more local currency lending, redirecting fossil fuel subsidy support towards clean energy alternatives, fortifying public financial management, and encouraging international collaboration (notably South-South collaboration) on trade and finance.

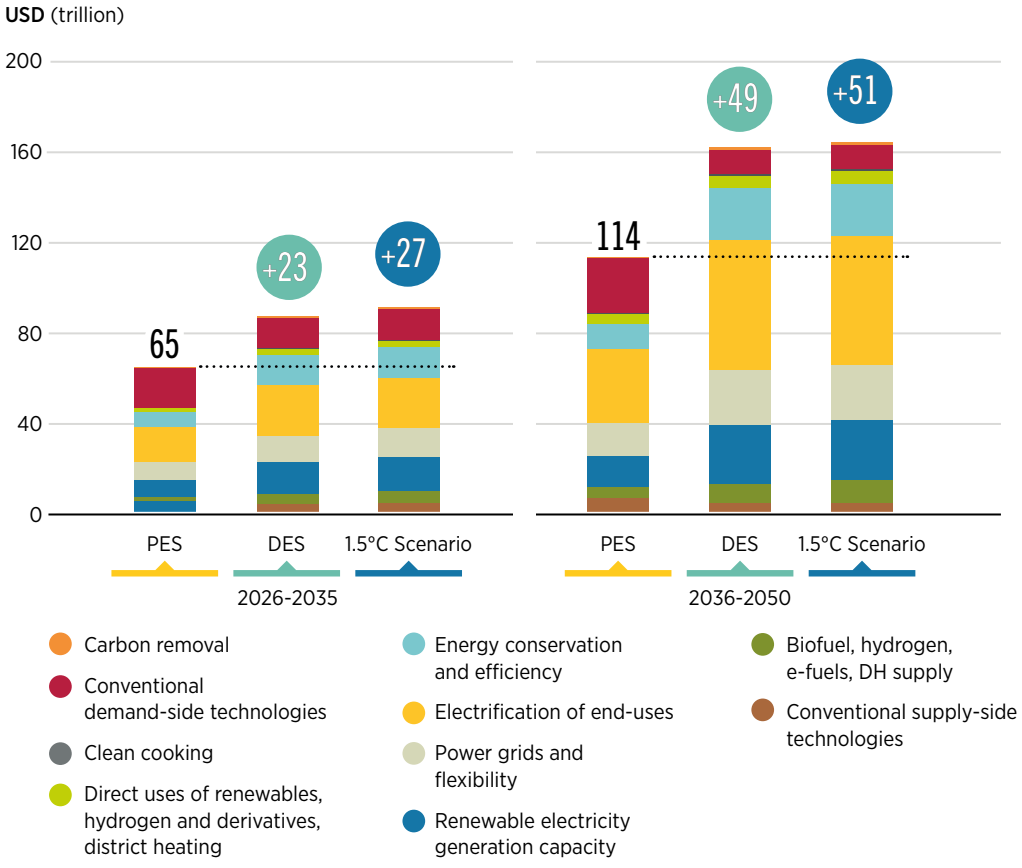
[15] *In this chapter, renewable energy investments are tracked at the time of financial close, meaning the funds have been legally obligated or committed. As the final investment decision method offers more granularity on investments by regions, sources and instruments, it is the preferred method for this chapter, as it provides deeper insights into historical trends. Elsewhere (IRENA, COP30 and GRA, 2025), the renewable energy investment figure is reported as USD 641 billion as it is calculated based on capacity commissioned in a given year (in megawatts) multiplied by the unit cost of that technology (in USD/MW).*

[16] *The remaining 3% (USD 24 billion) went to unknown projects that could not be attributed to either the power sector or other end uses.*

Investment needs

The global energy transition outlook hinges on investment in infrastructure and spending to acquire technologies and equipment. Investment and spending needs vary by scenario. The DES and the 1.5°C Scenario require substantially higher cumulative investment than the PES, with the investment gap widening after 2035 (Figure 1.12).

FIGURE 1.12 Global cumulative investments and expenditures (USD_{2025} trillion) under the PES, DES and 1.5°C Scenario, 2026-2050



Notes: Investment refers to capital costs in infrastructure (*e.g.* power plants and grids, manufacturing plants, charging stations). Expenditure covers the costs of acquiring technologies in end-use sectors (*e.g.* vehicles in transport; boilers and cookstoves in buildings).

DES = Decarbonising Energy Scenario; DH = district heating; e-fuel = electrofuels; PES = Planned Energy Scenario.

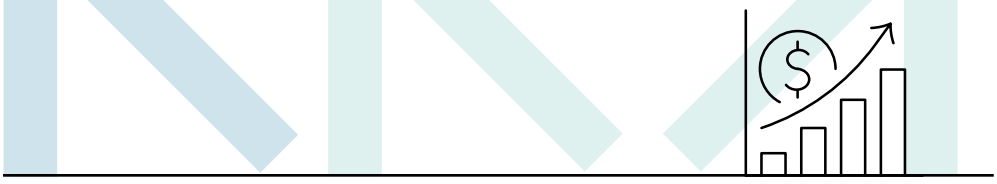
Under the 1.5°C Scenario, cumulative investment and expenditure needs are estimated at over USD 256 trillion between 2026 and 2050, equivalent to USD 10.3 trillion annually. This is USD 78 trillion and USD 6 trillion more than investments under the PES and DES, respectively, over the same period. Compared with WETO 2023, the annual requirement for the 1.5°C Scenario has increased by USD 3.8 trillion. The increase reflects the consequences of delayed progress, alongside greater granularity in regional coverage, updated technology costs and technological developments, as well as the additional measures captured under the revised 1.5°C Scenario introduced in WETO 2026.

The additional investment needed under the DES and 1.5°C Scenario compared with the PES, encompasses the investment in renewable power generation capacity, power grids and flexibility infrastructure, energy conservation and energy efficiency improvements, sustainable fuel infrastructure, and the electrification of end-use sectors.

The cumulative power sector investment under the PES, DES, and 1.5°C Scenario would reach USD 19.4 trillion, USD 28 trillion and USD 30 trillion over the 2026-2035 period, respectively. This is equivalent to an average annual investment of USD 1.9 trillion, USD 2.8 trillion and USD 3 trillion, respectively.

Under the PES, the cumulative investment needed for renewable power generation capacity, power grids, and flexibility amounts to USD 15.6 trillion over the period to 2035, representing an average annual investment of USD 1563 billion. The investment required for fossil fuel and nuclear power generation would reach USD 3.8 trillion by 2035, reflecting new capacity installations and continued operation. Current plans and policies indicate that the 2035 targets will not be fully achieved, further exacerbating the need for accelerated and costlier measures in subsequent years.

Amid the power sector's movement towards renewables under the DES and 1.5°C Scenario, a total of USD 26.2 trillion and USD 28 trillion, respectively, would be required through 2035, highlighting the scale of investment essential for a resilient and low-carbon power sector in alignment with climate goals. Relative to the PES, the cumulative investment required increases by 1.7-1.8 times under the DES and 1.5°C Scenario, respectively. This corresponds to an average annual investment of approximately USD 2620 billion and USD 2800 billion, respectively. Under the DES and 1.5°C Scenario, fossil fuel power plants are rapidly decommissioned, with few new installations. The corresponding investment required reaches USD 0.8-0.9 trillion by 2035. Overall, power sector investment constitutes more than 30% of cumulative investment by 2035 in both the DES and 1.5°C Scenario.



Global investment in renewable power generation capacity amounted to USD 625 billion in 2025, a slight reduction of 2% from the previous year. Analysis shows that under the 1.5°C Scenario, average annual investment needs in renewable power generation technology would reach USD 1520 billion between 2026 and 2035 (see Appendix 3). These levels are about 1.8 – 2 times higher than under PES.

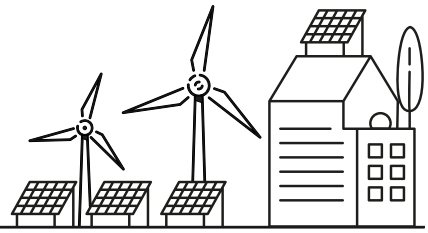
Variable renewable technology will attract the significant share of investment. Solar PV would require an average annual investment of USD 527 billion; onshore wind would need USD 360 billion; offshore wind, USD 221 billion. The annual investment required must increase 1.3, 2.7, and 11 times for solar, onshore wind, and offshore wind, respectively compared to 2025.

Beyond VRE technologies, investment in other renewable technologies must also accelerate to support the power sector transition. The annual investment in hydropower technologies must increase almost four times and bioenergy nine times. Substantial investment is needed across geothermal, concentrated solar power, and marine technologies 1.5°C Scenario.

A high share of VRE requires the power system to be flexible, resilient and digitalised. Investments in modernising and expanding transmission and distribution grids are essential to accelerate the global energy transition by supporting renewable energy growth, enabling efficient energy flows and reducing curtailment. Flexibility as referenced here includes battery storage, pumped hydropower, long-duration storage and smart grid deployment, with the balance between them varying by region according to resource mix, market design and permitting timelines.

Under the 1.5°C Scenario, the average annual investment in grids and flexibility amounts to USD 1283 billion between 2026 and 2035, up from the current investment of USD 525 billion. USD 1049 billion of the annual investment required during that period is assigned to strengthening electricity grids, which is double the 2025 investment of USD 422 billion. In addition, energy storage would require USD 234 billion in annual investment out to 2035 to support system flexibility and reliability.

The transition will depend as much on where investment flows as on how much capital is mobilised.



In the end-use sectors, countries' plans show that total investment for 2026-2035 would amount to almost USD 43 trillion with nearly 60% (USD 25 trillion) allocated to energy transition. Under both the DES and the 1.5 °C scenarios, the total investment amounts to just over USD 54 trillion with energy transition investment allocation of around USD 40 trillion over the same period. This investment includes investment in energy conservation and efficiency (USD 13.7 trillion), electrification in end-use sectors (USD 22.6 trillion, for regional aggregation [see Table 2-1 in Chapter 2]), adoption of sustainable fuels such as biofuels and hydrogen and its derivatives (USD 2.3 trillion under DES and USD 2.7 trillion under the 1.5°C Scenario), and clean cooking (USD 444 billion under both the DES and 1.5°C Scenario).

Under current plans, the annual average investment for the period 2026-2035 will be over USD 4 trillion, while under the DES and 1.5°C Scenario, slightly over USD 1 trillion more would be required. It is important to highlight that under the PES, between 2026 and 2035, the investment for conventional technologies is still higher in the PES compared to the DES and 1.5°C Scenario. For details on the investment required in each of the analysed categories in end-use sectors, see Appendix 4.

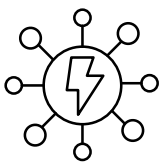
CHAPTER 02

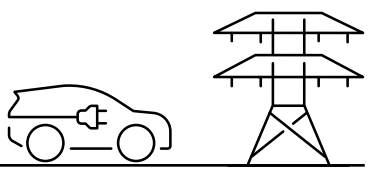
ADVANCING ELECTRIFICATION AS A KEY ELEMENT OF THE TRANSITION



KEY INSIGHTS

- Renewables-based electrification is a cornerstone of a 1.5°C-compatible pathway and a key driver of the transition away from fossil fuels in transport, buildings and industry.
- Electricity would become the dominant energy carrier in a transitioned economy, with its share in total final energy consumption rising from 23% today to more than 50% by 2050.
- Electrification improves energy efficiency, reduces fossil fuel demand, strengthens energy security and supports industrial competitiveness and innovation.
- Transport will electrify fastest, while buildings and industry will increasingly adopt heat pumps, electric heating, electric industrial processes and renewable hydrogen solutions.
- Electrification pathways differ across regions depending on development levels, infrastructure readiness and access to finance, with decentralised renewables playing a critical role in expanding energy access in developing economies.
- Electrification must be accompanied by rapid renewable energy deployment, grid expansion, storage, digitalisation and system flexibility to deliver deep decarbonisation.
- Co-ordinated policies, investments and international co-operation are essential to accelerate electrification while ensuring affordability, resilience and inclusive development.





Electrification with renewables as a cornerstone of the global energy transition

The Paris Agreement's key objectives are to transition energy systems away from fossil fuels and limit the increase in global temperature to 1.5°C. Electrification driven by renewable energy is one of the most effective, scalable and economically viable pathways to enable this transition while simultaneously advancing energy security, industrial competitiveness and sustainable development.

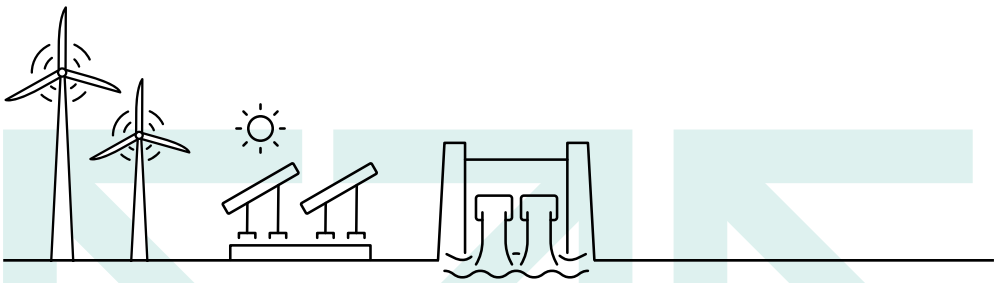
Historically, transport, buildings and industry have been dominated by fossil fuels. However, the rapid growth of renewable electricity generation, combined with technological progress and declining costs of electric technologies, is reshaping the economics and feasibility of electrification (IRENA, 2026j). Electrification reduces demand for fossil fuels directly by replacing combustion-based technologies in end-use sectors. Renewables-based hydrogen and other renewables-based fuels provide complementary solutions where direct electrification is not technically or economically feasible.

Combined with rapid deployment of renewable power and sustained improvements in energy efficiency, electrification is a core pillar of the 1.5°C-compatible energy system described in Chapter 1. Electrification and renewable power are mutually reinforcing: Higher shares of renewables increase the emissions-reduction potential of electrified end uses, while growing electricity demand from electrification expands the market for renewable energy deployment.

According to IRENA's scenario analysis, electrification through renewables, together with energy efficiency, could deliver a third of cumulative reductions in CO_2 emissions between 2026 and 2050, equivalent to approximately 110 $GtCO_2$. The scenarios referenced here – the PES, the DES, and the 1.5°C Scenario– are described in detail in Table 1.1 and surrounding text.

But electrification represents more than a decarbonisation solution. It is a structural transformation of the energy system that reshapes patterns of energy production, consumption, trade and infrastructure development. It delivers these wider benefits by:

- Strengthening energy security through reduced reliance on imported fossil fuels and lower exposure to geopolitical disruptions and fuel price volatility
- Lowering total energy demand through the higher efficiency of electric technologies.
- Enabling greater integration of renewable energy while supporting new industrial value chains – including batteries, renewable hydrogen, power electronics and digitalised energy systems
- Improving air quality, road noise levels in urban areas, public health and broader economic opportunities associated with clean energy industries (such as innovation, employment and industrial development).



As noted in Chapter 1, realising these benefits will require substantial investments in enabling infrastructure. As the share of variable renewable energy increases and electricity demand grows, power grids will need to become more flexible, interconnected and digitalised. Expanding the charging infrastructure, deploying energy storage and strengthening demand-side flexibility will also be critical to delivering reliable, resilient and affordable electricity systems. Appropriate policy frameworks, market design reforms and targeted financial mechanisms will be key to mobilising investment and accelerating deployment, especially in emerging markets and developing economies.

The economics of electrification have been improved by the falling cost of renewable electricity. The costs of solar PV and onshore wind fell by approximately 88% and 56%, respectively, between 2010 and 2025, making renewable electricity more competitive compared to fossil-fuel-based alternatives. In the process, electrification has become a "no-regret" option. It contributes to climate mitigation, energy efficiency, energy security and industrial competitiveness – and does so across all transition pathways. Electrification alone will not deliver the full transition required, but it is the most promising base for speeding up the transition away from fossil fuels.

The growing role of electricity in a 1.5°C-compatible pathway

Energy systems are fundamentally designed to deliver services – mobility, heating, cooling, lighting, communication and industrial production. Electrification transforms the way these services are provided by replacing fossil fuel combustion with electricity-based technologies that are significantly more efficient, more flexible and more compatible with renewable energy systems.

In a 1.5°C-compatible pathway, electricity would become the dominant energy carrier globally, playing a central role across all end-use sectors. The share of electricity in global total final energy consumption would increase from around 23% today to approximately 35% by 2035; by 2050 it would exceed 50% (see Figure 1.3 in Chapter 1). This represents one of the most profound structural shifts in modern energy systems, requiring the simultaneous expansion of renewable electricity, enabling infrastructure, markets and end-use technologies, while progressively transitioning away from fossil fuels.

The expanding role of electricity is underpinned by three mutually reinforcing trends. The accelerated deployment of renewable power gradually decarbonises electricity and makes it cost-competitive. The growing efficiency of electric technologies outpaces that of combustion-based alternatives. And advances in digitalisation, storage and smart grids improve the flexibility and reliability of the energy system.

This change occurs along two complementary pathways. *Direct electrification* replaces fossil fuel-based technologies with electric alternatives in transport, buildings and industry. *Indirect electrification* uses renewable electricity to produce renewable hydrogen and other renewables-based fuels for uses where direct electrification is still technically or economically challenging.

The pace of electrification varies across end-use sectors depending on technology readiness, infrastructure availability, investment requirements and operational constraints.

The buildings sector is one of the largest near-term electrification opportunities. Electricity is set to make up 77% of final energy consumption by 2050 under the 1.5°C Scenario, driven by heat pumps, electric cooking, electric water heating and more efficient appliances. Together with improvements in building efficiency, electrification significantly reduces both emissions and total energy demand, while improving air quality and reducing energy costs.

Transport would experience the fastest pace of electrification. Electricity would increase from around 1.5% of transport energy consumption today to nearly 50% by 2050 under the revised 1.5°C Scenario, driven primarily by the electric vehicles, electrified public transport and modal shifts towards rail, together with the gradual electrification of selected aviation and maritime applications.[17] Achieving this transition will require the rapid expansion of charging infrastructure, combined with the development of battery supply chains and supportive policy frameworks. Smart charging and vehicle-to-grid technologies will play an even greater role in providing flexibility to power systems.

Industry presents more diverse electrification pathways due to the wide range of industrial processes and the continued need for high-temperature heat in energy-intensive sectors such as steel, cement and chemicals. Industrial electrification would increase to around 40% by 2050 under the 1.5°C Scenario, particularly through electric motors, industrial heat pumps, electric furnaces and electrochemical processes. Renewable hydrogen and renewables-based fuels will complement direct electrification in hard-to-abate applications where electricity alone is not technically or economically feasible.

Beyond end-use sectors, the growing role of electricity fundamentally reshapes energy infrastructure and system operation. Electricity grids will need to expand considerably and become increasingly interconnected, digitalised and flexible to accommodate higher electricity demand and larger shares of variable renewable energy. Investments in transmission, distribution, energy storage and demand-side flexibility therefore become central components of the transition.

At the same time, electrification strengthens system integration across sectors. Flexible electricity demand from electric vehicles (EVs), heat pumps, industrial loads and renewable hydrogen production can help balance renewable generation, improve overall system efficiency, and reduce system costs through stronger coupling between electricity, transport, buildings, and industry.

Despite this rapid expansion, some applications – notably aviation, shipping and selected high-temperature industrial processes – will continue to require renewable hydrogen and other sustainable fuels. Electrification should therefore be seen as the backbone of the transition rather than its only solution. Its growing role reflects not only a technological transformation, but also a broader shift towards more efficient, interconnected, resilient and renewables-based economies.

[17] *In the maritime sector, port electrification through shore-to-ship power ("cold ironing") provides immediate emissions reductions. Shore-to-ship power can cut a cruise ship's carbon output from 72.2 t to 50.1 t during a typical 10-hour port stay (Arduino,* Carrillo Murillo and Ferrari*, 2011).*

Regional pathways and development dimensions

Although the role of electricity grows in all regions, under the IRENA 1.5°C Scenario, the pathways of that growth are by no means uniform. They are shaped by differences in economic development, industrial structures, resource endowments, infrastructure readiness, demographic trends and access to finance. Consequently, countries will follow different pathways towards the common objective of transitioning away from fossil fuels, reflecting their national circumstances and development priorities.

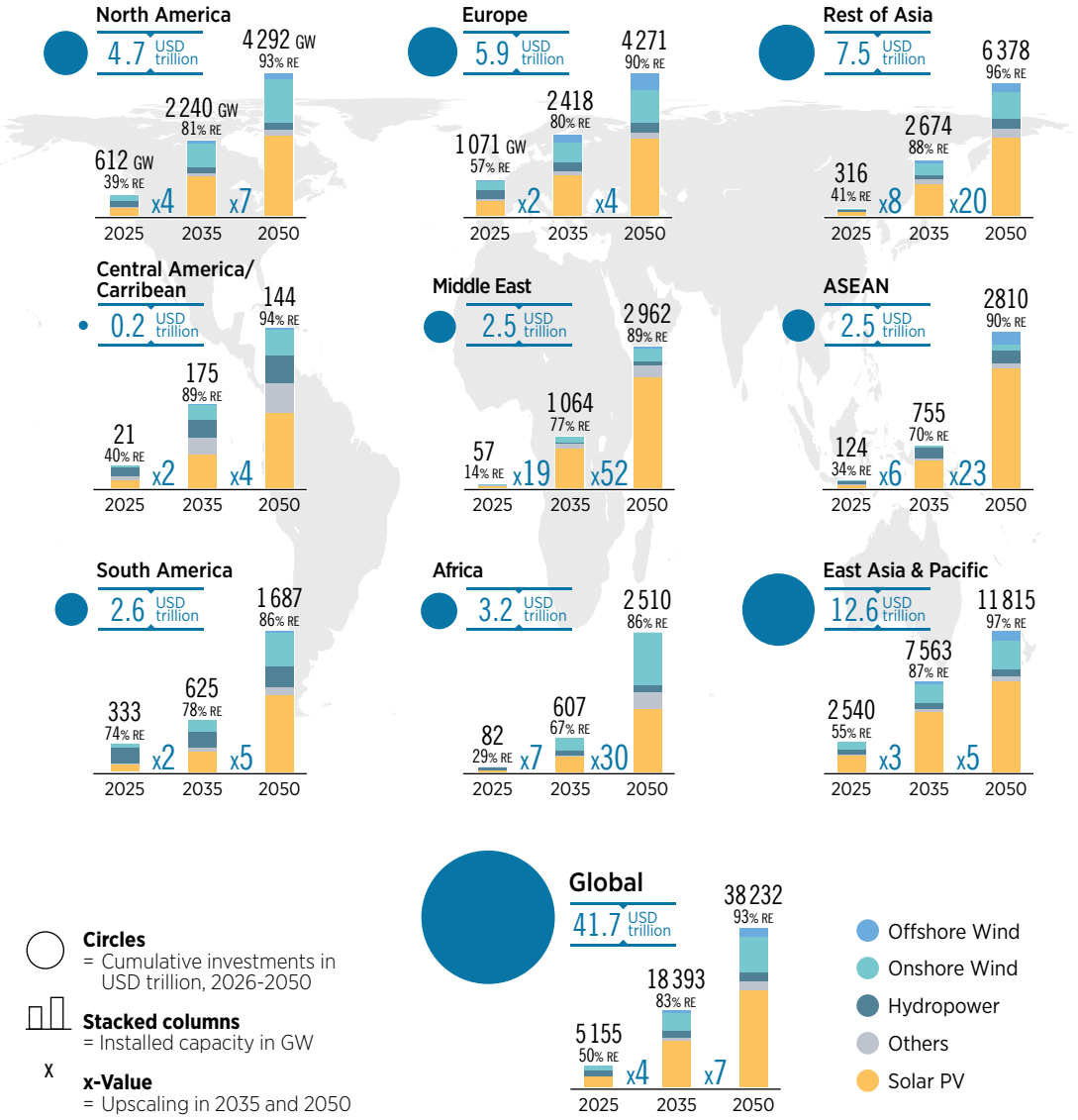
While advanced economies primarily focus on replacing existing fossil-fuel-based technologies with cleaner and more-efficient electric alternatives, many emerging markets and developing economies must simultaneously expand access to modern energy services, support industrialisation and strengthen energy security. Electrification therefore represents not only a decarbonisation pathway but also an important opportunity to foster economic development, improve energy access and enhance long-term competitiveness.

The renewable deployment needed to deliver the 1.5°C Scenario, by region

Progress in renewable power deployment continues to be unevenly distributed across regions and countries. In 2025, over 90% of new renewable capacity additions occurred in Asia, Europe and North America. The 1.5°C Scenario would require expansion of renewable power generation technologies across *all* regions based on their respective technical potential, resource availability and the pace of end-use sector electrification, supported by substantial investment (Figure 2.1).

There is a common direction, but no single pathway: regional transitions must reflect different starting points, resources and development priorities.

FIGURE 2.1 Regional distribution of total installed renewable capacity (GW) in 2025, 2035, 2050 and cumulative investments (USD trillion) of renewables for power generation under the 1.5°C Scenario for selected regions, 2026-2050



Note: Maritime and aviation bunkers are excluded. Regional values may not sum exactly to the global total owing to differences in aggregation in the underlying analysis. Europe includes the United Kingdom, the Western Balkans, Ukraine, Moldova, the Russian Federation and Türkiye. ASEAN-10 comprises the ten member states of ASEAN prior to October 2025; Timor-Leste acceded in that month and is analysed here within East Asia and the Pacific, consistent with the country coverage of the underlying modelling. Africa and South America each cover the full continent, with the Middle East reported separately. Components may not sum to totals owing to rounding.

GW = gigawatt; RE = renewable energy; PV = photovoltaic.

Asia will play a pivotal role in the global energy transition, considering the region's large share in global emissions and growth in electricity demand. Asia accounted for the majority of renewable capacity additions in 2025 (74%) and would see a considerable shift towards renewable energy, with the ASEAN countries growing their renewable power capacity to around 3 TW; East Asia and Pacific to around 12 TW; and the rest of Asia to around 6 TW by 2050, with variable renewables dominating.[18] These changes would necessitate large-scale cumulative investment over the outlook period to stay on track.

Europe added 85 GW of new renewable power capacity in 2025, bringing the total installed capacity to 1 071 GW, an increase of almost 9% compared to 2024.[19] To stay on track for the 1.5°C Scenario, Europe's renewable capacity needs to double by 2035 and quadruple by 2050, driven by vast wind and solar expansion (IRENA, 2025b). This would require a cumulative investment of USD 5.9 trillion from 2026 to 2050. Achieving a 1.5°C-compatible future, as in the 1.5°C Scenario, requires immediate and co-ordinated efforts to decarbonise the Europe's power sector (IRENA, 2025b).

North America added 42 GW of new renewable capacity in 2025 (+7.4% year-on-year growth), bringing its cumulative renewable capacity to 612 GW. North America is already a major contributor to global renewable deployment; however, under the 1.5°C Scenario, the region needs to expand almost four times by 2035 and seven times by 2050, compared to 2025, requiring a cumulative investment of USD 4.7 trillion.

South America's power sector is already fairly low in carbon, owing to the region's hydropower and bioenergy resources. Under the 1.5°C Scenario, renewable capacity 1.5°C Scenario would need to double by 2035 and grow by fivefold by 2050 compared with 2025 levels, supported by cumulative investment of USD 2.6 trillion over the outlook period. Solar and wind will drive most of future growth in renewables-based generation. Similarly, Central Americas' renewable power capacity by would need to double and quadruple by 2035 and 2050, respectively, over the 2025 level of 14 GW of renewables-based generation. Integrated regional planning for the energy transition will be needed to link energy policy with climate policy and country commitments.

Africa is in the early stages of the energy transition. The region experienced its largest renewable capacity growth on record in 2025 with 11.3 GW of additions, demonstrating increasing momentum towards the energy transition. Yet the current progress remains well below the pace required to meet rising future electricity demand as cumulative renewable capacity under the 1.5°C Scenario would need to increase by seven times in 2035 and thirty times by 2050 over the 82 GW generated in 2025. The scaling factor required for Africa is among the highest globally, underscoring the urgency of action. Achieving the goal will depend on overcoming obstacles like high financing costs, inconsistent policies, and the need for stronger infrastructure.

Historically, the Middle East region has been powered predominantly by natural gas and oil. The region needs to undergo a massive shift to diversify its generation mix to meet growing electricity demand. In 2025, the Middle East achieved record growth of 29.2% in renewable capacity, adding 12.8 GW. By 2050, renewable capacity would reach around 3 TW, with solar PV serving as the primary driver of expansion. This region possesses some of the world's best solar energy potential, positioning it as a key future hub for low-cost renewable electricity.

[18] *ASEAN refers to the Association of Southeast Asian Nations. It includes Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam. "Rest of Asia" excludes ASEAN and East Asia but includes Armenia, Azerbaijan, and Georgia.*

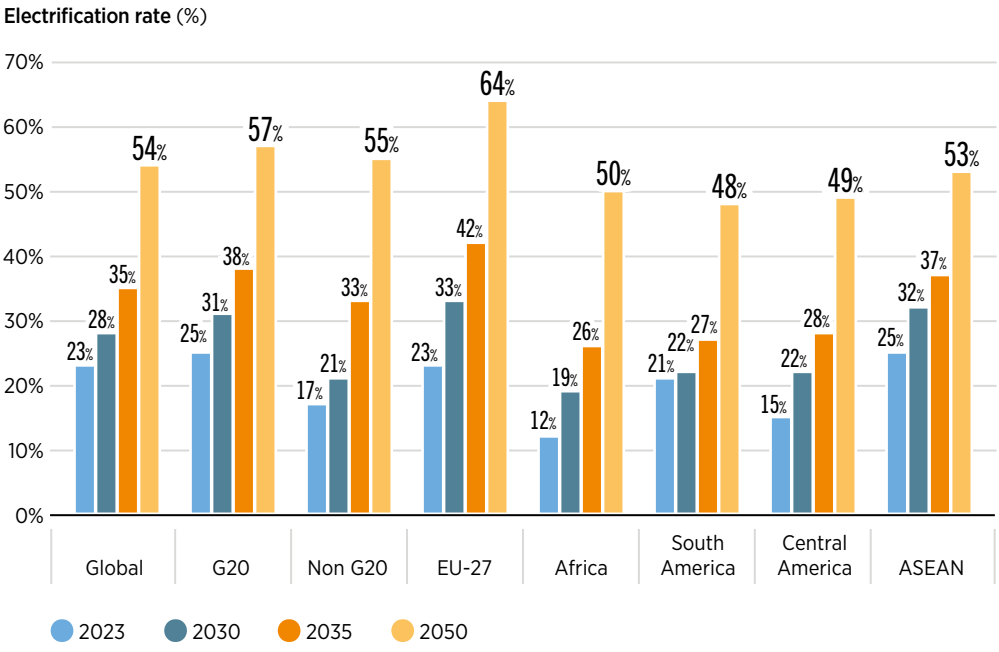
[19] *"Europe" comprises all European countries, including Russian Federation and Türkiye.*

To align with IRENA's 1.5°C pathway, regions must invest aggressively in electrification encompassing renewable energy technologies, grids and flexibility. Acceleration of the energy transition is a strategic necessity, as regions and countries failing to adapt or move slowly may struggle to maintain energy security, industrial competitiveness and economic resilience.

Regional electrification trajectories

Regional differences in electrification rates under a 1.5°C-compatible pathway also exhibit contrasting trajectories (Figure 2.2).

FIGURE 2.2 Evolution of the electrification rate for selected regions under the 1.5°C Scenario, 2023-2050



Source: Historical values (year 2023) are calculated based on (IEA, 2025b).

Note: Total final energy consumption excludes international marine and aviation bunkers, except at the global level; non-energy is excluded from the calculation of the shares.

ASEAN = Association of Southeast Asian Nations; EU = European Union; G20 = Group of 20, excluding the African Union.

By 2050, electricity would account for around 64% of total final energy consumption in the EU, reflecting widespread electrification across transport, buildings and industry, supported by mature electricity systems and ambitious climate policies (IRENA, 2025b). Africa would reach about 50%, but by a fundamentally different pathway. Electrification there is driven not only by replacing fossil fuel technologies, but also by increasing access to electricity, reducing dependence on traditional biomass, spreading urbanisation, and growing industrial development. Latin America and the Caribbean would also approach 50%, supported by already high shares of renewable electricity and the rapid electrification of transport and industry (IRENA, 2022b). The Association of Southeast Asian Nations (ASEAN) economies would come in at around 53%, reflecting rapid economic growth, industrialisation and urbanisation combined with expanding renewable electricity deployment (IRENA, 2022c).

Pathways for individual sectors reflecting different regional priorities

Although regional electrification rates gradually converge, the underlying contributions of each sector differ considerably according to each region's economic structure and development priorities.

The contributions of transport, buildings and industry to overall electrification vary significantly across regions (Figure 2.3), reflecting differences in technology maturity, infrastructure availability, industrial composition, patterns of energy demand and income levels.

The building sector is typically the largest opportunity for electrification in developing regions, with replacement of traditional biomass and greater access to modern forms of energy providing significant avenues for improving the quality of life and lowering emissions. This contrasts with advanced economies, where the electrification of transport stands out, accelerated by high uptake of electric vehicles and charging infrastructure and through supportive policy frameworks.

Industrial electrification shows the greatest regional variation. Countries with large energy-intensive industries will require a combination of direct electrification, renewable hydrogen and other renewables-based fuels, while economies with less energy-intensive industrial structures can depend more on direct electrification.

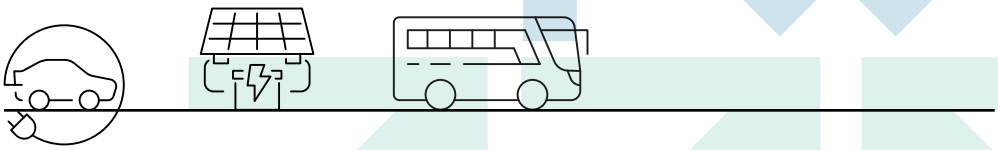


FIGURE 2.3 **Electrification rate by sector for selected regions under the 1.5°C Scenario, 2023, 2035 and 2050**



Based on: Historical values are calculated from (IEA, 2025b).

Notes: Total final energy consumption excludes international marine and aviation bunkers, except at the global level; non-energy is excluded from the calculation of the shares.

ASEAN = Association of Southeast Asian Nations; EU = European Union; G20 = Group of 20, excluding the African Union.

Although regional electrification pathways differ in terms of pace, sector-specific priorities and enabling conditions, the analysis also reveals important commonalities. Regardless of their starting points or development priorities, countries face many of the same implementation challenges, including the need for integrated planning, enabling infrastructure, supportive policy frameworks and access to affordable finance. These common priorities provide the foundation for a shared implementation agenda while allowing countries the flexibility to tailor their transition strategies to national circumstances (Box 2.1).

BOX 2.1 Electrification with renewables: Diverse national priorities, one common implementation agenda for COP31

The revised 1.5°C Scenario demonstrates that there is no single pathway to electrification. Countries will prioritise different sectors depending on their starting points, resource endowments, economic structures and development priorities. While advanced economies electrify primarily to decarbonise mature energy systems and strengthen industrial competitiveness, many emerging markets and developing economies also use electrification to expand energy access, support industrialisation and improve living standards.

Despite these different pathways, the 1.5°C Scenario consistently identifies a common set of implementation priorities:

- Accelerate deployment of renewable power to meet growing electricity demand with clean energy
- Expand and modernise electricity grids, storage, digitalisation and system flexibility
- Integrate electrification into national energy planning, together with renewable energy, grids, energy efficiency and sustainable fuels
- Strengthen enabling policy and regulatory frameworks, mobilise affordable finance and enhance international co-operation, particularly to support implementation in emerging markets and developing economies
- Accelerate innovation, digitalisation and modern power system operation, while investing in skills, institutional capacity and workforce development.

The common destination is clear, but countries will reach it through nationally tailored pathways. As countries prepare for COP31, IRENA's 1.5°C Scenario provides an analytical framework to guide implementation by identifying the common actions needed to deliver increasingly electrified energy systems powered by renewable energy.

Differentiated investment to meet different regional priorities

Successfully travelling the 1.5 °C pathway in different regions will require substantial but different mixes of investment in electricity generation, electricity networks and end-use technologies. Table 2.1 highlights the scale and geographical distribution of these requirements, pinpointing where financial resources, policy support and international co-operation will be most needed.

Advanced economies invest primarily in replacing existing infrastructure, expanding electricity networks, digitalisation, storage and flexibility. Many emerging markets and developing economies combine investments in electricity access, new infrastructure and productive uses of electricity, reflecting the dual objective of expanding modern energy services while supporting economic development.

Across all regions, electricity networks emerge as a common priority. This underlines the importance of integrating renewable deployment, electrification and grid expansion in national energy planning.

The regional analysis highlights that while countries will pursue different electrification pathways, several implementation priorities consistently emerge across all regions.

Buildings require accelerated deployment of efficient electric technologies, particularly heat pumps, electric cooking and electric water heating, alongside stronger building efficiency standards and appliance regulations. **Transport** requires continued expansion of charging infrastructure, accelerated deployment of electric mobility, supportive fiscal incentives and stronger integration between transport planning and electricity systems. **Industry** requires targeted support for industrial electrification alongside renewable hydrogen and renewables-based fuels in hard-to-abate sectors, supported by industrial policies that strengthen domestic manufacturing and innovation.

Transport represents the largest share of total electrification investment needs globally, accounting for 86% of cumulative requirements over 2026-2035 and 89% over 2036-2050. This preponderance reflects the scale of transformation required in mobility systems. G20 economies account for the majority of these investment needs, but non-G20 countries and regions will require a substantial increase in investments over time to achieve the milestones set out in IRENA's *Transition Away from Fossil Fuels* (TAFF; IRENA, 2026c) and support the COP31 electrification initiative currently under development.

Across all sectors, successful implementation will require integrated planning across renewable energy, electrification, energy efficiency and enabling infrastructure, together with accelerated investment in transmission and distribution networks, storage and flexibility, supportive regulatory frameworks, workforce development, strengthened domestic industrial capabilities, improved access to affordable finance and enhanced international co-operation.

In many emerging markets and developing economies, decentralised renewable energy systems are demonstrating how electrification can simultaneously expand energy access, stimulate local economic development and accelerate the transition away from fossil fuels. Box 2.2 illustrates how these approaches are supporting electrification in the African context.

Ultimately, regional electrification pathways demonstrate that the transition away from fossil fuels does not depend on a single model or sequence of actions. Countries will continue to progress at different speeds and prioritise different sectors according to their national circumstances. Nevertheless, analysis consistently shows that combining electrification with renewable energy deployment, enabling infrastructure and supportive policy frameworks provides the most effective pathway for accelerating the energy transition while strengthening energy security, industrial competitiveness and sustainable development.

TABLE 2.1 **Regional investment requirements linked to electrification in selected regions under the 1.5°C Scenario, by end-use sectors, 2026-2035 and 2036-2050**

	Sector	CUMULATIVE (billion 2025-USD)		ANNUAL (million 2025-USD)	
		2026-2035	**2036-2050**	2026-2035	**2036-2050**
Global	Buildings	2902	5584	290	372
	Industry	363	795	36	53
	Transport	19344	51551	1934	3437
G20	Buildings	2802	5215	280	348
	Industry	276	503	28	34
	Transport	17938	45735	1794	3049
Non-G20	Buildings	100	369	10	25
	Industry	87	292	9	19
	Transport	1405	5816	141	388
Africa	Buildings	70	309	7	21
	Industry	101	314	10	21
	Transport	1004	4399	100	293
EU	Buildings	1352	1853	135	124
	Industry	8	5	1	0
	Transport	4386	7194	439	480
South America	Buildings	20	41	2	3
	Industry	6	10	1	1
	Transport	764	3408	76	227
Rest of the World	Buildings	49	109	5	7
	Industry	2	4	0	0
	Transport	102	348	10	23

Note: Africa includes Democratic Republic of Congo (DRC), Egypt, Kenya, Nigeria, South Africa and rest of African countries in eastern, northern, southern and western African regions. EU includes Germany, France, Italy and Rest of EU 27. South America includes Argentina, Brazil, Colombia and rest of South America; Electrification numbers here, refers to investments and expenditure in electrification of end-use sectors, including buildings, transport, and industry. Buildings: heat pumps, electric boilers, electric heaters, etc. Transport: electric vehicles and EV charging infrastructure. Industry: electrification solutions such as electrolysis.

BOX 2.2 Decentralised electricity access in Africa: Accelerating access and development

Sub-Saharan Africa continues to have the largest electricity access deficit in the world, with over 565 million people still lacking access (IEA *et al.*, 2026). Most live in remote and rural areas where grid extension is either unaffordable or not technically feasible. In these contexts, decentralised renewable energy (DRE) solutions, especially mini-grids and standalone solar systems, have become an important complement to grid expansion, speeding up electrification while creating new economic opportunities and improving living standards.

In the last decade, DRE has become an important component of electrification strategies in Africa. Off-grid renewable capacity has increased from 294 MW in 2014 to 1.35 GW in 2024 (IRENA, 2025d), and mini-grid generation costs have fallen from USD 0.55/kilowatt hours (kWh) to USD 0.38/kWh since 2018 (ESMAP, 2022). The African Energy Commission now places mini-grids and off-grid solar at the centre of its 2030 access strategy and priorities (AFREC, 2025).

Reflecting this progress, IRENA's forthcoming regional energy transition outlook's for Africa finds that some 60% of new electricity connections foreseen by 2030 – encompassing approximately 401 million people – would be served most economically by mini-grids and standalone solar PV. Investment needs are concentrated in six countries: Democratic Republic of Congo, Ethiopia, Niger, Nigeria, Sudan, and Tanzania. It is in these countries that financing can have the greatest impact.

Therefore, mobilising finance is just as crucial as deploying technology. Initiatives such as Mission 300 (to provide electricity access to 300 million Africans by 2030) and Nigeria's DARES programme (targeting 17.5 million people and 1350 mini-grids, including 250 interconnected systems) (World Bank, 2023), are examples of the increasing momentum for electrification approaches that integrate public investment, private sector participation and international co-operation.

Beyond expanding access, DRE boosts energy security and resilience. By incorporating solar PV–battery hybrid mini-grids, diesel use can be reduced by as much as 80%, reducing exposure to volatile fuel prices and making the provision of electricity more cost effective and reliable. Hybrid PV with storage keep increases in the levelised cost of energy to 10-15% even when fuel prices double (IRENA, 2026k). As diesel gets more expensive, battery storage gets more valuable. Every dollar put into batteries avoids USD 2 to USD 4 in lifetime fuel costs, and the leverage grows further where transport markups and import dependence add to the price. Hybrid PV mini-grids with storage are often the most resilient option in access-deficit countries.

Electrification through DRE does more than reduce emissions. It widens economic opportunity and improves living standards in communities not reached or not served reliably by centralised infrastructure. In areas with weak grids DREs are powering clinics, schools and water pumps, enabling transformative and climate-resilient development across communities.

Decentralised renewables deployment, when informed with geospatial planning tools and frameworks such as IRENA's Strategic Energy Access Planning Support (SEAPS[20]). This enables countries to direct investments where they deliver the greatest gains in electricity access, local economic development and resilience.

Africa demonstrates that DRE is not an alternative to grid expansion, but a complementary component of integrated national electrification strategies, one capable of accelerating the transition away from fossil fuels while ensuring that no communities are left behind.

[20] *SEAPS is a country-level support framework IRENA is deploying through which national planning institutions produce settlement-level rural electrification plans covering grid, extension, mini-grids and standalone PV systems.*

System integration: Linking electrification, renewables and efficiency

Electrification cannot be considered in isolation. Its effectiveness and climate impact depend on parallel transformation of the larger energy system. Under the 1.5°C-compatible pathway, electrification, renewable energy deployment and energy efficiency improvements must evolve as an integrated package, rather than as separate policy or investment streams. Without this alignment, electrification risks shifting emissions across sectors instead of achieving system-wide decarbonisation.

A system-integrated approach enables electrification to deliver multiple co-benefits beyond emissions reductions. It:

- Improves overall energy system efficiency by replacing less efficient combustion-based technologies with electric alternatives
- Unlocks demand-side flexibility through electric vehicles, heat pumps, heat storage and industrial loads
- Optimises infrastructure investments through co-ordinated planning of generation, grids and storage
- Strengthens energy system resilience by diversifying supply sources and improving the adaptability of electricity systems.

Importantly, system integration also strengthens the economic case for electrification. Better co-ordination between renewable generation, electricity networks, storage and flexible demand reduces peak loads, improves utilisation of renewable assets and existing infrastructure, and lowers overall system costs.

These principles are increasingly reflected in international policy processes. The commitments adopted at COP28 to triple global renewable energy capacity and double the annual rate of energy efficiency improvements by 2030, together with the growing emphasis at COP29 on grid expansion, storage deployment and system flexibility, as well as on sustainable fuels at COP30, illustrate the increasing recognition that supply-side and demand-side transformations must advance together.

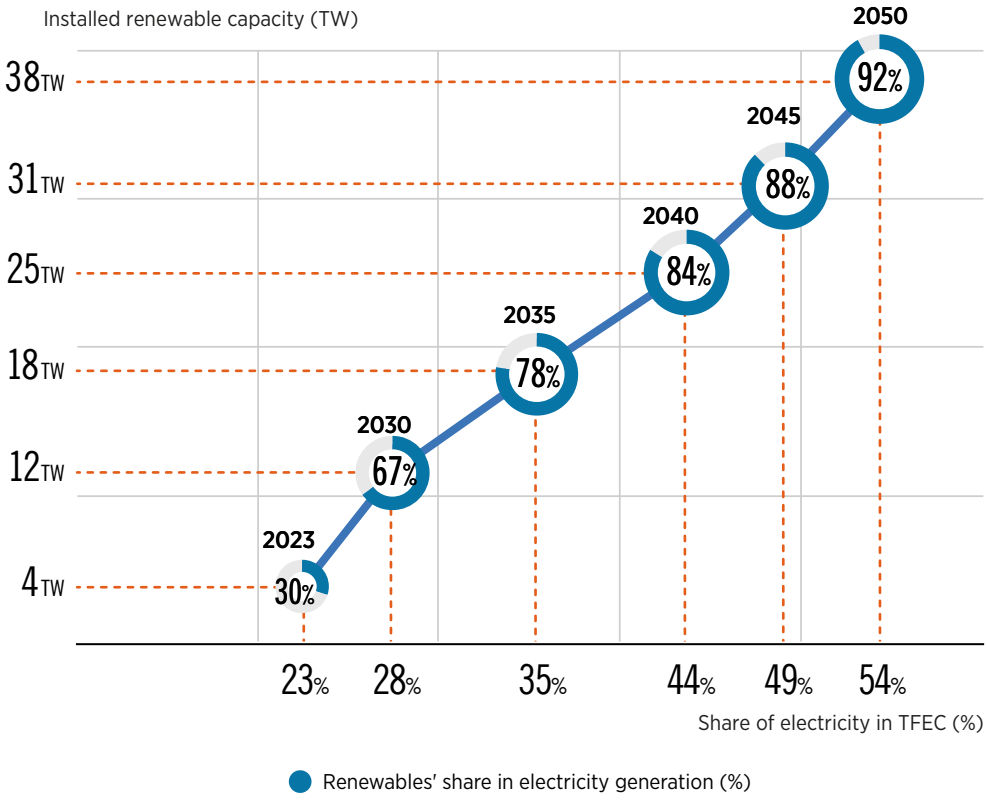
Electrification supports the necessary transformation through two mutually reinforcing channels. First, it directly displaces fossil fuel consumption in transport, buildings and industry. Second, it makes a business case for growing renewable electricity by increasing demand for clean power, speeding up investment in renewable generation and easing the transition away from fossil fuels.

As electrification accelerates across all end-use sectors, electricity demand rises sharply, calling for a parallel expansion of renewable power generation, electricity networks and system flexibility. In the revised 1.5°C pathway, renewable power capacity would increase to about 18 400 GW by 2035 and 38 200 GW by 2050. This would require unprecedented investment in solar, wind and other renewable technologies, as well as enabling infrastructure.



Average annual investment in electricity grids would need to increase from USD 0.5 trillion in 2025 to USD 1 trillion annually between 2026 and 2035, and to USD 1.2 trillion annually between 2036 and 2050, representing a total of almost USD 29 trillion in cumulative investment. At the same time, global installed storage capacity would increase from 416 GW in 2025 to 2 530 GW by 2035 and 6 860 GW by 2050, while daily flexibility would rise from 7% in 2019 to more than 13% by 2035 and 30% by 2050. The trajectory in Figure 2.4 illustrates the complementary growth needed under IRENA's revised 1.5°C Scenario in electrification rate, renewable share in electricity generation and renewable power capacity expansion. These dimensions must evolve together – alongside grids, storage and flexibility measures, and planning for the strategic phase-out of fossil fuel infrastructure – to enable a reliable and large-scale transition away from fossil fuels.

FIGURE 2.4 The energy transition to 2050 under the 1.5°C Scenario, 2023-2050



Source: (IRENA, 2026d).

Note: TW = terawatt; share of electricity in TFEC = share of electricity in the total final energy consumption; renewables include hydro power, solar, wind, geothermal and bioenergy-based technologies; values of "non-energy" uses are not included; Maritime and aviation bunkers are included in the TFEC at the global level.

However, expanding generation capacity alone will not be sufficient, as previously noted. Higher shares of variable renewables require power systems that are increasingly flexible, digitalised and interconnected. This means reinforcing transmission infrastructure to connect renewable resource areas with demand centres, reinforcing distribution networks to include distributed energy resources, deploying smart grid technologies and enabling real-time optimisation of power systems.

Energy storage will also play a central role of this transformation. Batteries, pumped storage hydropower and emerging long-duration storage technologies provide flexibility, support grid stability and improve the utilisation of renewable electricity. At the same time, demand-side flexibility – enabled through smart meters, dynamic pricing and digital energy management systems – allows electricity consumption to better match renewable generation, reducing system costs and improving overall efficiency.

Electrification delivers its full value only when renewables, efficiency, grids, storage and flexibility advance together as one integrated energy system.



Accelerating implementation through a global electrification agenda

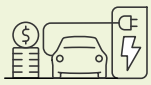
The analysis presented in this chapter demonstrates that electrification is a central pathway for accelerating the transition away from fossil fuels. Achieving the levels of electrification required under the 1.5°C Scenario will, however, depend less on technological availability than on the ability to implement co-ordinated policies and investments at the pace and scale required. While countries will follow different pathways according to their starting points, resource endowments and development priorities, the analysis points to a common implementation agenda centred on integrated planning, enabling infrastructure and supportive policy frameworks.

Recent international commitments have established an increasingly coherent foundation for this agenda. The UAE Consensus adopted at COP28 committed to tripling global renewable power capacity and doubling the annual rate of energy efficiency improvements by 2030. Building on this momentum, discussions at COP29 further highlighted the importance of expanding electricity grids, strengthening system flexibility and accelerating storage deployment, while COP30 reinforced the complementary role of sustainable fuels for sectors in which direct electrification remains technically or economically challenging. Together, these initiatives increasingly recognise that the transition away from fossil fuels requires simultaneous progress across renewable energy deployment, electrification, energy efficiency and enabling infrastructure.

Building on the scenario analysis presented throughout this chapter, IRENA proposes a global monitoring framework for electrification (Figure 2.5). The framework complements existing renewable energy and energy efficiency indicators by providing a practical approach to monitor the transformation of end-use sectors together with the enabling conditions required to support it. Rather than focusing on a single target, it recognises that successful electrification depends on co-ordinated progress across electricity demand, renewable electricity supply, enabling infrastructure and policy implementation.



FIGURE 2.5 Global monitoring framework for electrification under the IRENA 1.5°C Scenario

	**Share of electricity in total final energy consumption (TFEC) (%)**, as a core global electrification indicator.
	**Sector-specific (buildings, transport, industry) growth in electricity demand (TWh)**.
	**Electricity consumption per capita (in petajoules [PJ])**, an indicator of the uptake of modern energy services.
	**Deployment indicators (in number of units)** for key electric technologies, like electric vehicles and heat pumps and electrified industrial processes.
	**Annual capital investment in transmission and distribution grids (in USD)**, as a primary indicator of grid infrastructure scaling.
	**Socio-economic impacts[21] (on GDP, employment and welfare) and required investment (USD).**
	**Policies and regulatory frameworks** that enable electrification, such as standards, incentives , technology transfer, capacity building and infrastructure deployment.
	**Finance and support mechanisms** for end-use sectors and infrastructure adjustments, including access to low-cost financing and investments in grid infrastructure, particularly in developing countries.

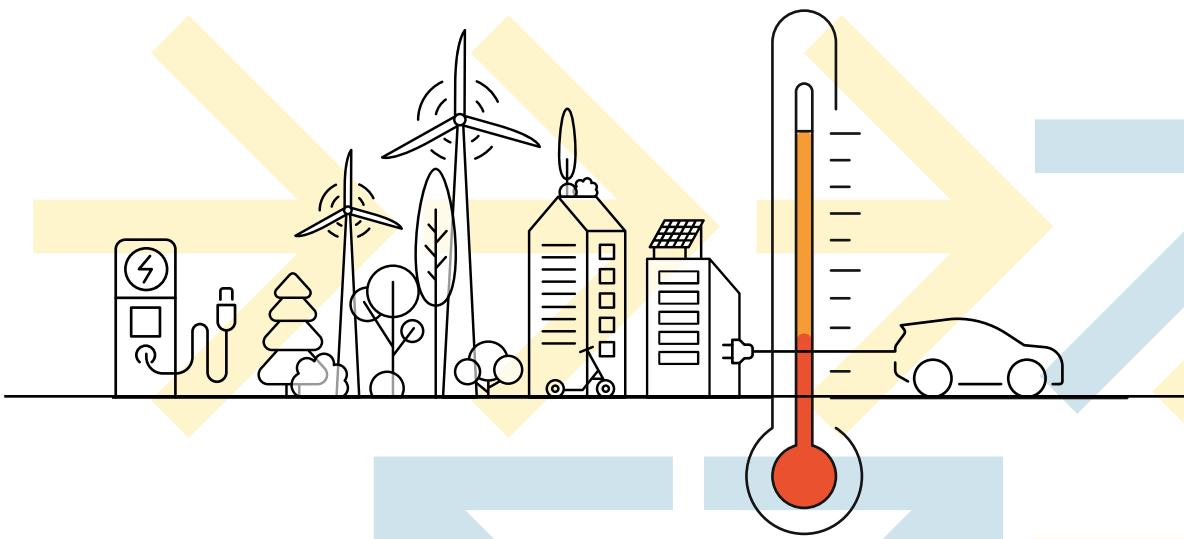
Source: (IRENA, 2026d).

[21] *IRENA analysis examines the macroeconomic implications of the transition, highlighting overall GDP, employment impacts and growth trends, underlying drivers of economic and employment trends. The analysis builds on identifying the key drivers (investment, trade, household consumption and government spending), providing an evidence-based foundation for policy makers to leverage the socio-economic benefits of the transition, while anticipating and managing its associated risks.*

The framework highlights five implementation priorities that consistently emerge across regions under the 1.5°C-compatible pathway:

- **Integrate electrification into national energy planning,** ensuring that renewable deployment, electricity demand, grids, storage, flexibility and sustainable fuels are planned together rather than through separate strategies for each sector.
- **Accelerate investment in enabling infrastructure,** particularly electricity transmission and distribution networks, storage systems, digitalisation and demand-side flexibility, to support growing electricity demand while maintaining system reliability.
- **Strengthen enabling policy and regulatory structures** that speed up electrification across transport, buildings and industry through long term investment signals, standards, market incentives and streamlined permitting.
- **Mobilise affordable financing and strengthen international co-operation,** especially for emerging markets and developing economies where access to capital remains a major obstacle to implementation.
- **Track progress through integrated indicators** to enable countries to measure electrification together with renewable energy deployment, energy efficiency improvements and supporting infrastructure while recognising different national circumstances and development trajectories.

↗1.5°C



China provides a practical example of how these implementation priorities can be translated into action. As illustrated in Box 2.3, the country has combined long-term planning, industrial policy, large-scale renewable deployment and sustained investment in electricity infrastructure to accelerate electrification across transport, buildings and industry. While implementation pathways will differ across countries, China's experience demonstrates that rapid electrification is achieved through co-ordinated action across the entire energy system rather than through isolated policy measures.

The global monitoring framework provides a practical basis for turning long-term ambition into measurable implementation. By tracking progress across end-use electrification and its enabling conditions, it can support policy learning, strengthen international co-operation and help identify implementation gaps early, while recognising that countries will advance at different speeds and from different starting points.

Ultimately, accelerating electrification is not an end in itself, but a means to deliver a broader energy transition that advances energy security, competitiveness, climate action and sustainable development. However, the success of this transition will ultimately be measured not only by changes in the energy system. It will also be measured by its wider impacts on economies, societies and the environment.

The next chapter examines how the different transition pathways analysed in this report influence economic performance, employment, welfare and environmental outcomes, highlighting the opportunities and trade-offs associated with different policy choices.

A successful electrification agenda requires more than a target: it requires co-ordinated progress across demand, clean power, infrastructure, finance and policy.

BOX 2.3 Electrification targets in China's 15th Five-Year Plan: Investment priorities and implications for economic growth

China is positioning electrification as a central pillar of its energy transition strategy, aligned with its green development goals, energy security considerations and broader industrial transformation agenda. Electrification is advancing rapidly across transport, industry and buildings, supported by large-scale expansion of renewable energy, power infrastructure and clean technology manufacturing. China is currently the world's largest market for electrification and renewable deployment, accounting for more than 60% of global electric vehicle sales and nearly half of global renewable capacity additions in 2023. The share of electricity in final energy consumption continues to rise steadily, reflecting the structural shift towards electricity-based energy systems.

Under the 15th Five-Year Plan period (2026-2030), China is expected to add more than 200 GW of new wind and solar capacity annually, with renewables projected to account for more than half of installed power capacity by 2030 (State Council of the People's Republic of China, 2026). According to the China Electrification Development Report 2025, the national electrification rate is projected to increase from 28.8% in 2024 to 35% by 2030 (National Energy Administration, 2025). The 15th Five-Year Plan for the New Energy System further translates these strategic priorities into concrete sector-specific targets for 2030. It sets a binding target to increase the share of non-fossil energy in total energy consumption from 21.7% in 2025 to 25% by 2030. At the same time, indicative targets include raising the share of non-fossil electricity generation from 42.3% to 50%, increasing renewable energy generation to 30% of total electricity generation, expanding vehicle-to-grid (V2G) aggregated flexible charging capacity to 50 GW, and scaling renewable hydrogen production to 2 million t/year. The plan also calls for accelerating progress towards ensuring that additional electricity demand is met by additional clean energy generation . Together, these measures provide a comprehensive policy framework to support the large-scale integration of renewable energy while strengthening energy security, power system flexibility and the broader clean energy transition.

The 15th Five-Year Plan further shifts the policy emphasis from expanding renewable capacity to strengthening the reliable substitution capability of renewable energy. By 2030, wind and solar power (including co-located storage) are expected to provide an average dependable capacity equivalent to 8% of installed capacity, contribute more than 20% of electricity supply during summer and winter peak demand periods, and deliver more than 300 GW of additional reliable peak generation capacity. This reflects a growing policy focus on ensuring that renewables increasingly provide firm system capacity alongside clean electricity generation. (NDRC and NEA, 2026b)

A key enabler of this transition is large-scale investment in power infrastructure, particularly grid expansion and modernisation. Investment is increasingly being directed to four complementary areas: strengthening ultra-high-voltage transmission networks to facilitate long-distance renewable power delivery; upgrading distribution grids to accommodate growing shares of distributed renewable generation; accelerating digitalisation through smart grid technologies; and expanding system flexibility via energy storage, virtual power plants and V2G resources. Under the newly released Five-Year Plan, China aims to enable the high-quality integration of more than 2.8 TW of renewable energy capacity by 2030 while expanding distribution networks capable of accommodating 900 GW of renewable generation. The plan also targets more than 50 GW of dispatchable virtual power plant capacity and 50 GW of aggregated V2G charging capacity, reinforcing demand-side participation and system balancing. (NDRC and NEA, 2026c).

China's experience highlights that electrification, and decarbonisation must advance in parallel. Electrification alone does not ensure emissions reductions unless it is matched by rapid expansion of low-carbon electricity supply and enabling infrastructure. The combination of electrification, renewable deployment and grid modernisation is therefore central to reducing carbon lock-in and aligning energy demand growth with clean energy supply.

At the same time, the transition is increasingly contributing to economic growth, industrial development and job creation. Clean energy sectors have become major drivers of investment and economic activity, particularly in electric vehicles, batteries, solar PV and power infrastructure. However, the benefits are unevenly distributed, with emerging clean industries concentrated in specific regions, while fossil-fuel-dependent areas face structural adjustment pressures. Managing these regional and labour market transitions remains an important policy priority.

Overall, China's experience illustrates how electrification, when supported by co-ordinated planning, large-scale investment and strong industrial policy, can serve as both a decarbonisation pathway and a driver of industrial transformation and economic growth. It also underscores the importance of integrating electrification with renewable energy expansion, grid modernisation and just energy transition policies to ensure a balanced and inclusive energy transition.

CHAPTER 03

SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF TRANSITION PATHWAYS



KEY INSIGHTS

- The energy transition offers a wide range of socio-economic and environmental benefits, provided supportive policies are in place.
- The Decarbonising Energy Scenario (DES) is projected to boost global gross domestic product (GDP) by an average of 0.7% annually until 2050, relative to the Planned Energy Scenario (PES). This implies a cumulative gain of USD 32 trillion – a value higher than the combined GDP of China, Germany, Japan and India.
- The revised 1.5°C Scenario would result in an average annual GDP that is 1.1% greater than under the PES over 2024-2050. This translates into a cumulative gain of USD 47 trillion by 2050.
- Renewable energy jobs are expected to reach 84 million by 2050, a 60% increase compared to the PES. While bioenergy will see the fastest job growth, nearly doubling the number of jobs in the PES, solar will remain the biggest employer, providing 38 million jobs under the DES by 2050.
- Accelerated decarbonisation boosts global welfare. Economic welfare is driven mainly by productivity, while industrial policies reshape value creation. Greater climate ambition can reinforce investment and productivity, but it can also increase household pressures if social protection and transition management do not keep pace. Climate, industrial and social policies therefore need to advance together.
- IRENA's Energy Transition Welfare Index improves across all scenarios and regions by 2050, with the DES 6.3% higher than the PES. The most favourable outcome will result from combining climate ambition with social protection, industrial development, fair distribution and a more circular use of materials.
- An investment of USD 443 billion in clean cooking, under both the DES and the 1.5°C Scenario, could enable a large share of the population currently lacking access to transition to renewables-based modern cooking alternatives, both through electrification and increased adoption of modern bioenergy. Pursuing these solutions, can deliver a clean cooking transition without compromising energy security local employment or livelihoods.
- While replacing fossil fuels with renewables generally reduces impacts on the environment and biodiversity at a global level, localised environmental impacts can occur throughout the life cycle, from rising material demand, construction, infrastructure expansion and end-of-life management of decommissioned equipment.
- Well-managed renewable energy projects, however, offer co-benefits for the local environment and biodiversity. For example, solar photovoltaic projects can aid in restoring degraded land, controlling desertification and improving land-use efficiency when combined with agricultural activities and livestock grazing.



Socio-economic impacts: Economic

The ongoing conflict in the Middle East highlights energy's critical role in sustaining livelihoods and economic prosperity. Disruptions to global oil and gas flows have led to sharp price volatility and increased fuel costs, the impacts of which have passed on to transport, food systems, supply chains and inflation, with the most vulnerable communities bearing the greatest burden.

Meanwhile, the economic viability of renewable energy and other energy-transition-related technologies has improved dramatically. In most cases, new utility-scale renewables are now cheaper than new fossil-fuel alternatives. The combination of renewables with storage increasingly offers reliable electricity at competitive costs (IRENA, 2026c, 2026j). This has created a strong case not only for utility-scale power systems but also for off-grid and mini-grid solutions in remote and low-income communities (IEA *et al.*, 2026).

Countries that made earlier investments in renewable energy have also demonstrated greater resilience to the current crisis. Higher shares of solar, wind and storage have reduced reliance on imported fossil fuels, improved self-sufficiency and limited exposure to shortages and price shocks. This holds true at the household level too, where rooftop solar, batteries, electric cooking and electric mobility can insulate consumers from fuel shortages, especially in economies dependent on energy imports.

Over the past decade, IRENA has documented the case for economic and social development through low-carbon technologies and increased energy self-sufficiency, particularly for developing and net-energy-importing countries. This has been done by using a macro-econometric modelling approach, developed and elaborated through a series of analytical reports (IRENA, 2016, 2018, 2019a, 2020, 2021a, 2022a, 2022b, 2023b, 2023c), alongside collection of empirical insights in areas such as job creation, gender and community benefits (IRENA, 2025e, 2025f; IRENA *et al.*, 2026). The remainder of this chapter compares a global economy – and selected regional and national economies – that meets decarbonisation goals under the Decarbonising Energy Scenario (DES) pathway with one that adheres to current policies under the Planned Energy Scenario (PES), as detailed in Chapter 1. Beyond the energy scenario and associated investment, the DES models only carbon taxes and fossil fuel subsidies as additional policies relative to the PES, recognising their foundational role to technology deployment in the energy transition.

To distinguish the socio-economic impacts of international collaboration from those associated with different energy pathways, this chapter introduces an additional scenario. While the DES serves as the central reference scenario, it is complemented by a scenario with higher international collaboration (referred to as the DES-IC). The DES-IC scenario follows the same energy pathway and policy assumptions as the DES but incorporates international collaboration funding[22] to finance additional energy transition investments and social expenditure.

The 1.5°C Scenario adopts the same policy assumptions as the DES-IC, including the international collaboration fund, but pursues a more ambitious energy pathway compatible with a 1.5°C goal, as explained in the preceding chapter. The results of the 1.5°C Scenario are therefore compared with the DES-IC, rather than the DES, to avoid confounding the effects of the energy pathway with those of international collaboration.

[22] *Details are discussed in (IRENA, 2021, 2023a; IRENA and AfDB, 2022).*

Together, these scenarios form a sequential analytical framework, where each comparison isolates a specific driver of socio-economic change. Comparing the DES with the PES identifies the impacts of accelerating the energy transition. Comparing the DES-IC with the DES isolates the additional socio-economic impacts of international collaboration. Finally, comparing the 1.5°C Scenario with the DES-IC isolates the impacts of transitioning to a more ambitious 1.5°C-aligned energy pathway while holding the international collaboration mechanism constant. Unless otherwise indicated, the DES remains the central scenario throughout this chapter, with the DES-IC and 1.5°C Scenario used where relevant to illustrate the additional impacts of international collaboration and heightened climate ambition.

The next section examines the socio-economic impacts under these conditions, analysing modelling results for gross domestic product (GDP) as well as focusing on jobs, results from IRENA's multi-dimensional welfare index, local environmental impacts of the energy transition, and a discussion of the need for both inclusivity and shared prosperity as part of a just energy transition.

Economy

The DES would boost global GDP by 0.7% on average relative to the PES over 2025-2050 (Figure 3.1). Modest as this looks in percentage terms, it translates into a cumulative[23] gain of USD 32 trillion – a value higher than the combined GDP of China, Germany, Japan and India; it is also higher than the combined GDP of the European Union, Latin America and the Caribbean, low-income countries,[24] and the Middle East and North Africa – a group of almost 90 countries and islands. The increase in economic gain is driven by investment in renewables and energy efficiency, further supported by enabling policies. In 2050 alone, the DES increases global GDP by roughly USD 2.2 trillion relative to the PES, a gain of around 1%.

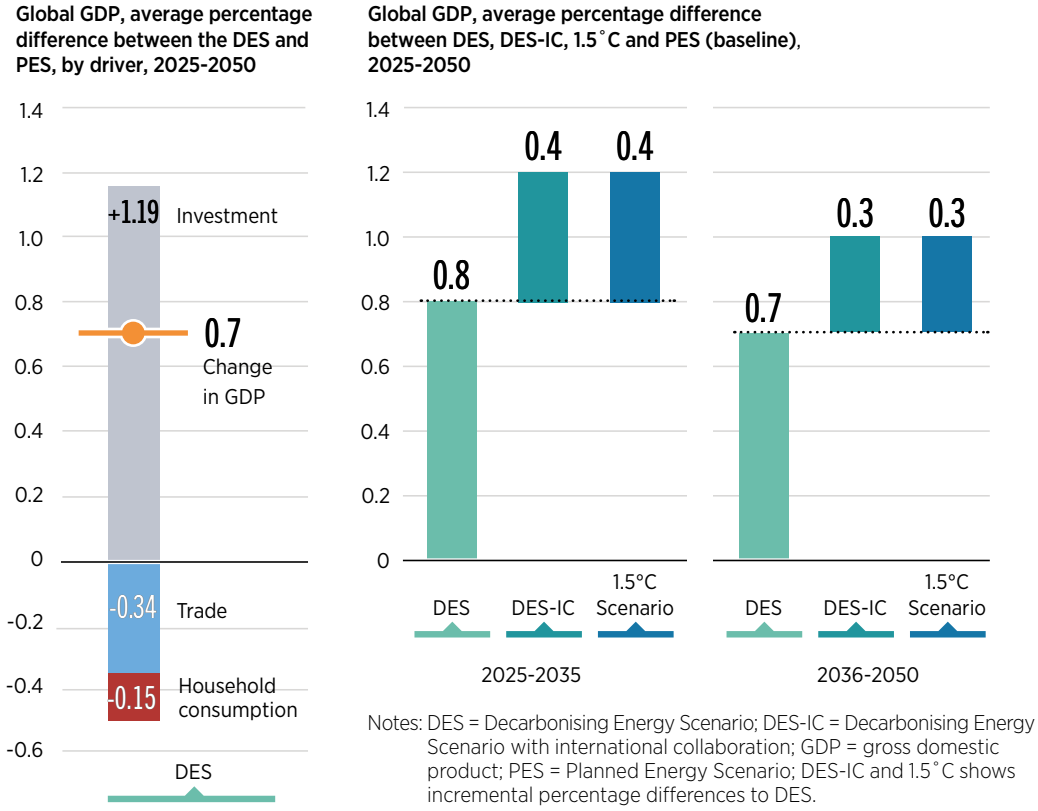
Investment is the main driver of this growth through to 2050. The investment effect runs at about 1.4% higher than the GDP in the PES over 2024-2030, dips slightly over 2031-2040, then strengthens again to around 1.35% over 2041-2050. It more than compensates for the drag on global GDP from suppressed trade activity. Household consumption is lower in the initial decades, before turning positive in the final decade. This reflects the effects of energy prices on consumers, as the energy transition initially imposes higher costs on households (because higher total energy prices raise both direct energy expenditures and prices of other consumer goods in the first period). Technology learning curves and efficiency gains later ease and reverse this pressure. Net trade is suppressed, particularly in the last decade of the transition. This is expected, as global fossil fuel trade falls sharply and reduces the revenues of exporting economies.

Results differ under the DES-IC as an additional investment layer, supported by an international collaboration fund, is added to the energy transition. This collaboration layer changes the financing method for capacity already under construction. That shift is reflected in the contribution of government spending, which brings additional positive impacts to the economy. Under the DES-IC, it contributes an additional 0.4% of GDP on average between 2025 and 2035, and a further 0.3% between 2036 and 2050 (Figure 3.1 left). Household consumption is also less depressed, as additional spending goes towards social policies and infrastructure.

[23] *The sum of all the annual gains from now through 2050.*

[24] *As per World Bank classification.*

FIGURE 3.1 Global GDP, average percentage difference between the DES and PES, by driver (left), and average percentage difference between the DES, DES-IC, 1.5°C Scenario and PES (right), 2025-2050



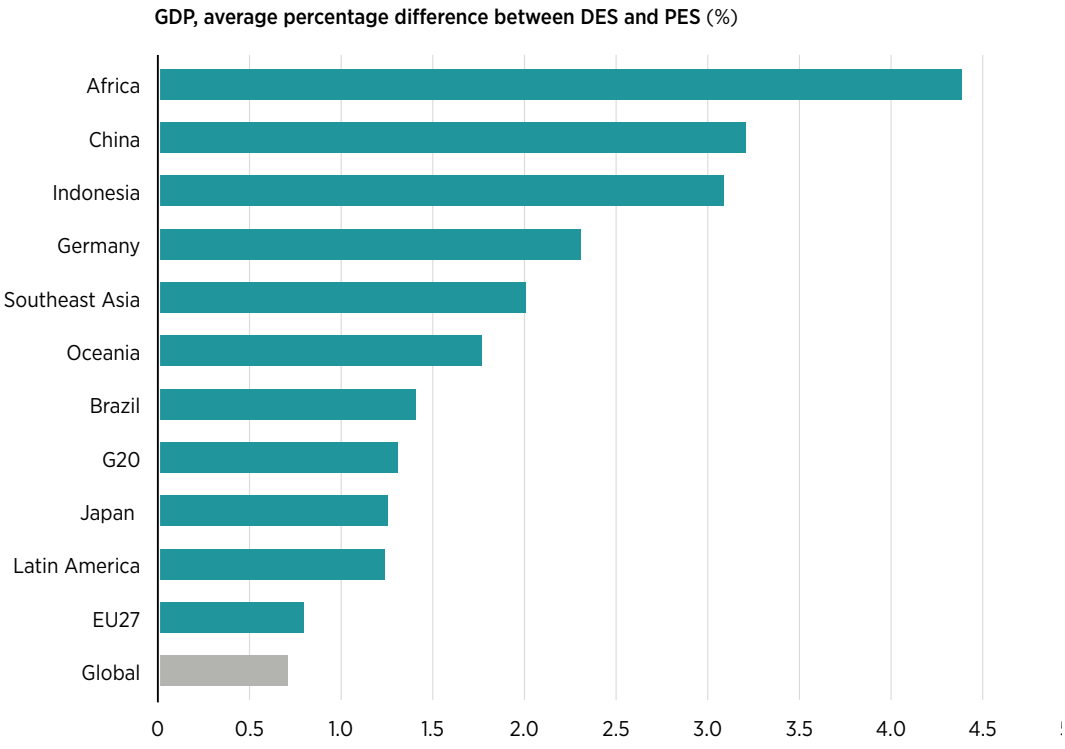
Notes: DES = Decarbonising Energy Scenario; DES-IC = Decarbonising Energy Scenario with international collaboration; GDP = gross domestic product; PES = Planned Energy Scenario; DES-IC and 1.5˚C shows incremental percentage differences to DES.

The 1.5°C Scenario shares the policy architecture of the DES-IC – the same carbon price and subsidy policies, and the same international collaboration layer – but follows a different energy pathway. It produces results similar to the DES-IC, with a comparable increment in GDP relative to the DES. The macroeconomic cost of the overshoot and of higher ambition towards the end of the period is small, with only marginal differences in drivers. On average, compared with the DES-IC, weaker government spending is offset by higher household consumption, leaving the aggregate broadly unchanged. The key takeaway is that this scenario would be more demanding of public balance sheets, as the deficit absorbed by governments is higher than in other scenarios.

The global picture, however, masks large geographical disparities. In absolute terms, all regions experience GDP growth in the PES. But the socio-economic benefits derived from the DES are not evenly distributed. This is because the various drivers manifest differently across countries and regions, depending on their energy systems, the ambition of their energy transition and their socio-economic characteristics. The shift towards a decarbonised energy sector will bring structural changes in the economy; some sectors and industries will see reduced activity, while others will thrive.

Figure 3.2 presents the impacts on GDP in 2050 alone under the DES across selected countries and regions, benchmarked against the global average. All regions, groupings and countries portrayed witness positive impacts relative to the global GDP, although the scale differs significantly. Africa records the largest increase, at around 4%, followed by Indonesia at roughly 3.3% and China at about 3.0%. Germany and Malaysia also experience notable increases at about 2.2% and 1.7%, respectively. In contrast, Brazil, Oceania, the Group of Twenty (G20) countries, Latin America and Japan show moderate gains, ranging from around 1.1% to 1.5%. The EU27 nations and the global average exhibit the smallest improvements, both remaining below 1%. Overall, the DES generates widespread economic benefits and is likely to create stronger relative opportunities in some emerging and developing regions, particularly Africa and parts of Asia, where there is greater scope for investment-led growth, structural transformation and development gains. IRENA has analysed this in detail for South America (Box 3.1). The transition pathway can therefore be viewed not only as an energy or climate strategy, but also as a potential driver of economic development.

FIGURE 3.2 GDP, comparison of percentage difference between the DES and PES, for selected countries/regions and groupings, 2050



Notes: DES = Decarbonising Energy Scenario; GDP = gross domestic product; PES = Planned Energy Scenario.

BOX 3.1 Benefits of South America's energy transition through regional integration and low-carbon development

IRENA's *Regional Energy Transition Outlook: South America* explores how the region can maximise the opportunities presented by the global energy transition through stronger regional integration and the implementation of low-carbon development pathways (IRENA, 2025c). The report provides technical guidance for policy makers, planners and private stakeholders to support energy plans, climate strategies and investment decisions. Covering 13 South American countries, the RETO analyses key areas such as renewable energy integration, clean hydrogen uses, sustainable bioenergy and power sector development, while also assessing the socio-economic impacts of the transition, including gross domestic product, employment and welfare outcomes.

South America's energy transition will centre on renewable electrification, the use of biomass and energy efficiency, supported by regional interconnection, modernised grids and the scaling up of sustainable fuels for both domestic consumption and export. Figure 3.3 shows the benefits of the Decarbonising Energy Scenario (DES), which targets net-zero emissions for the region during the 2050s to align with the global ambition of limiting temperature rise to well below 2°C. Achieving the DES will require an estimated USD 13 trillion between 2025 and 2050 (USD 7.5 trillion in infrastructure investment and USD 5.5 trillion in expenditure on technologies and devices for end-use sectors) or USD 501 billion a year.

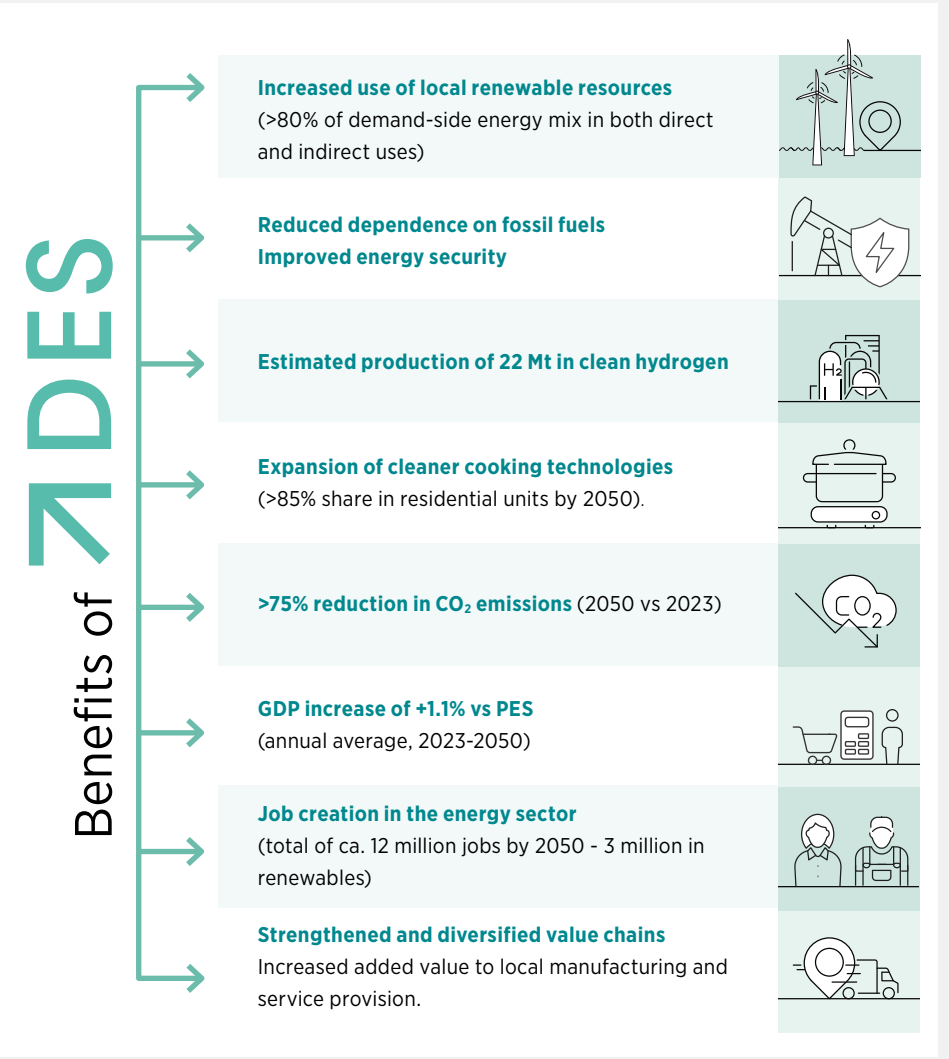
The report identifies six key enablers for implementing South America's energy transition: regional strategy, governance, skills, finance, infrastructure and energy planning. It highlights the need for integrated development approaches, harmonised policies, workforce upskilling and innovative financial mechanisms to lower investment risks. The study further underscores the importance of modernised infrastructure, regional co-ordination and advanced planning systems capable of addressing renewable energy integration, digitalisation and emerging energy demands, all while ensuring inclusive and equitable outcomes.

To accelerate implementation, IRENA proposes a regional action plan centred around seven priority actions:

- Reducing financing costs for sustainable infrastructure.
- Advancing an integrated regional electricity market.
- Developing regional solar and wind supply chains.
- Co-ordinating green hydrogen production.
- Promoting green industrialisation strategies.
- Establishing a co-ordinated regional biofuel strategy.
- Creating a regional hub for energy and material efficiency.

These actions aim to bolster regional competitiveness, enhance energy security and support long-term decarbonisation efforts.

FIGURE 3.3 Benefits of the Decarbonising Energy Scenario: South America

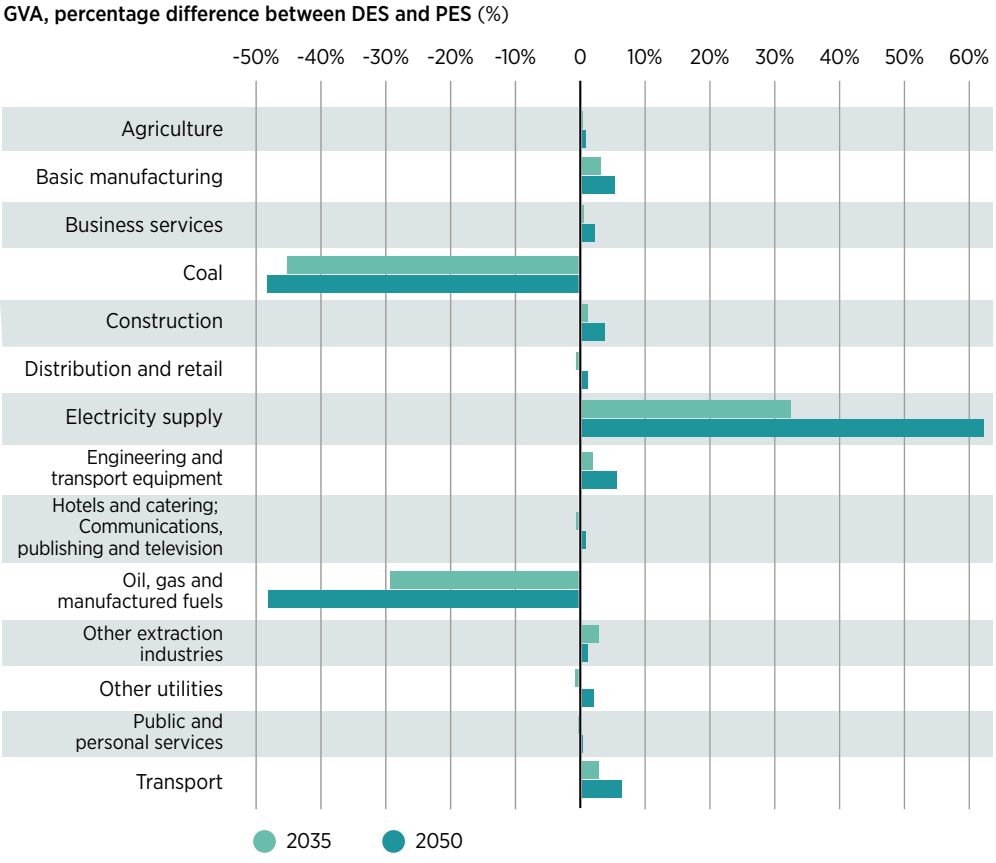


Notes: GDP = gross domestic product; Mt = million tonnes; PES = Planned Energy Scenario.

Structural changes: Higher industrial base

The case for economic development is compelling, particularly for regions that have more room to improve productive capacity and capture new investment. In a decarbonisation scenario, a significant increase in investment in capital-intensive renewables and energy efficiency would boost sectors related to capital goods and services, while those related to fossil fuels would experience a reduction in output. Such changes will substantially reshape the current structure of economies. How the DES affects output across sectors, compared with the PES, is shown in Figure 3.4.

FIGURE 3.4 Global GVA by sector; percentage difference between the DES and PES, 2035 and 2050



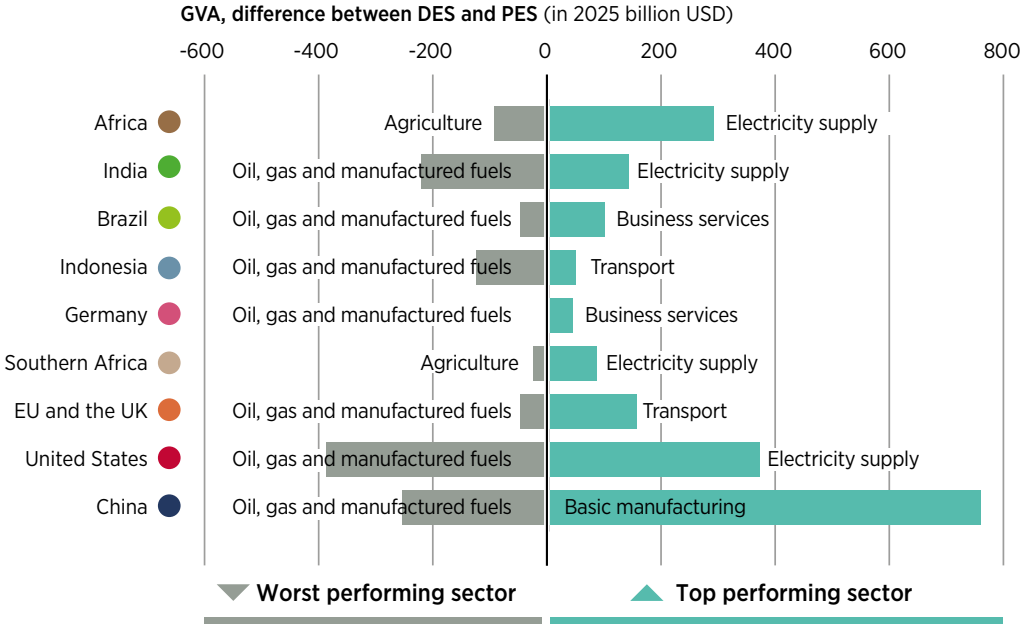
Notes: DES = Decarbonising Energy Scenario; GVA = gross value added; PES = Planned Energy Scenario.

The main negative impacts of decarbonisation would be felt within the fossil fuel industry. A decline in the demand for fossil fuels would lead to a slowdown in related activities, including exploration, production, refining and distribution. Prices would also drop, and this, combined with lower demand, would reduce overall output. The coal, oil and gas industries would be hit hardest, with output falling by over 40% in 2050 compared with the PES (Figure 3.4). With increased electrification, output from the power sector will increase. Existing fossil fuel power technologies will nonetheless see output fall sharply, while renewables and related activities such as transmission and distribution, smart grids and demand response will grow.

Figure 3.5 shows the productive base shifting towards higher-value sectors, notably manufacturing and electricity supply. Output in the electricity supply industry is almost 60% higher than under the PES. Similarly, output is over 5% higher under the DES in both manufacturing as well as engineering and transport equipment. This shows that the energy transition moves global economic activity up the value chain, and away from extraction and rent-based activity.

Similar structural shifts are observed in the DES-IC, as the collaboration layer alters the financing of the transition rather than its physical shape. Increased ambition towards the end of the period under the 1.5°C Scenario, modestly deepens these shifts, with global fossil fuel sectors (coal, oil, gas and manufactured fuels) falling 1-2% relative to the DES-IC.

FIGURE 3.5 GVA by sector; difference between the DES and PES for selected countries/ regions and groupings, 2050



Notes: DES = Decarbonising Energy Scenario; EU = European Union; GVA = gross value added; PES = Planned Energy Scenario; UK = United Kingdom..

Structural changes can also be expected at the country and regional levels, although they will vary with existing economic structure, demography and fuel reliance, among other factors. Countries heavily reliant on fossil fuels for a large share of their GDP could face a decline in economic activity. This dynamic is reflected in the GDP impacts experienced by different countries, which vary depending on the relative importance of their various sectors. This has important strategic, policy and political economy implications for individual nations and for global decarbonisation of the energy sector.

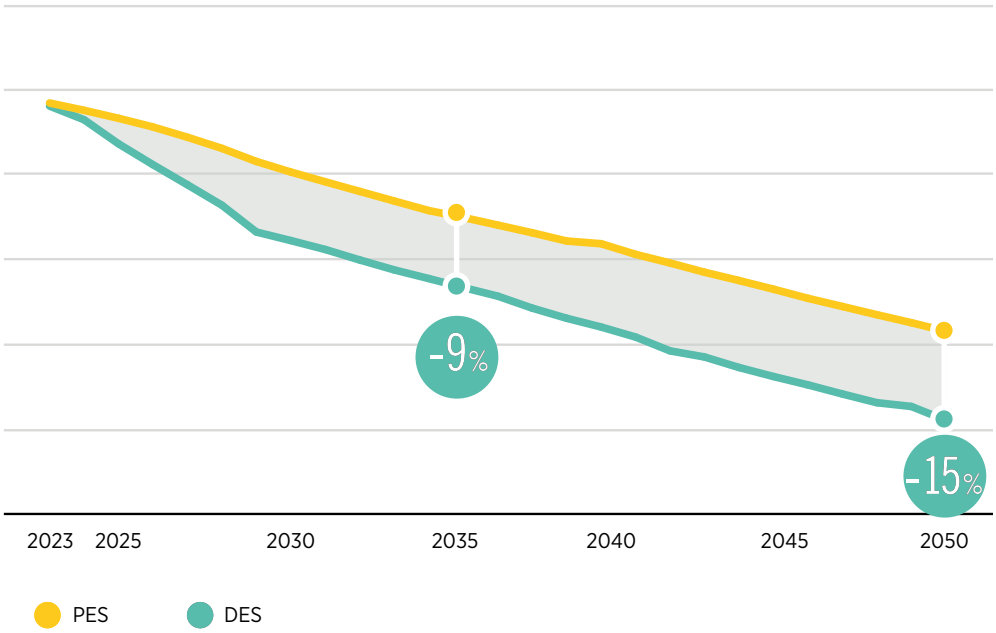
As seen in Figure 3.5, the energy transition creates sharply divergent structural outcomes across economies. Countries with existing industrial bases related to clean energy technologies, notably China, can capture substantial benefits by anchoring global supply chains. Mature economies (such as the European Union and Germany) experience manageable change in each sector, with gains in transport and business services offsetting modest fossil fuel losses. On the other hand, fossil-fuel-dependent economies such as India and Indonesia face steeper challenges, as losses in the oil and gas sector outstrip the gains in leading sectors. Africa is in a unique position as its gains in electricity supply surpass its agricultural losses, reflecting a transition driven by electrification build-out and an upward movement in the supply value chain, rather than industrial phaseout. Nevertheless, all countries and regions are expected to advance higher in the value chain, which will be at the expense of fossil fuel extraction and refining sectors. A crucial factor determining these results is whether an economy's existing industrial structure can effectively integrate and amplify clean energy value chains. The findings also indicate which sectors are strongest in each country, helping policy makers build on them to ensure a smooth transition and strengthen energy security.

Competitiveness: Lower electricity prices to support the industrial base

The shift towards a more productive economy and a larger industrial base is possible and will be reinforced by the competitiveness of renewable energy. Competitiveness can be measured in many ways, but on electricity prices alone – a fundamental economic indicator – the DES brings substantial benefits. The electricity price in this context is set by the average levelised costs of generation. Electricity prices should be clearly distinguished from total energy prices (discussed in the global GDP results and in Figure 3.10), as the two measure different dimensions of energy costs.

End-user electricity prices are lower under the DES relative to the PES, despite the higher carbon price applied in the scenario. Average prices are about 9% lower in 2035 and 15% lower in 2050 (Figure 3.6). This is attributable to zero-marginal-cost renewables and a lower fuel-cost burden, which offset the recovery of higher capital costs. Energy-intensive industries gain a direct unit-cost advantage and, importantly, energy security benefits – a double dividend, particularly in net-fuel-importing countries.

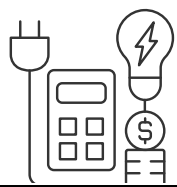
FIGURE 3.6 Global average electricity prices under the PES and DES, 2023-2050



Notes: DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

Lower prices prevail in the majority of regions and countries. For electricity the argument is clear: it is already more competitive and will become more so over time. The DES-IC has the same electricity prices, as the energy balances are identical; the 1.5°C Scenario differs only marginally, with electricity prices 14.7% below the PES in 2050. However, electricity is not the only element in the energy sector that defines overall prices.

The competitiveness of renewable energy will support the shift towards a more productive economy and a larger industrial base.



Energy security through an economic lens: Avoiding "double exposure"

Energy security is usually assessed through indicators such as import dependence, reserve margins and supply chain concentration. While these indicators remain relevant, they do not fully capture the economic effects of transitioning away from fossil fuels. This chapter therefore adds a complementary perspective by examining the interaction between changes in fuel trade and changes in domestic output from the oil, gas and manufactured fuels sector.

The indicator makes an important distinction to show how a transition can affect economies through two channels concurrently. Fossil-fuel importers will benefit from lower import requirements and reduced exposure to international fuel prices. Fossil-fuel producers and exporters, by contrast, could face declining export revenues alongside contraction in domestic activities that support employment, fiscal revenues and wider economic activity.

Figure 3.7 portrays these dimensions together by comparing the differences between the DES and PES in cumulative fuel trade gains/losses and in output from the oil, gas and manufactured fuels sector over the 2024-2050 period for selected countries.[25] The results show different economic exposure among countries and regions.

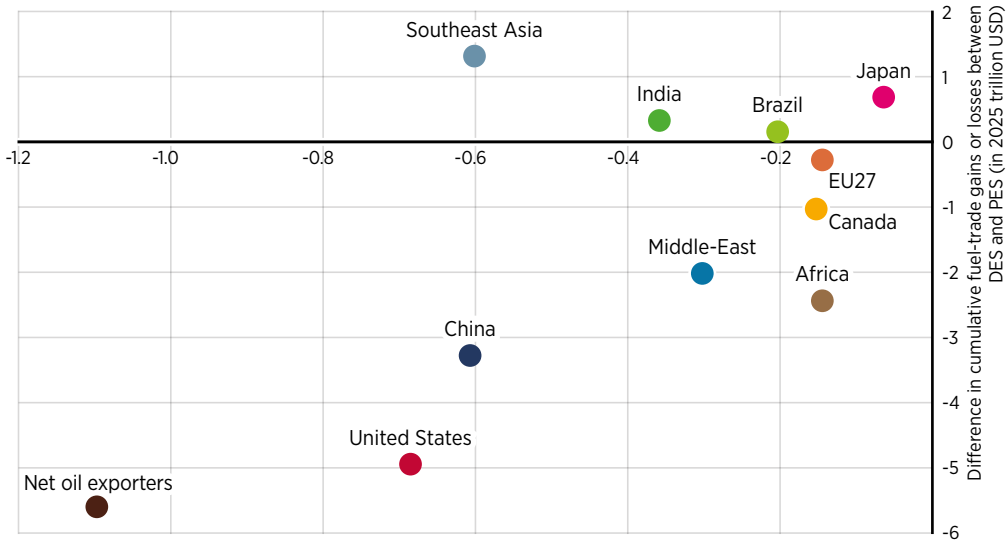
The greatest adjustment challenge arises where both dimensions deteriorate simultaneously. Net oil exporters, as well as certain countries of Africa and the Middle East, face this form of "double exposure", with declining fuel-trade revenues occurring alongside contraction in domestic fossil-fuel-related activity. For these economies, the transition extends beyond simply replacing one energy source with another. It is about managing a wider range of structural adjustments in economies where fossil fuels remain important sources of export earnings, employment and public revenues.

China illustrates a different but equally important case. The savings from lower fossil-fuel imports do not fully compensate for the losses associated with declining output and trade in manufactured fuels and coal. This shows that economic exposure cannot be understood from import dependence alone. Instead, what is important is the net position of an economy with regard to both fuel trade and domestic production as the energy system changes.

Other economies are positioned differently. Some fossil-fuel-importing countries, including Japan and India, benefit from lower fuel-import requirements while also capturing new activity in manufacturing and services associated with the energy transition. In these cases, reduced fossil-fuel exposure can reinforce gains in competitiveness and economic resilience.

[25] *The selected list of countries grouped under this are: Norway, Canada, the Russian Federation, Mexico, Brazil, Argentina, Colombia, Saudi Arabia, Nigeria, Malaysia and Kazakhstan.*

FIGURE 3.7 Cumulative difference in fuel trade gain/loss and change in "oil, gas and manufactured fuels" output between the DES and PES for selected countries/ regions, 2024-2050 (USD trillion, 2025 prices)



Difference in output of "Oil, gas and manufactured fuels" sector between DES and PES (in 2025 trillion USD).

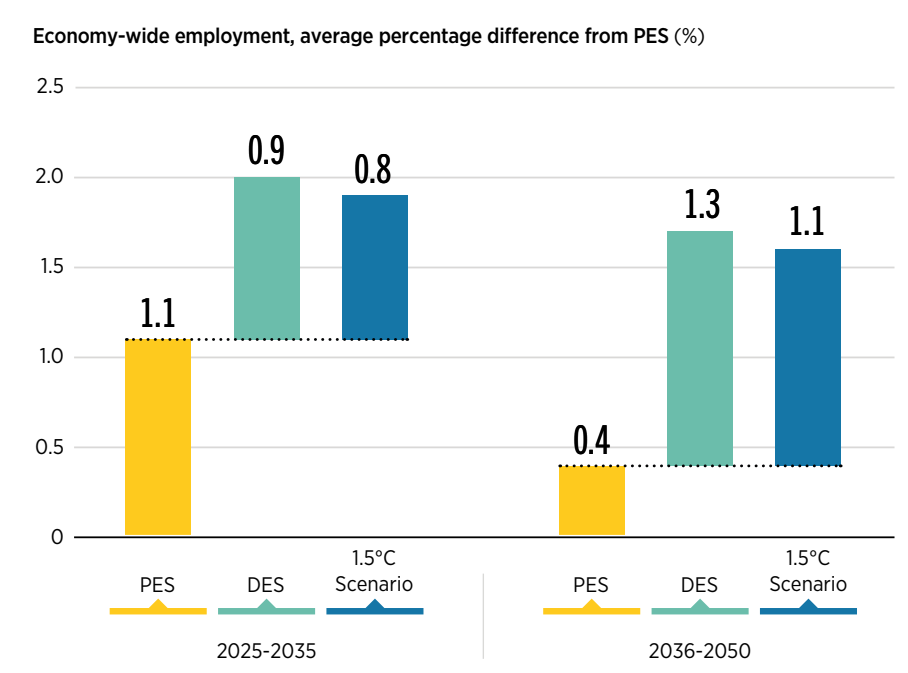
Notes: DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.



BOX 3.2 Global economy-wide employment

Globally, economy-wide employment is projected to be 1.1% higher on average in the years up to 2035, but only 0.4% higher between 2035 and 2050. During the initial 2024-2035 period, even when the investment's overall impact on employment is lower compared to the later phase, the drag from consumer expenditure and trade is also less pronounced. As the transition progresses, the negative impact of household consumption and trade intensifies, lowering the overall employment difference despite an increase in the positive impact of the investment. Investment has the largest impact on employment, because renewable energy capital expenditure, energy efficiency investment and electrification spending are more labour intensive relative to the fossil fuel activities they displace. These investments also generate multiplier effects through supply chains and induced services activities that sustain the employment gain, even as the direct construction phase matures. The same pattern holds under the DES-IC and the 1.5°C Scenario. However, the role that government spending plays in these scenarios alters the aggregate results significantly. While the drag from household consumption and trade remains the same, higher investment – funded by international collaboration and government spending – brings more jobs into the market. Figure 3.8 illustrates how these impacts on employment are closely mirrored by changes in gross domestic product across all scenarios.

FIGURE 3.8 Global economy-wide employment, average percentage difference between the DES, DES-IC, 1.5°C Scenario and PES, 2025-2050



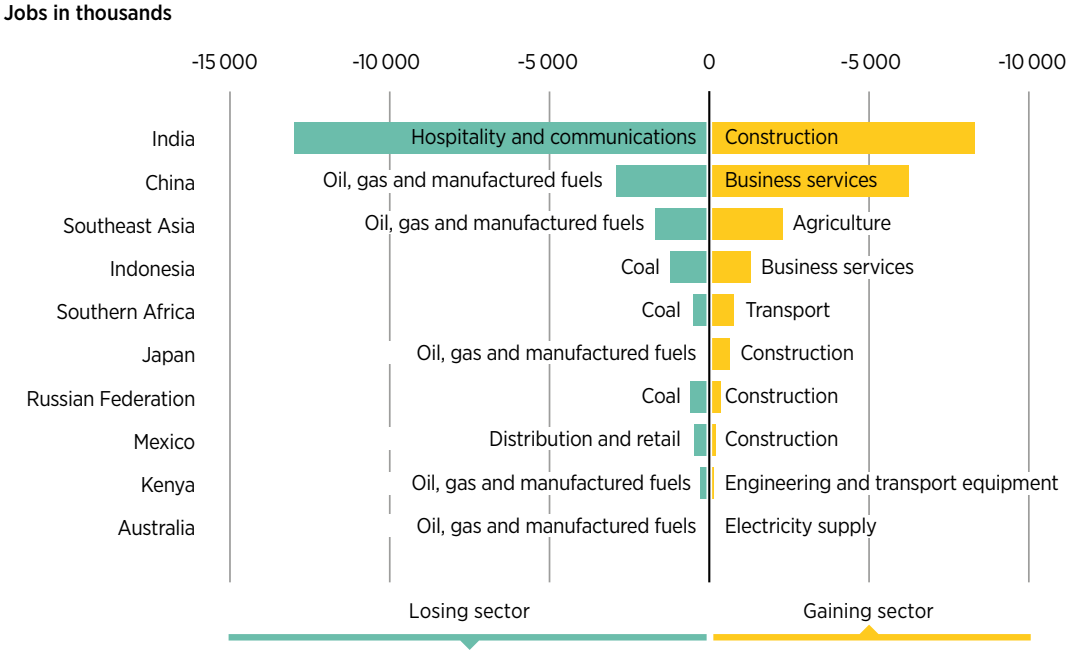
Notes: DES = Decarbonising Energy Scenario; DES-IC = Decarbonising Energy Scenario with international collaboration; PES = Planned Energy Scenario; 1.5°C = 1.5°C Scenario. DES-IC and 1.5˚C Scenario show incremental percentage differences to DES.

Economy-wide employment

The employment outcome depends as much on the investment and modes of financing as on the energy transition itself. The DES would deliver, on average, 0.7% higher employment than the PES over the 2024-2050 period. Under the DES-IC, employment averages 1.8% above the PES, while the 1.5°C Scenario improves on average by 1.7% – marginally below the DES-IC but substantially higher than the DES (Box 3.2).

At the sector level, however, regions stand to gain and lose from the transition in different ways. The structural change discussed in Figure 3.5 also applies from an employment perspective. Figure 3.9 demonstrates that the energy transition drives a structural reallocation of jobs across the whole economy, not only within the energy sector. Under the DES, compared with the PES, most job gains are concentrated in construction, business services, transport, electricity supply and engineering. This again reflects the impact of associated investment in infrastructure, electrification, grids and wider transition supply chains. In parallel, fossil-fuel-related sectors (such as coal, oil and gas) and manufactured fuels contract, alongside some exposed service sectors (such as hospitality in India). Most countries and regions will experience job losses in the fossil fuel sectors, while job creation in new sectors will vary, for instance, construction in India, Japan and Mexico; business services in China; and agriculture, possibly linked to biofuels, in Southeast Asia.

FIGURE 3.9 Sectors gaining and losing most jobs between the DES and PES in selected economies, 2050



Notes: DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

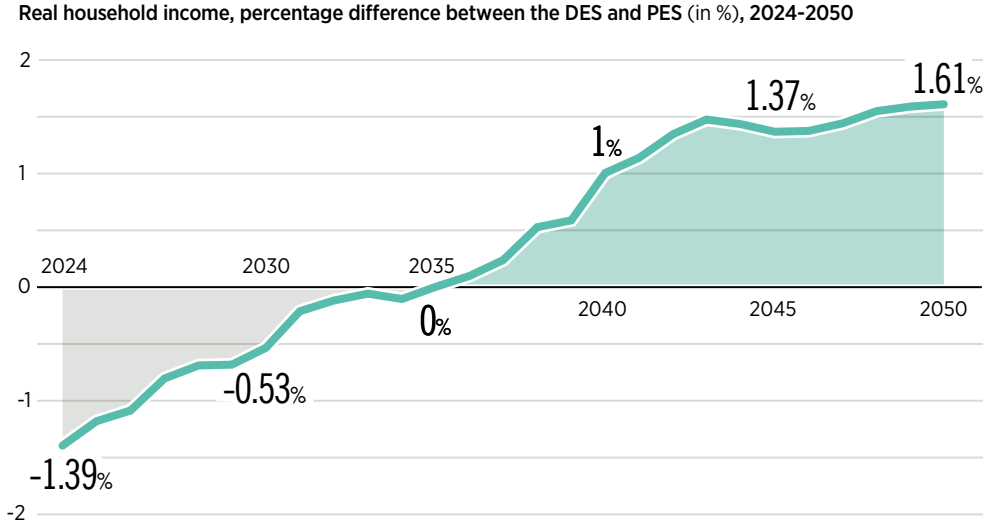
Household income

These employment changes feed directly into household incomes. For policy makers, public buy-in is essential to sustain support for the transition and avoid a backlash against crucial policies. Real household income is lower under the DES than the PES until around 2035. After 2035 it climbs steeply, opening a margin of over 1% above the PES. By 2050 it is around 1.6% higher globally than under the PES (Figure 3.10). The initial dip corresponds to the period when policies, such as carbon prices and fossil fuel subsidy reduction, impact consumption. This is later offset as productivity gains, lower electricity prices and new wage income from clean energy deployment are fully realised.

Through a political-economy lens, the most vulnerable decade for securing public support is 2025-2035. This is when households will be hit hardest by both technological and policy changes. Mismanagement during this period means that the subsequent gains, projected for 2035-2050, may not be politically feasible. Although this is a global average, the analysis shows the same household income pattern in most regions and countries. The challenge is therefore to bridge the gap, not to deny it. Policy makers (and politicians) should put supportive measures in place so that the transition does not leave households worse off.

Renewable energy deployment increasingly offers a tremendous opportunity to diversify a country's skill base, boost its industrial development and support broader developmental priorities for societies. The resulting gains in energy sector jobs and welfare are discussed in the next section.

FIGURE 3.10 Global real household income, percentage difference between the DES and PES, 2024-2050



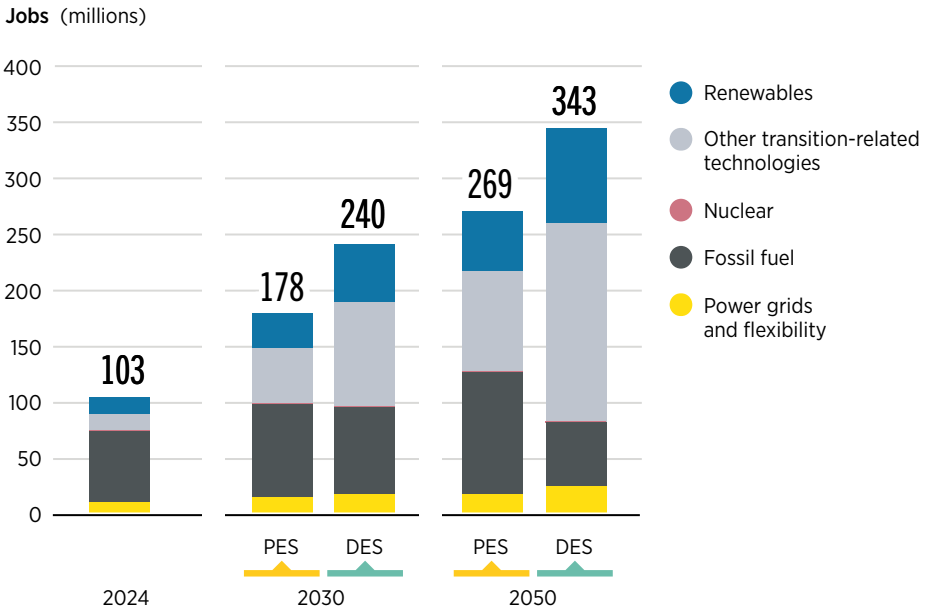
Notes: DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

Energy sector and renewable energy jobs

Energy sector jobs

By 2050 under the DES, total energy sector employment reaches 343.1 million jobs globally – a roughly threefold increase from around 103.2 million in 2024 (Figure 3.11). This reflects significant growth in the energy workforce, primarily driven by accelerated investment in clean technologies, efficiency measures and supporting infrastructure. In 2050, the PES is estimated to create about 268.7 million jobs, over 70 million fewer than the DES. Leading up to 2030, the gap is already emerging as the DES will create around 239.6 million jobs compared with 178.2 million under the PES. This widening divergence underscores a key message: decarbonisation actively drives stronger employment growth. Total energy sector employment grows under both scenarios, but the DES consistently generates a larger, more diversified workforce at every time horizon and across all segments of the value chain.

FIGURE 3.11 Global energy sector jobs under the PES and DES, by sector, 2024-2050



Notes: Other transition related technologies include energy efficiency and conservation, carbon removal. DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

The biggest shift is structural in nature. In 2024 the largest job category was fossil fuels and conventional technologies, with about 63.4 million jobs (just over 60% of total jobs). By 2050 the share of fossil-fuel-related jobs falls to only about 16% under the DES, while in the PES, it remains much higher, at 108.5 million. The largest employment gains under the DES come from other transition-related technologies,[26] which rise sharply from 7.4 million jobs in 2024 to 121.2 million in 2050. This becomes the dominant category, accounting for about 35% of all jobs under the DES in 2050. Energy conservation and efficiency also grow strongly, from 6.1 million jobs in 2024 to 56.4 million in 2050. These two sectors, together with renewables, show the largest gains compared with the PES. Renewables also grow substantially, from around 16.0 million jobs in 2024 to around 84.2 million by 2050 under the DES – around 60% higher than under the PES.

Under the DES, global energy sector employment is heavily concentrated in the developing world in 2050. Sub-Saharan Africa alone accounts for roughly a third of all jobs (32.5%), followed by East Asia (21.9%, dominated by China) and India (18.5%) (Figure 3.12). These three regions collectively hold over 70% of the jobs. The biggest observable job shift is from East Asia to Sub-Saharan Africa by 2050. Several factors contribute to this. Over the next 30 years, China's population is expected to decline while its GDP grows, whereas Africa's population is rising sharply, particularly among young people. Because baseline employment intensities are significantly higher than in China and East Asia, investment demand is more likely to be met by increased employment: the capital stock starts from a much lower base and takes time to translate into higher productivity.

The remaining jobs are spread thinly. The Middle East and North Africa (MENA) and the "Rest of world" each hold about 6%, Latin America 5.2%, Europe 4.3%, Southeast Asia 3%, North America 2.2% and Oceania just 0.3%. The results reflect where population increase, energy demand growth and labour-intensive transition activity are the greatest. Mature economies in Europe and North America (combined representing only about 6.5%) employ comparatively few workers, while Africa and Asia emerge as the centre of the energy workforce.

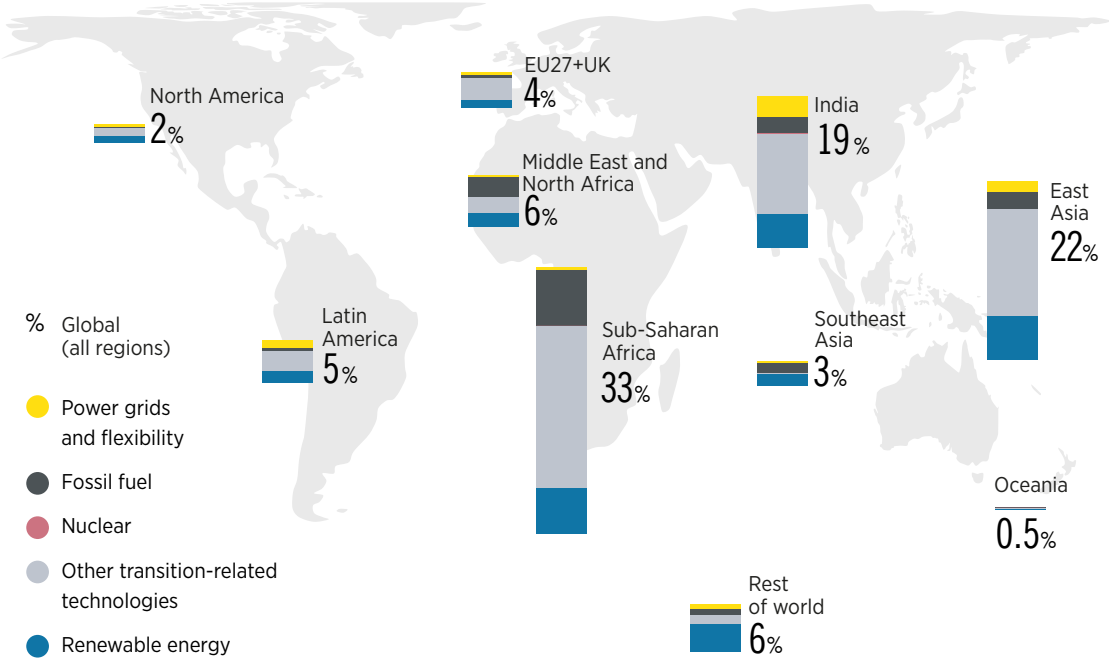


Renewable energy jobs grow substantially, from around 16.0 million jobs in 2024 to around 84.2 million by 2050 under the DES.

[26] *Technologies include electrification of end-uses, carbon removal, clean cooking and direct use of hydrogen/derivatives etc.*



FIGURE 3.12 Breakdown of energy sector jobs across regions under the DES, by sector, 2050



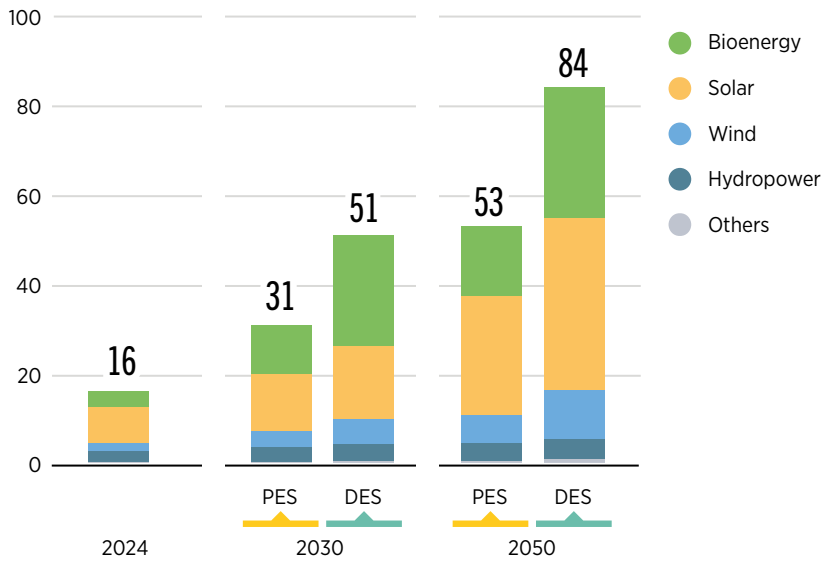
Notes: Other transition related technologies include energy efficiency and conservation, carbon removal.
DES = Decarbonising Energy Scenario.

Renewable energy jobs

Solar energy creates the most jobs within the renewables sector, growing from around 7.9 million jobs in 2024 to around 38.3 million under the DES in 2050 – nearly half of all renewables employment (Figure 3.13) and 11.7 million more jobs than under the PES in 2050. Bioenergy is the second-largest contributor, with around 29.5 million jobs under the DES in 2050. Benefiting from both on-shore expansion and accelerating off-shore deployment, wind energy jobs more than quintuple, from over 1.9 million in 2024 to around 11.1 million under the DES in 2050 – 4.9 million more than under the PES. Growth in hydropower is modest, reaching around 4.5 million, consistent with the maturity of the technology and the declining availability of greenfield sites. Geothermal and other renewables remain small in absolute terms but show rapid percentage growth, suggesting emerging niche opportunities particularly in regions with favourable resource endowments.

FIGURE 3.13 Global renewable energy jobs under the PES and DES, by technology, 2024-2050

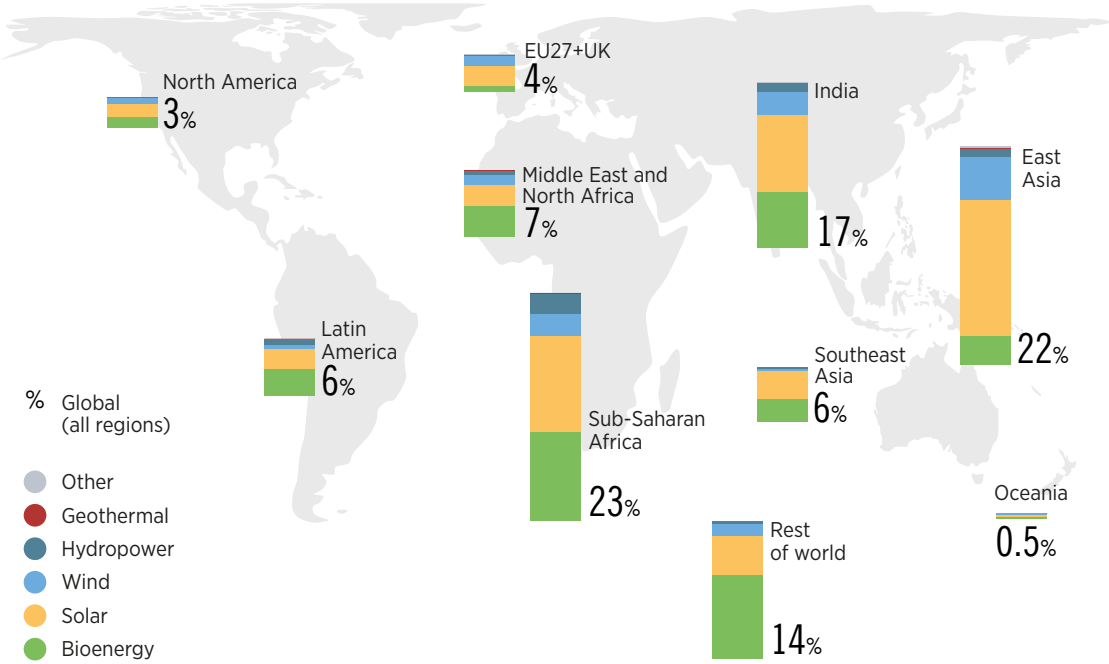
Renewable energy jobs (in millions)



Notes: Others include geothermal and tidal/wave. DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

Global renewable energy jobs are distributed somewhat more evenly than energy sector jobs as a whole, though the centre still lies in Asia and Africa. Sub-Saharan Africa holds the largest share (22.7%), marginally ahead of East Asia (21.8%), with India third at 16.6% (Figure 3.14). Together these regions and countries account for more than 60% of global renewable energy jobs. The "Rest of world" (which includes non-EU Europe, Eurasia, small island developing states and other parts of Asia) is notably larger, at around 13.7%, reflecting renewable energy activity spread across many markets. The MENA and Latin America each account for around 6.5% and 5.7%, respectively, while Southeast Asia accounts for 5.5%, Europe 3.8%, North America 3.2% and Oceania 0.5%. Compared with total energy sector jobs, Sub-Saharan Africa's dominance is less pronounced, while East Asia, India and Southeast Asia gain relative weight. This is driven largely by solar, which is the leading renewable employer across most of Asia, alongside strong bioenergy employment in Africa (Box 3.3).

FIGURE 3.14 **Breakdown of renewable energy jobs across regions under the DES, by technology, 2050**



Notes: Others include geothermal and tidal/wave. DES = Decarbonising Energy Scenario; PES = Planned Energy Scenario.

Solar energy and bioenergy remain the dominant sources of renewable energy employment across all regions in 2050.

BOX 3.3 Clean cooking as a contributor to renewable energy jobs

The Decarbonising Energy Scenario (DES) shows strong bioenergy employment in Africa, some of which would come from jobs in clean cooking. Significant efforts are underway to address the lack of access to clean cooking, which currently affects 2.1 billion people (IEA *et al.*, 2025), nearly half of them in Sub-Saharan Africa. Expanding electricity access is a major opportunity for meeting cooking energy needs with renewables and should remain the ultimate goal of the clean cooking transition. However, it is out of reach for up to 600 million people in Africa who still lack electricity, and for millions more whose connections are too unreliable or too low in capacity for cooking to be a viable end use. Bioenergy-based solutions therefore stand out for their practicality, immediate availability and self-reliance.

One often overlooked aspect of bioenergy is employment creation. Under the DES, bioenergy is the second-largest contributor to employment, with around 29.5 million jobs. The charcoal sector, which currently meets 30% of cooking energy demand, has a value chain that provides both direct and indirect employment across production, stove manufacturing, transport and trade (IRENA, 2026j). Evidence from several Sub-Saharan African countries indicates that this sector supports large segments of both rural and urban populations who might otherwise face unemployment. For example, the Food and Agriculture Organization estimated in 2017 that approximately 40 million people derived income from the charcoal sector. In Kenya, where charcoal accounts for more than 70% of domestic cooking energy demand, an estimated 600 000 people depended on the sector for their livelihoods in 2021 (Kamwilu *et al.*, 2021).

Modernising the charcoal value chain, however, requires significant investment catalysed by public financing. The current investment landscape is skewed: over 65% of investment, including that supported by public funds, is directed towards liquefied petroleum gas (IRENA, 2026k), while only a limited share goes to renewables-based cooking solutions such as e-cooking, bioethanol, biogas and bioenergy. This imbalance reduces the likelihood of these alternatives scaling and achieving widespread adoption.

This represents a missed opportunity. Renewable-energy-based clean cooking solutions offer potential advantages in energy security, cost efficiency and co-benefits across related sectors such as agriculture (IRENA, 2024b). Charcoal value chains continue to sustain livelihoods and provide critical income-generating opportunities during periods of economic volatility and climate-related shocks, contributing to resilience in both rural and urban contexts while meeting cooking energy demand. Local cookstove companies, often small and medium-sized enterprises, still lack a competitive edge in accessing the finance they need to grow. But they are usually better placed to understand local contexts and the specific needs of end users, enabling them to develop innovative and culturally appropriate products and business models that cater to these needs.

A just energy transition to clean cooking should therefore prioritise proven solutions that draw on local value chains and are easy to enter, and could thus generate local employment. It is equally important to provide alternative sources of income for traditional cooking fuel producers and traders, or to equip them with the skills to integrate into modern cooking value chains.

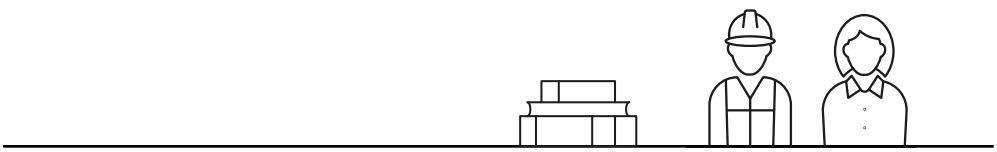
The success of the energy transition, and its ability to deliver broad socio-economic benefits, depends on the availability of a skilled, adaptable and inclusive workforce. This requires scaling up investment in education, training and lifelong learning through universities, vocational programmes, apprenticeships and workplace-based learning, while also strengthening co-ordination between industry, training providers and policy makers to align skills development with evolving needs (IRENA *et al.*, 2026). Reskilling and upskilling will be crucial to support workers and communities affected by the decline of fossil fuel industries and to ensure that new opportunities are accessible across regions and sectors (IRENA, 2026g). These efforts should be supported by effective labour market policies, regulations and industrial strategies that build resilient, diversified supply chains and create quality employment in sustainable energy industries (IRENA *et al.*, 2026).

A successful transition requires a broader and more diverse talent pool. Despite some progress, women remain under-represented in renewable energy, reflecting wider structural inequalities in the labour market. IRENA's latest analysis indicates that women hold 32% of full-time renewable energy jobs. While this is higher than in oil and gas (23%) and nuclear energy (25%), it remains below the global workforce average of 43.4% (IRENA, 2025e). Addressing barriers to participation – unequal access to skills development, limited career progression and workplaces that are not inclusive – is essential to build the workforce the transition needs (IRENA, 2025e, 2026g).

More broadly, a robust decent work agenda must underpin the energy transition by ensuring fair wages, safe working conditions, social protection, workers' rights and meaningful opportunities for communities and workers affected by structural changes (IRENA, 2026g; IRENA and ILO, 2021).



Reskilling and upskilling will be crucial to support workers and communities affected by the decline of fossil fuel industries.



Socio-economic impacts: Energy Transition Welfare Index

GDP remains the standard measure of economic output, but it does not capture much of what society values, such as human health, fulfilling jobs and environmental quality. And while climate change will probably depress future GDP, it will also affect societies, nature and economies in ways no GDP measure captures. Relying on GDP alone is therefore incomplete and potentially misleading. To better reflect social well-being in the context of the energy transition, IRENA has developed and continuously refined its Energy Transition Welfare Index (ETWI) (IRENA, 2016, 2019a, 2019b, 2020, 2021, 2022a, 2023a, 2024a) for extended impact analysis. The ETWI provides a comprehensive framework for assessing the impacts of the transition and has been updated this year to include four complementary dimensions – economic, social, environmental and distributional – captured by ten indicators in total (Figure 3.15).[27]

To maximise human welfare, a decarbonised energy system must be managed through holistic policies that deliver sustained economic and environmental dividends equitably, alongside an inclusive approach that broadens access in support of development goals.

The ETWI allows direct comparison between scenarios, illustrating how targeted policies can improve socio-economic outcomes while identifying potential challenges for policy makers. The index and its four dimensions run on a scale from 0 (low performance) to 1 (high performance). The analysis focuses on three core scenarios – the PES as the benchmark, the DES and the DES-IC (directed towards social outcomes and industrial policies) – together with the supplementary 1.5°C Scenario pathway. Comparing the 1.5°C Scenario with the DES-IC isolates how a more stringent climate pathway changes welfare under a broadly similar policy package.

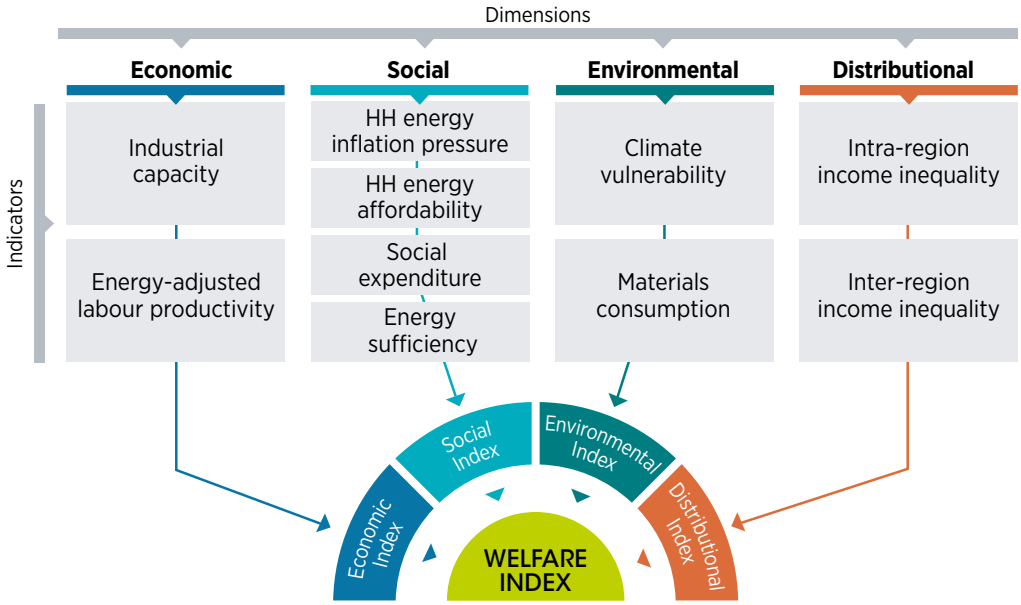
[27] *The economic dimension comprises two indicators: (1) industrial capacity, which is a composite score derived from two measures designed to capture industrial production capacity and reliance on external value chains; and (2) the energy-adjusted labour productivity indices.*

The social dimension comprises four indicators: (1) the household energy inflation pressure index, which measures the share of overall household inflation attributable to energy prices, thereby capturing household exposure to energy price shocks and cost-of-living volatility; (2) the household energy affordability index, which measures the share of energy expenditure within total household budgets; (3) social expenditure, which is expressed as per capita public expenditure and refers to public spending on education, health and social welfare as well as transition-related public investment and budgets related to climate policies; and (4) progression along the energy sufficiency level, which is measured via the per capita total final energy consumption indicator and assumes an energy sufficiency level of 20 kilowatt hours/capita/day, in line with the literature (Millward-Hopkins et al., 2020).

The environmental dimension comprises two indicators: (1) climate vulnerability, which acknowledges countries' exposure, sensitivity, adaptive capacity and readiness to adapt to climate change impacts; and (2) per capita materials consumption, which is formulated in terms of domestic materials consumption and includes metals, non-metallic minerals and biomass (wood, food), but excludes fossil fuels.

The distributional dimension comprises two indicators that measure income inequality: (1) within countries –defined as the quintile ratio between the income held by the highest 20% of the population and that held by the lowest 20% of the population; and (2) across countries – to highlight directly how a transition pathway can be inclusive at the global/regional level by calculating the absolute log distance of a country's GDP per capita from the global average.

FIGURE 3.15 Structure of IRENA's Energy Transition Welfare Index (ETWI)



Note: HH = household.

Accelerated decarbonisation and global welfare

The global Welfare Index increases under all three core scenarios between 2024 and 2050, but the largest step change occurs between the PES and the DES. Under the PES, the ETWI improves by around 10% over 2024-2050; under the DES it rises a further 6.3% above the PES. The result confirms that the energy-system transformation itself is the main driver of higher welfare, as improvements in productivity, affordability and climate resilience accumulate.

The policy-enhanced scenarios further improve the outcome, but through different channels. The DES-IC increases the global index by around 1% above the DES, with additional gains coming from stronger social expenditure, improved affordability and greater income convergence, particularly in regions with limited fiscal space and significant unmet development needs. In contrast, the 1.5°C Scenario delivers a very similar overall welfare outcome, only around 0.1% higher, but with a different composition. While economic performance and income convergence improve further, household energy price pressures become more pronounced. This illustrates why the ETWI needs to be interpreted through its underlying dimensions rather than as an aggregate index alone.

Even under the highest-performing pathway, the global ETWI reaches only around 0.25 by 2050. This does not imply that the transition delivers limited benefits. Rather, it reflects that decarbonisation alone cannot resolve persistent structural challenges such as inequality, low social expenditure, uneven industrial capabilities or high material footprints. Achieving higher welfare therefore requires complementary economic, social and industrial policies alongside accelerated decarbonisation.

Economic welfare: The role of productivity and industrial policies

The global economic dimension is projected to improve by 3.4% between the PES and the DES in 2050, with the score increasing from 0.340 to 0.351. The economic dimension combines two indicators: industrial capacity and energy-adjusted labour productivity. Most of the improvement stems from enhanced energy-adjusted labour productivity, while the global structure of value chains evolves more gradually as countries develop their skills, infrastructure, supplier networks and industrial ecosystems.

Industrial capacity is determined by two factors: the import content of exports and export competitiveness. A lower import content means a larger portion of the export value is produced domestically, whereas higher export competitiveness signifies a stronger ability to sell domestic production internationally. Under the DES, the relatively small difference compared with the PES (around -0.12% in 2050) reflects the time needed to strengthen domestic productive capabilities. Conversely, energy-adjusted labour productivity improves much more significantly, with the underlying productivity-energy ratio increasing by around 30% between the PES and the DES.

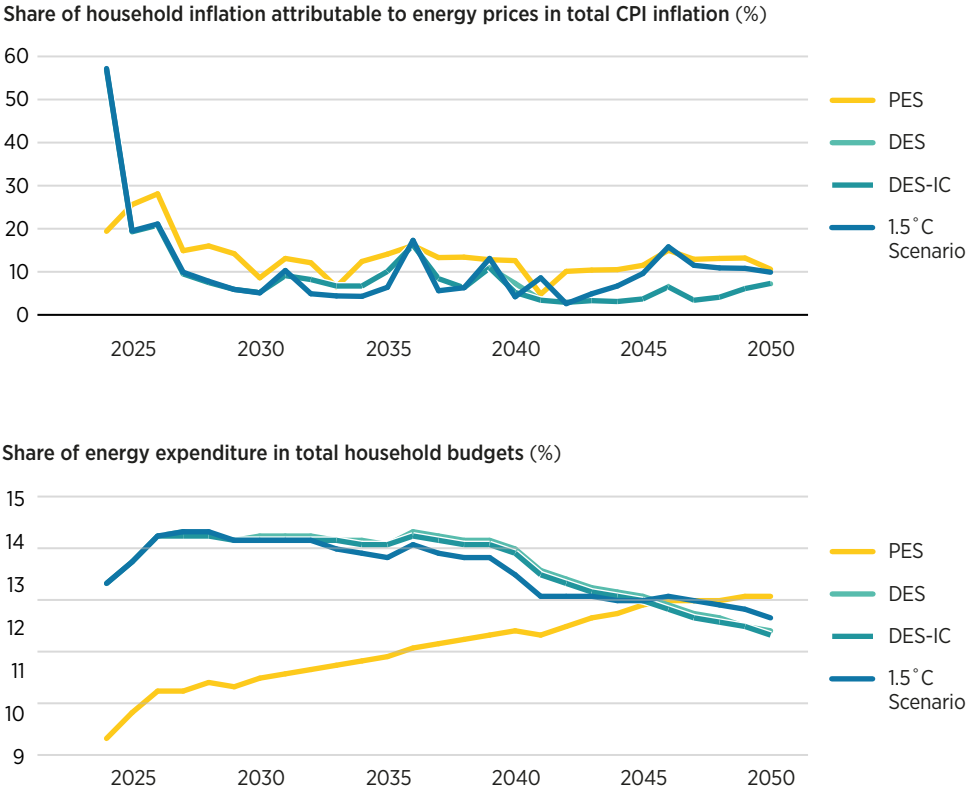
The DES-IC further improves the economic dimension, increasing its score to 0.356 through higher productivity and stronger industrial capacity. The results show how international collaboration focused on social and industrial policies can help countries to retain more value from the transition, rather than primarily serving as importers of technology and equipment. The 1.5°C Scenario pathway records the strongest economic result (0.359), reflecting the additional investment and industrial transformation associated with this more ambitious climate pathway.

Social outcomes: Short-term transition pressures followed by long-term gains

The global social dimension improves steadily across all accelerated transition pathways, increasing from 0.393 under the PES to 0.404 under the DES and 0.410 under the DES-IC by 2050. Its evolution reflects four complementary indicators: household exposure to energy inflation, household energy affordability, social expenditure per capita and access to a sufficient level of final energy (Figure 3.16).



FIGURE 3.16 Evolution of selected underlying social dimension indicators at the global level, 2024-2050



Notes: DES = Decarbonising Energy Scenario; DES-IC = Decarbonising Energy Scenario with international collaboration; PES = Planned Energy Scenario.

The analysis highlights an important feature of the transition: short-term household pressures are succeeded by longer-term social gains. Under the DES, energy accounts for 26.7% of the modelled global Consumer Price Index increase during 2024-2027. This contrasts with 22.0% under the PES, reflecting up-front investment, price adjustments and cost reallocation during the early years of the transition. Conversely, over the period 2041-2050, energy accounts for only 4.4% of inflation under the DES, compared with 11.2% under the PES.

Household energy affordability follows a similar pattern. Although the household energy burden initially increases during the transition, it falls to 11.9% of household expenditure under the DES by 2050, compared with 12.7% under the PES. Consequently, renewables, electrification and efficiency enhance long-term affordability by reducing reliance on fossil fuels. However, the short-term pressures associated with front-loaded investment need to be anticipated and managed.

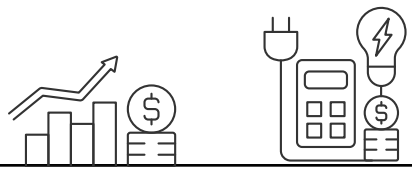
The DES-IC delivers the strongest social outcome by further improving affordability, reducing the household energy burden to 11.8% in 2050 and increasing social expenditure from around USD 4 019 to USD 4 083/capita (2025 prices). Compared with the previous WETO edition, the international collaboration policy package places greater emphasis on strengthening productive capacity alongside social outcomes.

Energy sufficiency declines from around 46 kWh/capita/day in 2024 to about 34 kWh in the accelerated pathways by 2050. This does not imply lower access to energy services; rather, it reflects the higher efficiency of electrified technologies, which can deliver mobility, heating, cooling and productive services using less final energy. Importantly, the global average remains well above the 20 kWh sufficiency threshold, although significant disparities persist across countries.

The 1.5°C Scenario pathway underscores the importance of complementing stronger climate ambition with targeted social measures. Compared with the DES-IC, the household energy inflation pressure increases from 7.3% to 9.9% and the household energy expenditure burden rises slightly from 11.8% to 12.2%, while energy sufficiency declines marginally. Social expenditure remains unchanged. These results indicate that stronger climate ambition should be accompanied by affordability support, progressive fiscal measures and carefully sequenced price reforms to maintain public acceptance and ensure widespread distribution of transition benefits.



Long-term gains do not remove short-term household pressures



The effect of international collaboration on various welfare constraints

The global welfare gains from the DES-IC are modest relative to the DES, though their regional impacts vary considerably. The largest additional gains are observed in regions with the greatest fiscal constraints, industrial gaps and unmet development needs, underscoring the importance of tailoring international collaboration to specific regional circumstances.

Africa provides the clearest illustration of this. By 2050, its Welfare Index rises from 0.432 under the DES to 0.460 under the DES-IC. International collaboration funding boosts social expenditure, alleviates household energy burdens and narrows income inequality, while industrial policies further strengthen productive capacity and economic performance. This demonstrates the complementary nature of socially and industrially oriented international collaboration. Social expenditure and protection facilitate more inclusive and politically sustainable structural change, while industrial policies strengthen productive capacity, employment and fiscal revenues.

Conversely, the additional welfare gains are more modest in regions already possessing robust public institutions and productive capabilities. In the EU27 and the G20 nations, the DES-IC produces only limited improvements in the overall index. In contrast, Southeast Asia records broader gains across several welfare dimensions, while in South America and the Middle East, persistent inequality continues to constrain overall welfare improvements.

Environmental gains from lower emissions: Partly offset by material requirements

The environmental dimension records the most significant improvement between the PES and the accelerated transition pathways, increasing from 0.619 under the PES to 0.754 under the DES in 2050. However, its two underlying indicators move in opposite directions.

The primary driver of this improvement is the sharp reduction in cumulative CO_2 emissions, which decline from around 1147 $GtCO_2$ under the PES in 2050 to around 500 $GtCO_2$ under the DES pathways. Reduced climate vulnerability is therefore the single-largest contributor to enhanced environmental welfare.

At the same time, the transition increases demand for materials. Materials consumption reaches around 5.37 t/capita under the DES and around 5.39 t under the DES-IC in 2050, slightly above the 5.30 t recorded under the PES. This is because renewable power, electricity grids, storage, electric vehicles and other transition technologies require substantial quantities of minerals and construction materials, particularly during the investment-intensive phase.

The climate benefits of accelerated decarbonisation substantially outweigh the increase in material requirements. Nevertheless, the results underscore the growing importance of circular design, recycling, material substitution, higher utilisation rates and longer product lifetimes to prevent the transition from merely shifting environmental pressures from emissions to resource extraction.

The environmental dimension under the 1.5°C Scenario pathway remains very close to the DES-IC, despite a difference of 80 Gt in cumulative CO_2 emissions over 2026-2050. This small difference underlines the importance of assessing cumulative emissions and their timing alongside the composite welfare index.

Distributional outcomes and the focus on equity

The distributional dimension remains the weakest component of the global ETWI, reflecting persistent inequalities both within and across countries. Its score increases from 0.0368 under the PES to 0.0387 under the DES, and further to around 0.0398 under both the DES-IC and the 1.5°C Scenario pathways in 2050.

Within-country inequality, measured by the ratio of income held by the highest quintile to that held by the lowest quintile, rises from 322 under the PES to 344 under the DES in 2050. This increase reflects a transition where new assets, investment opportunities and high-productivity jobs initially accrue disproportionately to better-positioned households and economies. However, international collaboration substantially improves this outcome, reducing the ratio to around 298. Despite this improvement, the remaining level of inequality continues to constrain the overall distributional index.

Across countries, inequality is measured by the coefficient of variation of GDP per capita. This declines steadily from 0.924 under the PES to 0.899 under the DES, and further to 0.883 under the DES-IC, indicating greater convergence across economies. While the 1.5°C Scenario pathway strengthens this convergence further, it produces a slightly less favourable within-country distributional outcome. This highlights that stronger climate ambition alone does not automatically improve all dimensions of equity.

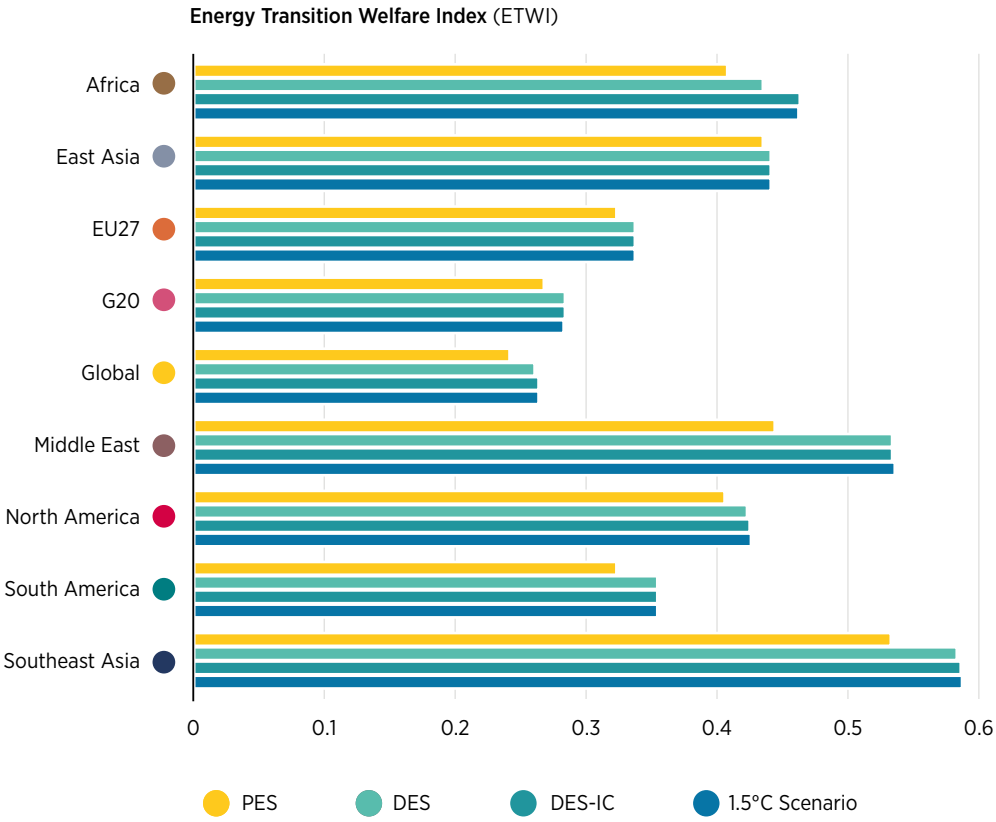
This analysis demonstrates that distributional outcomes do not automatically improve with decarbonisation. Explicit policies that broaden access to ownership, investment opportunities, finance, skills and high-productivity employment are essential to ensure that the benefits of the transition are shared more widely.

Binding constraints on regional welfare outcomes

While accelerated decarbonisation improves welfare across all regions, the drivers of these improvements differ considerably (Figure 3.17). This variation reflects the differences in economic structure, institutional capacity, resource endowments and development priorities. The ETWI thus highlights that there is no single pathway to maximise welfare; instead, countries face different constraints and policy priorities as they progress through the transition.

The Middle East records the largest relative improvement between the PES and the DES, driven mainly by economic diversification and productivity gains from renewable energy deployment. Complementary distributional policies remain important, since persistent income inequalities continue to constrain overall welfare outcomes. Africa records the second-largest welfare improvement across all scenarios. The region benefits from higher energy access, stronger productivity gains and rising social spending, while international co-operation further improves affordability, productive capacity and income convergence. The results underscore the need for a combination of fast decarbonisation and targeted financial and industrial support. Southeast Asia records widespread improvements across all four dimensions of welfare. Economic and social outcomes are strengthened by ongoing industrial development, deeper international collaboration and rising productive capacity, illustrating how industrial policies and faster clean energy deployment can reinforce one another. In the EU27, the G20, North America and South America, incremental improvements are modest. Future gains depend less on basic development indicators and more on reducing inequality, raising productivity, improving affordability and lowering materials consumption, factors that continue to limit environmental welfare.

FIGURE 3.17 IRENA's Energy Transition Welfare Index (ETWI) for selected regions, 2050



Notes: The Welfare Index, which ranges from 0 (low performance) to 1 (high performance), represents the absolute value of the overall Welfare Index. DES = Decarbonising Energy Scenario; DES-IC = Decarbonising Energy Scenario with international collaboration; EU = European Union; PES = Planned Energy Scenario.

These regional differences reinforce an important conclusion: while the energy transition follows different pathways across countries, successful outcomes consistently depend on integrating climate ambition with economic development, social inclusion and industrial transformation.

Climate ambition and the role of strong social policies

The 1.5°C Scenario results significantly qualify the analysis. While greater climate ambition reinforces long-term investment, productivity and environmental performance, it can also increase short-term affordability and inflationary pressures if social protection and transition management do not keep pace. Therefore, climate ambition, industrial development and social policies need to advance together.

This finding is particularly important given the current context, where households in many countries are already facing cost-of-living pressures early in the transition. Proactively managing these pressures through targeted support, progressive fiscal policies and well-designed transition strategies will be essential for maintaining public acceptance and sustaining the pace of implementation.

The comparison between the 1.5°C Scenario and the DES-IC (a less than 1.5°C pathway) thus demonstrates that heightened climate ambition alone does not automatically maximise welfare (Figure 3.18). The quality of implementation, including affordability, social protection and equitable distribution of benefits, becomes increasingly important as ambition increases.

Policy implications

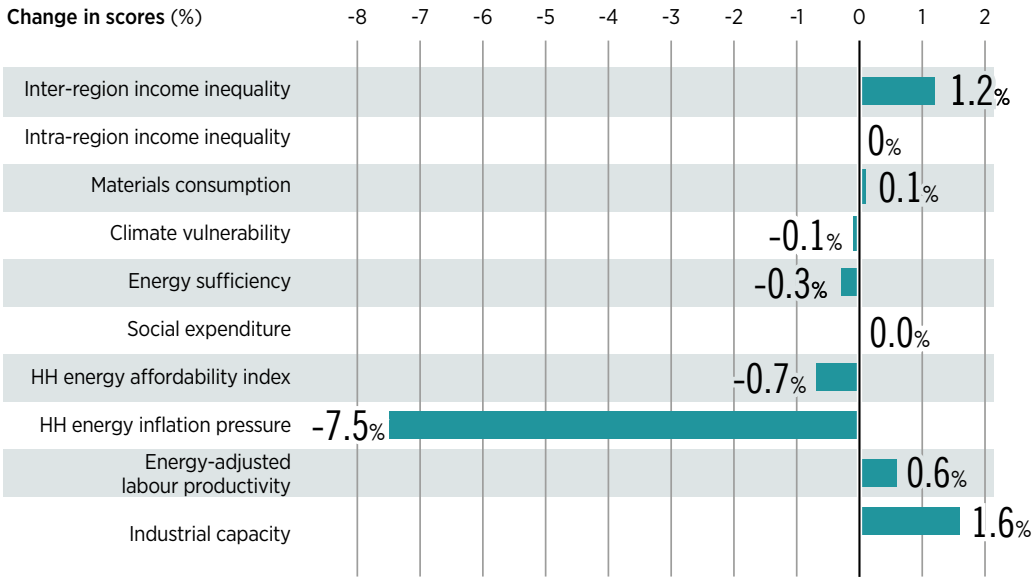
The indicator-level analysis confirms that the energy transition can improve welfare well beyond the effects captured by GDP. As stated in earlier section, while greater climate ambition can reinforce investment and productivity, it can also increase household pressures if social protection and transition management do not keep pace. Therefore, climate, industrial and social policies need to advance together.

Five priorities emerge from the analysis: (1) accelerated decarbonisation remains fundamental for improved welfare; (2) early affordability and inflationary pressures need to be anticipated and managed; (3) international collaboration should support social expenditure and productive capacity, particularly where domestic fiscal space is constrained; (4) distributional policies need to widen participation in ownership, investment and high-productivity employment; and (5) circular-economy and material efficiency measures must be integrated into transition planning from the outset.

The ETWI demonstrates that the quality of the transition is as crucial as its pace. A pathway that lowers emissions but fails to address affordability, inequality or material use will not fully realise the welfare potential of the energy transition. The most favourable outcome will result from combining climate ambition with social protection, industrial development, fair distribution and a more circular use of materials.



FIGURE 3.18 **Global welfare change in underlying indicator scores between the 1.5°C Scenario and DES-IC, 2050**



Notes: HH = household; DES-IC = Decarbonising Energy Scenario with international collaboration.

The quality of the transition matters as much as its pace: climate ambition must advance together with social protection, industrial development, fair distribution and a circular economy.

DES-IC

Local environmental impacts of the energy transition

Understanding the local environmental impacts of the energy transition

Beyond the two environmental aspects discussed in section 3.1 – reducing climate vulnerability and materials consumption – the energy transition can also produce environmental benefits at the local level. However, as discussed before, policies are needed for these benefits to be fully realised.

Fossil fuels remain one of the largest threats to the global environment and to biodiversity, as their production and consumption are directly associated with environmental degradation and biodiversity loss (UNEP, 2025b; WWF, 2024). Coal mining is responsible for most of the mining sector's negative environmental impacts (Montgomery and English, 2024). The use of fossil fuels (such as oil, coal and fossil gas) produces hazardous air pollutants and damages public health, while oil spills from extraction and refining pollute water and harm wildlife. These environmental impacts damage crops, forests and wildlife, costing billions every year (Bertrand, 2021). Halting global environmental degradation and addressing major environmental threats require an urgent and accelerated transition from fossil fuels to renewable energy.

However, like all human activities, the development, construction and operation of renewable energy projects and infrastructure can also affect the local environment and disrupt wildlife habitats across the whole life cycle (Figure 3.19). Energy transition technologies, for example, will require growing quantities of minerals, including cobalt, lithium, copper, antimony and nickel. If most of this demand is met from virgin minerals, mining can cause pollution, land degradation and habitat disruption (IRENA, 2026n; UNEP, 2025b). Where renewable energy projects such as solar farms, wind turbines or hydropower infrastructure overlap with areas of high biodiversity value, construction and operation may cause environmental degradation and disturb wildlife habitats (IRENA, 2026n; IUCN, 2024). When renewable energy technologies reach the end of their service life, unsustainable disposal can also contaminate the local environment and threaten local communities and public health (IRENA, 2026o).

Rapid expansion of renewables and supporting infrastructure calls for an integration of environmental considerations from the outset. Under the 1.5°C Scenario, renewable energy capacity has to scale up by nearly 2.2 times in the five years to 2030 and 7.4 times by 2050 compared with 2025 levels. Meanwhile, energy infrastructure, such as power grids and storage facilities, would also need to expand significantly to support a higher share of renewables. Such a major development must be handled carefully to ensure the transition does not create larger environmental burdens or aggravate the biodiversity crisis.

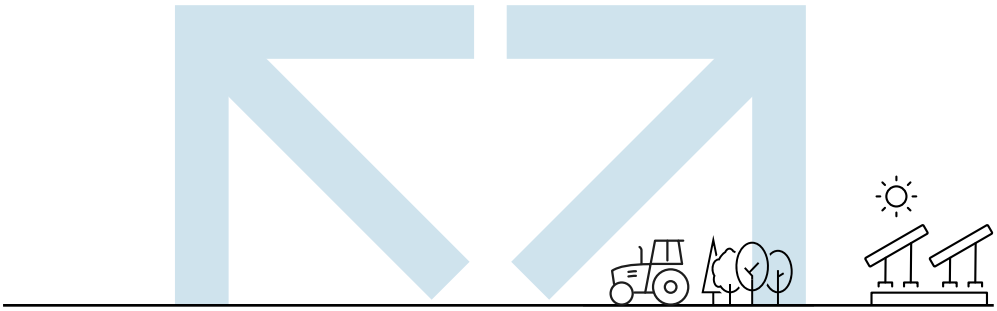
Under certain circumstances, impacts on the environment and biodiversity can be positive, contributing to accelerated land restoration, improved biodiversity and more resilient agriculture. Evidence has shown that, during years of operation, large-scale solar PV projects can change the micro-climate and other environmental factors, such as wind speed, soil temperature and moisture. Where solar plants are deployed in arid and semi-arid areas, these changes may accelerate the restoration of degraded land and help control desertification. For off-shore wind farms, the foundations can create artificial reef effects with positive biodiversity impacts (Bennun *et al.*, 2021; IRENA, 2026o). Sustainable biomass programmes can also support sustainable forestry management and improve livelihoods of local communities (IRENA, 2024c). However, these impacts can be complex because the net impact on biodiversity and ecosystem functions are not clear, and require continuous monitoring and precautionary measures.

FIGURE 3.19 Renewables' impacts on the local environment along the life cycle



	DIRECT INTERACTIONS	IMPACTS ON MICRO-CLIMATE CONDITIONS, SOIL AND VEGETATION	IMPACTS ON WILDLIFE, HABITAT AND ECOLOGICAL SERVICE/ FUNCTION	IMPACTS ON PEOPLE AND LOCAL COMMUNITY
Overall impacts on materials and land use	• Material demand • Land use	• Vegetation loss (*e.g.* deforestation) driven by increased mining activities	• Threats to wildlife and their habitat	• Land use competition • Threats to public health linked to extractive industry waste
Project design and planning phase	• Overlapping with protected area, key biodiversity area or cultural heritage		• Threats to wildlife and their habitat • Wildlife habitat loss or fragmentation	• Local jobs
Construction phase	• Land clearing • Excavation for foundation and cables • Noise and waste	• Vegetation loss • Introduction of invasive species • Air/waste/noise pollution • Soil erosion/degradation • Water/marine pollution	• Wildlife habitat loss • Disturbance to nesting and breeding • Disturbance to marine species • Risk of flooding	• Increased risks to local communities due to pollution and geological hazards
Operation and maintenance	• Panel shading • Offshore foundations as artificial reef	• Temperature • Evaporation • Wind speed • Soil quality • Vegetation coverage • Vegetation diversity • Marine/freshwater ecosystem	• Enhanced or restored ecological services • Recovery of degraded land • Increased biodiversity richness	• Visual impacts to local community • Additional income • Local jobs

Source: (IRENA, 2026n).



Most unwanted environmental impacts can be prevented by integrating environmental considerations into the early planning and design stages of renewable energy projects (IRENA Coalition for Action, 2025; IUCN, 2024). An increasing number of organisations have developed guidelines or tools that can help project developers. Key measures to anticipate and prevent possible impacts include careful site selection (to avoid locations in high-risk areas), integrated project design (to integrate wildlife and habitat conservation measures) and scheduling of construction (to prevent disturbances during the breeding and nesting seasons). Existing tools, such as biodiversity sensitivity maps and risk screening tools, can help project developers assess the biodiversity risks in specific areas and prevent most unwanted impacts from the outset (IRENA, 2026n). Prioritising deployment on degraded land, or on disturbed areas already altered by construction or mining, is another important approach (TNC, 2024).

Siting and permitting of renewable energy projects and transition infrastructure remain critical to avoid and mitigate most negative land-use impacts. Six key siting and permitting principles can support industrial players in achieving nature-positive energy projects and infrastructure. They emphasise proactive efforts to conserve, restore and enhance ecosystems, as well as engagement with local actors through participatory processes to secure public support, shared benefits and the integration of local knowledge (IRENA Coalition for Action, 2025).

Generating local environmental benefits with renewables

Based on careful site selection, proper design and cross-sector collaboration, renewable energy projects can have positive impacts on the local environment. Many of the observed benefits stem from changes across several environmental factors, which can gradually create or strengthen the ecosystem services a site provides to the surrounding area. Wildlife and local communities benefit from these newly emerged or strengthened ecosystem services.

Utility-scale solar PV projects have been shown to accelerate the restoration of degraded land and the control of desertification in arid and semi-arid areas. This is linked to the shading of large areas by solar panels and its long-term impacts on the surrounding area's micro-climate, including its temperature, air humidity, soil moisture and light availability. In China, Germany and the United States, it has been observed that solar PV plant operation can reduce ground evaporation by over 20%, reduce wind speed by 20% to 40% and significantly improve soil moisture (IRENA, 2026n), thereby enhancing vegetation cover and biodiversity richness. In arid and semi-arid conditions, solar PV deployment can help restore degraded land, such as abandoned mining sites and brownfields, and help control desertification and sandstorms.

Off-shore wind can also bring positive changes in biodiversity, through the artificial reef and refuge effects of wind turbines. For example, the foundation of an off-shore wind turbine can support up to four tonnes of shellfish, which attracts a range of other marine organisms to the area. The initial colonisation is followed by crabs, and small and predatory fish, leading to positive effects on the local ecosystem and biodiversity. Also, wind farm areas often exclude fishing activities and, as a result, provide shelter for benthic marine species, fish and marine mammals (Bennun *et al.*, 2021).

Agriculture can also benefit from renewable energy's positive impacts to the local environment including agrivoltaics and solar grazing. Combining agricultural activities with solar PV plants, after making the necessary modifications to accommodate machinery, can improve land-use efficiency, enhance food security and generate additional income. In the United Republic of Tanzania, an agrivoltaics pilot project cut water demand for crop irrigation by 13.8% and significantly improved seedling survival rates (Randle-Boggis *et al.*, 2025). Similarly, livestock grazing in solar PV plants can reduce fire hazards from overgrown vegetation, save costs on vegetation management and possibly increase meat and milk production.

Enabling a policy framework integrating environmental and biodiversity considerations

Policies are key to minimising unwanted environmental impacts and realising co-benefits through renewables, supported by regulations and appropriate incentive structures. Various approaches and principles can assist policy makers and industrial players in identifying the opportunities and drivers most suitable for their local context (Figure 3.20). The environmental impacts mitigation hierarchy highlights measures and actions to avoid and minimise potential impacts during planning and design, and to mitigate residual threats through adaptive measures. Integrating energy generation with environmental considerations can optimise sustainable deployment, ensure a smooth deployment process, and avert disruptions and unnecessary costs during the construction and commissioning phases of renewable energy projects. Continuous stakeholder engagement and protection of smallholders' interests should also be key components of these policies, to maximise the socio-economic benefits for both nature and the local communities.

FIGURE 3.20 Policy framework for maximising synergies between renewables and the local environment



Source: (IRENA, 2026n).

Barriers nonetheless continue to slow the expansion of sustainable practices beyond a few major markets. They include high upfront costs, knowledge gaps, unclear or inconsistent land-use policies, challenges related to smallholder farmers' tenure rights and a lack of industrial standards.

Government strategies enable sustainable planning of individual energy transition projects. A national long-term strategy based on co-ordinated energy and environmental targets can send a clear signal to investors and prevent inconsistent policies across government departments. Such a strategy should be supported by industry standards and guidelines that can help expand sustainable practices from pilot projects into more markets. Policies should prevent the deployment of renewable energy projects in areas that are legally protected or designated as high value for biodiversity. Deployment can instead be encouraged on disturbed or degraded land, including brownfield sites and abandoned mines. In some contexts, renewables such as solar PV and off-shore wind can deliver co-benefits such as land recovery, marine ecosystem restoration and more resilient agriculture. However, training and capacity building are needed to bridge the knowledge gap.

A just energy transition lens to support inclusive energy transitions and shared prosperity

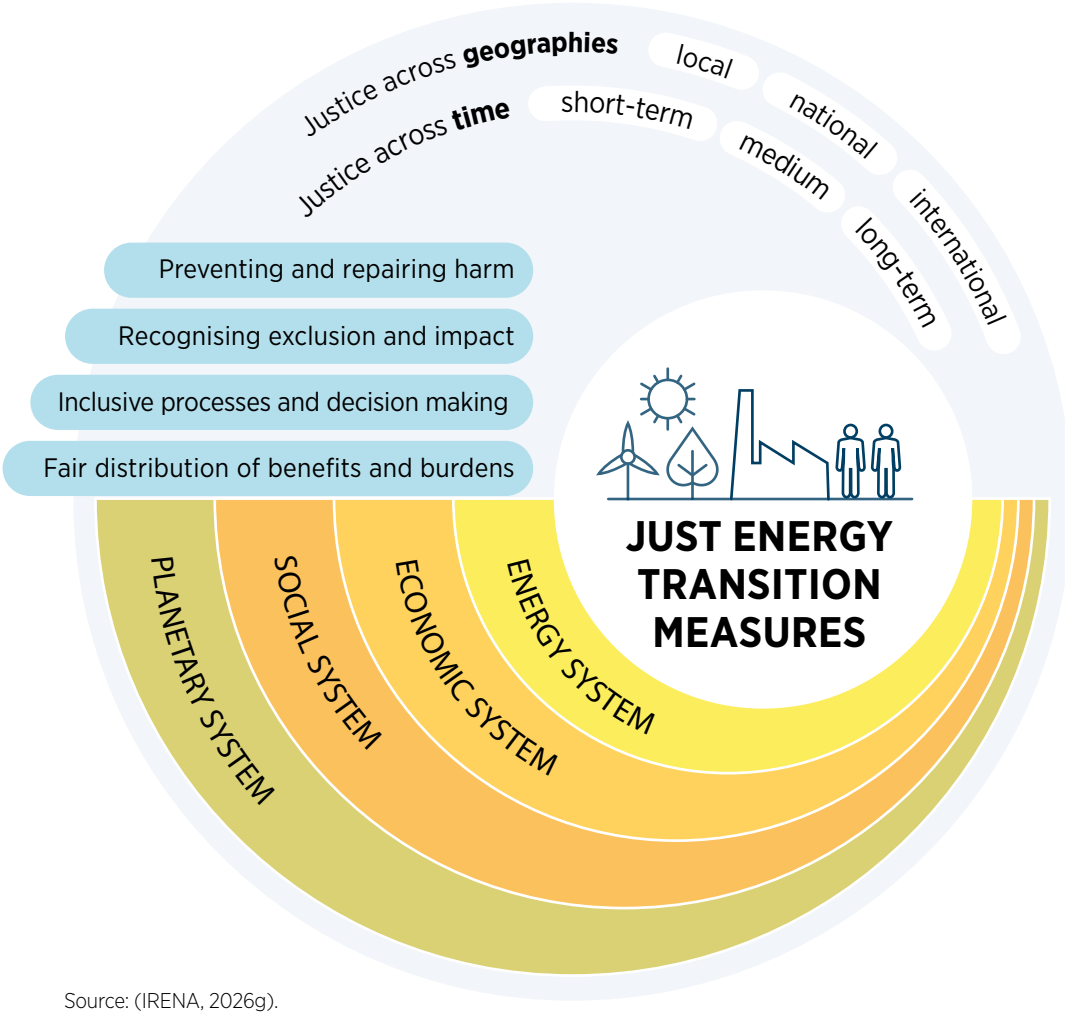
As this chapter has illustrated, the energy transition is deeply intertwined with economic, social and environmental systems, with far-reaching implications for economic development opportunities, labour markets, social inclusion efforts, welfare benefits and environmental outcomes.

The different scenarios presented in this report underscore that the pace, direction and distributional outcomes of the energy transition will depend on policy choices, strategic priorities and institutional frameworks. The growing emphasis on a just and inclusive transition in international, regional and national fora reflects both stakeholder expectations and concerns about the broader social, economic and environmental implications of this structural transformation. Ensuring that these concerns are adequately addressed will also be critical to building public support and maintaining the social legitimacy of the transition.

What constitutes a just energy transition is highly context specific and needs to be negotiated among affected stakeholders, both at the international and national level. However, several key considerations can inform policy design and implementation (Figure 3.21).

A useful starting point is the following working definition: "A just energy transition requires the equitable distribution of benefits and burdens, grounded in inclusive processes and decision making, and committed to addressing the challenges experienced by affected and marginalised groups as well as preventing and repairing harm that may occur during the transition" (IRENA, 2026g). Translating these considerations into policy action requires an integrated approach that addresses multiple dimensions of the transition, including energy affordability and access, economic development and diversification, inclusive workforce development, social protection and environmental sustainability. It also requires robust governance mechanisms, including public consultation, participatory planning, impact assessments, rights-based approaches, responsible supply chain standards and the consideration of intergenerational impacts in policy making (IRENA, 2026g).

FIGURE 3.21 **Considerations for just energy transition policy making and a whole-system perspective**



Source: (IRENA, 2026g).

CHAPTER 04

A WAY FORWARD WITH 10-YEAR ACTIONABLE PRIORITIES



Building on the analysis presented throughout this report, this chapter sets out practical priorities for the coming decade. As discussed in the introduction, the energy transition is taking place in a world characterised by increasing uncertainty, geopolitical fragmentation and growing economic pressures. Recent crises have exposed vulnerabilities in fossil-fuel-dominated energy systems, supply chains and investment flows. In so doing they have reinforced the importance of renewable energy, electrification and energy efficiency. What was once viewed primarily as a climate agenda is now recognised as a pathway to strengthen energy security, improve industrial competitiveness, reduce exposure to external shocks and support long-term economic resilience while ensuring just energy transitions.

Progress is evident. Renewable energy deployment continues to reach record levels; technology costs have declined significantly; and electrification is advancing across multiple sectors. Yet the pace of change remains insufficient to achieve climate goals. Rising electricity demand, infrastructure bottlenecks and uneven investment flows continue to create implementation challenges. The question facing governments is therefore no longer whether the transition should occur, but how it can be accelerated in ways that simultaneously advance climate objectives, energy security and sustainable development.

Importantly, many of the challenges described throughout this report also create opportunities. Fossil fuel price volatility highlights the value of domestic renewable resources. Growing electricity demand strengthens the case for grid expansion and system modernisation. Industrial competition is driving investment in clean technology manufacturing and innovation. Concerns around energy security are accelerating efforts to diversify energy systems and reduce strategic dependencies. The challenge for policy makers is therefore not only how to respond to current risks, but how to transform them into drivers of a faster, more resilient and more inclusive energy transition.

Building on the analysis presented in previous chapters, this chapter proposes a set of practical priorities for the coming decade. The recommendations are organised around six strategic questions facing governments today: How to align plans and investments, accelerate the transition away from fossil fuels while ensuring affordability and public acceptance, build the infrastructure needed for electrification, capture industrial opportunities, mobilise capital at scale and strengthen international co-operation. Together, these priorities provide a practical roadmap for translating today's uncertainties into long-term opportunities for sustainable development, economic resilience and energy security.



Aligning national plans, infrastructure and investment

The energy transition is a challenge of scale and complexity which requires a level of co-ordination beyond individual technologies, sectors or policy instruments. As countries pursue multiple objectives at the same time, including energy security, competitiveness, affordability and climate action, the success of the transition increasingly depends on the consistency of national strategies, infrastructure plans and investment signals.

The first step towards such coherence is to align Nationally Determined Contributions (NDCs), long-term energy and climate strategies, renewable energy targets, electrification pathways and infrastructure development plans (IRENA, 2026f). Too often, these components are developed in isolation, resulting in a mismatch between policy ambition and implementation capacity. Renewable energy targets should be established with corresponding grid expansion plans. Likewise, electrification strategies should be supported by adequate planning for renewable power generation, transmission and distribution networks, energy storage systems and flexibility to ensure reliable and affordable system expansion. Goals for industrial development should be pursued with regard to the implications for energy systems and infrastructure needs.

Integrated planning can help to overcome these challenges by aligning energy supply, infrastructure development and end-use demand across power, transport, industry and buildings. Governments need to take a holistic view, rather than treating these sectors separately, recognising the interdependencies between them. This includes the interaction between renewable deployment, electrification, energy efficiency, flexibility solutions and emerging technologies throughout the planning process. Integrated planning and well-functioning markets are complementary, not competing approaches. Planning provides long-term direction and anticipates system needs, while markets, competition and effective price signals help determine how those needs can be met efficiently.

The increasing importance of electricity adds to the rationale for integrated planning. Electricity systems will need to expand significantly in the coming decades to meet rising demand from transport, buildings, industry, cooling, digitalisation and emerging technologies. Co-ordinating the evolution of generation, networks and demand can reduce infrastructure bottlenecks, lower system costs and can provide greater certainty for investors and consumers alike.



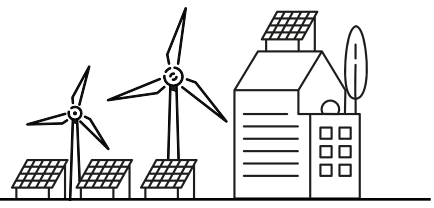
Integrated planning can help align energy supply, infrastructure development and end-use demand across sectors.

Several countries already demonstrate the benefits of this integrated approach. Across the European Union, National Energy and Climate Plans increasingly align renewable energy deployment, electrification, grid expansion and energy efficiency within a common planning framework (European Commission, 2024a). Portugal has complemented this approach with accelerated permitting reforms and transmission planning (Miranda, 2026). China has similarly integrated renewable energy expansion with large-scale transmission planning through its ultra-high-voltage network, enabling electricity generated in resource-rich regions to supply major demand centres (Li and Bourgault, 2025). These experiences illustrate that co-ordinated planning across generation, networks and end-use sectors can significantly accelerate implementation while maintaining system reliability.

Also important is institutional co-ordination. Effective implementation will require closer co-operation among ministries and agencies responsible for energy, industry, transport, housing, education, finance, infrastructure and regional development. The efficiency of public and private investments, and the reinforcement of investor confidence, can be enhanced by clear governance arrangements, consistent policy frameworks and long-term planning.

Planning frameworks should also incorporate uncertainty. Technology costs, demand growth, geopolitical developments and market conditions are changing fast (IRENA, 2026c, 2026a, 2026p). Scenario-based approaches can help governments assess alternative pathways, identify potential risks and maintain flexibility in decision making. In a fast-changing world, effective planning is less about predicting the future, and more about preparing for a range of possible futures.

Finally, planning needs to explicitly recognise the role of decentralised renewable energy solutions alongside utility-scale investments. Mini-grids and off-grid systems and distributed generation can support energy access, resilience and local economic development, in addition to infrastructure development at the national level. Recent IRENA analyses for Senegal and Nigeria demonstrate how integrating decentralised renewable energy solutions into national planning frameworks can simultaneously expand energy access, strengthen energy security and support long-term development objectives (IRENA, 2026q, 2026r). Integration of these solutions into national planning processes can accelerate progress towards development and energy transition goals. The energy transition cannot be realised through isolated projects or fragmented policy actions. This needs a coherent strategy that links long-term ambitions to infrastructure development, market design and investment decisions. Governments that can successfully align plans, infrastructure and investment signals will be better placed to accelerate implementation, attract capital and capture the wider economic and social benefits of the transition.



Accelerating the transition away from fossil fuels while strengthening energy security

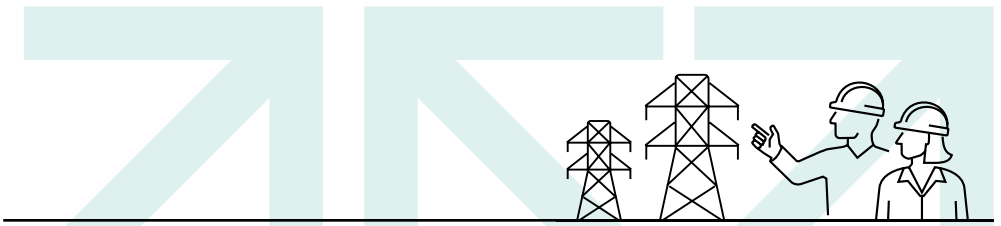
The recent geopolitical shocks have shown that dependence on fossil fuels remains a major source of economic vulnerability. External risks to households, industry and public finances persist owing to price volatility, supply disruptions and geopolitical tensions. In this sense, the transition away from fossil fuels is no longer just about climate targets. As stated in the introduction to this chapter, it is becoming an increasingly important strategy for enhancing energy security, increasing economic resilience and improving long-term competitiveness.

Transitioning away from fossil fuels demands a structural transformation of both energy supply and end-use sectors. It goes well beyond replacing fossil fuel electricity with renewable electricity. It requires parallel advances in renewable energy deployment, electrification, energy efficiency improvements, grids, flexibility solutions and sustainable fuels. Progress across these dimensions must be co-ordinated to ensure that energy systems remain reliable, affordable and secure throughout the transition.

Given the systemic nature of this transformation, governments should set out clear and nationally relevant transition pathways that define the sequencing, timing and distribution of fossil fuel phase-down by sector, while reflecting national circumstances such as resource endowments, industrial structures, fiscal capacity and development priorities. These pathways would offer investors greater certainty, reduce risks of stranded assets and align short-term policy choices with long-term transition goals.

Electrification with renewables represents one of the most effective pathways to reduce the reliance on fossil fuels in transport, buildings and much of industry. But not all sectors can be electrified directly. As such, sustainable fuels, including renewable hydrogen and its derivatives, sustainable bioenergy and advanced biofuels, will play an important complementary role in the decarbonisation of hard-to-abate sectors such as aviation, maritime transport and selected industrial processes. Governments should therefore pursue integrated strategies that recognise the complementary roles of direct electrification and sustainable fuels, rather than treating them as competing solutions.

The transition also requires a progressive reallocation of investment away from fossil-fuel-based systems towards renewable energy and enabling technologies. Governments can support an orderly transition through clear long-term policy signals, phasing out inefficient fossil fuel subsidies, supporting investments in clean energy alternatives and supporting economic diversification in fossil fuel-dependent regions.



Based on experiences in different regions, there is no single route for transitioning away from fossil fuels. Brazil has been able to combine one of the world's cleanest electricity systems with a long-established biofuels programme and growing electrification to help bolster energy security while reducing fossil fuel dependence in the transport sector (IRENA, 2025c). The REPowerEU Plan in the European Union has helped increase renewable energy deployment, electrification and energy efficiency in response to recent geopolitical disruptions, demonstrating how energy security concerns can accelerate the transition away from fossil fuels (European Commission, 2022; IRENA, 2025b). China continues to combine large-scale renewable energy deployment with rapid electrification and industrial development, while fossil fuel-producing countries such as the United Arab Emirates and Saudi Arabia are increasingly investing in renewable energy embedded within broader development plans, including the UAE Energy Strategy 2050 and Saudi Arabia's Vision 2030 (IEA, 2025f; IRENA and CPI, 2025; IRENA, 2026j; Ozkan, 2026). Together, these examples illustrate that while transition pathways are different according to national circumstances, the strategic benefits of reducing fossil fuel dependence are widely shared. This transition must also be managed carefully in its social and economic aspects. The workers, industries and communities that rely on fossil fuel value chains must be supported today with reskilling programs, regional development strategies and just energy transition policies that create new jobs and minimise negative social impacts. Broadening the benefits of the transition to maintain public buy-in and long-term policy credibility will be critical.

Ultimately, the transition away from fossil fuels should not be viewed as a constraint on economic development. Well managed, it offers an opportunity to enhance energy security, reduce exposure to volatile fossil fuel markets, improve air quality and health, foster innovation and support more resilient and competitive economies. The challenge for governments is therefore not whether to speed up the transition but how to do it in a way that is just and in line with national development priorities.

Building the infrastructure for a high-electrification future

The success of the energy transition will depend not only on how quickly renewable energy and electrification expand, but also on whether the supporting infrastructure develops at the same pace. As electricity becomes the dominant energy carrier across transport, buildings, industry and emerging applications, electricity systems will need to become larger, smarter, more flexible and more resilient.

Power systems are entering a new phase of transformation. In addition to replacing conventional generation with renewable energy, they must accommodate rapidly growing electricity demand, higher shares of variable renewable energy, distributed energy resources and new large electricity consumers such as data centres and artificial intelligence (AI) applications. These developments require a fundamental evolution in the way electricity systems are planned, operated and regulated.

Grid expansion is becoming one of the most critical enablers of the energy transition. In many regions, transmission and distribution infrastructure is no longer expanding at the pace required to integrate new renewable generation and growing demand for electricity. Delays in permitting, long connection queues and aging infrastructure are increasingly becoming major constraints on renewable energy deployment and electrification. Accelerating investment in transmission and distribution networks should therefore become a strategic priority alongside renewable energy deployment itself.

At the same time, future electricity systems will require significantly greater flexibility. Traditionally, flexibility has been provided primarily by dispatchable thermal generation. As the penetration of renewable energy advances, flexibility will increasingly be delivered through a portfolio of complementary solutions, including battery storage, pumped storage, demand-side response, sector coupling, interconnections, dispatchable renewable generation and sustainable fuels. No single technology can provide all of the needed flexibility services. Instead, governments should adopt technology-neutral approaches that enable the combination of flexibility solutions best suited to national system characteristics.

Digitalisation will play an equally important role in improving system performance. Smart grids, advanced forecasting, digital control systems and AI can improve system operation, optimise network utilisation and facilitate the integration of distributed energy resources. At the same time, the rapid expansion of digital infrastructure, particularly AI and data centres, is creating a significant new source of electricity demand. Rather than becoming a constraint on the transition, this demand can strengthen the business case for renewable energy deployment and grid expansion if it is supported by proactive planning, appropriate market signals and timely infrastructure development.

Market design will also need to evolve. Electricity markets should increasingly reward flexibility, storage, demand response and other system services that support reliability as well as energy generation. Regulatory frameworks should facilitate faster infrastructure deployment, encourage innovation and provide long term investment certainty while maintaining affordability for consumers.

Several countries and regions are already demonstrating how infrastructure can become an accelerator rather than a bottleneck for the energy transition. The European Union has adopted its Action Plan for Grids, recognising electricity networks as the missing link in the clean energy transition and accelerating transmission expansion, grid digitalisation and permitting reforms (European Commission, 2023b). Australia is establishing Renewable Energy Zones to co-ordinate renewable generation, transmission infrastructure and investment planning for the purpose of reducing connection delays and improving system efficiency (Australian Energy Regulator, n.d.; Simshauser, 2021; VicGRid, 2026). India is scaling up its Green Energy Corridors programme to reinforce interstate transmission networks and enable the integration of its rapidly expanding renewable energy capacity across the country (ADB, 2022; IMPRI, 2025; KfW, 2026; MNRE, n.d.a). These experiences underscore the importance of anticipating infrastructure needs rather than reacting to them, a key to accelerating electrification and renewable energy deployment.

Ultimately, the challenge is not just to build more infrastructure, but also to ensure that infrastructure development keeps pace with the accelerating transformation of the energy system. Grids, storage, flexibility, digitalisation and market reform are no longer supporting elements of the transition. They have become core enablers of a reliable, resilient and cost-effective electricity system capable of supporting deep electrification and high shares of renewable energy.



Turning the energy transition into an industrial development strategy

The global energy transition is becoming more and more a matter of industry transformation and development. Industrial policy is re-emerging as a key component of transition strategies as countries aim to improve energy security, competitiveness and economic development – and to reduce strategic dependencies. The challenge now is not just to deploy renewable energy technologies, but also to develop industrial capabilities to manufacture, install, operate and maintain them.

This has been reinforced by recent geopolitical developments. The intensifying competition for clean energy technologies, manufacturing capacity, and critical materials has prompted many governments to pursue industrial strategies that strengthen domestic production, reinforce critical minerals and regional value chains, and attract investment to clean energy industries. This new focus on industrial policy is already visible in an increasing number of national and regional initiatives. Europe's Green Deal Industrial Plan and the Net-Zero Industry Act aim to enhance the competitiveness of European clean technology industries, while building stronger resilient supply chains and strategic autonomy (European Commission, 2023a, 2024b). Japan's Green Transformation strategy prioritises industrial decarbonisation and long-term investment in innovation and low-carbon technologies (GR Japan, 2023; METI, 2025), whereas India's Production-Linked Incentive schemes promote domestic manufacturing of solar photovoltaic modules, advanced batteries and other strategic clean technologies (MHI, n.d.; MNRE, n.d.b; PIB, 2025). When well designed, these strategies can help to accelerate renewable energy deployment, increase economic resilience and generate new opportunities for innovation, employment and productivity growth.

Industrial policy should therefore look beyond short-term localisation objectives to build competitive and resilient industrial ecosystems. Chief among the goals should be investing in research and innovation, building skilled workforces, strengthening small- and medium-sized enterprises, expanding manufacturing capacity and establishing stable long-term markets for clean energy technologies. Public procurement, targeted fiscal incentives, industrial clusters and innovation programmes can all help in speeding up the development of competitive domestic industries.

Initially, industrial development should be anchored on existing national and regional comparative advantages, not on trying to replicate all components of global value chains. Some countries may be specialised in the production of renewable energy equipment, batteries or electrolysers, while others may be specialised in mineral processing, sustainable fuels, engineering services or digital technologies. The identification of such comparative advantages can contribute to maximise domestic value creation as well as to strengthen regional economic integration. Recent experiences demonstrate this opportunity. Morocco is positioning itself as a future renewable hydrogen and green industrial hub by combining abundant renewable resources with industrial development strategies (AEP, 2025; GIZ, 2023). Indonesia is also expanding downstream processing of critical minerals to capture more value from battery value chains (AfDB, 2025; Fadhillah, 2026; IRENA, 2024d; Soamole and Mokodompit, 2025) while the African Union's Africa Green Minerals Strategy aims to promote regional value addition, manufacturing and industrial development based on the continent's mineral resources (African Union, 2024). These examples show how industrial strategies can be tailored to national conditions and at the same time enhance competitiveness and support the energy transition.

Capturing greater value from the transition also requires investment in human capital. Expanding education, technical training and reskilling programmes for workers will be critical to prepare workers for emerging clean energy industries and to support communities affected by structural changes in fossil fuel sectors. Policies that promote innovation, entrepreneurship and local supply chains – while also boosting the socio-economic benefits of the transition – can further enhance industrial competitiveness.

Industrial development should not come at the expense of international co-operation. Open trade, technology transfer, international investment and regional industrial partnerships remain essential for accelerating technology diffusion and reducing costs. Rather than promoting fragmentation, industrial policy should contribute to more diversified, resilient and interconnected global clean energy value chains.

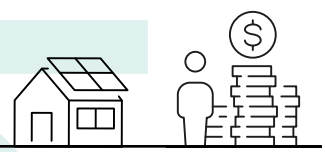
Ultimately, the energy transition represents one of the largest industrial opportunities of this century. Countries that combine ambitious renewable energy deployment with forward-looking industrial strategies will be better positioned to strengthen competitiveness, create quality employment, attract investment and capture a larger share of the economic value generated by the transition.

Mobilising capital where it is most needed

Achieving the scale of investment required for the energy transition is no longer primarily constrained by technology availability. Renewable energy technologies have become increasingly cost-competitive across most regions of the world (IRENA, 2026c). The central challenge now lies in directing sufficient capital towards the countries, sectors and infrastructure where investment needs are greatest.

Investment gaps persist (IRENA and CPI, 2025). The transition requires deployments beyond renewable power generation. These include electricity networks, storage, flexibility, electrification, sustainable fuels, industrial transformation and digital infrastructure. Meanwhile, geopolitical uncertainty, rising borrowing costs and intensifying competition for capital are creating a more challenging global investment environment. These trends are affecting emerging and developing economies in particular, where financing costs remain much higher, often despite the presence of some of the world's best renewable energy resources.

Closing the substantial investment gap will require lowering the cost of financing, which in turn will require concerted action across multiple stakeholders. Governments that can establish a clear policy direction grounded in long-term planning, create stable regulatory environments, and introduce appropriate fiscal and financial incentives will be better positioned to attract capital, accelerate implementation and build long-term economic resilience. For South Africa, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has successfully mobilised important private investment through competitive auctions, demonstrating how stable policy environments combined with risk mitigation support from multilateral institutions can reduce investment risks and speed up the deployment of renewable energy (Eberhard and Naude, 2017; IRENA, 2018, 2026p).



Building on the REIPPPP, South Africa's government in 2023 endorsed the Independent Transmission Projects (ITP) Programme to allow private sector participation in the development, financing, construction, and operation of new transmission infrastructure under a transparent competitive bidding framework. As of December 2025, seven companies were prequalified to bid to build 1164 kilometre of powerlines and associated substation infrastructure across seven preselected corridors (Smith, 2026). The ITP framework has successfully been deployed in Brazil and other parts of Africa, including Uganda, Mozambique and Angola. It could be further piloted in developing markets to address the vast grid investment gap (Carter, 2026).

Public financial institutions are well-positioned to fund underinvested areas, while using their resources strategically to mobilise larger volumes of private investment. Going forward, multilateral development banks, development finance institutions and national public financial institutions must scale-up concessional finance, guarantees, and other risk-mitigation instruments that can improve project bankability and attract private capital. These instruments are particularly needed for supporting investments in electricity infrastructure, sustainable industrial development and emerging clean technologies. Tailored and dedicated financing is also required to support the social dimensions of the energy transition, including investments in inclusive workforce development, affordability strategies for low-income households, the decent work agenda, strong institutions and participatory processes to ensure that the energy transition is planned with and for people (IRENA, 2026g).

Initiatives like the World Bank's Scaling Solar programme (IFC, 2019; World Bank, n.d.) have helped pilot utility-scale solar projects in a number of African countries. By standardising procurement and providing a suite of risk mitigation instruments, the projects under this programme reached record-low tariffs in the region after its inception in 2015. However, moving from a few pilot projects to unlocking investments at scale requires addressing systemic issues related to utility creditworthiness, grid access and curtailment, lengthy permitting and project development timelines, and regulatory uncertainty. Many of these constraints cannot be resolved quickly, and blended finance and risk mitigation instruments will be necessary in the interim to make projects bankable. Going forward, these should be structured to address underlying risks at their source, so that they benefit the broader project pipeline, and scarce public resources can be targeted where they are most needed.

At the same time, governments should continue strengthening domestic financial markets, which can help reduce the cost of financing, reduce currency risk, and channel long-term domestic savings into energy transition projects that may otherwise depend solely on foreign debt. Instruments denominated in local currencies – such as green bonds and other sustainability-linked financial instruments, transition finance frameworks, and dedicated green investment facilities – can be key in mobilising domestic and international investor bases. The government of Chile has adopted its Sustainable Bond Framework, positioning the country as one of the pioneers in sovereign sustainable finance and providing an effective mechanism for financing low-carbon infrastructure projects and fostering the growth of its sustainable finance markets (CBI, 2025; Chile Ministry of Finance, 2024, 2026; Madeira and Perez, 2023).

Stronger international co-operation will be needed to mobilise capital at scale. This entails renewed efforts to reform the global financial architecture to better reflect the needs and realities of debt-distressed developing countries that urgently need financing to translate renewable energy potential and political will into projects.

Ultimately, mobilising capital is not simply about increasing investment volumes. It is about directing finance towards the technologies, infrastructure and countries where it can have the greatest impact while ensuring that the cost of capital does not become a barrier to the global energy transition.

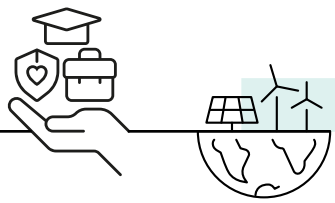
Strengthening international co-operation and avoiding new dependencies

The energy transition is reshaping global patterns of trade, investment and industrial development. While renewable energy systems reduce dependence on fossil fuels trade, they increase the strategic importance of manufacturing capacity, critical materials, technology, skills and infrastructure. Managing these new interdependencies will require stronger international co-operation, particularly in a world characterised by increasing geopolitical fragmentation and growing competition for strategic resources.

Rather than replacing one form of dependency with another, governments should pursue strategies that diversify and expand supply chains, promote regional co-operation, and foster more opportunities for technology diffusion and industrial development. Diversification does not imply self-sufficiency in every segment of the value chain. Instead, it calls for the development of more resilient and geographically diversified production networks underpinned by open markets, international investment and long-term industrial partnerships.

Technology transfer and international co-operation are still crucial elements to accelerate deployment of renewable energy and to strengthen domestic capabilities, particularly in emerging and developing economies. Expanding technical co-operation, knowledge exchange and capacity-building can help countries build the institutional, technical and industrial capacities to implement the energy transition, while tailoring solutions to national circumstances.

Several recent initiatives demonstrate how international co-operation is increasingly moving from commitment to implementation. The Just Energy Transition Partnerships in countries such as South Africa, Indonesia, Senegal and Viet Nam have been designed to support policy reforms, investment mobilisation and technical assistance (EC DG CLIMA, 2025). In Africa, the Mission 300 initiative led by the African Development Bank and the World Bank Group, along with international donors, philanthropies, and partners, aims to extend electricity access to 300 million people by 2030 through co-ordinated investments, policy reforms and enhanced public-private partnership (AfDB and WBG, 2024). Mission Innovation (MI), a global initiative that brings together governments and partners to accelerate clean energy research and innovation promotes international collaboration on clean energy research and innovation (MI, n.d.), while the Energy Transition Accelerator Financing platform managed by IRENA is helping mobilise finance and technical assistance for renewable energy projects in emerging and developing economies (ETAF, n.d.). Together, these initiatives illustrate how international co-operation is supporting implementation, strengthening institutional capacity and accelerating the energy transition.

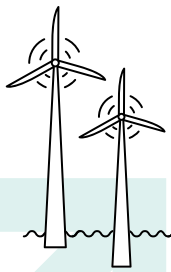


Critical materials are a key component of international co-operation. As demand for minerals that support renewable energy technologies increases, governments should encourage responsible resource development, transparent governance, diversified processing capacity, and circular economy approaches to improve resource efficiency and reduce supply risks. Recycling, material recovery, substitution and innovation can all help to bolster the resilience of long-term supply chains while reducing environmental impacts.

It is expected that South-South co-operation will also play an increasing role in the transition. Emerging and developing countries have complementary strengths in renewable energy resources, industrial capabilities, manufacturing potential and critical materials. Enhancing regional co-operation, infrastructure connectivity, technical partnerships, environmental and social safeguards, skills development and investment frameworks can boost higher regional value creation, while supporting technology diffusion and knowledge sharing on inclusive development.

International co-operation should also help ensure a more equitable distribution of the benefits of the transition. Resource-rich countries should be encouraged to move from extracting raw materials to higher value-added activities like processing, manufacturing and clean industrial development. At the same time, stronger international partnerships can help ensure that technology, finance and innovation are more widely accessible, reducing inequalities in transition outcomes across countries and regions.

Ultimately, the transition will not be accelerated through isolated national strategies alone. A more interconnected and resilient global energy system requires co-operation across governments, industry, financial institutions and international organisations. While national policies will continue to shape implementation, international co-operation remains indispensable for strengthening energy security, reducing new strategic dependencies and ensuring that the economic and social benefits of the transition are broadly shared.



Ten-year priorities for accelerating implementation

The analysis presented throughout this report demonstrates that accelerating the energy transition requires co-ordinated action across multiple policy areas. While implementation pathways will differ according to national circumstances, several priorities consistently emerge as critical for delivering a secure, competitive and resilient energy future over the coming decade.

To translate ambition into implementation, governments should prioritise the following actions:

- **Develop integrated planning and market frameworks** to align the deployment of renewable energy, electrification pathways, infrastructure development and investment, while delivering clear long-term signals and facilitating responses by competitive markets and private investment. Such frameworks should identify and reduce bottlenecks to implementation, without constraining solutions that are market driven.



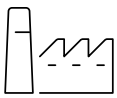
- **Develop and implement country-tailored transition roadmaps** including renewable energy deployment, electrification, energy efficiency, sustainable fuels and just energy transition policies in order to accelerate the transition away from fossil fuels while enhancing the security of energy systems, affordability for families, and resilient economies.



- **Accelerate investment to expand and modernise energy infrastructure** in transmission and distribution networks, storage systems, flexibility solutions, digital infrastructure and market reforms to ensure that electricity supply can keep pace with the rollout of renewables and electrification.



- **Design integrated industrial strategies** to support internationally competitive clean energy industries, strengthen domestic and regional value chains, expand workforce capabilities through skills development, and maximise local value creation while remaining connected to international markets and technology partnerships.



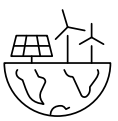
- **Establish stable policy and investment frameworks** to lower the cost of capital, provide predictable investment signals, deepen domestic financial markets and deploy public finance strategically to support investments in renewable energy, infrastructure, inclusive workforce development and industrial transformation, all while mobilising additional private capital – in emerging and developing economies in particular.



- **Maximise social, economic and environmental benefits for a just energy transition** through policy measures that promote household affordability, community benefits, equitable economic opportunities, social and environmental protection. This goal will also require institutional arrangements that support inclusive decision making, stakeholder participation, evidence-based impact assessments and rights-based approaches to ensure public support, trust and legitimacy.



- **Strengthen international co-operation** through technology transfer, diversified supply chains, regional industrial partnerships, South-South co-operation and knowledge exchanges in order to accelerate implementation and support a more resilient, inclusive and secure global energy transition.



Together, these priorities demonstrate that the energy transition is no longer a collection of separate policy agendas, but a systemic transformation requiring co-ordinated implementation. Progress in one area reinforces progress across the others, enabling countries to simultaneously strengthen energy security, improve competitiveness, accelerate the transition away from fossil fuels and support sustainable development.

The coming decade will be defined not by new ambitions, but by accelerating implementation. Countries that act early, that plan strategically and that make consistent investments will be well placed to reap the economic, social and environmental benefits of the energy transition while building more resilient and prosperous societies.

REFERENCES

ADB (2022), "India : Green Energy Corridor and Grid Strengthening Project", *Asian Development Bank*, www.adb.org/projects/44426-016/main

AEP (2025), "Morocco Approves $32.5B Green Hydrogen Mega Projects", *Africa Energy Portal*, https://africa-energy-portal.org/news/morocco-approves-325b-green-hydrogen-mega-projects

AfDB (2025), *Advancing from Nickel Mining to Downstream Processing Lessons Learned from the Indonesian Experience*, African Development Bank Group, www.afdb.org/sites/default/files/documents/publications/case_study_nickel_value_addition_indonesia.pdf

AfDB, and WBG (2024), "Mission 300 Africa", World Bank Group (WBG) and African Development Bank (AfDB), https://mission300africa.org/

AFREC (2025), *Africa Sustainable Development Goal 7*, Africa Energy Commission, https://au-afrec.org/sites/default/files/2026-01/Africa-SDG7.pdf

African Union (2009), *Africa Mining Vision* (AMV), African Union, https://au.int/sites/default/files/documents/30995-doc-africa_mining_vision_english_1.pdf

African Union (2024), *Africa's Green Minerals Strategy*, African Union, https://au.int/sites/default/files/documents/44539-doc-AGMS_Final_doc.pdf

Aramendia *et al.* (2024), "Estimation of useful-stage energy returns on investment for fossil fuels and implications for renewable energy systems", *Nature Energy*, Vol. 9, pp. 803-816.

Arduino, G., Carrillo Murillo, D.G. and Ferrari, C. (2011), "Key factors and barriers to the adoption of cold ironing in Europe", Working Papers 11-15, SIET Società Italiana di Economia dei Trasporti e della Logistica.

Australian Energy Regulator (n.d.), "Renewable Energy Zones", *Australian Energy Regulator*, www.aer.gov.au/about/strategic-initiatives/renewable-energy-zones

Bal, M., *et al.* (2023), "A fairway to fairness: Toward a richer conceptualization of fairness perceptions for just energy transitions", *Energy Research & Social Science*, Vol. 103, pp. 103213, https://doi.org/10.1016/j.erss.2023.103213

Bennun, L. *et al.* (2021), "Mitigating Biodiversity Impacts Associated with Solar and Wind Energy Development: Guidelines for Project Developers", International Union for Conservation of Nature and The Biodiversity Consultancy, Gland, Switzerland and Cambridge, UK, https://doi.org/10.2305/iucn.ch.2021.04.en

Bertrand, S. (2021), "Fact Sheet | Climate, Environmental, and Health Impacts of Fossil Fuels (2021), White Papers, EESI", www.eesi.org/papers/view/fact-sheet-climate-environmental-and-health-impacts-of-fossil-fuels-2021 (accessed 12 May 2026).

BNEF (2025), *Electric Vehicle Outlook 2025*, BloombergNEF, https://about.bnef.com/insights/clean-transport/electric-vehicle-outlook/ (accessed 14 May 2026).

BNEF (2026a), *1H 2026 Energy Storage Market Outlook*, BloombergNEF.

BNEF (2026b), "Energy Transition Investment Trends 2026", BloombergNEF, https://about.bnef.com/insights/finance/energy-transition-investment-trends/ (accessed 11 May 2026).

Böse *et al.* (2026), "The 'Nuclear Energy Paradox' - Investigating nuclear imaginaries in energy projections", *Energy Research & Social Science*, Vol. 135, 104676 https://doi.org/10.1016/j.erss.2026.104676

Carter, R. (2026), "First African Independent Transmission Project set to reach construction phase - Gridworks", https://gridworkspartners.com/news/first-african-independent-transmission-project-set-to-reach-construction-phase/ (accessed 5 August 2026).

CBI (2025), *Sustainable Debt Global State of the Market 2024*, Climate Bonds Initiative, www.climatebonds.net/files/documents/publications/Climate-Bonds_Sustainable_Debt_2024_Global-State-of-the-Market_24-Sep-2025.pdf

Chile Ministry of Finance (2024), *Chile's Sustainability-Linked Bonds Report*, Ministry of Finance Chile, www.hacienda.cl/english/work-areas/international-finance/public-debt-office/esg-bonds/sustainability-linked-bonds/annual-reports

Chile Ministry of Finance (2026), *Chile's Sustainable Bond Framework*, Ministry of Finance Chile, https://clgchile.cl/wp-content/uploads/2026/03/Chiles-Sustainable-Bond-Framework-2026-vf.pdf

Copernicus Climate Change Service and World Meteorological Organization (2025a), "Heat and drought in southeastern Europe", *European State of the Climate 2024*, Copernicus Climate Change Service (C3S), ECMWF, Reading, https://climate.copernicus.eu/esotc/2024/heat-and-drought-southeastern-europe (accessed 6 August 2026).

Copernicus Climate Change Service and World Meteorological Organization (2025b), "4. Thermal stress", *European State of the Climate 2024*, Copernicus Climate Change Service (C3S), ECMWF, Reading, https://climate.copernicus.eu/esotc/2024/thermal-stress (accessed 6 August 2026).

Crippa, M., *et al.* (2025), *GHG Emissions of All World Countries - 2025 Report*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2760/981691 (accessed 10 April 2026).

Dave, B. B. (2025), "Geo-politics of rare earth elements: Assessing the influence of foreign direct investment, trade agreements, and environmental policies on rare earth elements: Production and global trade.", *The Clarion-International Multidisciplinary Journal*, https://doi.org/10.5958/2277-937x.2025.00003.0

Eberhard, A., and Naude, R. (2017), *Recommendations for the design of successful renewable energy auctions or competitive tenders in Africa: Lessons from South Africa*, Graduate School of Business, University of Cape Town, www.gsb.uct.ac.za/files/EberhardNaude_REIPPPPLessonsRecommendations1.pdf

EC DG CLIMA (2025), "Joint article on Just Energy Transition Partnerships", *European Commission Directorate-General for Climate Action*, European Commission, https://climate.ec.europa.eu/news-other-reads/news/joint-article-just-energy-transition-partnerships-2025-01-20_en

ESMAP (2022), *2022 Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers*, World Bank, Washington, D.C., https://doi.org/10.1596/38082

ETAF (n.d.), "An inclusive multi-stakeholder climate finance platform to advance the global energy transition", Energy Transition Accelerator Financing Platform, https://etafplatform.org/

ETC (2025), *Energy productivity: Increasing efficiency in an expanded, electrified energy system*, Insights Briefing, Energy Transitions Commission, www.energy-transitions.org/wp-content/uploads/2025/10/14248-SYS-Energy-Productivity-Report-Layout-v13-Web-ready-Version.pdf

European Commission (2022), "REPowerEU at a glance", *European Commission*, Brussels, https://commission.europa.eu/topics/energy/repowereu_en

European Commission (2023a), *A Green Deal Industrial Plan for the Net-Zero Age*, European Commission, Brussels, https://commission.europa.eu/document/41514677-9598-4d89-a572-abe21cb037f4_en

European Commission (2023b), *Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions: Grids*, the missing link - An EU Action Plan for Grids, COM(2023) 757 final, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0757

European Commission (2024a), "National energy and climate plans: EU countries' 10-year national energy and climate plans for 2021-2030", European Commission, https://energy.ec.europa.eu/strategy/energy-union/national-energy-and-climate-plans_en

European Commission (2024b), "Net-Zero Industry Act: Making the EU the home of clean technologies manufacturing and green jobs", European Commission, https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/net-zero-industry-act_en

Eyre, N. (2021), "From using heat to using work: reconceptualising the zero carbon energy transition", *Energy Efficiency*, Vol. 14, 77, https://doi.org/10.5958/2277-937x.2025.00003.0

Fadhillah, D. R. (2026), "Indonesia's Downstreaming Strategy: The Nickel Boom and the Value Chain Gap - Moving beyond midstream: Unlocking downstream value in Indonesia", *YCP*, Energy & Natural Resources, , https://ycp.com/insights/expert-insights/indonesia-downstreaming-strategy

Friedlingstein, P., *et al.* (2025), "Global carbon budget 2025", Earth System Science Data, Vol.18 (5), pp. 3211–3288, https://doi.org/10.5194/essd-18-3211-2026

Geng, Q. (2021), "The Belt and Road Initiative and its Implications for Global Renewable Energy Development", *Current Sustainable Renewable Energy Reports*, Vol. 8/1, pp. 40–49, https://doi.org/10.1007/s40518-020-00172-2

Gibb, D., Thomas, S., and Rosenow, J. (2022), *Metrics matter: Efficient renewable heating and cooling in the Renewable Energy Directive*, Regulatory Assistance Project, www.raponline.org/wp-content/uploads/2023/09/2022-08_RED-Metrics-brief_FINAL.pdf

GIZ (2023), *Harnessing the potential of the hydrogen economy in Morocco*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, www.giz.de/en/downloads/giz2023-en-Energy-transition-through-power-to-X.pdf

GR Japan (2023), "Overview of Japan's Green Transformation (GX)", https://grjapan.com/sites/default/files/content/articles/files/gr_japan_overview_of_gx_plans_january_2023.pdf

Green Hydrogen Business Alliance (2025), *Enhancing Offtake in the European Hydrogen Market*, Green Hydrogen Business Alliance, https://green-hydrogen-business-alliance.de/new-report-enhancing-offtake-in-the-european-hydrogen-market/ (accessed 8 April 2026).

Hache, E. (2024), "Prospective de l'insécurité minérale: anticiper la nouvelle ère métallique de la transition bas-carbone [Mineral insecurity outlook: anticipating the new metallic era of the low-carbon transition]", *Futuribles*, 458, pp.15, https://ifp.hal.science/hal-04525496/document

He *et al.* (2023), "Research on Key Technologies Framework for Digitalization Empowering New Power System Operations", *Proceedings of the 2nd International Conference on Public Management, Digital Economy and Internet Technology*, https://doi.org/10.4108/eai.1-9-2023.2338825

Hydrogen Council (2025), *Global hydrogen compass 2025: Industry progress and lessons learned from the first wave of mature clean hydrogen projects*, Hydrogen Council, https://hydrogencouncil.com/en/global-hydrogen-compass/ (accessed 8 April 2026).

IEA (2021), *Global Energy Review 2021*, International Energy Agency, Paris, www.iea.org/reports/global-energy-review-2021 (accessed 9 April 2026).

IEA (2024), *CO_2 Emissions in 2023: A new record high, but is there light at the end of the tunnel?*, IEA International Energy Agency, Paris, www.iea.org/reports/co2-emissions-in-2023

IEA (2025a), "China's share in global PV manufacturing capacity, 2024 and 2030", www.iea.org/data-and-statistics/charts/china-s-share-in-global-pv-manufacturing-capacity-2024-and-2030 (accessed 21 April 2026).

IEA (2025b), "World energy balances", International Energy Agency, Paris, www.iea.org/data-and-statistics/data-product/world-energy-balances

IEA (2025c), *Global Energy Review 2025*, International Energy Agency, Paris, https://iea.blob.core.windows.net/assets/5b169aa1-bc88-4c96-b828-aaa50406ba80/GlobalEnergyReview2025.pdf

IEA (2025d), *Electricity Mid-Year Update 2025*, International Energy Agency, Paris, https://iea.blob.core.windows.net/assets/cc64f0aa-30e4-4497-9cca-1ffae2c55fe5/ElectricityMid-YearUpdate2025.pdf

IEA (2025e), *Global Hydrogen Review 2025*, International Energy Agency, Paris, www.iea.org/reports/global-hydrogen-review-2025 (accessed 31 October 2025).

IEA (2025f), *World Energy Investments 2025*, International Energy Agency, www.iea.org/reports/world-energy-investment-2025

IEA (2026a), *Global Critical Minerals Outlook 2026*, International Energy Agency, Paris, www.iea.org/reports/global-critical-minerals-outlook-2026

IEA (2026b), *Global Energy Review 2026*, IEA, www.iea.org/reports/global-energy-review-2026 (accessed 14 May 2026).

IEA (2026c), *Global Hydrogen review 2026*, International Energy Agency, Paris, www.iea.org/reports/global-hydrogen-review-2026/production (accessed 3 August 2026).

IEA (2026d), *Global Energy Review 2026*, International Energy Agency, Paris, www.iea.org/reports/global-energy-review-2026 (accessed 6 May 2026).

IEA (2026e), "Hydrogen Production and Infrastructure Projects Database", International Energy Agency, Paris, www.iea.org/data-and-statistics/data-product/hydrogen-production-and-infrastructure-projects-database (accessed 10 April 2026).

IEA (2026f), "CCUS Projects Database", www.iea.org/data-and-statistics/data-product/ccus-projects-database (accessed 14 April 2026).

IEA, *et al.* (2025), *Tracking SDG7: The energy progress report 2025*, International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank and World Health Organization, www.irena.org/Publications/2025/Jun/Tracking-SDG-7-The-Energy-Progress-Report-2025

IEA, *et al.* (2026), *Tracking SDG7: The Energy Progress Report 2026*, International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, the World Bank and World Health Organization, www.irena.org/Publications/2026/Jun/Tracking-SDG-7-The-Energy-Progress-Report-2026

IEF (2025), *A Critical Minerals Enabled Energy Future*, International Energy Forum, www.ief.org/reports/a-critical-minerals-enabled-energy-future

IFC (2019), *Scaling Solar: The Complete Package*, International Finance Corporation - World Bank Group, https://documents1.worldbank.org/curated/en/478221582537751050/pdf/Scaling-SolarThe-Complete-Package.pdf

IHA (2026), *2026 World Hydropower Outlook: Pathways to Sustainable and Secure Energy Systems, International Hydropower Association*, www.hydropower.org/publications/2026-world-hydropower-outlook (accessed 27 July 2026).

IMF (2026), *World Economic Outlook: Global Economy in the Shadow of War*, International Monetary Fund, Washington D.C., www.imf.org/en/publications/weo/issues/2026/04/14/world-economic-outlook-april-2026 (accessed 6 May 2026).

IMPRI (2025), "Advancing Renewable Integration Through India's Green Energy Corridor 2015", *Impact and Policy Research Institute*, www.impriindia.com/insights/green-energy-corridor/

IPCC (2023), "Summary for policymakers", In: *Climate Change 2023: Synthesis Report*, Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, pp. 1-34, www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

IRENA (2016), *Renewable energy benefits: Decentralised solutions in the agri-food chain*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2016/Sep/Renewable-Energy-Benefits-Decentralised-solutions-in-agri-food-chain

IRENA (2018), *Renewable energy auctions: Cases from sub-Saharan Africa*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2018/Apr/Renewable-energy-auctions-Cases-from-sub-Saharan-Africa

IRENA (2019a), *Global energy transformation: A roadmap to 2050, International Renewable Energy Agency*, Abu Dhabi, www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

IRENA (2019b), *Measuring the socio-economic footprint of the energy transition: the role of supply chains*, International Renewable Energy Agency, Abu Dhabi, UAE, www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_-Measuring_socio-economic_footprint_2019_summary.pdf?la=en&hash=98F94BCC01598931E91BF49A47969B97ABD374B5

IRENA (2020), *Global renewables outlook: Energy transformation 2050*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020

IRENA (2021), *World energy transitions outlook: 1.5°C pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook

IRENA (2022a), *World Energy Transitions Outlook 2022: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022

IRENA (2022b), *Renewable energy roadmap for Central America: Towards a regional energy transition*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2022/Mar/Renewable-Energy-Roadmap-for-Central-America (accessed 16 December 2022).

IRENA (2022c), *Renewable energy outlook for ASEAN: Towards a regional energy transition (2nd Edition)*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2022/Sep/Renewable-Energy-Outlook-for-ASEAN-2nd-edition (accessed 16 December 2022).

IRENA (2023a), *World Energy Transitions Outlook 2023: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

IRENA (2023b), *Renewables-based electric cooking: Climate commitments and finance*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Dec/Renewables-based-electric-cooking-Climate-commitments-and-finance

IRENA (2024a), *World Energy Transitions Outlook 2024: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Nov/World-Energy-Transitions-Outlook-2024

IRENA (2024b), *Advancing renewables-based clean cooking solutions: Key messages and outcomes*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Mar/Advancing-renewables-based-clean-cooking-solutions-Key-messages-and-outcomes

IRENA (2024c), *Sustainable aviation fuels in Southeast Asia: A regional perspective on bio-based solutions*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Dec/Sustainable-aviation-fuels-in-Southeast-Asia-A-regional-perspective-on-bio-based-solutions

IRENA (2024d), *Critical materials: Batteries for electric vehicles*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Sep/Critical-materials-Batteries-for-electric-vehicles

IRENA (2025a), *Digitalisation and AI for power system transformation: Perspectives for the G7*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Oct/Digitalisation-and-AI-for-power-system-transformation-Perspectives-for-the-G7

IRENA (2025b), *Regional energy transition outlook: European Union*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Jun/Regional-energy-transition-outlook-European-Union

IRENA (2025c), *Regional energy transition outlook: South America*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Nov/Regional-Energy-Transition-Outlook-for-South-America

IRENA (2025d), *Off-grid renewable energy statistics 2025*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Dec/Off-grid-Renewable-Energy-Statistics-2025

IRENA (2025e), *Renewable energy: A gender perspective (Second edition)*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Oct/Renewable-Energy-A-Gender-Perspective

IRENA (2025f), *A just energy transition for communities: Large-scale wind and solar projects in Sub-Saharan Africa*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Jan/A-just-energy-transition-for-communities-Large-scale-wind-and-solar-projects-in-Sub-Saharan-Africa

IRENA (2026a), *From energy crisis to energy security: Actions for policy makers*, IRENA policy advisory, No. 4/26/1, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Apr/Renewables-from-energy-crisis-to-energy-security

IRENA (2026b), *Renewable capacity statistics 2026*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Mar/Renewable-capacity-statistics-2026

IRENA (2026c), *Renewable power generation costs in 2025*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jul/Renewable-Power-Generation-Costs-in-2025

IRENA (2026d), *Transitioning away from fossil fuels: A roadmap powered by renewables, electrification and grid enhancement*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/May/Transitioning-away-from-fossil-fuels

IRENA (2026e), *Digitalisation and AI for transforming power systems: Case studies from IRENA Innovation Week 2025*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/May/Digitalisation-and-AI-for-transforming-power-systems

IRENA (2026f), Long-term energy scenarios and low-emission development strategies: Aligning energy and climate planning, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Sep/Long-term-energy-scenarios-and-low-emission-development-strategies-Aligning-energy-climate-planning

IRENA (2026g), *Fostering a just energy transition: A framework for policy design*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jan/Fostering-a-just-energy-transition-A-framework-for-policy-design

IRENA (2026h), *Renewable energy statistics 2026*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jul/Renewable-Energy-Statistics-2026

IRENA (2026i), *Flexibility for a secure and affordable power sector transformation*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jan/Flexibility-for-a-secure-and-affordable-power-sector-transformation

IRENA (2026j), *24/7 renewables: The economics of firm solar and wind*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/May/24-7-renewables-The-economics-of-firm-solar-and-wind

IRENA (2026k), *Unlocking battery storage potential for sustainable mini-grid electrification in West Africa*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Aug/Unlocking-battery-storage-potential-for-sustainable-mini-grid-electrification-in-West-Africa

IRENA (2026l), *Charcoal in the modern cooking transition*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Mar/Charcoal-in-the-modern-cooking-transition

IRENA (2026m), *Tracking financial support across 100 clean cooking access-deficit countries*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Mar/Tracking-financial-support-across-100-clean-cooking-access-deficit-countries

IRENA (2026n), *Local environmental impacts and benefits of large-scale solar PV plants*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jan/Local-environmental-effects-and-benefits-of-large-scale-solar-PV-plant

IRENA (2026o), *End-of-life Management for A Circular Economy: Solar PV Panels*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jul/End-of-life-management-for-a-circular-economy-Solar-PV-panels

IRENA (2026p), *Renewable energy auctions: Design for risk allocation*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Jan/Renewable-energy-auctions-Design-for-risk-allocation

IRENA (2026q), *Sustainable development powered by renewables: Senegal*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/May/Sustainable-development-renewables-Senegal

IRENA (2026r), *Sustainable development powered by renewables: Nigeria*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/May/Sustainable-development-renewables-Nigeria

IRENA (2026s), *Renewable capacity statistics 2026*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2026/Mar/Renewable-capacity-statistics-2026

IRENA and AfDB (2022), *Renewable energy market analysis: Africa and its regions*, International Renewable Energy Agency and African Development Bank, Abu Dhabi and Abidjan, www.irena.org/publications/2022/Jan/Renewable-Energy-Market-Analysis-Africa

IRENA and NUPI (2024a), *Critical materials for renewable energy: Improving data governance*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Oct/Critical-materials-for-renewable-energy-Improving-data-governance

IRENA and NUPI (2024b), *Constructing a ranking of critical materials for the global energy transition*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Oct/Constructing-a-ranking-of-critical-materials-for-the-global-energy-transition

IRENA Coalition for Action (2025), *Nature-positive energy principles: Environmental siting and permitting of solar, wind and grid infrastructure*, International Renewable Energy Agency, Abu Dhabi, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/Publication/IRENA_PAR_Coalition_Nature_positive_energy_principles_2025.pdf

IRENA, COP30, and GRA (2025), *Delivering on the UAE Consensus: Tracking progress toward tripling renewable energy capacity and doubling energy efficiency by 2030*, International Renewable Energy Agency, COP30 Presidency, Global Renewables Alliance, Abu Dhabi, www.irena.org/Publications/2025/Oct/UAE-Consensus-2030-tripling-renewables-doubling-efficiency

IRENA, COP31 and GRA (2026), Delivering on the UAE Consensus: Tracking progress toward tripling renewable energy capacity and doubling energy efficiency by 2030, International Renewable Energy Agency, COP31 Presidency, Global Renewables Alliance, Abu Dhabi, www.irena.org/Publications/2026/Sep/UAE-Consensus-2030-tripling-renewables-doubling-efficiency

IRENA and CPI (2025), *Global landscape of energy transition finance 2025*, International Renewable Energy Agency and Climate Policy Initiative, Abu Dhabi, www.irena.org/Publications/2025/Nov/Global-landscape-of-energy-transition-finance-2025

IRENA and ILO (2021), *Renewable energy and jobs: Annual review 2021*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021 (accessed 23 March 2022).

IRENA and ILO (2026), *Renewable energy and jobs: Annual review 2025*, International Renewable Energy Agency and International Labour Organization, Abu Dhabi, www.irena.org/Publications/2026/Jan/Renewable-energy-and-jobs-Annual-review-2025

IUCN (2024), *Spatial planning for wind and solar developments and associated infrastructure*, International Union for Conservation of Nature, Gland, https://portals.iucn.org/library/node/52091

Jomaa, H. (2026), "Labor Market and Ecological Implications of the Shift from Fossil Fuels to Renewable Energy: A Systematic Literature Review", *Ecocycles*, Vol. 12 (1), 1–13, https://doi.org/10.19040/ecocycles.v12i1.609

Kamwilu, E., *et al.* (2021), "The potentials and challenges of achieving sustainability through charcoal producer associations in Kenya: A missed opportunity?", *Sustainability*, Vol. 13 (4), pp. 2288, https://doi.org/10.3390/su13042288

KfW (2026), "Green Energy Corridors: How India aims to unite growth and climate action", *KfW*, www.kfw-entwicklungsbank.de/SDG-portal/SDG-7/Green-Energy-Corridors-India/ (accessed 1 August 2026).

Koukoufikis, G., *et al.* (2026), *Addressing Residential Cooling Demand and Summer Energy Poverty in the EU: Towards a Cooler Future*, JRC Science for Policy Report, No. 978-92-68-36263-1 (Volume EUR 40612), Publications Office of the European Union, Luxembourg, https://doi.org/10.2760/8743866

Li, M., and Bourgault, C. (2025), "China's renewable energy boom has its own challenges. Here's what we can learn", World Economic Forum, www.weforum.org/stories/energy-transition/china-adding-more-renewables-to-grid/

Liu, H., *et al.* (2020), "How green is the 'Belt and Road Initiative'? – Evidence from Chinese OFDI in the energy sector", *Energy Policy*, Vol. 145, 111709, https://doi.org/10.1016/j.enpol.2020.111709

Liubachivska, R. Z. (2025), "Енергетична дипломатія в епоху відновлюваних джерел: Зміни в глобальних енергетичних альянсах [Energy diplomacy in the age of renewables: Shifts in global Energy Alliances]", *Business Inform*, Vol. 5/568, https://doi.org/10.32983/2222-4459-2025-5-68-77

Madeira, C., and Perez, A. (2023), "The Role of Sovereign Green Bonds in Chile's Development", *SFS – Georgetown Journal of International Affairs*, Georgetown University, https://gjia.georgetown.edu/business-economics/the-role-of-sovereign-green-bonds-in-chiles-development/

Martin, P. (2024), "The Primary Energy Fallacy; or, Committest Thou NOT the 2nd Sin of Thermodynamics!", www.linkedin.com/pulse/primary-energy-fallacy-committest-thou-2nd-sin-paul-martin-nty3e/

METI (2025), *GX Policy Achieving Decarbonization and Economic Growth Together*, Ministry of Economy, Trade and Industry, www.enecho.meti.go.jp/en/category/special/article/detail_214.html.

MHI (n.d.), "PLI Scheme for National Programme on Advanced Chemistry Cell (ACC) Battery Storage", *Ministry of Heavy Industries, Government of India*, https://heavyindustries.gov.in/en/pli-scheme-national-programme-advanced-chemistry-cell-acc-battery-storage (accessed 1 August 2026).

MI (n.d.), "Mission Innovation - Catalysing clean energy solutions for all", Mission Innovation, https://mission-innovation.net/ (accessed 1 August 2026).

Millward-Hopkins, J., *et al.* (2020), "Providing decent living with minimum energy: A global scenario", *Global Environmental Change*, Vol. 65, 102168, https://doi.org/10.1016/j.gloenvcha.2020.102168

Miranda, A. (2026), "Power Generation, Transmission & Distribution 2026 Portugal", *Chambers and Partners*, https://practiceguides.chambers.com/practice-guides/power-generation-transmission-distribution-2026/portugal/trends-and-developments

MNRE (n.d.a), "Green Energy Corridors", *Ministry of New and Renewable Energy of India*, https://mnre.gov.in/en/green-energy-corridors/ (accessed 1 August 2026).

MNRE (n.d.b), "Production Linked Incentive (PLI) Scheme: National Programme on High Efficiency Solar PV Modules", *Ministry of New and Renewable Energy of India*, https://mnre.gov.in/en/production-linked-incentive-pli/

Montgomery, E., and English, A. (2024), "How coal mining harms the environment", *Environment America Research & Policy Center*, https://environmentamerica.org/center/articles/how-coal-mining-harms-the-environment/ (accessed 12 May 2026).

MSP Forum (2024), "Joint Statement of the Minerals Security Partnership Principals' Meeting 2024", *US DoS Minerals Security Partnership*, https://2021-2025.state.gov/joint-statement-of-the-minerals-security-partnership-principals-meeting-2024/

Murphy *et al.* (2022), "Energy Return on Investment of Major Energy Carriers: Review and Harmonization", *Sustainability*, Vol. 14 (12), 7098, https://doi.org/10.3390/su14127098

National Energy Administration (2025), " 2030年全国电气化率预计达到35%左右 [The National Electrification Rate Expected to Reach Around 35% by 2030]", *National Energy Administration*, www.nea.gov.cn/20250926/6aaeb916cc444a02b58d683ab501c26b/c.html (accessed 14 April 2026).

NDRC and NEA (2026a), 新型能源体系建设“十五五”规划, [*New Energy System 15th Five-Year Plan*], NDRC Energy Document No. 884, National Development and Reform Commission, National Energy Administration, Beijing, www.nea.gov.cn/20260625/0ccfdc1674e84868b49480edf584eb5f/c.html

NDRC and NEA (2026b), 可再生能源发展“十五五”规划 [*Renewable Energy Development 15th Five-Year Plan*], NDRC Energy Document No. 1067, National Development and Reform Commission, National Energy Administration, Beijing, www.ndrc.gov.cn/xxgk/zcfb/tz/202607/t20260723_1406641.html

NDRC and NEA (2026c), 新型电力系统建设 “十五五” 规划 [*New Power System Development 15th Five-Year Plan]*, NDRC Energy Document No. 942, National Development and Reform Commission, National Energy Administration, Beijing, www.nea.gov.cn/20260803/f90e2bdec3744f3c90898ca65e31e597/c.html

Ozkan, A. H. (2026), "Gulf Energy Transition: The UAE and Saudi Arabia", *Middle East Policy*, Vol. 33 (3), e70067, https://doi.org/10.1111/mepo.70067

PIB (2025), "PLI scheme: Powering India's industrial renaissance", *Press Information Bureau*, Government of India, www.pib.gov.in/PressNoteDetails.aspx?NoteId=155082&ModuleId=3&reg=48&lang=1 (accessed 1 August 2026).

PMINDIA (n.d.), *Prime Minister India*, Major Initiatives – Make In India, www.pmindia.gov.in/en/major-initiatives/

Rajaperumal, T. A., and Columbus, C. C. (2025), "Transforming the electrical grid: The role of AI in advancing smart, sustainable, and secure energy systems", *Energy Informatics*, Vol. 8, p. 51, https://doi.org/10.1186/s42162-024-00461-w

Randle-Boggis, R. J., *et al.* (2025), "Harvesting the sun twice: Energy, food and water benefits from agrivoltaics in East Africa", *Renewable and Sustainable Energy Reviews*, Vol. 208, pp. 115066, https://doi.org/10.1016/j.rser.2024.115066

Riahi *et al.* (2022), "Mitigation pathways compatible with long-term goals", In IPCC, *2022: Climate Change 2022: Mitigation of Climate Change*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter03.pdf

Rosenow, J. (2024), "Have we been duped by the primary energy fallacy?", *Medium*, https://medium.com/@jan.rosenow/have-we-been-duped-by-the-primary-energy-fallacy-167f53c58961

Rothwell, G. (2022), "Projected electricity costs in international nuclear power markets", *Energy Policy*, Vol. 164, 112905 https://doi.org/10.1016/j.enpol.2022.112905

Schneider *et al.* (2025), *The World Nuclear Industry Status Report 2025*, Mycle Schneider Consulting, Paris, www.worldnuclearreport.org/IMG/pdf/wnisr2025-v1.pdf

Simshauser, P. (2021), "Renewable Energy Zones in Australia's National Electricity Market", *Energy Economics*, Vol. 101, 105446, https://doi.org/10.1016/j.eneco.2021.105446

Singh, S. D., *et al.* (2025), "AI-Enhanced and Other Load Modelling in Modern Power Systems: A Comprehensive Review of Advances, Challenges, and Future Directions", *Revista Internacional de Métodos Numéricos Para Cálculo y Diseño En Ingeniería*, Vol. 41 (4), pp.1-23, www.scipedia.com/public/Singh_et_al_2025b

Smith, T. (2026), "Turning South Africa's Transmission Development Plan into action", *ESI-Africa.com*, www.esi-africa.com/business-and-markets/south-africa-transmission-development-plan/ (accessed 5 August 2026).

Soamole, S., and Mokodompit, E. (2025), "Indonesia's nickel downstreaming in the geopolitics of the global EV battery industry: a political economy and scenario modeling analysis", *Mineral Economics*, https://doi.org/10.1007/s13563-025-00588-6

State Council of the People's Republic of China (2026), "中华人民共和国国民经济和社会发展第十五个五年规划纲要 [Outline of the Fifteenth Five-Year Plan for National Economic and Social Development of the People']", State Council of the People's Republic of China, www.gov.cn/yaowen/liebiao/202603/content_7062633.htm?enable_bottom_share_style=1&hybrid_event_param=HybridEventP (accessed 14 April 2026).

TNC (2024), *Mining the sun: Clean energy on mines and brownfields*, The Nature Conservancy, www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/mining-the-sun-solar-energy-former-mine-sites/#hero-banner_immersive_hero-subsection

UN (2026), *Secretary-General's call to action on methane: Three sectors, nine actions by 2030*, United Nations, New York, un.org/en/climatechange/methane. (accessed 10 July 2026).

UNDP and FAO (2025), "Advancing clean cooking for climate action: Pathways to higher-tier solutions and scaled investment", United Nations Development Programme and Food and Agriculture Organization, New York and Rome, https://doi.org/10.4060/cd7421en

UNEP (2025a), *Emissions Gap Report 2025: Off Target*, United Nations Environment Programme, www.unep.org/resources/emissions-gap-report-2025 (accessed 10 April 2026).

UNEP (2025b), *Global Environment Outlook 7: A future we choose – Why investing in Earth now can lead to a trillion-dollar benefit for all*, United Nations Environment Programme, Nairobi, https://wedocs.unep.org/handle/20.500.11822/49014

UNEP (2026a), *Limiting Overshoot: Navigating exceedance of 1.5°C and pathways towards return*, United Nations Environment Programme, Nairobi, https://wedocs.unep.org/handle/20.500.11822/49857

UNEP (2026b), "Reducing methane emissions is the single fastest way to slow global warming as we decarbonize, but the world needs empirical data to enable climate action at scale", www.unep.org/topics/energy/methane/international-methane-emissions-observatory (accessed 14 August 2026).

UNFCCC (2025), "Nationally determined contributions under the Paris Agreement. Synthesis report by the secretariat", United Nations Framework Convention on Climate Change https://unfccc.int/documents/650664

VicGrid (2026), "Renewable energy zones", *VicGrid*, Victoria, www.vicgrid.com.au/transmission-planning/renewable-energy-zones

WHO (2025), "Household air pollution", World Health Organisation, www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (accessed 22 April 2026).

World Bank (n.d.), "Scaling Solar Programme", World Bank Group, www.scalingsolar.org/ (accessed 1 August 2026).

WWF (2024), *Living Planet Report 2024 – A System in Peril,* WWF, Gland, https://livingplanet.panda.org/

Yergin, D., *et al.* (2025), "The troubled energy transition – How to find a pragmatic path forward", *Foreign Affairs*, Vol. 104/2, www.foreignaffairs.com/united-states/troubled-energy-transition-yergin-orszag-arya

APPENDICES

APPENDIX 1 Planned Energy Scenario: Comparison of key performance indicators from WETO 2023 and 2026 editions

		WETO 2023 → PES				WETO 2026 → PES				
		2023*	2030	2035	2050	2023**	2030	2035	2050	
Renewable energy installed capacity (GW)	Global	3 797	6 773	9 039	15 835	3 876[1]	8 326	11 342	21 329	Relative to the WETO 2023 PES, the updated PES shows an upward revision of renewable installed capacity, highlighting the growing commitment behind renewable energy deployment.
Electrification rate in TFEC (%)	Global	22	23	25	29	23[2]	24	27	34	The current analysis shows more ambitions for electrification of end-use sectors in countries' plans compared to WETO 2023 with the market for more efficient technologies maturing.
Renewable energy share in TFEC (%)	Global	13	18	21	30	14[2]	19	23	36	The current analysis shows scale up in renewable energy share in TFEC compared to WETO 2023, due to upwardly revised renewable capacity target combined with ambitious electrification of end-use sectors.
Production in Clean Hydrogen (Mt)	Global	0.7	2	5	21	0.7[3]	10	38	150	The current analysis shows more ambitions in scaling up the use of clean hydrogen in countries' plans compared to WETO 2023 as countries strategies become more detailed.
Net Fossil CO_2 emissions (Gt)	Global	37	37	36	34	37[4]	37	35	28	Compared to WETO 2023, the current analysis shows more ambitions in national plans to reduce CO_2 emissions after by 2035 and afterwards.

Notes: * are based on projections of PES modelling results for WETO 2023 edition

** corresponds to historical statistics and calibrated data used for WETO 2026 edition.

[1] 2023 data based on (IRENA, 2026s)

[2] 2023 data based on latest world energy balances (IEA, 2025b)

[3] 2023 data based on IEA's Global Hydrogen Review 2026 (IEA, 2026c)

[4] 2023 data based on CO_2 Emissions in 2023 report (IEA, 2024)

WETO = World Energy Transition Outlook; PES = Planned Energy Scenario; GW = gigawatt; TFEC = total final energy consumption; Mt = million tonne; CO_2 = carbon dioxide; Gt = gigatonne

APPENDIX 2 Evolution of key indicators for the energy transition under different scenarios

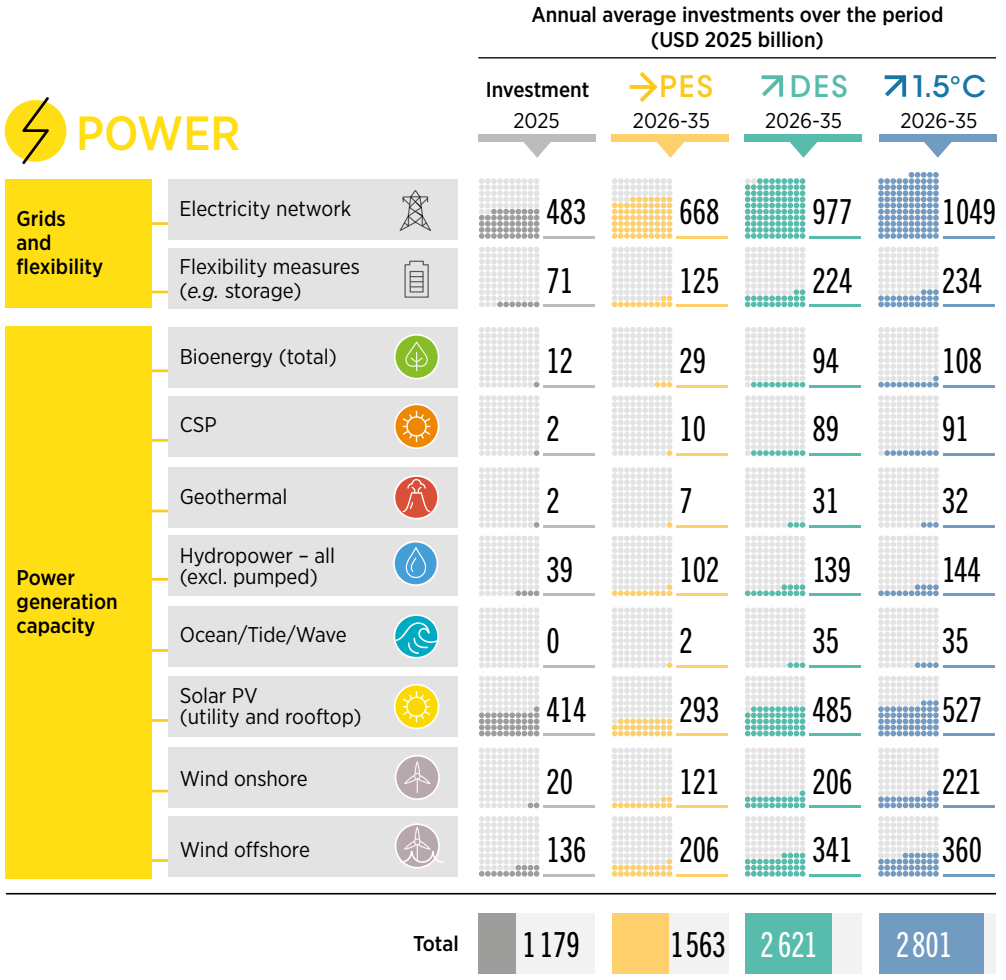
			PES			DES			1.5˚C Scenario		
		Recent years	2030	2035	2050	2030	2035	2050	2030	2035	2050
KPI. 01		ELECTRIFICATION IN END-USE SECTORS (DIRECT)									
Electrification rate in TFEC (%)	Global	23[1]	24	27	**34**	28	34	**54**	28	35	**54**
	G20	25[1]	27	30	**38**	31	37	**57**	31	38	**57**
Electrcity use in TFEC (EJ)	Global	91[1]	116	132	**183**	124	149	**232**	124	154	**231**
	G20	78[1]	97	108	**140**	103	118	**163**	103	120	**162**
KPI. 02		RENEWABLES IN END-USE SECTORS									
Total renewable energy share in TFEC (%) – direct & indirect	Global	14[1]	19	23	**36**	28	39	**72**	29	45	**77**
	G20	15[1]	21	26	**40**	31	43	**76**	32	49	**80**
Direct renewable energy share in TFEC (%)	Global	7[1]	7	8	**10**	10	12	**17**	10	16	**19**
	G20	7[1]	7	8	**10**	10	13	**17**	10	16	**18**
Modern use of bioenergy (EJ)	Global	29[1]	33	37	**52**	40	49	**62**	40	54	**67**
	G20	19[1]	23	26	**34**	29	35	**41**	29	37	**41**
KPI. 03		RENEWABLES (POWER)									
Renewable energy electricity generation (TWh/yr)	Global	8928[2]	17720	23870	**44979**	25855	39134	**84293**	27386	42383	**86483**
	G20	7518[2]	15127	20060	**35803**	21813	31119	**59401**	23251	33013	**60452**
Renewable energy share in electricity generation (%)	Global	30%[2]	47%	55%	**71%**	63%	75%	**90%**	67%	78%	**92%**
	G20	30%[2]	48%	57%	**74%**	64%	76%	**90%**	69%	79%	**92%**
Variable renewable energy share in electricity generation (%)	Global	13%[2]	31%	40%	**58%**	44%	56%	**72%**	47%	58%	**74%**
	G20	15%[2]	33%	42%	**62%**	47%	58%	**74%**	50%	60%	**75%**
Renewable energy installed capacity (GW)	Global	5149[3]	8326	11342	**21329**	11250	17267	**36846**	11549	18393	**38232**
	G20	4626[3]	7388	9842	**17348**	9724	14150	**26865**	10022	14824	**27509**
Renewable energy share in installed capacity (%)	Global	49%[3]	61%	69%	**82%**	74%	82%	**93%**	75%	83%	**93%**
	G20	51%[3]	64%	71%	**84%**	77%	83%	**94%**	77%	84%	**94%**

APPENDIX 2 Evolution of key indicators for the energy transition under different scenarios (continued)

		Recent years	PES 2030	PES 2035	PES 2050	DES 2030	DES 2035	DES 2050	1.5°C Scenario 2030	1.5°C Scenario 2035	1.5°C Scenario 2050
KPI. 03		RENEWABLES (POWER)									
Variable renewable energy share in installed capacity (%)	Global	35%[3]	50%	58%	**73%**	61%	70%	**82%**	62%	71%	**83%**
	G20	39%[3]	53%	62%	**76%**	65%	73%	**84%**	66%	74%	**85%**
Battery Storage (GW)	Global	257[4]	556	973	**2 833**	911	1899	**5 475**	954	2030	**5 696**
	G20	~230[4]	541	932	**2 558**	871	1758	**4 427**	914	1860	**4 561**
KPI. 04		ENERGY INTENSITY									
Energy intensity improvement rate (%)	Global	2[5]	3[6]	2.3[7]	**1.7[8]**	4.2[6]	2.5[7]	**2[8]**	4.4[6]	2.7[7]	**2[8]**
KPI. 05		CLEAN HYDROGEN AND DERIVATIVES									
Production of clean hydrogen (Mt)	Global	0.8[9]	10	38	**150**	26	112	**462**	26	135	**460**
	G20	0.7[9]	9	34	**140**	23	92	**372**	23	111	**369**
Electrolyser capacity (GW)	Global	2[10]	90	320	**1 241**	205	927	**4 548**	205	1084	**4 524**
KPI. 06		CCS, BECCS AND OTHERS									
CO_2 captured from CCS and BECCS and other CO_2 removals (Gt)	Global	0.06[11]	0.07	0.3	**1.1**	0.2	1.3	**4.5**	0.2	1.4	**5.5**
	G20	0.06[11]	0.07	0.3	**1.1**	0.1	1.1	**3.5**	0.1	1.2	**4.3**
Net Fossil CO_2 Emissions (Gt)	Global	38.1[12]	37.4	35.0	**28.4**	31.2	22.4	**4.3**	29.4	18.9	**0.6**
	G20	31.6[12]	29.2	26.3	**18.6**	23.3	16.1	**2.0**	22.1	13.9	**0.1**

Notes: [1] 2023 value, calculated based on (IEA, 2025b); [2] 2023 value from (IRENA, 2025c); [3] 2025 value from (IRENA, 2026c); [4] 2025 value from (BNEF, 2025); [5] The energy intensity improvement achieved in 2025 is calculated as the rate of improvement of energy intensities between 2024 to 2025 using the total energy supply and energy demand growth data from IEA for total energy supply 2024 and 2025 calculation and the GDP and economic growth data from the International Monetary Fund (IMF) for associated GDPs; [6] 2025 value is from IEA Hydrogen Projects Database (IEA, 2026a); [7] 2025 value is from (World Bank, 2026); [8] 2025 value from IEA CCUS Projects database 2026 (IEA, 2026b); [9] 2025 value from Global Energy Review 2026 (IEA, 2026a); PES = Planned Energy Scenario; DES = Decarbonising Energy Scenario; TWh = terawatt hour; GW = gigawatt; RE = renewable energy; VRE = variable renewable energy ; G20 = Group of 20.; BECCS = bioenergy with carbon capture and storage; CCS = carbon capture and storage; CO_2 = carbon dioxide; Gt = gigatonne.

APPENDIX 3 Required average annual investments in the power sector under the PES, DES and 1.5°C Scenario, 2026-2035



Notes: PES = Planned Energy Scenario; DES = Decarbonising Energy Scenario; 1.5°C = 1.5°C Scenario; CSP = concentrated solar power; PV = photovoltaic.

[1] Historical investment are based on (BNEF, 2026b), IRENA estimation as of March 2026.

[2] Grids and flexibility: Investment in transmission and distribution networks, smart meters, pumped hydropower, battery storage including other energy storage technologies.

[3] Renewable power generation capacity: Investment in deployment of renewable technologies for power generation.

APPENDIX 4 Required average annual investments and expenditures in end-use sectors under different scenarios

	Global annual average (USD billion)					
	2026-2035			2036-2050		
	PES	DES	1.5˚C Scenario	PES	DES	1.5˚C Scenario
Conventional demand-side technologies	1 791	1 383	1 383	1 655	704	704
Power grids and flexibility	22	25	25	22	25	25
Electrification of end-uses	1 579	2 259	2 261	2 197	3 863	3 862
Energy conservation and efficiency	681	1 369	1 369	755	1 550	1 550
Direct uses of renewables, hydrogen and derivatives, district heating	173	233	273	291	369	367
Clean cooking	21	44	44	26	60	60
Carbon removal	16	45	45	15	81	81
Total	4 282	5 359	5 401	4 962	6 652	6 650

Notes: PES = Planned Energy Scenario; DES = Decarbonising Energy Scenario.

Direct uses of renewables and district heat applications (*e.g.* solar thermal, modern bioenergy) and ammonia and methanol production from biomass. Includes associated district heating and cooling networks, renewable heat integration, waste heat recovery systems, and infrastructure enabling direct end-use of renewable energy and biomass-based chemical production.

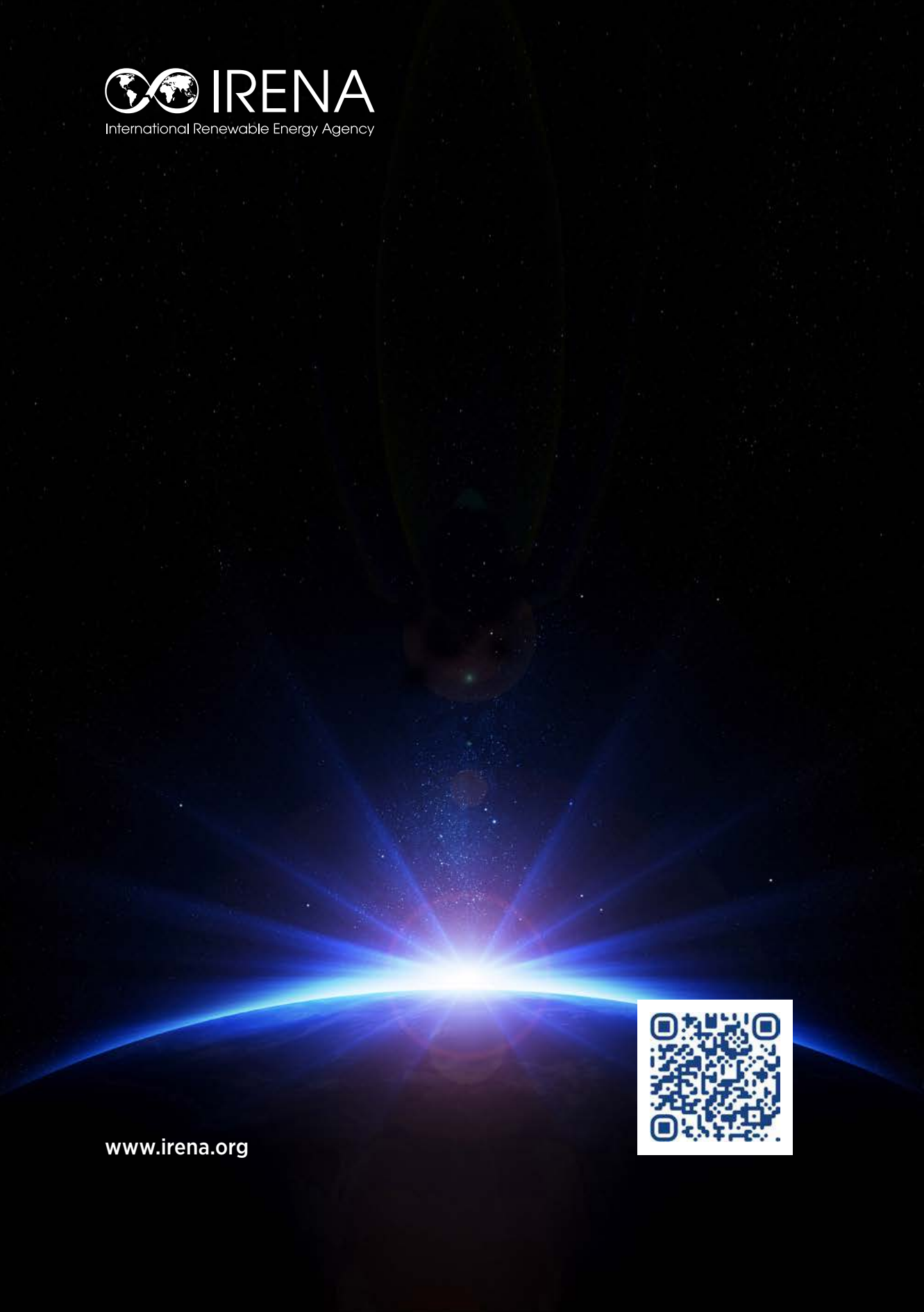
Hydrogen and its derivatives (including infrastructure): Investment in hydrogen stations, expenditure in hydrogen vehicles and hydrogen used industry for iron and steel production.

Electrification in end uses: Investment and expenditure related to electrification in the buildings sector (*e.g.* heat pumps and electric boilers), the industrial sector (*e.g.* industrial process heat supply via heat pumps, electric boilers, and electric furnaces), and the transport sector (*e.g.* electric veihicles, charging infrastructure for EVs, and other electric public transport infrastructure).

Energy efficiency in industry: Improving process efficiency, demand-side management solutions, highly efficient energy and motor systems and improved waste processes. Energy efficiency in transport: All passenger and freight transport modes, notably road, rail, aviation and shipping. Vehicle stock investments are excluded. Energy efficiency in buildings: Improving building thermal envelopes (insulation, windows, doors, etc.). Energy conservation: Investments in energy conservation includes those in bio-based plastics and organic materials, chemical and mechanical recycling and energy recovery.

Carbon removal infrastructure: carbon capture and storage and bioenergy with carbon capture and storage. Includes CO_2 transport networks (pipelines, shipping), storage site development, monitoring and verification systems, and direct air capture where applicable.

Clean cooking: Includes electric cooking appliances, liquefied petroleum gas transition infrastructure, biogas cooking systems, improved cookstoves and supporting access infrastructure for clean household energy.


IRENA
International Renewable Energy Agency
www.irena.org