IRENA
International Renewable Energy Agency

WORLD ENERGY TRANSITIONS OUTLOOK 2023

1.5°C PATHWAY

EXECUTIVE SUMMARY

IRENA
International Renewable Energy Agency

ISBN: 978-92-9260-527-8

CITATION

IRENA (2023), *World Energy Transitions Outlook 2023: 1.5°C Pathway,* International Renewable Energy Agency, Abu Dhabi.

Available for download: www.irena.org/publications

For further information or to provide feedback: publications@irena.org

ABOUT IRENA

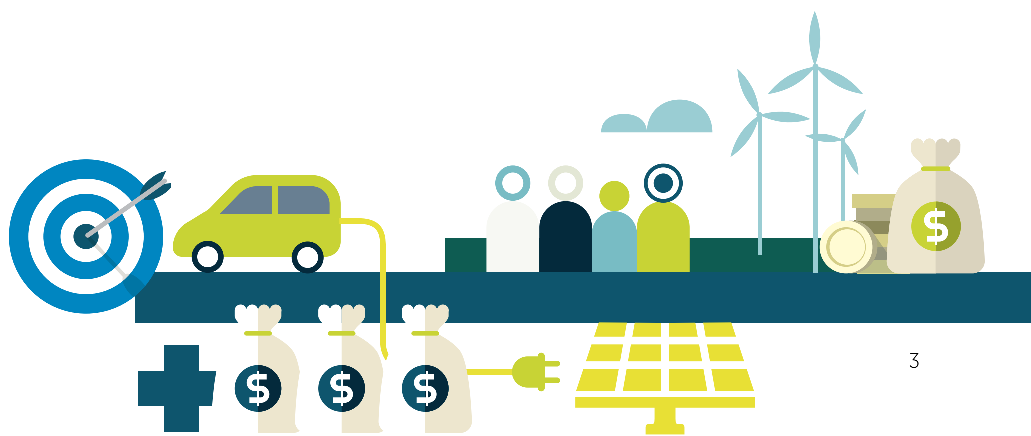
The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. A global intergovernmental organisation established in 2011, 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. **www.irena.org**

DISCLAIMER

TABLE OF CONTENTS

FIGURES

TABLES



FOREWORD

WORLD ENERGY
TRANSITIONS OUTLOOK 2023

The Synthesis Report of the IPCC Sixth Assessment delivered a sobering message – our collective ability to adhere to a 1.5°C pathway hangs in the balance. This decade, our success in reducing greenhouse gas emissions will determine whether global temperature rise can be limited to 1.5°C or even 2°C. The ramifications of each fraction of a degree cannot be overstated – particularly for the world's most vulnerable populations, who are already suffering the destructive impacts of climate change. The ubiquity of climate-induced disasters – be they floods, droughts or fires – demonstrates the pressing need for a course correction.

Within the timeframe to 2030, we must simultaneously realise the goals of the sustainable development agenda and significantly reduce emissions. Energy plays an essential role in climate course correction and the realisation of sustainable development. IRENA's 1.5°C pathway, set out in the *World Energy Transitions Outlook*, positions electrification and efficiency as key transition drivers, enabled by renewable energy, clean hydrogen and sustainable biomass. Increasingly, countries are positioning these technological avenues at the centre of their climate action, as well as their economic, energy security and universal access strategies.

Volume 1 of the *World Energy Transitions Outlook 2023* provides an overview of progress by tracking implementation and gaps across all energy sectors. It shows that most of the progress achieved to date has been in the power sector, where a virtuous circle of technology, policy and innovation has taken us a long way; but the scale and extent of implementation fall far short of what is required to stay on the 1.5°C pathway. An equally concerning trend is the geographic concentration of these deployments, which remains limited to a few countries and regions. This pattern, which has persisted for the past decade, has excluded almost half of the global population, and particularly those in countries with significant energy access needs.

The business case for renewables is strong, but deeply entrenched barriers stemming from the systems and structures created for the fossil-fuel era continue to hamper progress. The World Energy Transitions Outlook sets out a vision for overcoming these barriers. It envisages three pillars that would form the foundations for a way forward: first, building the necessary infrastructure and investing at scale in grids, and both land and sea routes, to accommodate new production locations, trade patterns and demand centres; second, advancing an evolved policy and regulatory architecture that can facilitate targeted investments; and finally, strategically realigning institutional capacities to help ensure that skills and capabilities match the energy system we aspire to create.

This also requires a realignment of the way in which international cooperation works. Multilateral financing institutions should prioritise building the infrastructure that would underpin the new energy system. This would coherently and simultaneously help deliver development and climate priorities, triggering virtuous economic and social dynamics. Importantly, this would enable private sector investment in countries and regions that currently face barriers such as high capital costs. The bulk of this funding should be in the form of concessional loans, whilst for the most vulnerable such as least developed countries (LDCs) and small island developing states (SIDS), a share of grant funding is needed.

IRENA's work has long emphasised the need for a holistic approach to the energy transition, encompassing not only technological developments, but also socio-economic aspects. This requires an understanding of the far-ranging transformations that will unfold as the world moves from fossil fuels to renewables and greater energy efficiency.

Volume 2 of the *World Energy Transitions Outlook 2023* discusses the socio-economic impacts of IRENA's 1.5°C Scenario, compared to the Planned Energy Scenario – the two IRENA roadmaps presented in Volume 1. It is based on IRENA's macro-econometric modelling work and provides policy makers with insights into how economic activity, employment and wellbeing may be affected under the 1.5°C pathway, compared to current policy settings. This analysis can assist countries to design policies that maximise the benefits of the energy transition and minimise adjustment burdens.

Any structural economic change will result in winners and losers; therefore, securing beneficial outcomes for all regions and peoples will require a broad set of policies. These must be guided by an understanding that the energy sector is essential to all human activity across the economy; that the economy ultimately exists to serve human well-being; and that economies and societies depend on the integrity of the planet's ecosystems.

Successful policy making must not be restricted to the energy sector alone; different government ministries and diverse stakeholders should be involved in decision making concerning the energy transition. Echoing the messages from previous editions of the Outlook, this volume outlines the comprehensive holistic policy framework required to deliver a just and effective energy transition.

The collective promise embodied by the Paris Agreement was to secure a climate-safe existence for current and future generations. We simply cannot continue with incremental changes; there is no time for a new energy system to evolve gradually over centuries, as was the case for the fossil fuel-based system.

The energy transition must also become a strategic tool to foster a more equitable and inclusive world. The 28th Conference of the Parties to the UNFCCC (COP28) and the Global Stocktake must not only confirm our deviation from a 1.5°C pathway but also provide a strategic blueprint to steer us back on track. It is my belief that the *World Energy Transitions Outlook* can offer critical input to shaping our collective action following this important climate action milestone.

Francesco La Camera
Director-General, IRENA

EXECUTIVE SUMMARY

The energy transition is off-track. The aftermath of the COVID-19 pandemic and the ripple effects of the Ukraine crisis have further compounded the challenges facing the transition. The stakes could not be higher - every fraction of a degree in global temperature change can trigger significant and far-reaching consequences for natural systems, human societies and economies.

Limiting global warming to 1.5°C requires cutting carbon dioxide (CO_2) emissions by around 37 gigatonnes (Gt) from 2022 levels and achieving net-zero emissions in the energy sector by 2050. Despite some progress, significant gaps remain between the current deployment of energy transition technologies and the levels needed to achieve the goal of the Paris Agreement to limit global temperature rise to within 1.5°C of pre-industrial levels by the end of this century. A 1.5°C compatible pathway requires a wholescale transformation of the way societies consume and produce energy.

Current pledges and plans fall well short of IRENA's 1.5°C pathway and will result in an emissions gap of 16 Gt in 2050. Nationally Determined Contributions (NDCs), long-term low greenhouse gas emission development strategies (LT-LEDS) and net-zero targets, if fully implemented, could reduce CO_2 emissions by 6% by 2030 and 56% by 2050, compared to 2022 levels. However, most climate pledges are yet to be translated into detailed national strategies and plans - implemented through policies and regulations - or supported with sufficient funding. According to IRENA's Planned Energy Scenario, the energy-related emissions gap is projected to reach 34 Gt by 2050, underscoring the urgent need for comprehensive action to accelerate the transition.

Annual deployment of some 1 000 GW of renewable power is needed to stay on a 1.5°C pathway. In 2022, some 300 GW of renewables were added globally, accounting for 83% of new capacity compared to a 17% share combined for fossil fuel and nuclear additions. Both the volume and share of renewables need to grow substantially, which is both technically feasible and economically viable.

Policies and investments are not consistently moving in the right direction. While there were record renewable power capacity additions in 2022, the year also saw the highest levels of fossil fuel subsidies ever, as many governments sought to cushion the blow of high energy prices for consumers and businesses. Global investments across all energy transition technologies reached a record high of USD 1.3 trillion in 2022, yet fossil fuel capital investments were almost twice those of renewable energy investments. With renewables and energy efficiency best placed to meet climate commitments - as well as energy security and energy affordability objectives – governments need to redouble their efforts to ensure investments are on the right track.

Every year, the gap between what is achieved and what is required continues to grow. IRENA's energy transition indicators (Table S1) show significant acceleration is needed across energy sectors and technologies, from deeper end-use electrification of transport and heat, to direct renewable use, energy efficiency and infrastructure additions. Delays only add to the already considerable challenge of meeting IPCC-defined emission reduction levels in 2030 and 2050 for a 1.5°C trajectory (IPCC, 2022a). This lack of progress will also increase future investment needs and the costs of worsening climate change effects.

TABLE S1 Tracking progress of key energy system components to achieve the 1.5°C Scenario

	Indicators	Recent years	2030 [1]	2050 [1]	Progress (off / on track)
RENEWABLES	**ELECTRIFICATION WITH RENEWABLES**				
	Share of renewables in electricity generation	28 % [2]	68 %	91 %	
	Renewable power capacity additions [3]	295 GW/yr [4]	975 GW/yr	1 066 GW/yr	
	Annual solar PV additions [3]	191 GW/yr [5]	551 GW/yr	615 GW/yr	
	Annual wind energy additions [3]	75 GW/yr [6]	329 GW/yr	335 GW/yr	
	Investment needs for RE generation	486 USD billion/yr [7]	1 300 USD billion/yr	1 380 USD billion/yr	
	Investment needs for power grids and flexibility	274 USD billion/yr [8]	605 USD billion/yr	800 USD billion/yr	
	DIRECT RENEWABLES IN END-USES AND DISTRICT HEAT				
	Share of renewables in final energy consumption	17 % [9]	35 %	82 %	
	Solar thermal collector area	585 million m²/yr [10]	1 552 million m²/yr	3 882 million m²/yr	
	Modern use of bioenergy (direct use)	21 EJ [11]	46 EJ	53 EJ	
	Geothermal consumption (direct use)	0.9 EJ [12]	1.4 EJ	2.2 EJ	
	Renewables based district heat generation	0.9 EJ [13]	4.3 EJ	13 EJ	
	Investment needs for renewables end uses and district heat [14]	13 USD billion/yr [15]	290 USD billion/yr	210 USD billion/yr	

▸ continued

(contd.) TABLE S1 Tracking progress of key energy system components to achieve the 1.5°C Scenario

	Indicators	Recent years	2030 [1]	2050 [1]	Progress (off / on track)
ENERGY EFFICIENCY	Energy intensity improvement rate	1.7 %/yr [16]	3.3 %/yr	2.8 %/yr	
	Investment needs for energy conservation and efficiency [17]	295 USD billion/yr [18]	1780 USD billion/yr	1525 USD billion/yr	
ELECTRIFICATION	Share of direct electricity in final energy consumption	22% [19]	29 %	51 %	
	Passenger electric cars on the road	10.5 million [20]	360 million	2 180 million	
	Investments needs for charging infrastructure of EV's and EV adoption support	30 USD billion/yr [21]	137 USD billion/yr	364 USD billion/yr	
	Investment needs for heat pumps	64 USD billion/yr [22]	237 USD billion/yr	230 USD billion/yr	
HYDROGEN	Clean hydrogen production	0.7 Mt/yr [23]	125 Mt/yr [24]	523 Mt/yr [25]	
	Electrolyser capacity	0.5 GW [26]	428 GW	5 722 GW	
	Investment needs [27] for clean hydrogen and derivatives infrastructure	1.1 USD billion/yr [28]	100 USD billion/yr	170 USD billion/yr	
CCS AND BECCS	CCS/U - emissions abated	0.04 $GtCO_2$ captured/yr [29]	1.4 $GtCO_2$ captured/yr	3.2 $GtCO_2$ captured/yr	
	BECCS and others to abate total emissions	0.002 $GtCO_2$ captured/yr [30]	0.8 $GtCO_2$ captured/yr	3.8 $GtCO_2$ captured/yr	
	Investment needs for carbon removal and infrastructure	6.4 USD billion/yr [31]	38 USD billion/yr	107 USD billion/yr	

▸ Notes: see next page

Table S1 notes: [1] Average annual investments requirement to reach the 1.5°C target during the period 2023 - 2030 and 2023 - 2050 are shown in the investments rows under 2030 and 2050, respectively. All investment figures for recent years are in current USD; the particulars of recent years used for the indicators are: [2] 2020; [3] net capacity additions for 2030 and 2050 are excluding replacement stock for end-of-life units; [4] 2022; [5] 2022; [6] 2022; [7] 2022; [8] 2022; [9] 2020; [10] 2021; [11] 2020 - non-energy uses are not included; [12] 2020; [13] 2020; [14] future investments needed in renewables in end uses, district heating, biofuels and bio-based innovative fuels; [15] 2022; [16] Recent years value is an average between 2010 and 2020; [17] future investments in energy conservation and efficiency include those in bio-based plastics and organic materials, chemical and mechanical recycling and energy recovery; [18] 2021; [19] 2020; [20] 2022; [21] 2022; [22] 2022; [23] 2021; [24] the share for green hydrogen is 40% in 2030; [25] the share for green hydrogen is 94% in 2050; [26] 2022; [27] future investments needed in electrolysers, infrastructure, H_2 stations, bunkering facilities and long-term storage; [28] 2022; [29] Includes CO_2 capture in natural gas processing, hydrogen, other fuel supply, power and heat, industry, direct air capture of facilities in operation, 2022; [30] Current total capture corresponds to fuel supply, 2022; [31] 2022. CCS/U = carbon capture and storage/use; BECCS = bioenergy, carbon capture and storage; EV = electric vehicle; RE = renewable energy; yr = year; m^2 = square metre; EJ = exajoule; Gt = gigatonne.

The share of renewable energy in the global energy mix would increase from 16% in 2020 to 77% by 2050 in IRENA's 1.5°C scenario. Total primary energy supply would remain stable due to increased energy efficiency and growth of renewables. Renewables would increase across all end-use sectors, while a high rate of electrification in sectors such as transport and buildings would require a twelve-fold increase in renewable electricity capacity by 2050, compared to 2020 levels. Globally, annual renewable power capacity additions would need to reach an average of 1 066 GW per year from 2023 to 2050 under the 1.5°C scenario.

Electricity would become the main energy carrier, accounting for over 50% of total final energy consumption by 2050 in the 1.5°C scenario. Renewable energy deployment, improvements in energy efficiency and the electrification of end-use sectors would contribute to this shift. In addition, modern biomass and hydrogen would both play more significant roles, meeting 16% and 14% of total final energy consumption by 2050, respectively.

By 2050, 94% of hydrogen would be renewables-based in the 1.5°C scenario. Hydrogen would play a key role in the decarbonisation of end-uses and flexibility of the power system. The 1.5°C Scenario envisages that total final energy consumption would decrease by 6% between 2020 and 2050, due to efficiency improvements, deployment of renewables, and changes in behaviour and consumption patterns.

An enduring investment gap

A cumulative USD 150 trillion is required to realise the 1.5°C target by 2050, averaging over USD 5 trillion in annual terms. Although global investment across all energy transition technologies reached a record high of USD 1.3 trillion in 2022, annual investment must more than quadruple to remain on the 1.5°C pathway. Compared with the Planned Energy Scenario - under which a cumulative investment of USD 103 trillion is required – an additional USD 47 trillion in cumulative investment is required by 2050 to remain on the 1.5°C pathway. Around USD 1 trillion of annual investments in fossil fuel-based technologies currently envisaged in the Planned Energy Scenario must therefore be redirected towards energy transition technologies and infrastructure.

Renewable energy investment remains concentrated in a limited number of countries and focused on only a few technologies. Investment in renewable energy (including both power and end-uses) reached USD 0.5 trillion in 2022 (IRENA and CPI, 2023); however, this is around one-third of the average investment needed each year in renewables under the 1.5°C Scenario. Furthermore, 85% of global renewable energy investment benefitted less than 50% of the world's population and Africa accounted for only 1% of additional capacity in 2022 (IRENA, 2023a; IRENA and CPI, 2023). Investments in off-grid renewable energy solutions in 2021 amounted to USD 0.5 billion (IRENA and CPI, 2023) – far below the USD 15 billion needed annually to 2030. While many technology choices exist, most investments were in solar PV and wind power, with 95% channelled toward these technologies (IRENA and CPI, 2023). Greater volumes of funding need to flow to other energy transition technologies such as biofuels, hydropower and geothermal energy, as well as to sectors beyond power that have lower shares of renewables in total final energy consumption (*e.g.* heating and transport).

Some 75% of global investment in renewables from 2013 to 2020 came from the private sector. However, private capital tends to flow to the technologies and countries with the least associated risks, be they real or perceived. In 2020, 83% of commitments in solar PV came from private finance, whereas geothermal and hydropower relied primarily on public finance - only 32% and 3% of investments in these technologies, respectively, came from private investors in 2020 (IRENA and CPI, 2023). Stronger public sector intervention is required to channel investments towards countries and technologies in a more equitable way.

Public finance and policy should crowd in private capital, but greater geographical and technological diversity of investment requires targeted and scaled-up public contributions. For many years, policy has focused on mobilising private capital. Public funding is urgently needed to invest in basic energy infrastructure in the developing world, as well as to drive deployment in less mature technologies (especially in end uses such as heating and transport, or synthetic fuel production) and in areas where private investors seldom venture. Otherwise, the gap in investment between the Global North and the Global South could continue to widen.

Overcoming barriers to the transition

Policy makers need to strike the right balance between reactive measures and proactive energy transition strategies that promote a more resilient, inclusive and climate-safe system. Several of the root causes of current crises stem from the fossil fuel-based energy system, such as overdependence on a limited number of fuel exporters, inefficient and wasteful energy production and consumption, and the lack of accounting for negative environmental and social impacts. An energy transition based on renewables can reduce or eliminate many of these. It is therefore the speed of the change that will determine the levels of energy security and economic and social resilience at the national level and offer new opportunities for improved human welfare globally.

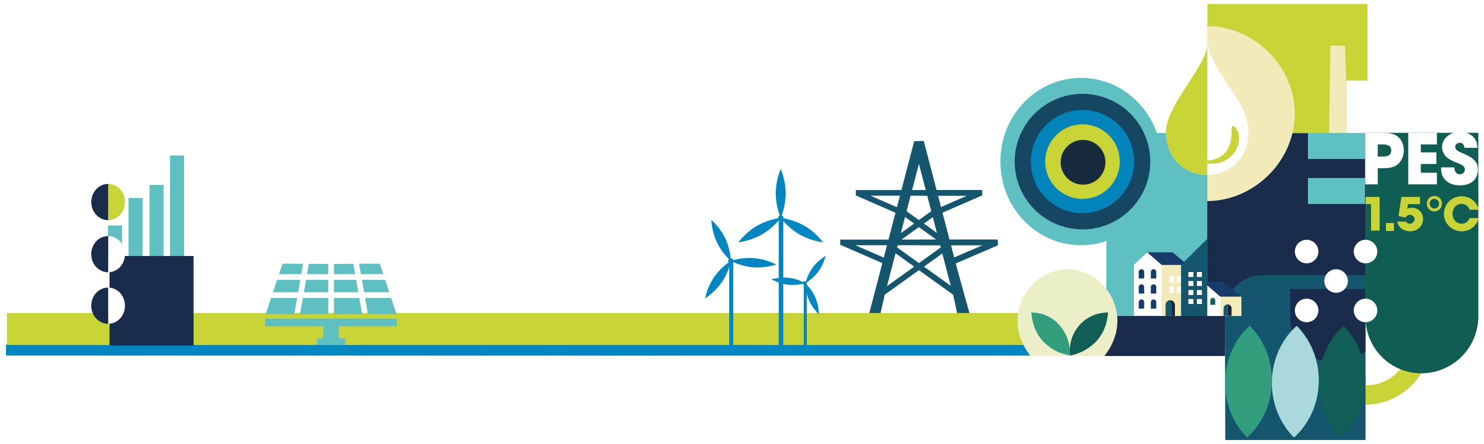
Accelerating progress worldwide requires a shift away from structures and systems built for the fossil fuel era. The energy transition can be a tool with which to proactively shape a more equal and inclusive world. This means overcoming existing barriers across infrastructure, policy, workforces and institutions that hamper progress and impede inclusivity (Figure S1).

More can be done in the short term. While the energy transition undoubtedly requires time, there is significant potential to implement many of the available technology options today. Upward trends in the deployment of these solutions demonstrate that the technical and economic case is sound. However, comprehensive policies are needed across all sectors to ramp up deployment, as well as to instigate the systemic and structural overhaul required to realise climate and development objectives.

FIGURE S1 Key energy transition barriers and solutions

	Enabling infrastructure	Policy and regulations	Skills and institutional capacity
Barriers	▶ **Insufficient infrastructure to connect renewable energy to markets**, including energy storage and grid integration infrastructure. ▶ **Lack of readiness of the distribution infrastructure** for electricity, gases and fuels. ▶ **Unpreparedness of end-use sector facilities** to switch to renewables.	▶ **Policy and regulatory frameworks that are still shaped around fossil fuels,** offering insufficient public funding for energy transition support. ▶ **Lack of integrated planning for energy production and consumption.** ▶ **Insufficient attention to the socio-economic dimension**, including a lack of industrial policy for viable supply chains.	▶ **Misalignments between fossil fuel job losses and renewable job gains** (skills-related, sectoral, spatial, temporal). ▶ **Skills gaps** due to inadequate education and training opportunities; uneven access for women, youth, minorities; and unmet reskilling and upskilling needs. Also lack of awareness of opportunities. ▶ **Job quality issues**, including wages, occupational health and safety, and overall workplace conditions.
Solutions	**Forward-looking planning, modernisation and expansion of supporting infrastructure both on land and sea to facilitate the development, storage, distribution, transmission and consumption of renewables.** Infrastructure should facilitate national, regional and global strategies for new supply-demand dynamics.	**Design policy and regulatory frameworks that facilitate deployment, integration and trade of renewables-based energy, improve socio-economic and environmental outcomes and promote equity and inclusion.** These need to enable the energy transition at various levels, from local to global, and reflect new supply-demand dynamics.	**Awareness- and capacity-building of institutions, communities and individuals to acquire requisite skills and knowledge to drive and sustain the energy transition.** This includes co-ordination between educational institutions and industry. Strengthened institutions, social dialogue and collective bargaining will help bring about greater socio-economic benefits.

A profound and systemic transformation of the global energy system must occur within 30 years



The Global Stocktake at the 2023 United Nations Climate Change Conference (COP28) must serve as a catalyst for scaling up action in the years to 2030 to implement existing energy transition options. Whilst planning must provide room for innovation and additional policy action, a significant scale up of existing solutions is paramount. For example, advancing efficiency and electrification based on renewables is a cost-effective avenue for the power sector, as well as for transport and buildings. Clean hydrogen and its derivatives, and sustainable biomass solutions, also offer various solutions for end uses.

The period following COP28 will be pivotal for efforts to curb climate change and achieve the sustainable development goals outlined in the 2030 Agenda. The energy transition is crucial for delivering on economic, social and environmental priorities. It is imperative for governments, financial institutions and the private sector to urgently re-evaluate their aspirations, strategies and implementation plans to realign the energy transition with its intended trajectory.

Developing structures for a renewables-based energy system

A profound and systemic transformation of the global energy system must be achieved within 30 years. This condensed timeframe necessitates a strategic shift that expands beyond the focus on decarbonisation of energy supply and energy consumption, toward designing an energy system that not only reduces carbon emissions but also supports a resilient and inclusive global economy. As a result, planning needs to extend beyond borders and the narrow confines of fuels to focus on the requirements of the new energy system and the economies it will sustain.

Focusing on the enablers of a renewables-dominated system can help address the structural barriers that hinder progress in the energy transition. Pursuing fuel and sectoral mitigation measures is necessary, but is insufficient to transition to an energy system fit for the dominance of renewables. From energy production and transportation to processing coal, oil and gas, the global infrastructure dedicated to energy will need to change. This will have impacts on power generation, industrial production and manufacturing, as well as on rail, pipelines, shipyards and other means of supplying fossil fuels. Enhancing the focus on systems design will help accelerate the development of a new energy infrastructure and sustain its implementation.

Governments can proactively shape a renewables-based energy system, overcome the flaws and inefficiencies of current structures, and more effectively influence outcomes. The simultaneous, proactive shaping of physical, policy and institutional structures will be essential to realising development and climate objectives, and achieving a more resilient and equitable world. These underpinnings should form the pillars of a structure that supports the energy transition:

Physical infrastructure upgrades, modernisation and expansion will increase resilience and build flexibility for a diversified and interconnected energy system. Transmission and distribution will need to accommodate both the highly localised, decentralised nature of many renewable fuels, as well as different trade routes. Planning for interconnectors to enable electricity trade, and shipping routes for hydrogen and derivatives, must consider vastly different global dynamics and proactively link countries to promote the diversification and resilience of energy systems. Storage solutions will need to be widespread and designed with geo-economic impacts in mind. Public acceptance is also critical for any large-scale undertaking and can be secured through project transparency and opportunities for communities to voice their perspectives.

Policy and regulatory enablers must systematically prioritise the acceleration of the energy transition and a reduction in the role of fossil fuels. Today, the underlying policy and regulatory systems remain shaped around fossil fuels. While it is inevitable that fossil fuels will remain in the energy mix for some time, their share must dramatically decrease as we approach mid-century. Policy frameworks and markets should therefore focus on accelerating the transition and provide the essential underpinnings for a resilient and inclusive system.

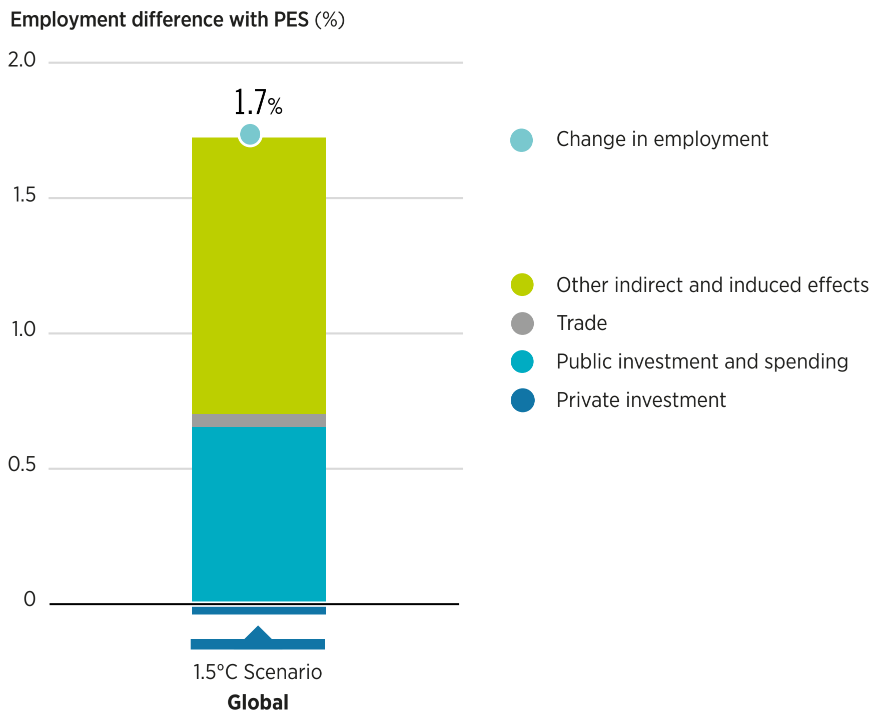
A well-skilled workforce is a lynchpin of a successful energy transition. A broad range of occupational profiles will be needed. Filling these jobs will require concerted action in education and skills building, and governments have a critical role in co-ordinating efforts to align the offerings of the education sector with projected industry needs - whether in the form of vocational training or university courses. To attract talent to the sector, it is crucial that jobs are decent, and that women, youth and minorities have equal access to job training, hiring networks and career opportunities.

Employment and livelihoods

The 1.5°C pathway would create more employment throughout the economy. The 1.5°C Scenario would lead to, in average annual terms, 1.7% higher economy-wide employment than the PES over the 2023-2050 period (Figure S2). Reflecting front-loaded investments, global economy-wide annual employment would be 1.8% greater on average in the years to 2040, but only 1.5% higher in the final decade (2041-2050).

The 1.5°C pathway would lead to a 1.7% increase in average annual employment over the PES in the 2023-2050 period.

FIGURE S2 **Global economy-wide employment, average percentage difference between PES and 1.5°C Scenario, by driver, 2023-2050**

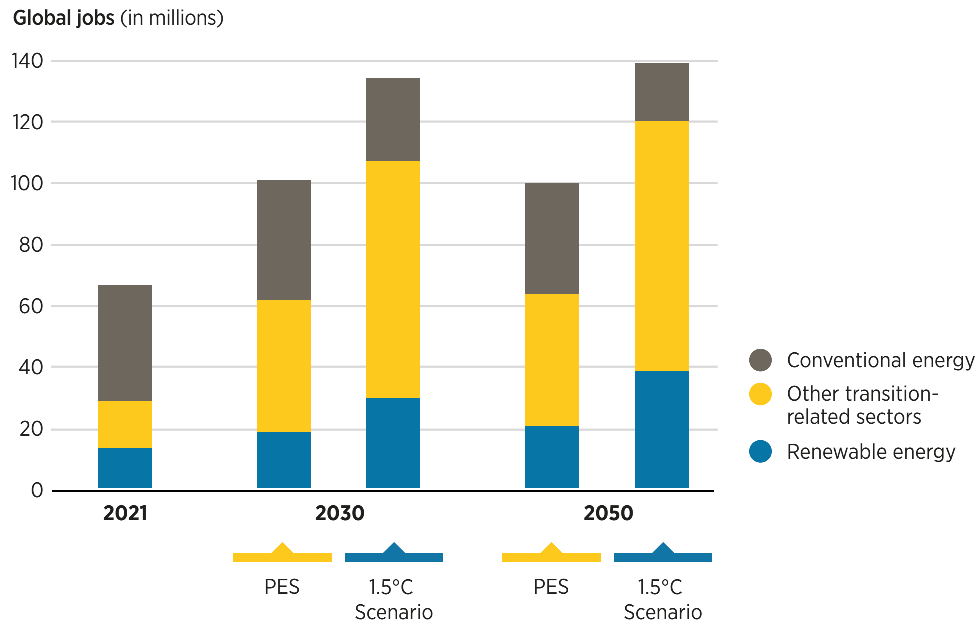


Note: PES = Planned Energy Scenario.

The energy transition will increase energy sector employment. Given front-loaded investments, by 2030 the number of jobs in the energy sector could grow to 101 million under the PES. Under the 1.5°C Scenario, the number would be 134 million – double the current 67 million (Figure S3). Between the PES and 1.5°C Scenario, substantial job losses in fossil fuels (around 12 million) are more than offset by gains of 45 million jobs in the energy transition – namely in renewables (around 11 million) and other energy transition-related sectors (energy efficiency, power grids and flexibility, vehicle charging infrastructure and hydrogen at around 34 million) by 2030. Employment changes after 2030 are marginal.

Under the 1.5°C Scenario, renewable energy sector employment is expected to triple from 2021 levels to about 40 million jobs worldwide by 2050. Solar energy jobs are expected to rise to around 18 million (*i.e.* around 45% of the total renewable energy jobs) by 2050 under the 1.5°C Scenario, almost a four-fold increase compared to 2021. Wind energy will also see high job creation and is expected to rise five-fold from 2021, reaching over 6 million (around 17% of the total renewable energy jobs). Bioenergy jobs will grow from over 4 million (33% of renewable jobs) in 2021 to over 10 million (27% of renewables jobs) in 2050.

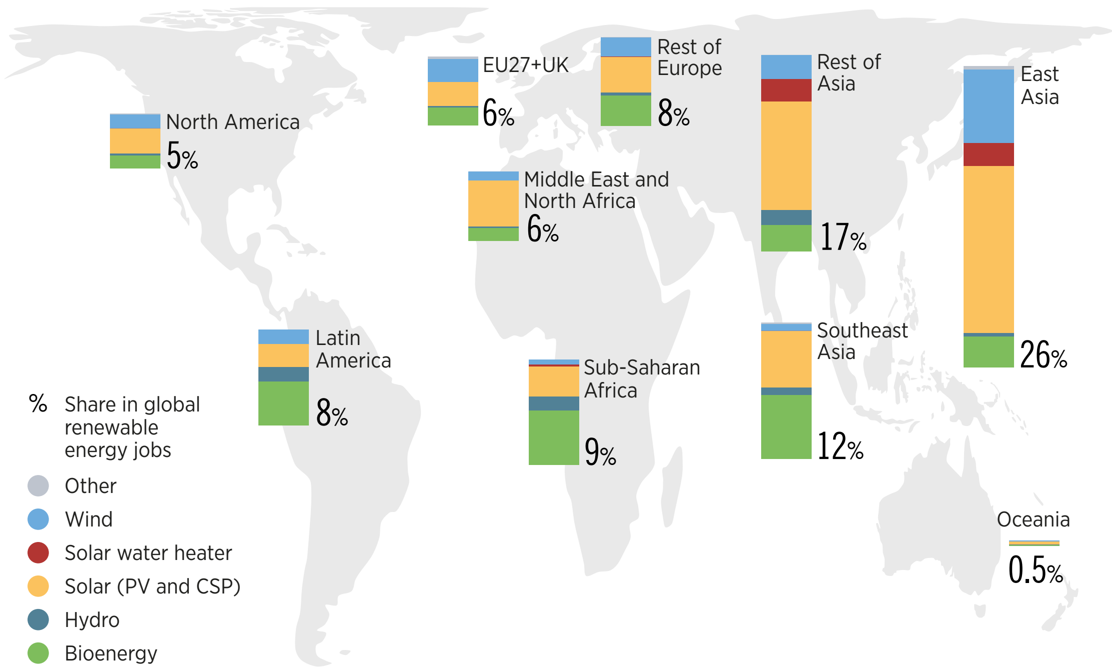
FIGURE S3 **Global energy sector jobs in the PES and 1.5°C Scenario, 2021-2050**



Note: PES = Planned Energy Scenario.

However, these jobs are unevenly distributed across regions. Figure S4 shows the regional and technological distribution of renewables jobs under the 1.5°C Scenario by 2050. Asia is expected to account for a 55% share of global renewable energy jobs, followed by Europe at 14%, the Americas at 13% and Sub-Saharan Africa at 9%. Whilst factors like the size of populations and economies influence regional distribution, these outcomes will also reflect the extent to which countries are able to scale up the deployment of renewable energy and whether they have significant domestic supply chains in place.

FIGURE S4 Share of renewable energy jobs by region, 2050



Note: "Other" includes geothermal and tidal/wave. CSP = concentrated solar power; EU = European Union; PV = photovoltaic; UK = United Kingdom.

Socio-economic impacts of the energy transition

To date, policy makers have predominantly concentrated on the technological, institutional, regulatory and policy facets of the energy transition, with less attention to its socio-economic implications. Current transition narratives may not resonate with all stakeholders, largely due to their omission of central socio-economic dimensions. Whilst not exclusive to the energy transition, distributional issues (regarding income, wealth, investment and social expenditure, energy and materials use, climate change impacts and others) should be addressed to maximise socio-economic benefits, and strengthen acceptance and support for the transition. Bridging gaps in climate policy ambition and fostering essential structural changes necessitate unparalleled global collaboration.

Connecting the socio-economic and technological/regulatory facets of the energy transition necessitates policy interventions that transcend the shift from fossil fuels to renewables. Policy makers must aim for coherence between energy policy and other national policies over the long term to promote an inclusive and just energy transition. The latter must keep people at its heart and embrace diversity and inclusion across several population demographics (e.g. women, youth, older workers, people with disabilities, migrant workers, indigenous people, unemployed people, vulnerable workers). In addition to the specific economic and employment benefits discussed above, a key advantage of the energy transition lies in its ability to improve overall global welfare. IRENA measures potential welfare impacts through its welfare index. The index consists of five dimensions – economic, social, environmental, distributional and access – each one informed by two sub-indicators.

Achieving a just, inclusive and more sustainable world cannot be solely entrusted to market forces. Priorities must be determined in open debate, with policy choices guided by social dialogue. Governments and stakeholders must actively partake in reshaping economic and social structures. This reiterates a foundational premise in IRENA's socio-economic reports: policy making must be inspired by a holistic framework that balances technological considerations with social, economic and environmental imperatives.

The way forward: Prioritising bold and transformative actions

Achieving the necessary course-correction in the energy transition will require bold, transformative measures that reflect the urgency of the present situation. A considerable scale-up of renewables needs to go hand-in-hand with investments in enabling infrastructure. Comprehensive policies are needed not only to facilitate deployment but also to ensure the transition has broad socio-economic benefits.

Net-zero commitments must be embedded in legislation and translated into implementation plans that are adequately resourced. Without this crucial step, climate announcements remain aspirational, and the necessary progress out of reach. The current energy system is deeply woven into socio-economic structures that have evolved over centuries. This means significant structural change must occur in a condensed timeframe of less than three decades to successfully deliver on the goals of the Paris Agreement.

Every investment and planning decision concerning energy infrastructure today should consider the structure and geography of the low-carbon economy of the future. Energy infrastructure is long-lived, so investment in fixed infrastructure should consider the long term. Electrification of end uses will reshape demand. Renewable power will require existing infrastructure to be modernised, with grid reinforcement and expansion on both land and sea. Green hydrogen production will also occur in locations other than today's oil and gas fields. The technical challenges and economic costs of redesigning infrastructure should be accounted for, and the environmental and social aspects adequately addressed from the outset.

A just and inclusive energy transition will help to overcome deep disparities that affect the quality of life of hundreds of millions of people. Energy transition policies must be aligned with broader systemic changes that aim to safeguard human well-being, advance equity among countries and communities, and bring the global economy in line with climate, broader environmental and resource constraints.

Supporting developing countries to accelerate the energy transition could improve energy security while preventing the global decarbonisation divide from widening. A diverse energy market would reduce supply chain risks, improve energy security and ensure local value creation for commodity producers. Access to technology, training, capacity building and affordable finance will be vital to unlock the full potential of countries' contributions to the global energy transition, especially for those rich in renewables and related resources.

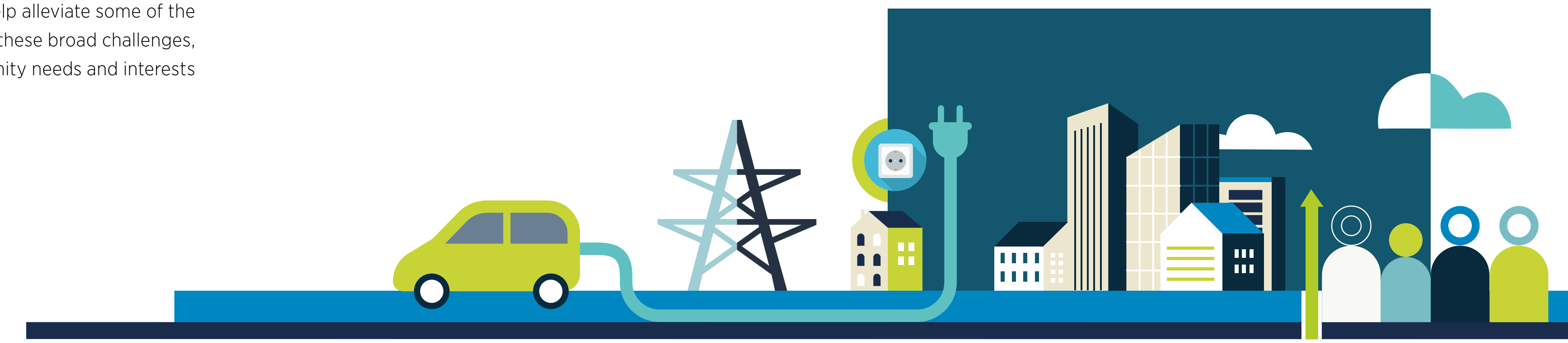
Human welfare and security must remain at the heart of the energy transition. Systemic changes beyond the energy sector will be needed to overcome pervasive problems related to human welfare and security, as well as deeply embedded inequalities; a renewables-based energy transition can help alleviate some of the conditions that underly these issues. The more the energy transition can help solve these broad challenges, the more its popular acceptance and legitimacy will rise, provided also that community needs and interests are well represented and integrated into transition planning.

Rewriting international co-operation

The dynamism of energy sectors and geopolitical developments necessitates greater scrutiny of international co-operation modalities, instruments and approaches to ensure their relevance, impact and agility. To achieve a successful energy transition, international co-operation needs to be enhanced and redesigned. The centrality of energy to the global development and climate agenda is undisputed, and international co-operation in energy has increased exponentially in recent years. This co-operation plays a decisive role in determining the outcomes of the energy transition and is a critical avenue for achieving greater resilience, inclusion and equality.

The expanding variety of actors engaged in the energy transition requires an assessment of roles to leverage respective strengths and efficiently allocate limited public resources. The imperatives of development and climate action, coupled with changing energy supply and demand dynamics, require coherence and alignment around priority actions. For instance, investment in systems for cross-border and global trade of energy commodities will require international co-operation on an unprecedented scale. It is, therefore, essential to reconsider the roles and responsibilities of national and regional entities, international organisations, and international financial institutions and multilateral development banks to ensure their optimal contribution to the energy transition.

Achieving the energy transition will require collective efforts to channel funds to the Global South. In 2020, multilateral and bilateral development finance institutions (DFIs) provided less than 3% of total renewable energy investments. Going forward, they need to direct more funds, at better terms, towards large-scale energy transition projects. Moreover, financing from DFIs was provided mainly through debt financing at market rates (requiring repayment with interest rates charged at market value) while grants and concessional loans amounted to just 1% of total renewable energy finance (IRENA and CPI, 2023). These institutions are uniquely placed to support large-scale and cross-border projects that can make a notable difference in accelerating the global energy transition.



WORLD ENERGY TRANSITIONS OUTLOOK 2023

The *World Energy Transitions Outlook* outlines a vision for the transition of the energy landscape to reflect the goals of the Paris Agreement, presenting a pathway for limiting global temperature rise to 1.5°C and bringing CO_2 emissions to net zero by mid-century.

The report builds on two of IRENA's key scenarios to capture global progress toward meeting the 1.5°C climate goal:

Planned Energy Scenario

The **Planned Energy Scenario** is the primary reference case for this study, providing a perspective on energy system developments based on governments' energy plans and other planned targets and policies in place at the time of analysis, with a focus on G20 countries.

1.5°C Scenario

The **1.5°C Scenario** describes an energy transition pathway aligned with the 1.5°C climate goal to limit global average temperature increase by the end of the present century to 1.5°C, relative to pre-industrial levels. It prioritises readily available technology solutions, which can be scaled up to meet the 1.5°C goal.

IRENA

International Renewable Energy Agency

www.irena.org